Вихлопні газі автомобілів є основним джерелом забруднення повітря в навколишньому середовищі. Забруднення вихлопними газами автомобілів може бути скорочено, якщо приділяти увагу системі технічного обслуговування, сучасним концепціям управління двигуном, очищенню палива і скороченню викидів вихлопних газів. Каталітичні нейтралізатори є найбільш ефективним інструментом боротьби з забрудненням навколишнього середовища, оскільки вони скорочують майже 80 % шкідливих газів, що утворюються в результаті неповного згоряння в двигуні. Для з'ясування явищ, що протікають, проведено моделювання структури потоку вихлопних газів зі зміною кількості і форми фільтра каталітичного нейтралізатора. Дане дослідження починається зі створення конструкції каталітичного нейтралізатора, яка включає в себе розміри нерозрізаного фільтра і розміри розрізаного фільтра. Потім конструюються розміри рами каталітичного нейтралізатора з різною кількістю фільтрів: 2, 3, 4 і 5 штук і виконується моделювання. Результати моделювання показують, що збільшення відсотка швидкості обумовлено потоком вихлопних газів, що проходить через невеликі отвори в фільтрі, таким чином тиск газу впливає на збільшення швидкості. Рекомендується встановлювати 2 нерозрізаних фільтра, оскільки вакуумна зона відсутня. Збільшення кількості фільтрів збільшує площу вакууму, що пов'язано з довговічністю каталітичного нейтралізатора. Результати моделювання передбачають використання 3 найбільш довговічних розрізаних фільтрів в порівнянні з використанням 2, 4 і 5 фільтрів. У нерозрізаних фільтрах (3, 4 і 5 штук) випадковий розподіл тиску обумовлений нерівномірним тиском. Цей нерівномірний потік знижує ефективність і довговічність каталітичного нейтралізатора, на відміну від випадку з 3 розрізаними фільтрами, які мають більш рівномірний розподіл тиску, більш тверді і сплавлені.

Ключові слова: вихлопні гази, забруднення повітря, навколишнє середовище, скорочення викидів вихлопних газів, каталітичний нейтралізатор, моделювання, нерозрізаний фільтр, площа вакууму, розрізаний фільтр, нерівномірний тиск

UDC 616 058+616 036.86+613.95
DOI: 10.15587/1729-4061.2018.145638

A STUDY OF MODELING OF FLUE GAS PATTERNS WITH NUMBER AND SHAPE VARIATIONS OF THE CATALYTIC CONVERTER FILTER

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1. Introduction

Exhaust gas in motorized vehicles is the main source of air pollution in the environment. The pollutant in the exhaust gas is in the form of particulate matter, volatile organic compounds and imperfect combustion remnants such as Carbon monoxide (CO), Carbon dioxide (CO_2), Sulfur dioxide (SO_2) and Nitrogen oxide (NOx). In addition to the primary pollutants mentioned above, exhaust gases also produce secondary pollutants, namely: Ozone (O_3) and secondary organic aerosols. These secondary pollutants are dangerous pollutants and are very concerning because of the adverse effects caused to the environment and human health. Pollution due to exhaust gas from motorized vehicles can be reduced by taking into account maintenance systems, modern engine control concepts, and fuel cleaners. However, this cannot improve air quality significantly due to the severe air pollution in major cities in the last 10 years. To overcome this, a Catalytic converter that has good quality in the absorption of exhaust emissions, a design that is reliable and durable, so that environmental pollution problems can be overcome.

2. Literature review and problem statement

Catalytic converters have gone through many amazing processes and evolution over the past 30 years. The most effective tool to fight pollutants in our environment, because it reduces nearly 80 % of the harmful gases produced by incomplete combustion from the engine. Catalytic converters in the form of stainless steel containers are installed along the engine exhaust pipe and in the container contain porous ceramic structures through which the exhaust gas flows [1]. Catalytic converter forms vary square, triangle, hexagonal and sinusoidal. Initially, the converter uses loose granular ceramic with the gas passing between the balls. Because it is difficult to keep the ball in place, many converter developers choose ceramic monoliths that offer various advantages. Among the advantages are smaller volume, lower mass and greater ease of packaging [2].

The active catalyst layer placed on the monolithic wall is called "waistcoat", consisting of pores, which are composed of an inorganic oxide such as γ-Al_2O_3 (Gamma alumina), CeO_2 (Ceria) and ZrO_2 (Zirconia). Catalysts derived from precious metals, such as Platinum (Pt), Palladium (Pd) and Rhodium (Rh), are deposited on the surface and inside the pores of the washcoat [3]. The exhaust gas flowing in the Catalytic converter diffuses through the washcoat pore structure to the catalytic site where heterogeneous catalytic reactions occur. Washcoat layer thickness is 20–100 μm. Thicker cleaning deposits ("fillets") form in the corners of cells, especially in sinusoidal channels of metal substrates. Oxidation catalysts are widely used in automotive industries such as Carbon monoxide and Oxide hydrocarbons. Reduction of toxic gas (NOx) began to be implemented in the majority of vehicle exhaust systems [2]. Three-way Catalytic converters provide oxidation and reduction processes to replace a two-way converter and generally, CO reactions begin first, followed by HC and NOx reactions. With the condition of lean-mixture, the catalyst is able to oxidize HC and CO following the reaction as follows:

$$2CO+O_2 \rightarrow 2CO_2, \quad (1)$$

$$4HC+5O_2 \rightarrow 4CO_2+2H_2O. \quad (2)$$

With the operation of a rich mixture, catalysts help NOx reduction reactions with reactions involving HC and CO as follows:

$$2CO+2NO \rightarrow 2CO_2+N_2, \quad (3)$$

$$4HC+10NO \rightarrow 4CO_2+2H_2O+5N_2. \quad (4)$$

Reducing emissions of toxic substances from engine combustion can be achieved by primary measurements (inside the engine) and secondary measurements (outside the engine). As a major measure of various possibilities and technical methods to reduce exhaust emissions used for example combustion of mixed non-fat air fuels, multi-stage injection fuel, re-circulation of exhaust gas in the gas fuel after burning, additional water loading into the cylinder volume [4, 5]. In the exhaust gas treatment process in the exhaust, various advanced technologies are applied based on the oxidation and three-way catalyst adsorption and filtration process [6]. This allows the reduction of Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen oxides (NOx) and particulate emissions from gasoline or diesel engines to meet the regulatory demands of future exhaust emissions [7, 9].

Research by [10] made an effort to make a gas flow uniform by using solid workflow assistance using simulation. The results of this simulation find that the circular channel is the best in creating a uniform exhaust gas flow. In the development of a circular channel, this is often not possible because of the limitations of the room from the Catalytic converter design. Therefore, a short expansion combined with a guide blade is often used [11].

To minimize the design and save material modification, the filter form can be done to direct the exhaust gas flow. The hole diameter in the filter affects the back pressure flow in the Catalytic converter. The back pressure flow that occurs is greater when the diameter of the hole is small and vice versa. Backflow in the Catalytic converter causes a vortex so turbulence and vacuum areas occur [12].

The occurrence of turbulence flow is very effective in reducing flow velocity and increasing the filtration process in exhaust gases [13]. To increase the occurrence of flow turbulence and prevent the occurrence of a wide vacuum area, it is necessary to do a simulation with variations in the number and shape of the filter-cut with a zig-zag arrangement in the Catalytic converter. So that the design of a catalytic converter is obtained which meets the absorption standards of exhaust emissions.

3. The aim and objectives of the study

The aim of the paper is to find out the phenomenon of exhaust gas that passes through the filter-cut and filter-not-cut in the Catalytic converter. So that a design that is durable with maximum absorption of exhaust emissions is obtained.

To achieve the aim, it is necessary to accomplish the following objectives:

– Analysis of the behavior of the exhaust gas when passing through the filter-cut and filter-not-cut forms, the advantages and, disadvantages when used in catalytic converters.

– Know the effect of flow and decrease pressure on durability in the design of catalytic converter models.

– Looking for the best design so that the aging of the catalytic converter can be overcome.

4. Materials, methods, and models of research

This research method, starting from making the Catalytic converter design which includes: filter-not-cut image dimensions (Fig. 1, *a*) and filter-cut images (Fig. 1, *b*). Then designing the Catalytic converter frame dimensions and filter placement distance with variations: 2, 3, 4 and 5. Perform simulations with CFD 14.5 software, student version with the following parameters:

User mode: Viscous-laminar.

Analysis mode: Steady state.

Fluid type: Air.

Boundary condition: inlet, outlet, wall.

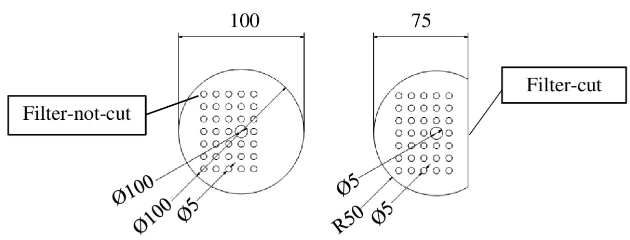


Fig. 1. Cut-filter model: *a* — Filter dimensions; *b* — Filter-not-cut model

Fig. 2 shows the mounting distance between two filters, with a single axis arrangement and the distance between one filter and another filter is 45 mm. The central part is an iron pipe with a 10mm outer diameter that serves as a filter handle.

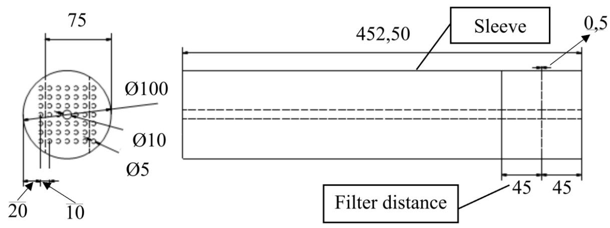


Fig. 2. Filter installation distance

The steps in this simulation follow the research flowchart as shown in Fig. 3. The first step is the Catalytic converter design in the form of Filter-not-cut and Filter-cut with variations: two, three, four and five filters. Then simulate the ANSYS software and analyze the results.

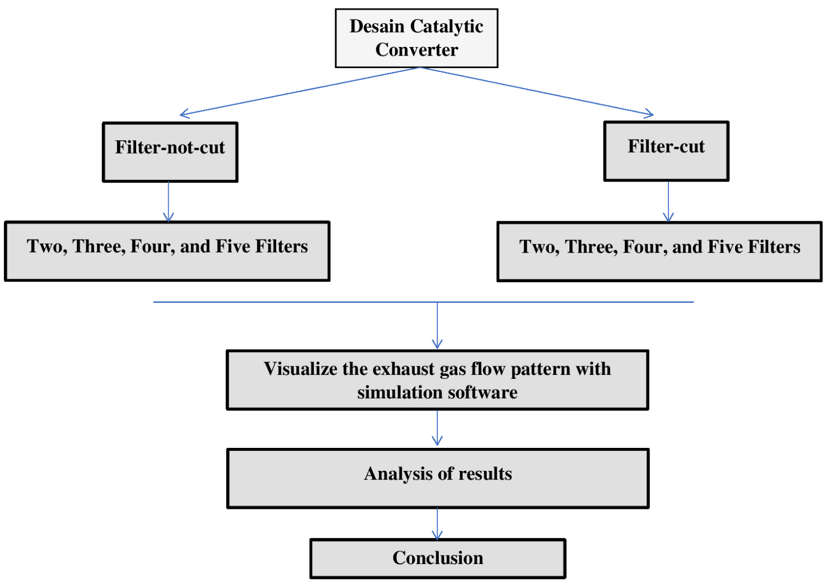


Fig. 3. Research flow chart

5. Research results of the flue gas flow pattern with variations in the number and shape of the catalytic converter filter

Fig. 4 is a simulation image of filter-not-cut and filter-cut when flushing gas. There are six forms of simulations made here, namely: 2, 3, 4 and 5, type filter-not-cut and filter-cut, each of which is shown in Fig. 4, *a–h*. The arrangement of filters is in one axis with a number of 2–5.

The filter-cut is designed in such a way that the exhaust gas is in turbulence condition, with the hope that the exhaust gas absorption process is more effective.

Table 1 shows the condition of the flue gas flow velocity that occurs in the Catalytic converter. The highest speed occurs in the variation of 2 filter-not-cut with a value of 49.39 m/s and there is a decrease in speed in the modification 2 filter-cut of 42.54 m/s. While the lowest value occurs in the variation of 5 filters-not-cut with a value of 34.94 m/s and the filter-cut modification is able to reduce the speed by 34.43 m/s.

Fig. 5 is a graph of the relationship between the number of filters and the exhaust gas velocity, the results show that the difference in exhaust gas velocity is getting smaller with the increasing number of filters. The number of filters 4 and 5 shows that the difference in speed is getting smaller, this shows that the addition of a number of filters increases the resistance to the exhaust gas flow. When the flow velocity decreases, the contact between the filter and the exhaust gas is more effective in the absorption of pollutant gases.

The difference in the highest speed increase between filter-not-cut and filter-cut occurs in variations in the number of filters: 2 with a percentage value: 685 % (shown in Fig. 6) and the lowest in the number of filters: 4 with a percentage value: 31 % (shown in Fig. 6). The increase in velocity percentage is caused by the flow of exhaust gas passing through the small holes in the filter so that it changes the gas pressure to increase speed.

Fig. 7 shows simulation results of exhaust gas flow through a Catalytic converter with two filters. In the filter-not-cut, the turbulence that occurs is small in the hole out of the filter as shown by the ellipse image (Fig. 7, *a*) and on the two filters-the cut turbulence shape that occurs is greater as shown in the figure (Fig. 7, *b*). This is due to gas flow waste more freely when passing through the filter cut. The effect of the appearance of turbulence is to reduce the flow rate of the exhaust gas in the Catalytic converter.

This turbulence area is increasing as the number of filters increases. Each turbulence area is shown in Fig. 8, *b* and Fig. 9, *b* and Fig. 10, *b*. From the simulation results, it appears that turbulence is greater than turbulence in Fig. 8, *a*, Fig. 9, *a*, and Fig. 10, *a*. This turbulence condition is very effective in reducing flow velocity and increasing the filtration process in the exhaust gas.

Table 1

Shows the condition of the flue gas flow velocity that occurs in the Catalytic converter

No.	Number of Filters	Entry Speed (m/s)	Design speed filter-not-cut (m/s)	Percentage of speed increase (%)	Entry Speed (m/s)	Design speed filter-cut (m/s)	Percentage of speed increase (%)	Difference in speed percentage (%)
1.	2	1	49.39	4,839	1	42.54	4,154	685
2.	3		43.16	4,216		41.26	4,026	190
3.	4		38.32	3,732		38.01	3,701	31
4.	5		34.94	3,394		34.43	3,343	51

Note: V_{in} (exhaust gas velocity)=1 m/s, P (exhaust gas pressure)=1 atm

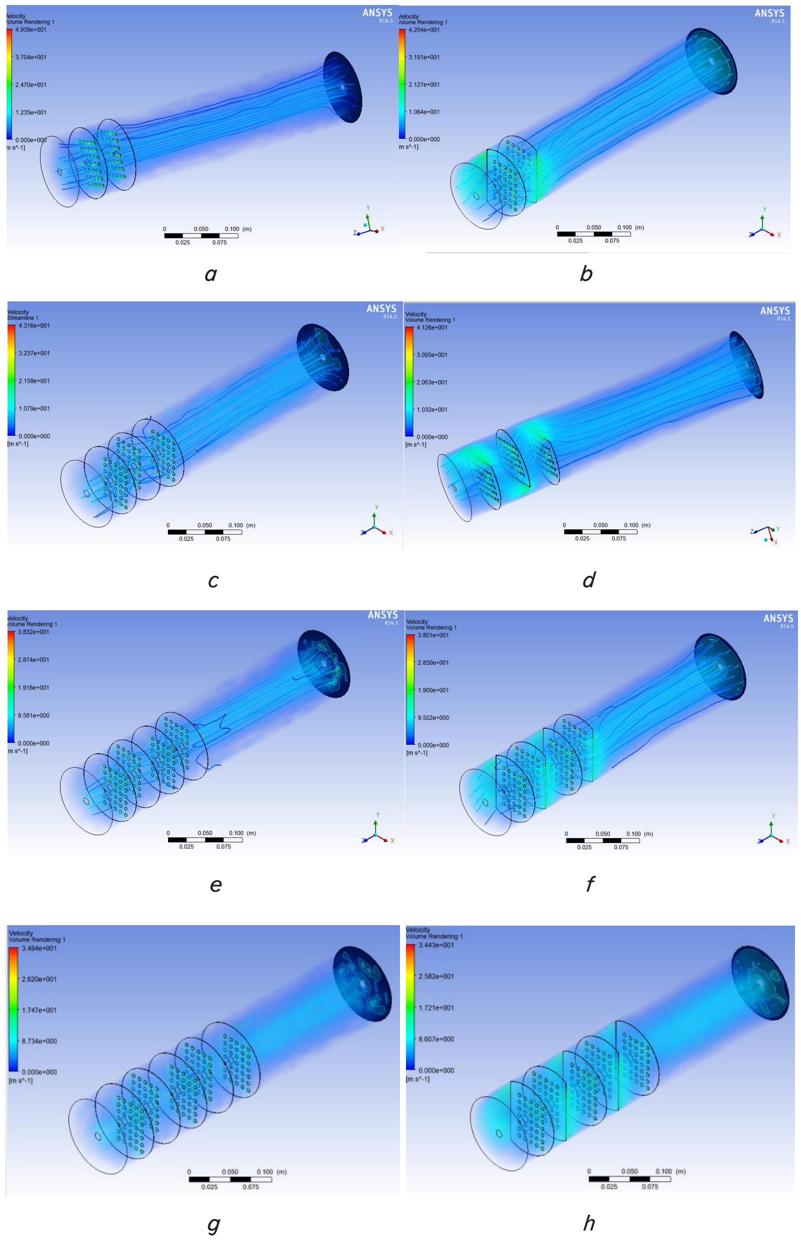


Fig. 4. The flue gas flow pattern passes through filters: *a* – Type 2 filter-not-cut; *b* – Type 2 filter-cut; *c* – Type 3 filter-not-cut; *d* – Type 3 filter-cut; *e* – Type 4 filter-not-cut; *f* – Type 4 filter-cut; *g* – Type 5 filter-not-cut; *h* – Type 5 filter-cut

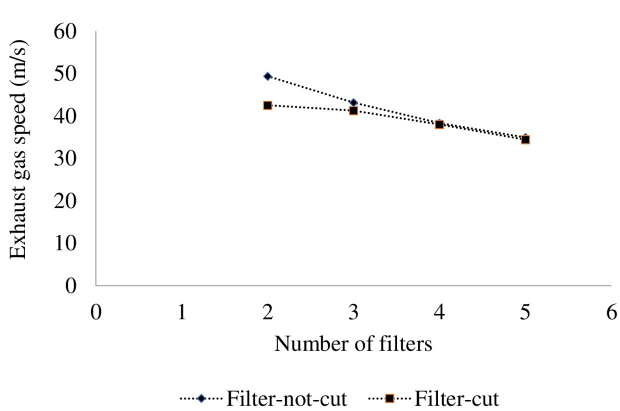


Fig. 5. Graph of the relationship between the number of filters and the exhaust gas speed

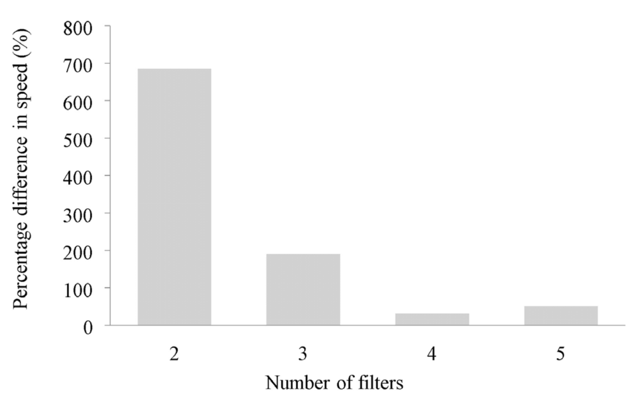
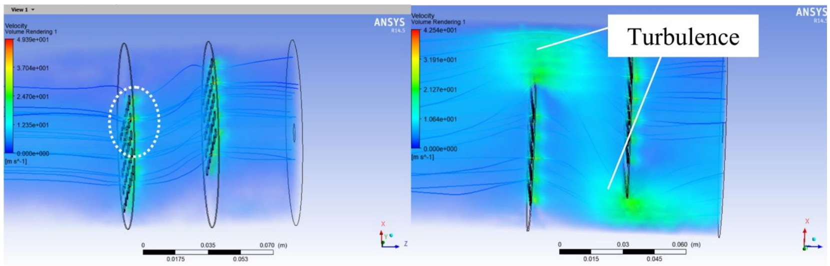
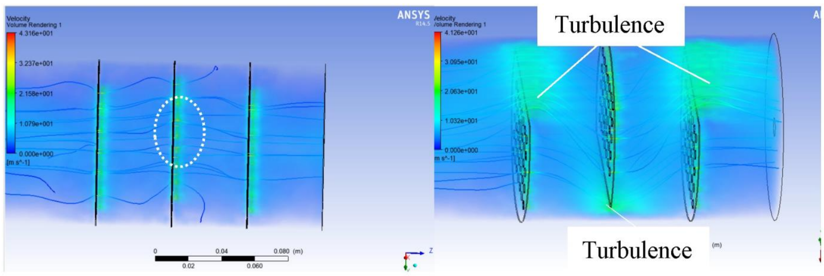


Fig. 6. Graph of the relationship between the number of filters and the percentage of the speed difference between Filter-not-cut with Filter-cut



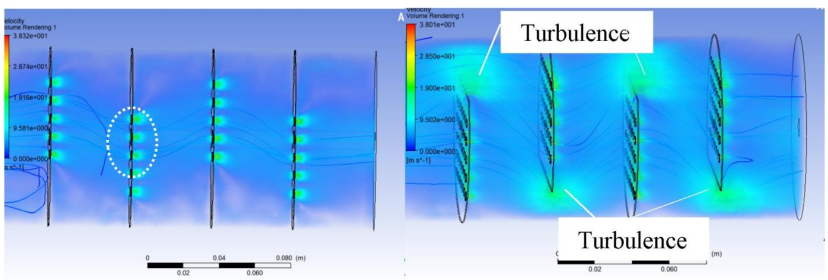
a *b*

Fig. 7. The flue gas flow pattern passes through two Catalytic converters: *a* — Filter-not-cut and; *b* — Filter-cut



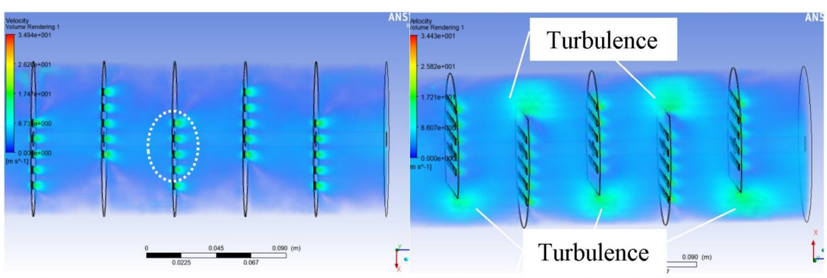
a *b*

Fig. 8. The pattern of exhaust gas passes through three catalytic converters: *a* — Filter-not-cut and; *b* — Filter-cut



a *b*

Fig. 9. The exhaust gas flow pattern passes through four Catalytic converters: *a* — Filter-not-cut and; *b* — Filter cut



a *b*

Fig. 10. The flue gas flow pattern passes through five Catalytic converters: *a* — Filter-not-cut and; *b* — Filter cut

6. Discussion of the research results of the of Flue Gas Patterns with Number and Shape Variations of the Catalytic converter filter

Fig. 11 shows the pressure distribution that occurs along the Catalytic converter channel. From the simulation results, it appears that the vacuum is increasing with the increasing number of filters. The addition of the number of filters triggered a vacuum in the Catalytic converter channel, the green area of the image (Fig. 11, *d*) shows the increasing vacuum value. From this phenomenon, it can be concluded that the installation of 2 filter-not-cut pieces as shown in Fig. 11, *a* is a safe condition where there is no vacuum. From the results of this simulation, it can be concluded that the addition of a number of filters increases the vacuum area that occurs as shown in the figure (Fig. 11, *b–d*) and this is related to the durability of the Catalytic converter.

Fig. 12 shows the distribution of pressure that occurs in the Catalytic converter channel. The yellow color occurs at the ends of the filter-cut, this shows the occurrence of vacuum areas. The ends of the filter are damaged more quickly due to receiving a high vacuum level as shown in the figure (Fig. 12, *a*, *c*, *d*). From the results of this simulation, it is advisable to use 3 filter-cut images (Fig. 12, *b*) which are the most durable compared to the number of filters 2, 4 and 5 pieces. This is due to the relatively smaller vacuum area compared to the area (Fig. 12, *a*, *c*, *d*).

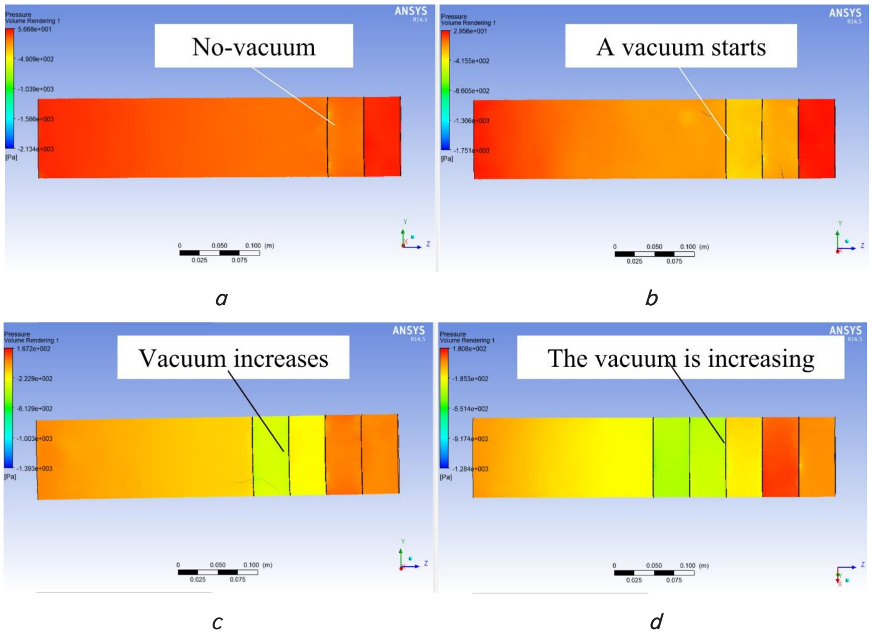


Fig. 11. Distribution of exhaust gas pressure in the filter-not-cut variation:
a – Filters 2; *b* – Filters 3; *c* – Filters 4 and; *d* – Filters 5

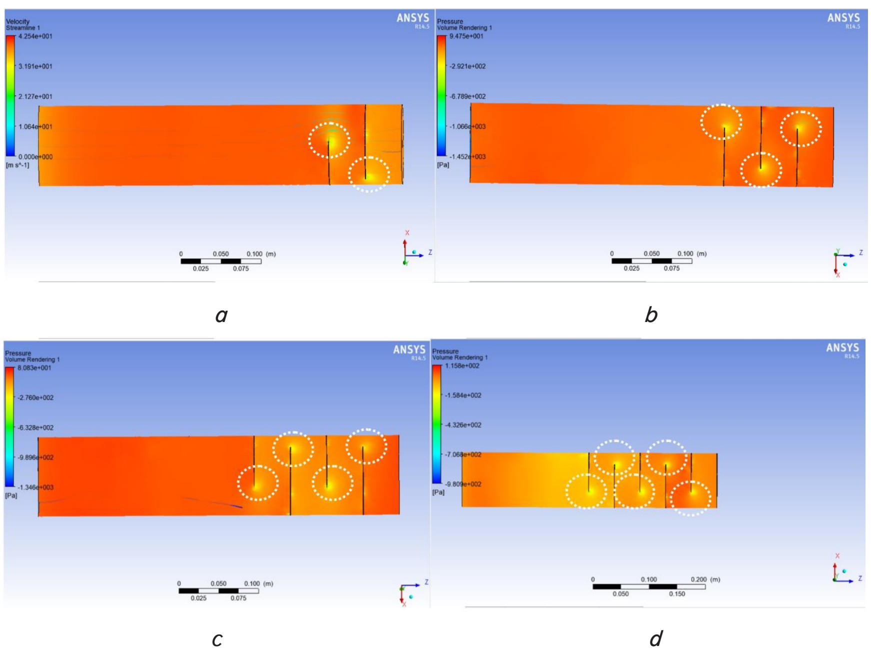


Fig. 12. Distribution of exhaust gas pressure on filter-cut variations:
a – Filters 2; *b* – Filters 3; *c* – Filters 4 and; *d* – Filters 5

Fig. 13 shows the pressure analysis in the 2-filter-cut/filter-cut section as shown in the figure (Fig. 13, *a*, *b*) and 3 filter-not-cut/filter-cut images (Fig. 13, *c*, *d*). The results of the pressure analysis show that the pressure distribution of the 2-note-cut filters is more stable because the direction of centrifugal pressure flow is the same and evenly distributed as indicated by the white arrow while the 2 filter-cut direction of the pressure flow changes as shown by the arrow (red, yellow and black). The results of this analysis show that the 2-filter-not-cut pressure distribution is better than the 2-cut filters.

The opposite is true for variations in the filter-not-cut and filter-cut, in the random pressure distribution not-cut filter due to the presence of dark blue (low pressure) dots in light blue (higher pressure) as indicated by the yellow arrow. This causes a random and non-uniform pressure flow direction. This non-uniform flow decreases the efficiency and durability of the Catalytic converter. Unlike the case with filter-cut, the pressure distribution is more regular than the filter-not-cut as shown by the green arrow. The distribution of pressure on the cut-filter is more solid and fused, divided into two compressive distributions: dark blue (low pressure) and light blue (higher pressure).

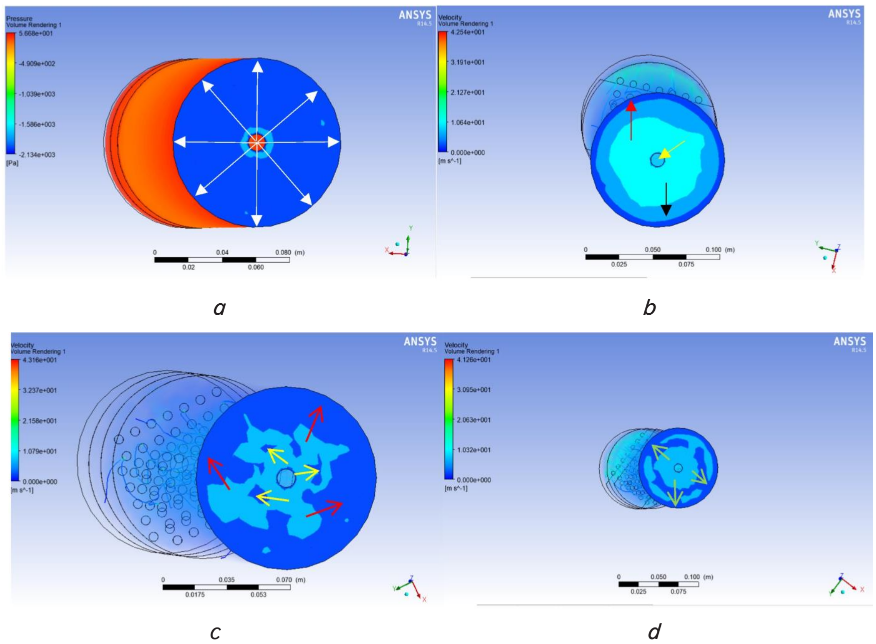


Fig. 13. Distribution of pressure on: *a* — Filter-not-cut 2; *b* — Filter-cut 2; *c* — Filter-not-cut 3 and; *d* — Filter cut 3

7. Conclusions

1. The increase in velocity percentage is caused by the exhaust gas flowing through the small holes in the filter so that it changes the gas pressure to increase speed.

2. Installation of 2 not-cut filters is a safe condition where there is no vacuum. The addition of the number of filters increases the vacuum area, which is related to the durability of the Catalytic converter.

3. From the results of this simulation, it is advisable to use the 3 filter-cut pieces that are most durable compared to the number of filters 2, 4 and 5 pieces. This is caused by the smaller vacuum formed.

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