



CFD Analysis of Exhaust Manifold for Different Designs

Ömer Cihan* , Mehmet Bulut 

Department of Mechanical Engineering, Hakkari University, Hakkari, Turkey

Abstract

The exhaust manifold as a simple part of the engine plays an important role for automotive industry, and it significantly effects on efficiency and performance of the engine depending on various parameters of the manifold such as material type and geometric sizes of the manifold. Therefore, in the current study, two different exhaust manifolds (type A and type B) were proposed for modelling of manifold, and their solid models were drawn with help of SOLIDWORKS software. Computational fluid dynamic (CFD) analyses were performed by using ABAQUS V6.13 software with importing manifold solid model from SOLIDWORKS software. Three different fluid materials as gasoline, alcohol and LPG were used in the fluid flow analyses for each manifold. Variation of pressure, velocity and temperature was numerically explored at different points of the manifolds. Results showed that exhaust manifold with type A exhibited higher pressure compared with type A exhaust manifold with indicating that performance and efficiency of engine can be improved by designing the manifold with respect to type A manifold.

Keywords: Exhaust manifold, CFD analysis, Modelling, Fluid flow.

1. INTRODUCTION

Development of an internal combustion engines having low fuel consumption depends on various basic parameters such as improvement of performance and combustion, material life, structural change in the engine, wide range of operated, the desired value of exhaust emission and noise. For high performance of combustion engine as specified, it is necessary to decrease the time and cost during research and development process. In this context, numerical methods like finite element analyses would be better choice to decrease time and modelling nonlinear and complex problems. Therefore, researches with numerical methods have been increasing in engines automotive industry.

The exhaust manifold is an important part for the engine to operate regularly and efficiently in terms of engine efficiency and exhaust emissions, although it is seen as a simple component which allows the burned gases to be ejecting from the engine. A well-designed exhaust manifold will provide the improvements of engine's mechanical and thermal efficiency, comfortable and noiseless operation of the engine as well as reduced exhaust emissions. An exhaust manifold consists of pressure loss due to the high speed of gas flow. In this case, the engine exhibits to deteriorate burning and emission as a result of the backfire of the exhaust gas and power loss [1].

Exhaust manifold design is a complex structure depending on several parameters such as back pressure, exhaust speed and mechanical efficiency. Researchers [2] compared the efficiency and performance of an exhaust manifold with considering different types of manifold designs. In another study, the exhaust manifold of a four-stroke and four-cylinder gasoline engine was analyzed by using gasoline, alcohol and LPG (Liquefied Petroleum Gas) fuels. In addition, some parameters like flow, thermal characteristics and back pressure were considered for numerical analyses with ANSYS software. It was concluded that LPG fuel exhibits a minimum back pressure as compared with other fuels [3].

Two different models were used and compared for back pressure with the CFD (Computational Fluid Dynamics) analyses in the ANSYS software. As a result of the analysis, back pressure was decreased in the engine, and the volumetric efficiency was increased [4-5]. Researchers [6] analyzed exhaust manifold with five different models, and solid models were drawn by using CATIA V5 software and their numerical analyses were performed by using ANSYS software. It was concluded that one of exhaust design selected provided the highest performance with lowest emission values. For a multi-cylinder engine, CFD analyses for three exhaust manifold models were performed at pipe diameters, and results of pressure contours and velocity streamlines were presented by researchers at three different speeds by using ANSYS

* Corresponding author
Email: omercihan@hakkari.edu.tr



software. Selected manifold model showed the lowest back pressure compared with others [7]. In another study, different manifold materials were used for designing exhaust manifold [8]. Some researchers [9] studied numerical analyses of an exhaust manifold, and indicated that the natural frequency of the exhaust manifold should be predicted and needs to be worked in optimum frequency ranges in the manifold structure. Other researchers studied numerical analyses for two different exhaust manifolds of a four-cylinder gasoline engine at constant speed. It was proven that flow through the exhaust highly dependent on the position of the crank angle, and flow rate was increased as the cross sectional area was decreases in the manifold [10].

Multi-cylinder engine performance can be improved with charge change optimization. In one study, the charge change of a natural gas engine is optimized. The engine optimized using finite differences method. The numerical method has been confirmed by experiments. In numerical study, it has been emphasized that the exhaust manifold geometry is particularly effective on engine efficiency [11].

Some researchers [12-13] showed that exhaust manifold designs could be optimized with respect to back pressure and the speed of exhaust gases. Girish et al. [14] studied CFD analysis of the exhaust manifold of a multi-cylinder and four-stroke gasoline engine, and it was confirmed that reducing the exhaust back pressure and increasing the exhaust gas velocities resulted in increase in engine performance. Martínez et al. [15] studied numerical analyses of different exhaust manifolds by using ANSYS software. The cast, 4-2-1 and L-shaped exhaust manifold designs were examined, and it was concluded that 4-2-1 and L-shaped exhaust manifold designs compared to the cast type were obtained that velocity was changed in narrower range, and flow uniformity function indexes were found about of 0.98. In addition, L-shaped design provided the lowest total pressure drop compared with others. Prakash et al. [16] investigated the exhaust manifolds having higher volumetric flow efficiency

with higher average speeds because of sweeping leading to independent exhaust runners Krishnara et al. [17] showed that volumetric efficiency was increased throughout the manifold, and engine power was increased as a result of reducing flow resistance of the fluid. Galindo et al. [18] studied the design of optimum manifold to increase in engine performance, and it was shown that transient performances were increased with an improvement in torque at low speeds. Manohar and Krishnaraj [19] considered redesign of an exhaust manifold by detecting thermal stresses and deflections occurring under different operating conditions with different materials and temperatures. Numerical analyses were performed on manifolds to study CFD analyses, and several flow parameters like pressure velocity and temperature, and post-convection temperature were identified with the surrounding air to examine higher performance and back pressure factors than the same temperature. Agilesh [20] also studied to redesign an exhaust manifold made of cast iron by identifying thermal stresses and deflections occurring under various operating conditions with different materials and temperatures. It was stated that redesigned curved profiles resulted in that exhaust gases could reduce the turbulence effect on welds. Raghuwanshi [21] analysed high performance of manifolds to be required to effectively expel exhaust gases for turbocharged engines. Factors of heat flux, pressure, velocity and stress were evaluated by changing manifold geometries. Ahmed [22] carried out CFD analyses for different shape of exhaust manifolds using CFD software, aim was to achieve the optimal geometry for low back pressure and high exhaust speed. Five different models were designed and extensively analyzed with the help of speed contours and pressure contours.

In general, exhaust manifold design significantly effects on engine performance, flow, velocity and pressure. In this study, two different exhaust manifold designs were modelled in the SOLIDWORKS software. Then, the modelled manifold designs were imported to the ABAQUS V6.13 software

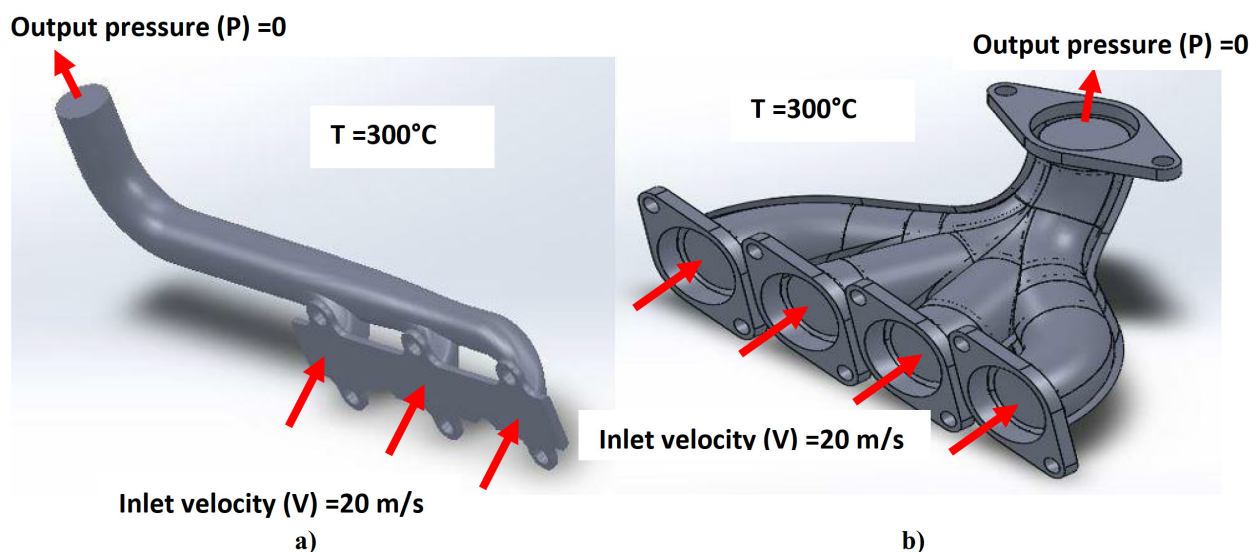


Figure 1. Type A (a) and type B (b) solid drawings

for numerical analyses. Two different manifold designs were considered for analyses, and three different flow materials were used to compare the effects of flowing materials. Parameters of pressure, velocity and temperature have been studied through the manifold parameters of pressure, velocity and temperature have been analyzed and compared in the manifolds

2. NUMERICAL STUDY

In this study, two different exhaust manifolds having four-cylinder engine were drawn in the SOLIDWORKS software (Figure 1). Then, the manifold designs were transferred to the ABAQUS V6.13 software in order to perform numerical analyses. The burnt gases of gasoline, alcohol and LPG fuels were considered as major flowing materials for each manifold. Variations of pressure, speed and temperature were determined through the manifolds. The average gas temperature inside the exhaust was 300°C for analysis. For each three type of fuels, physical properties of the fluids for analysis are given in Table 1. For both of manifold models, the inlet velocity of the fluid to the manifold is 20 m/s. In the initial state, the output pressure is assumed to as zero.

Table 1. Material fluid properties used in analysis [3].

Material	Fuel Type		
	Gasoline	Alcohol	LPG
Density (kg/m ³)	1.0685	1.255	1.2631
Viscosity (Pa-s)	3.0927 x 10 ⁻⁵	2.57 x 10 ⁻⁵	2.57 x 10 ⁻⁵
Specific heat (J/kg-K)	1056.6434	1150.6	1138.4
Thermal conductivity (W/m-K)	0.025	0.025	0.025

Element type of FC3D4 with 5906 nodes and 5553 elements was used for type A exhaust manifold. For type B exhaust manifold, element type of FC3D4 was used, and number of nodes and elements were 1716 and 7356, respectively. Before analyses, a mesh convergency was conducted for accuracy of results. Type A of exhaust manifold was analyzed for five different regions for each outlet runner (Figure 2) while type B was analyzed for 4 different regions (Figure 3).

3. RESULTS

In this study, CFD analyses for two different manifold design were performed for three different flowing materials called as gasoline, alcohol and LPG fuel. For the analyses of pressure, temperature and velocity changes during the flow in the manifolds, three different points (1, 2, and 3) considered. Table 2 presents the variation of pressure, temperature and velocity maps obtained from results of ABAQUS analyses. It was seen from the images in Table 2 that high pressure at inlets of manifolds was decreased towards the end of the manifold. A little change in velocity and temperature values was found through the flow. In addition, it was observed that the temperature was decreased while the velocity was increased towards the manifold outlet. Pressure temperature and velocity graphs of type A of exhaust manifold design (Headers type manifold) were given according to measured points as shown in Figure 4. It was clear that pressure was decreased from inlet to outlet, and pressure value of exhaust outlet was slightly above from atmospheric pressure, and this situation was supported by studies in the literature.

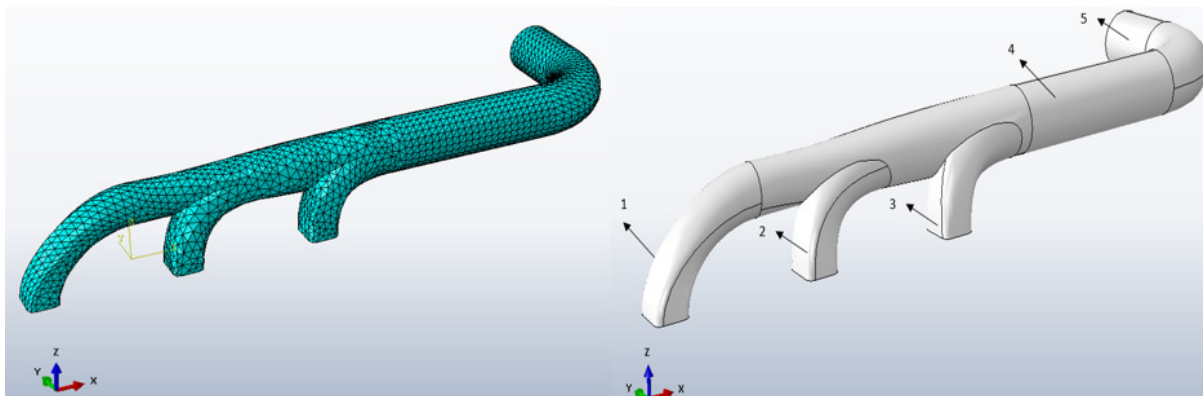


Figure 2. Analysis and node locations for type A.

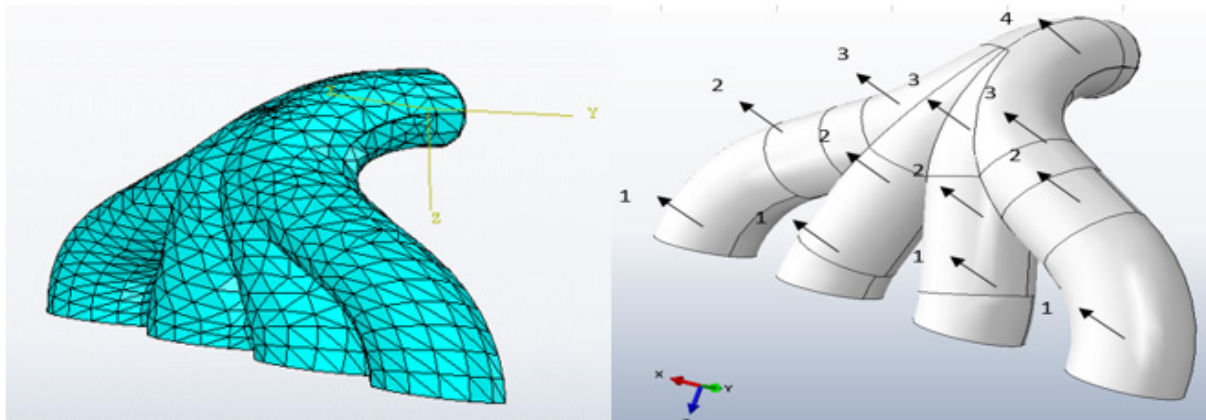
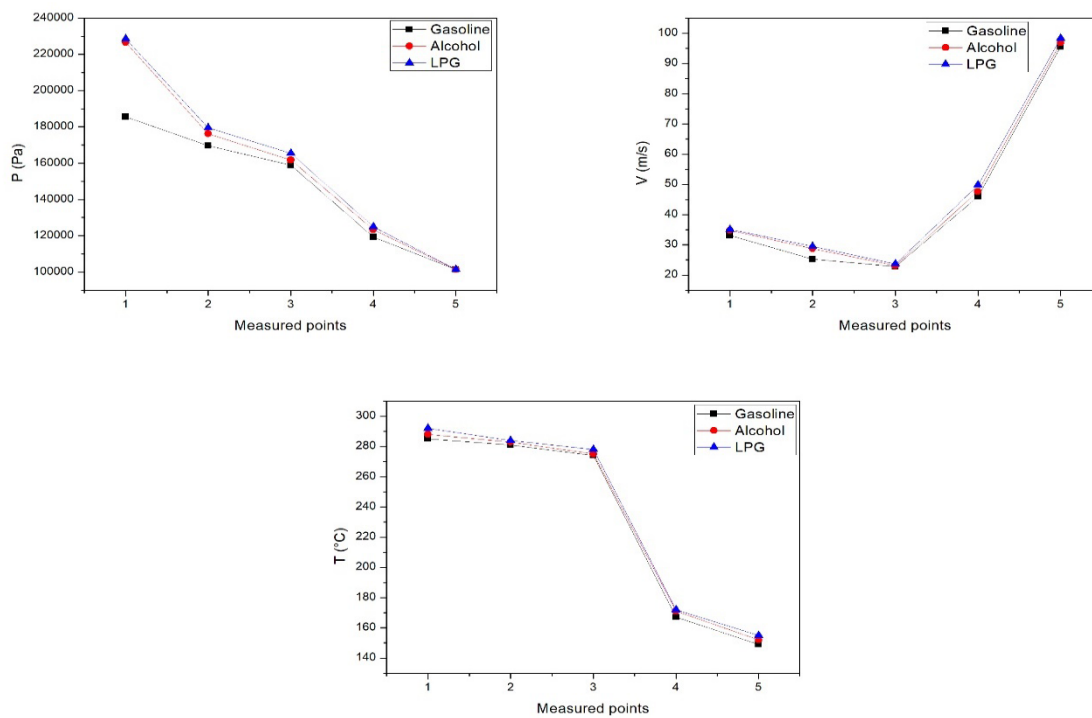
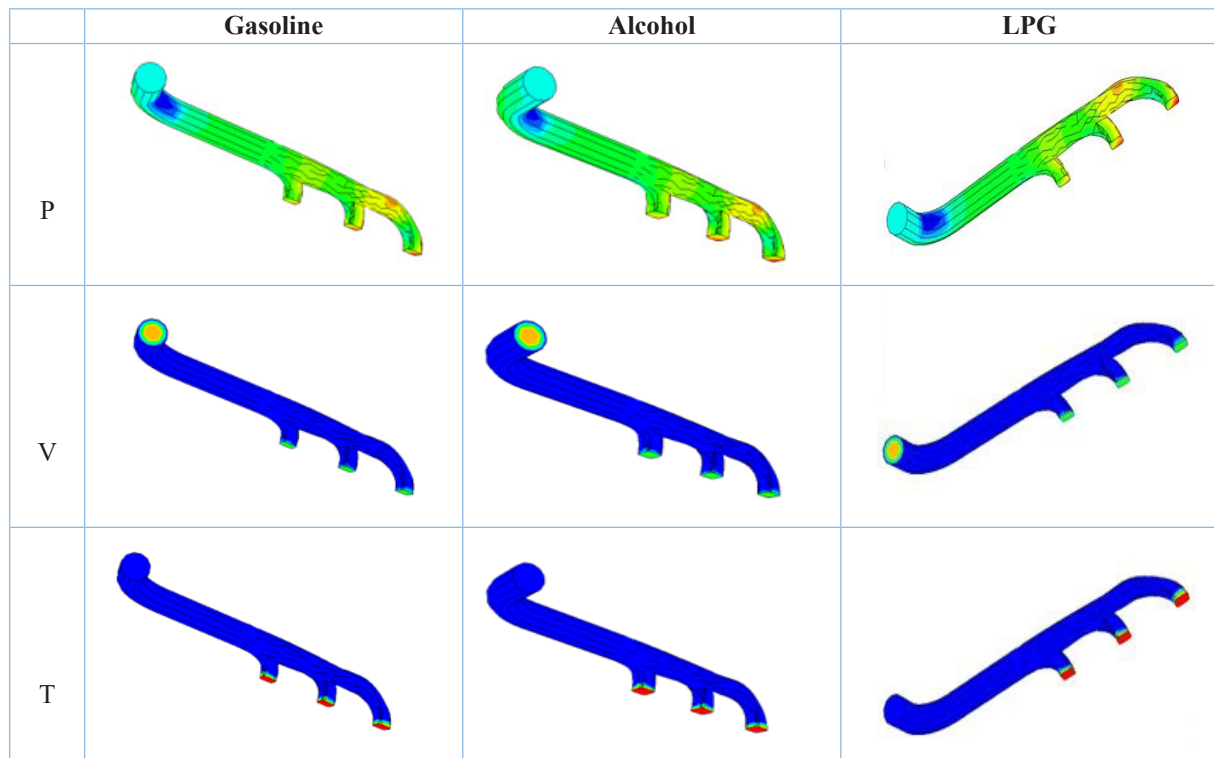


Figure 3. Analysis and node locations for type B.

Table 2. Type A Exhaust manifold pressure-temperature-velocity images**Figure 4.** Pressure-temperature-velocity changes according to measured points of the type A exhaust manifold

In Figure 4, it was seen that velocity was decreased at measured points from 1 to 3, then it was rapidly increased up to the point 5 for the each type of fuels. This velocity reduction was attributed to the closer positions of point 2 and 3 which were close to exhaust outlet, resulting in slightly reduction in flow rate. When variation of temperature was analyzed, temperature at measured points of 1, 2, and 3 was very close to each other. Then, it was followed with reducing trend up to the manifold outlet through the flow inside the manifold.

The other exhaust manifold design is the type B manifold which is widely used in the market. Variation of pressure, velocity and temperature results of the type B exhaust manifold was presented in Table 3. It was observed from Table 3 that two channels in the exhaust manifold reached to high pressures, while the other two channels had a lower pressure value, and it was attributed the manifold geometry. When velocity images were analyzed, it was seen that flow velocity was increased towards the exhaust outlet for all three fuels. Although there existed little change in temperature images,

Table 3. Type B exhaust manifold pressure-temperature-velocity images

	Gasoline	Alcohol	LPG
P			
V			
T			

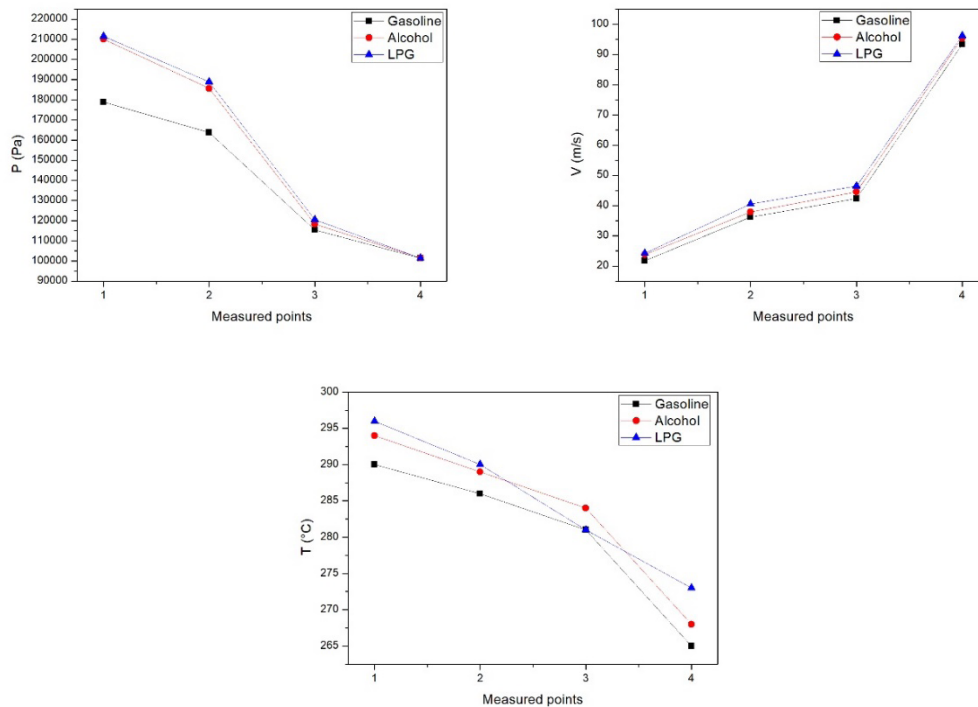


Figure 5. Pressure-temperature-velocity changes according to measured points of the type B exhaust manifold

temperature in the exhaust gas was slightly decreased for three fuels. This result was supported by studies in the literature.

Measured pressure, temperature and velocity values at different points were shown in Figure 5. During the analyses, average values of the channel points were taken into consideration. It was concluded that pressure towards the exhaust outlet was decreased in the pressure map, and lower

pressure was obtained from gasoline fuel compared to alcohol and LPG fuels due to the fuel flow characteristic of gasoline fuel. This situation significantly effects on engine efficiency and performance. When velocity of the fuels were compared, results were very close to each other at initial condition through the inlets. However, velocity at outlet rapidly increased due to accumulating all fuels into the single channel. Additionally, it can be said that temperature values were slightly decreased for all three fuels through the flow.

4. CONCLUSIONS

In this study, two different manifold designs which were commonly used in automotive industry were numerically analyzed in terms of flowing material and manifold types. In the numerical analyses, pressure, velocity and temperature changes were explored and compared through the manifold at different points. Following conclusions can be drawn from this study,

- Lower pressure and velocity were obtained at gasoline fluid compared to the other two fuels due to characteristics of gasoline fuel. For type A of manifold,
- While the velocity increases towards the exhaust outlet, the pressure decreases to atmospheric pressure,
- Pressure and velocity values of type A exhaust were higher than those of type B,
- For all fuels, high pressure values of type A were obtained, and this improves the performance and efficiency of the engine.

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