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THE RESONANCE EXPANSION SYSTEM FOR EMISSIONS REDUCTION OF INTERNAL COMBUSTION ENGINES

Summary. One of the main problems of today's automotive manufacturers are emission norms that are getting much stricter. According to these high demands, car manufacturers are developing new systems to keep exhaust emissions at the lowest possible level. The resonance expansion system for emissions reduction of internal combustion engines could decrease emissions production not only in modern vehicles but also in older vehicles by additional mounting on the exhaust system. This article shows the resonance expansion system technical solution and simulations of fluid flow done in flow simulation software. The resonance expansion system is also patented, and further experiments for design improvement are planned in the near future.

Keywords: analysis, muffler, catalytic converter

1. INTRODUCTION

The automotive industry and especially its drive systems are currently undergoing fundamental changes, which are a reaction to significantly stricter emission standards with

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the aim of achieving carbon neutrality [1,2]. Emission-free propulsion is currently primarily understood as the emission-free operation of a car. However, it is necessary to consider the entire chain during the production and operation of a car [3]. In the case of electric cars, the largest production of CO₂ occurs during the production and recycling stage. At the same time, the possibility of reducing CO₂ in the stage of using an electric car is very limited, especially when the charging current is not produced from renewable energy sources [4,5]. The internal combustion engine as a propulsion unit of vehicles, despite several disadvantages, remains the most popular choice from the customers' point of view [6]. At the same time, it forms an important element in hybrid propulsion, and therefore research and development in the field of new engine technologies remain essential from an ecological point of view. Attention is mainly focused on technologies that use the combustion of a homogeneous fuel mixture, which, together with carbon-neutral fuels, have considerable potential in reducing the emission footprint of vehicles [7,8]. Several concepts have been developed so far, but mastering the entire combustion process is a difficult technical challenge. An important element of the entire engine system is the exhaust system, which, in addition to reducing acoustic emissions and harmful substances with the use of a catalyst, significantly affects the filling of the cylinder with a fresh mixture and its homogenization [9]. Therefore, one of the new technical solutions is a resonance expansion system for reducing emissions of combustion engines, which forms part of the compression ignition system of a homogeneous mixture and can contribute to solving the emission problem of vehicles [10,11].

2. TECHNICAL SOLUTION

Emission norms are getting stricter lately and many modern cannot pass emission tests equipped with a standard exhaust system. This technical solution offers one possible way for vehicle owners to pass emission controls without serious modification of the engine itself or ECU (engine control unit) which is often done in a bad way and can damage engine components. The muffler can be added to the standard exhaust system as a secondary or tertiary catalytic converter with an additional muffler [12].

The resonance expansion system for emissions reduction of internal combustion engines consists of an inlet pipe opening mouthed into a dual resonance chamber with a symmetrical baffle. This symmetrical baffle is connected to the catalytic converter by a compression perforated tube and an expansion perforated tube passing through the absorption section. The last part of the muffler consists of a reverse-cone outlet pipe that feeds into the catalytic converter by an asymmetric baffle that separates the expansion chamber from the catalytic converter. The essence of the technical solution is that the dual resonance chamber is divided by a symmetrical partition into two equal parts, and the length dimensions of the absorption section, the catalyst, and the expansion chamber are the same as the length dimensions of the half of the dual resonance chamber, and at the same time, the smallest inner diameter of the reverse cone in the area of the asymmetric partition is identical with the diameter of the compression perforated pipe and the diameter of the expansion perforated pipe. Theoretically, there is a maximum and minimum temperature for the exhaust pipe, defined by its shape and dimensions. In this temperature interval, the exhaust gases move in the exhaust pipe at an optimal speed and, with the help of reverse resonance, ensure appropriate homogenization of the fuel mixture. The reverse resonance positively affects the engine performance and torque and has a positive effect on the emission parameters. This concept, according to research,

represents a contribution to the subject area due to its compactness and positive influence on the monitored parameters [13].

Fig. 1 shows a resonant expansion system for reducing combustion engine emissions. The vertical cross-section of a dual resonance chamber with a symmetrical partition can be seen in Fig. 2, and Fig. 3 shows a vertical cross-section of an asymmetric partition [14-16]. The resonance expansion system for reducing emissions of combustion engines consists of an inlet pipe (1) opening into a dual resonance chamber (2) with a symmetrical partition (3), connected to the catalytic converter (4) by compression perforated pipe (5) and an expansion perforated pipe (6). Perforated pipes are surrounded by absorption material (7). The outlet pipe (8) with a reverse cone (9) opens into the catalytic converter (4) through an asymmetric baffle (10) that separates the expansion chamber (11) from the catalytic converter (4). The dual resonance chamber (2) is divided by a symmetrical baffle (3) into two equal parts and the length dimensions of the absorption section (7), the catalytic converter (4), and the expansion chamber (11) are the same as the length of the half of the dual resonance chamber (2) and at the same time, the smallest inner diameter of the reverse cone (9) in the area of the asymmetric baffle (10) is identical to the diameter of the compression perforated tube (5) and the diameter of the expansion perforated tube (6).

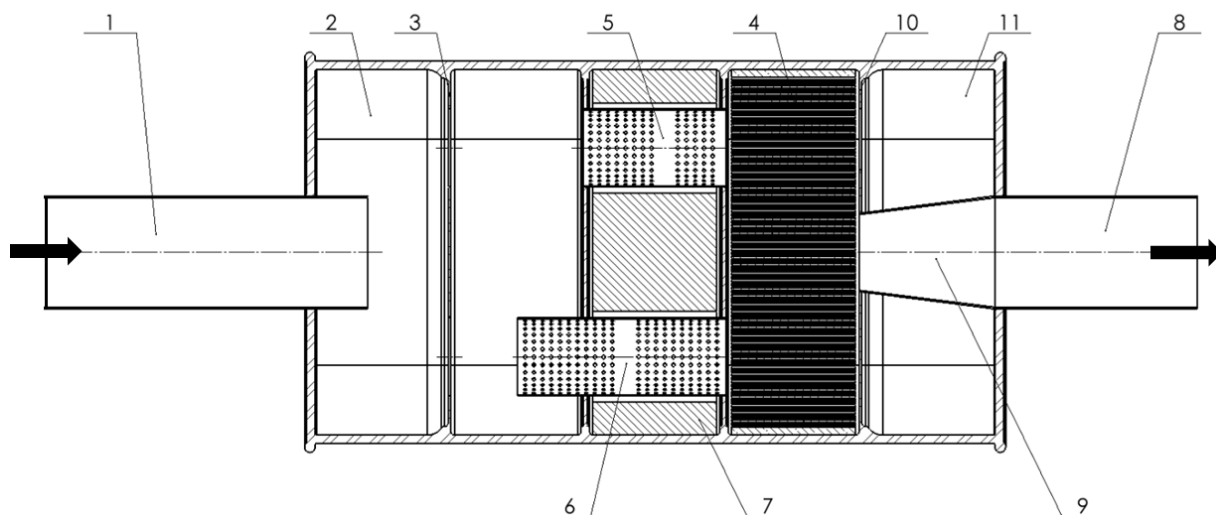


Fig. 1. The resonant expansion system for reducing combustion engine emissions (1. Inlet pipe, 2. Dual resonance chamber 3. Symmetrical baffle, 4. Catalytic converter, 5. Compression perforated pipe, 6. Expansion perforated pipe, 7. Absorption section, 8. Outlet pipe, 9. Reverse cone pipe area, 10. Asymmetric baffle, 11. Expansion chamber)

2.1. Design application

Resonant expansion system for reducing emissions of combustion engines according to Fig. 1, 2, 3 was applied to an internal combustion engine, where it forms part of the engine system as well as the exhaust system to ensure higher efficiency in the use of a homogeneous fuel mixture [17].

The principle of operation of the resonance expansion system for reducing the emissions of combustion engines is that the exhaust gases from the combustion chamber of the engine flow through the inlet pipe into the dual resonance chamber with a symmetrical baffle. Subsequently, with the help of the compression perforated pipe and the expansion perforated pipe, the exhaust

gases flow through the absorption section into the catalytic converter and through the reverse cone. The asymmetric baffle and the expansion chamber push exhaust gases into the outlet pipe. The compactness of the designed muffler offers very good noise and emission parameters and has a significant effect on resonance waves, which significantly affects better fuel homogenization and higher efficiency of the combustion engine [18,19].

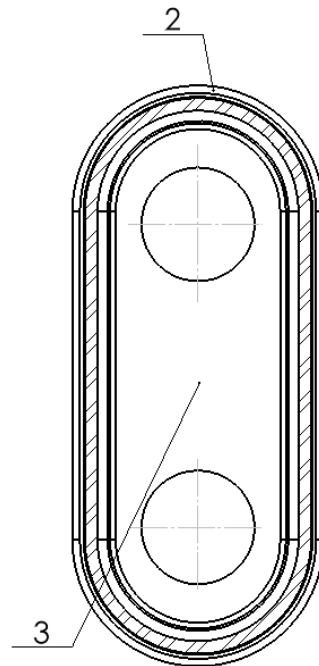


Fig. 2. The vertical cross-section of a dual resonance chamber with a symmetrical baffle

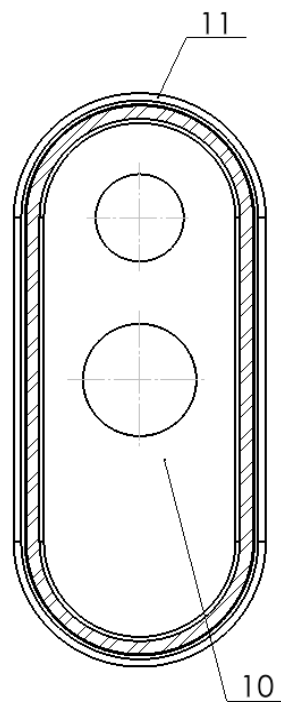


Fig. 3. Vertical cross-section of an asymmetric baffle

3. EXPERIMENTAL RESULTS

The resonance expansion system for reducing emissions of combustion engines underwent basic flow simulation in ANSYS Fluent software which showed results of the velocity, pressure, and temperature. The results of velocity inside the system are shown in Fig. 4.

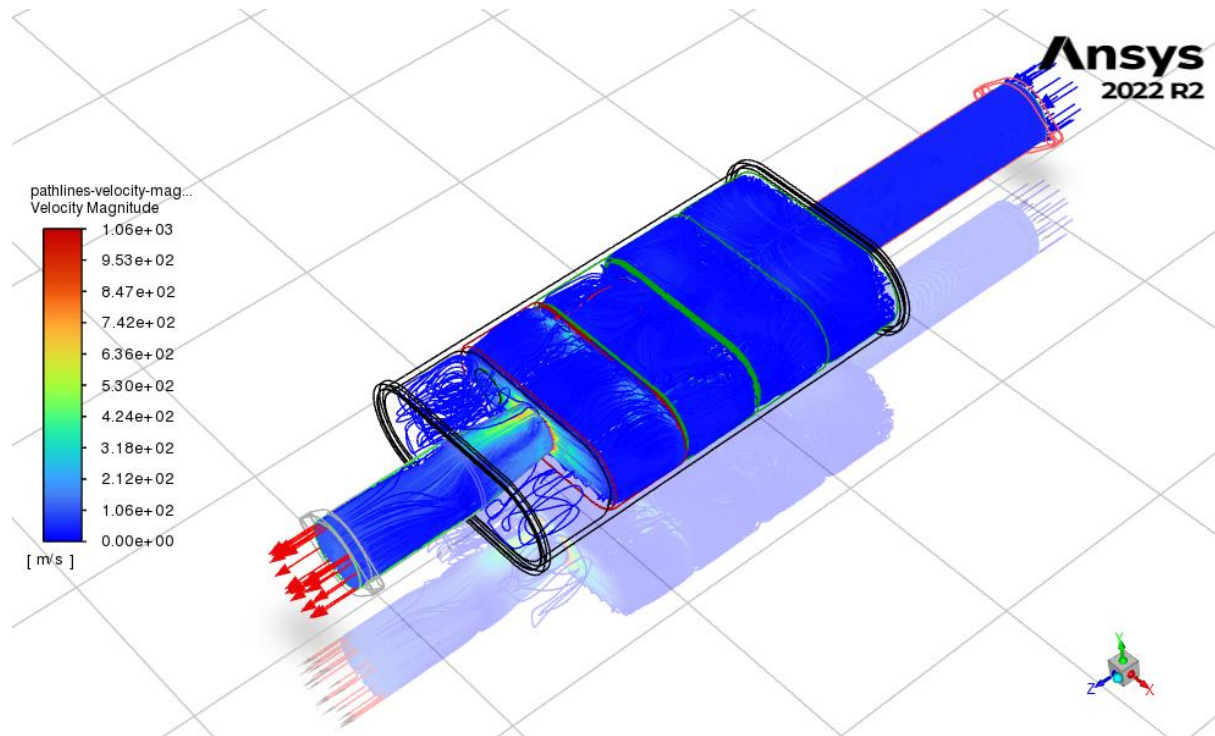


Fig. 4. Fluid velocity inside the resonance system

The velocity at the system inlet was set to 115 m.s^{-1} which increased after the catalytic converter portion, mainly thanks to the conical inlet of the outlet pipe. Increased velocity has a positive effect for better exhaust gas flow from the engine and decreases created backpressure in the system. More detailed results are shown in Fig. 5.

According to Fig. 5, the velocity reaches a minimum at the area of the catalytic converter with a value of around 5 m.s^{-1} and rapidly increases to a value of around 550 m.s^{-1} which represents the conical part of the outlet pipe.

Simulation software provided information about fluid pressure which flows through the system. These results are shown in Fig. 6.

The pressure inside the resonance system decreases in the catalytic converter area while the cone part of the outlet pipe shows slightly negative pressure which will be further examined and changes to the design would be made. The current design will be constructed and tested if the negative pressure is real or the error of the simulation.

Further details of the pressure are shown in Fig. 7.

The fluid flow in the system shows a rapid pressure decrease which starts at the beginning of the catalytic converter section. As mentioned, there is slight negative pressure at the area of the conical part of the outlet pipe, which will be examined in further experiments and simulations.

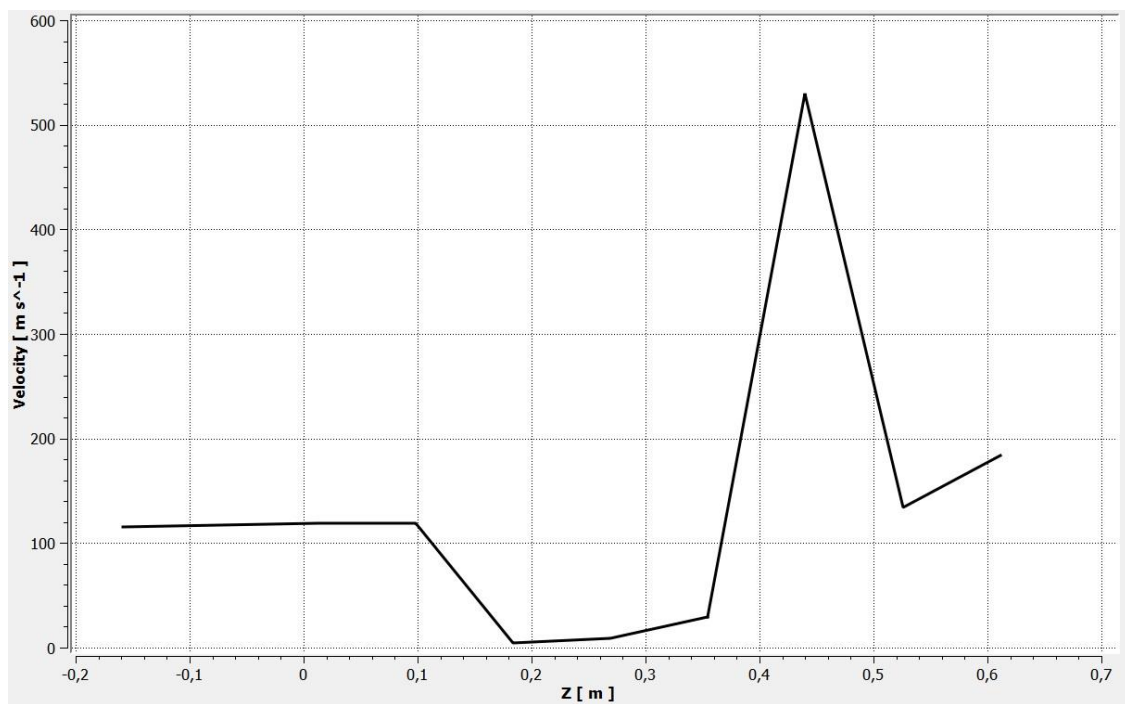


Fig. 5. Chart of the velocity and system length

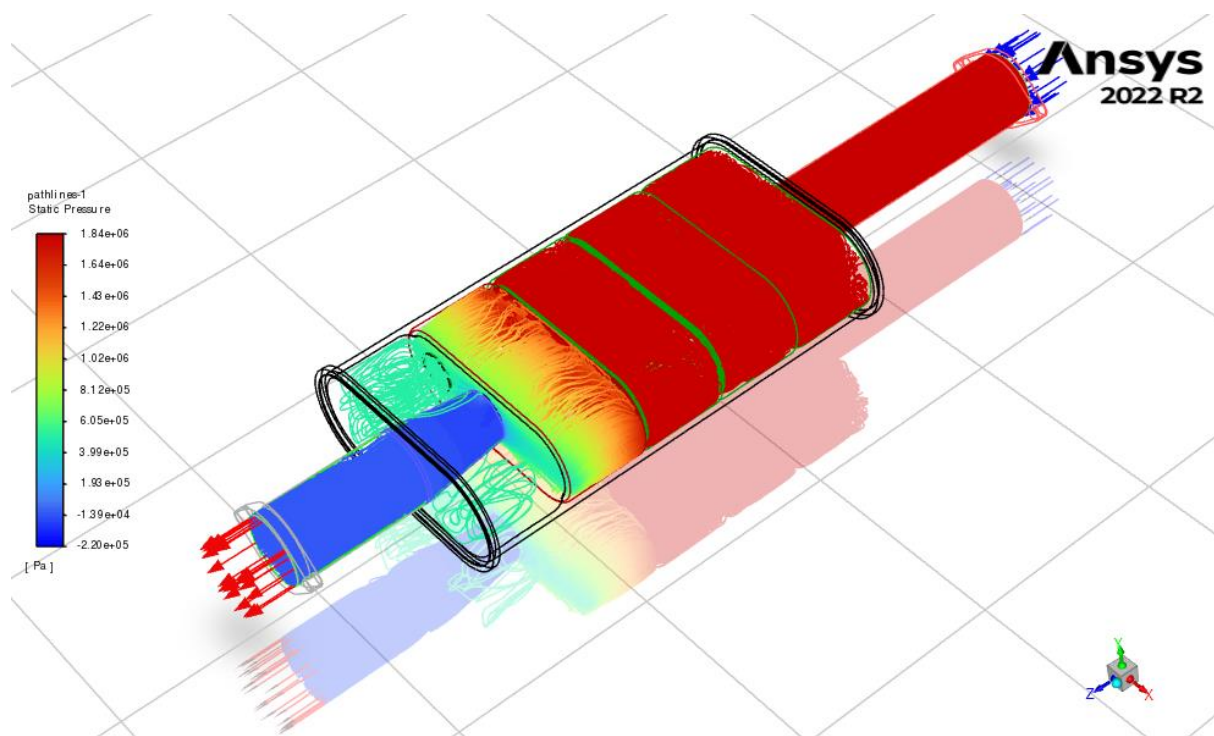


Fig. 6. Fluid pressure inside the resonance system

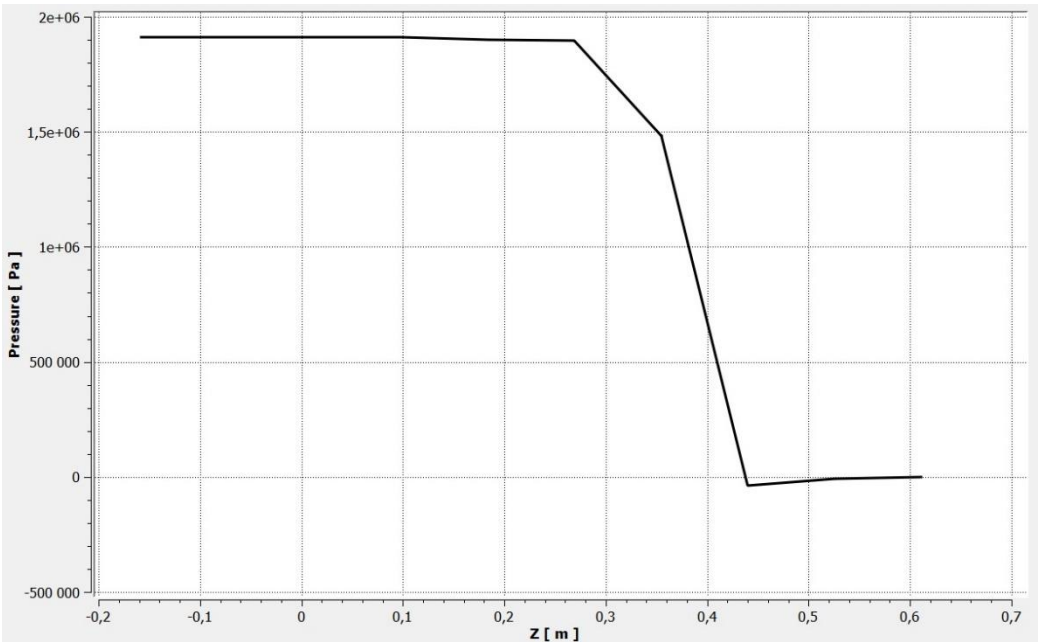


Fig. 7. Chart of the pressure and system length

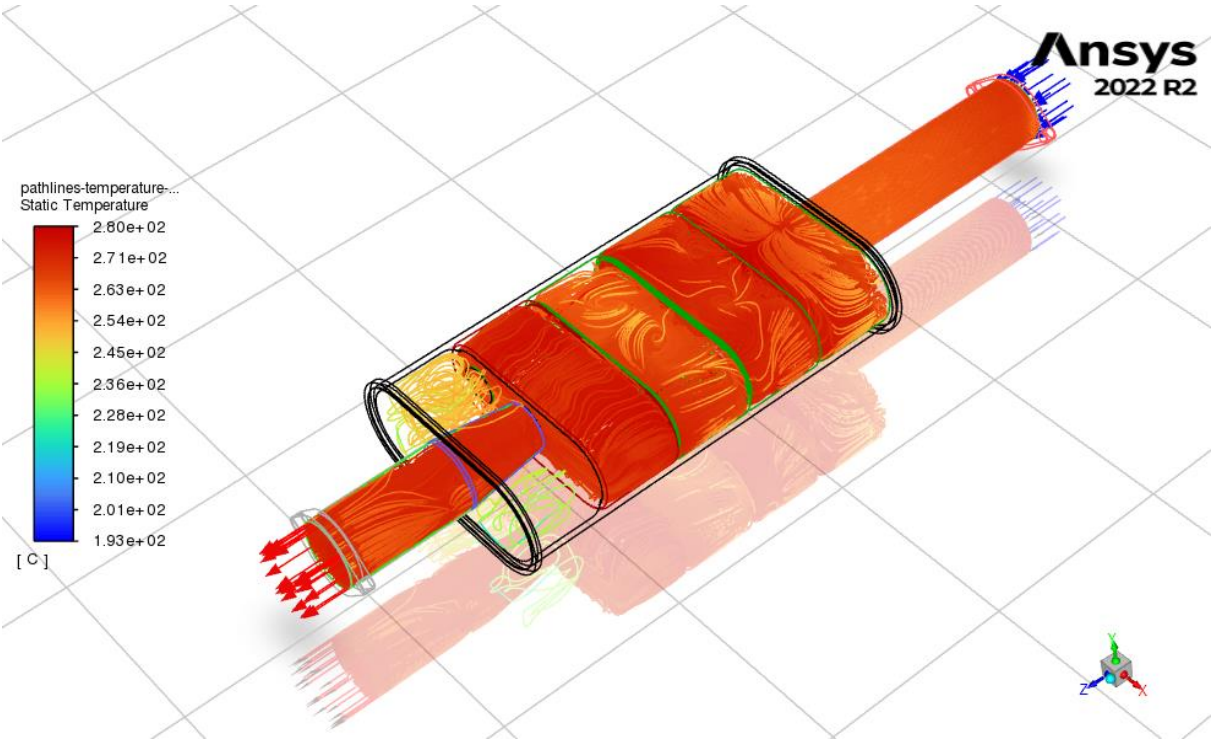


Fig. 8. Fluid temperature inside the system

The fluid temperature inside the muffler system, Fig. 8, shows a temperature increase in the catalytic converter, which was also the aim of the design to secure additional chemical reactions to decrease the number of pollutants contained in exhaust gases. The inlet temperature was set to $280\text{ }^{\circ}\text{C}$ which corresponds with after primary catalytic converter temperature to see if the additional catalytic converter can reach the temperature for chemical reactions. The inlet temperature can vary depending on engine type and engine speed. The walls' heat transfer coefficient was set to $50\text{ W}/(\text{m}^2\text{K})$ and the free stream temperature was set to $126\text{ }^{\circ}\text{C}$ which also can be changed according to the operating condition of a tested engine.

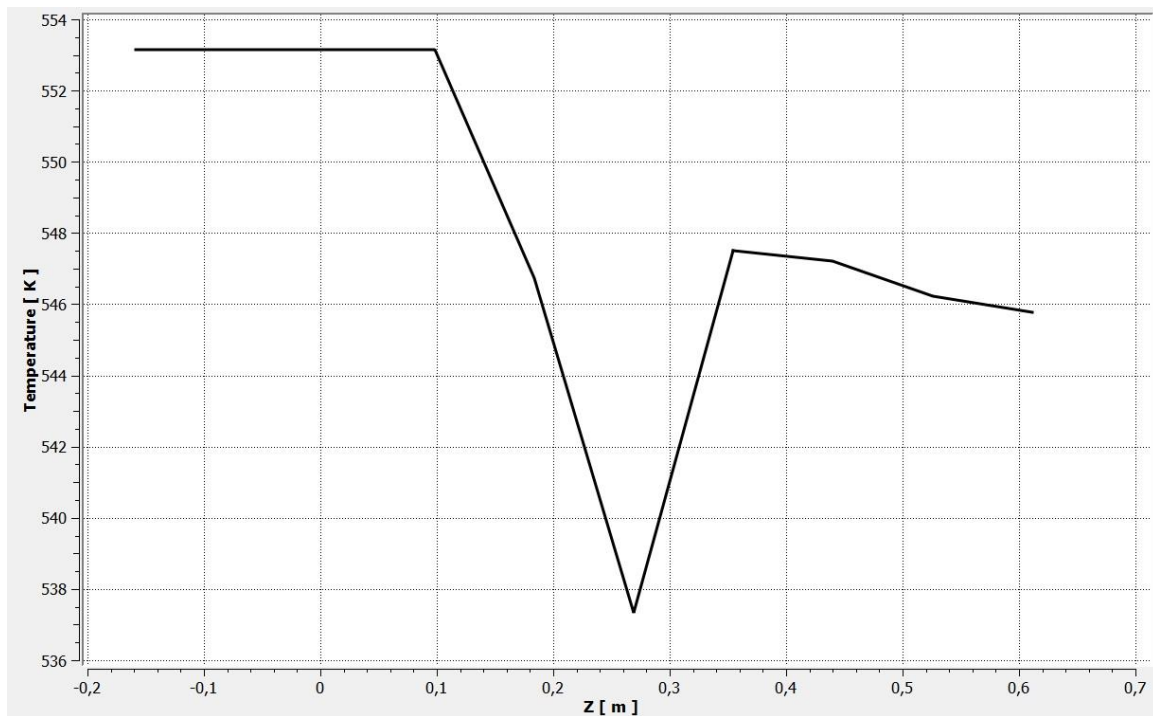


Fig. 9. Chart of the temperature and system length

The chart in Fig.9 shows the fluid temperature progress in the system, which decreases in two regions, before the catalytic converter and after the catalytic converter. The highest temperature in the system is around 553 K and the lowest is around 537 K .

The system design as well as system geometry created in 3D CAD software used for calculating simulations and results obtained can be seen in Fig 10.

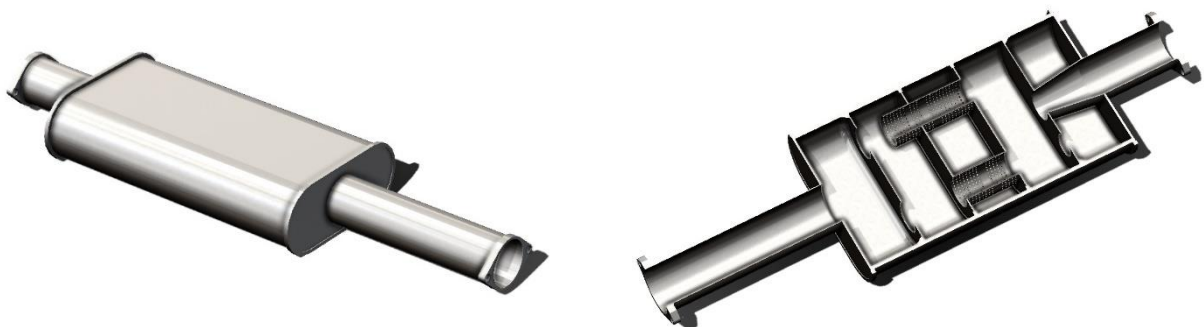


Fig. 10. System normal and cross-section view

4. CONCLUSION

The resonance expansion system for reducing emissions of combustion engines is intended for engines using advanced mixture combustion technologies and, as part of a homogeneous mixture compression ignition system, contributes to solving the application problems of this technology and reducing emissions. Since this technology represents one of the options that will guide the future of modern automobile engines, it is possible to assume its good industrial applicability and development of advanced combustion technology with the aim of reducing the emission footprint of automobiles.

Analysis results show promising results of the design correctness. The temperature, pressure, and velocity of the fluid flow have nearly the required values according to the system design. The temperature value increased in the catalytic convertor as wanted. The increase in the velocity value could be seen in the cone part of the outlet pipe. The pressure value decreased in the catalytic convertor; however, the negative pressure was present in the cone part of the outlet pipe which will be the subject of further experiments.

Support for research activities focused on innovative technologies provides a prerequisite for potential future industrial applicability of this exhaust technical solution.

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