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Modeling and Analysis of Engine Exhaust Manifold Performance with Numerous Alternative Fuels

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Abstract: The exhaust system plays a crucial role in the performance of internal combustion (IC) engines, significantly influencing fuel consumption, exhaust emissions, and operating temperature. Exhaust manifolds are particularly important for improving IC engine efficiency, with their design being critical for achieving optimal performance. Alcohols, due to their bio-based origins, are promising renewable alternatives to gasoline. This study utilizes Computational Fluid Dynamics (CFD) analysis to examine the effects of velocity, temperature, and back pressure on the volumetric efficiency of exhaust manifolds. Two different manifold designs are analyzed, and the impact of various fuels including LPG, alcohol, and gasoline on their performance is assessed. By leveraging ANSYS and FUSION 360 software, the study identifies that gasoline yields lower pressure and velocity values, while a specific manifold design exhibits higher pressure values, highlighting its superior efficiency and overall performance.

Keywords: Alternative Fuels, Computational Analysis, Combustion Processes, CFD Modeling, Engine Efficiency, Exhaust Manifold Design.

I. INTRODUCTION

The performance of an internal combustion (IC) engine is heavily dependent on the exhaust manifold [1]. This component plays a vital role in regulating temperature, preventing overheating, and improving efficiency. It functions by collecting exhaust gases from multiple cylinders and channeling them into a single pipe for release into the atmosphere. During the exhaust stroke, the piston expels burnt gases through the open exhaust valve, while the inlet valve remains closed [2, 3].

An inadequately designed exhaust manifold can lead to power losses and, in extreme cases, engine failure. A crucial factor influencing its performance is backpressure, which arises from the pressure difference between the combustion chamber and the exhaust manifold during the exhaust stroke [4, 5]. Backpressure is defined as the difference between atmospheric pressure and the average pressure within the exhaust manifold.

Key design parameters of an exhaust manifold include runner length, runner volume, collector configuration, and backpressure [6, 7]. Equal runner lengths ensure uniform distribution of exhaust pulses, while runner volume determines the spacing between the exhaust valve and manifold flange. The collector merges gases from multiple cylinders into a single outlet for efficient expulsion [8].

Excessive backpressure forces the engine to compress exhaust gases at higher pressures, increasing mechanical work. This can result in oil leaks within the exhaust system, higher fuel consumption, increased emissions, and reduced engine performance [9, 10, 11]. This study explores two exhaust manifold designs and investigates the effects of alternative fuels, including LPG, gasoline, and alcohol, on engine efficiency. Alternative fuels refer to non-conventional energy sources that serve as substitutes for traditional fossil fuels.

II. METHODOLOGY

A. Construction

The dimensions of the manifold are detailed in Figure.1 and Table 1 below.

TABLE 1: Dimensions used for engine exhaust manifold.

Parameter	Unit
Diameter (d)	55
Distance between the manifolds (D)	130
Length from end to end of the manifold	492.18

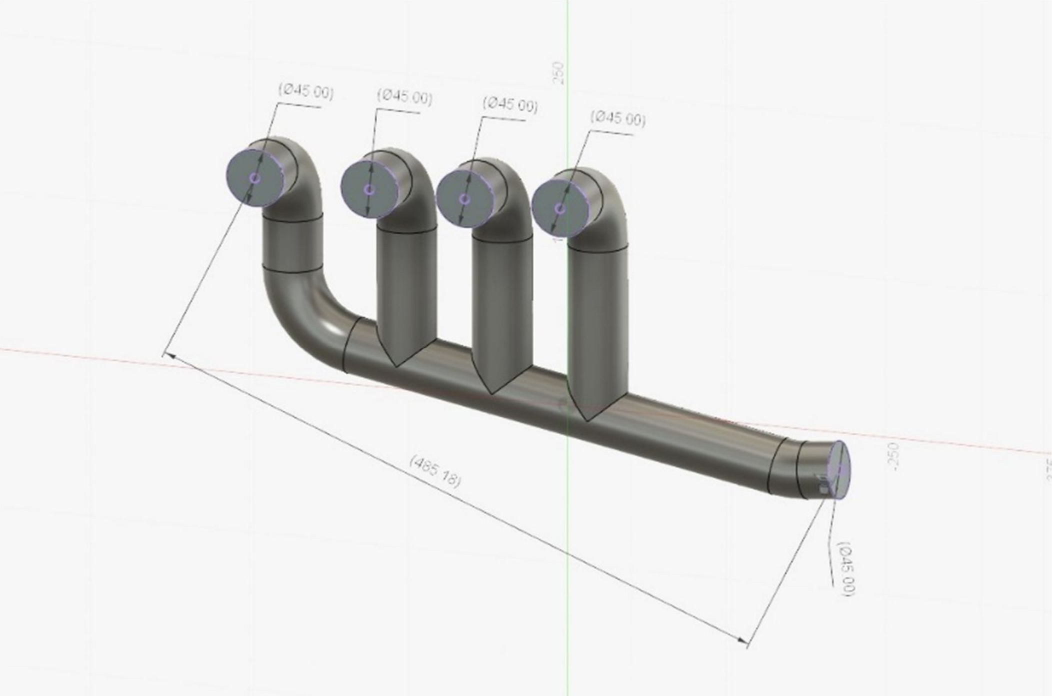


Figure 1. Engine exhaust manifold

B. Meshing

The meshing was performed using ANSYS software, with the detailed meshing parameters listed in Figure.2 and Table 2 below.

TABLE 2: Parameters utilized for the meshing process

Meshing parameters	Value
Elements	42001
Nodes	9200

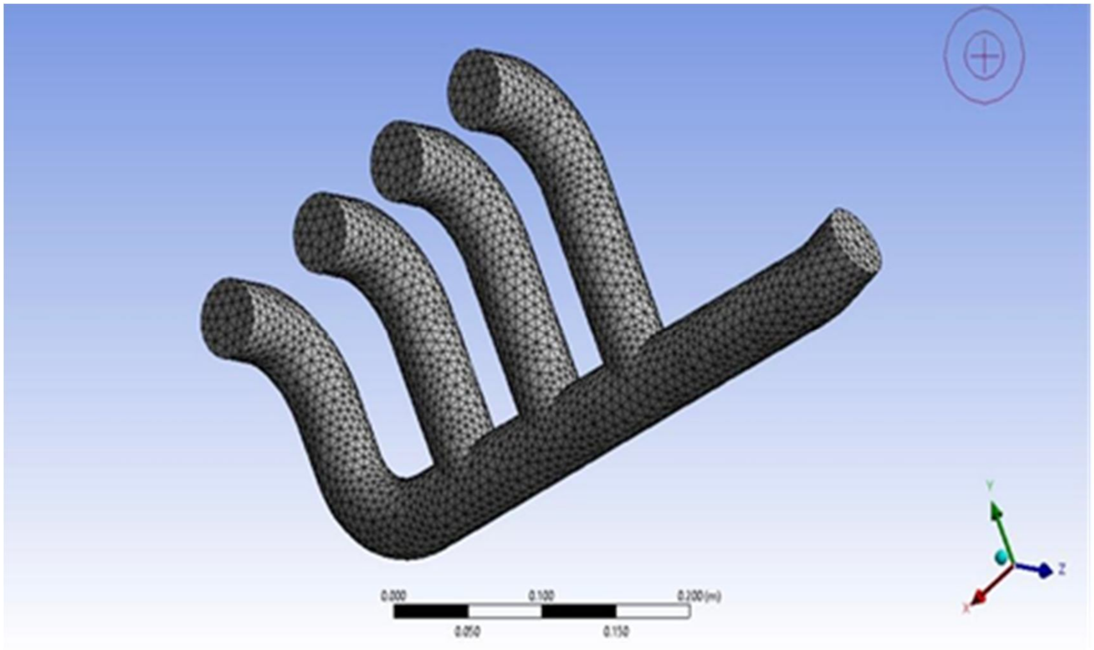


Figure 2. Meshing of Engine exhaust manifold

C. Boundary Conditions

The manifold designs were loaded into ANSYS 18.1 software for numerical analysis, with LPG, alcohol, and gasoline serving as the flow materials for each respective manifold. The analysis focused on evaluating the changes in pressure, velocity, and temperature within the manifold. The fuel material properties and the boundary conditions are listed in Figure 3 and Table. 3 [12].

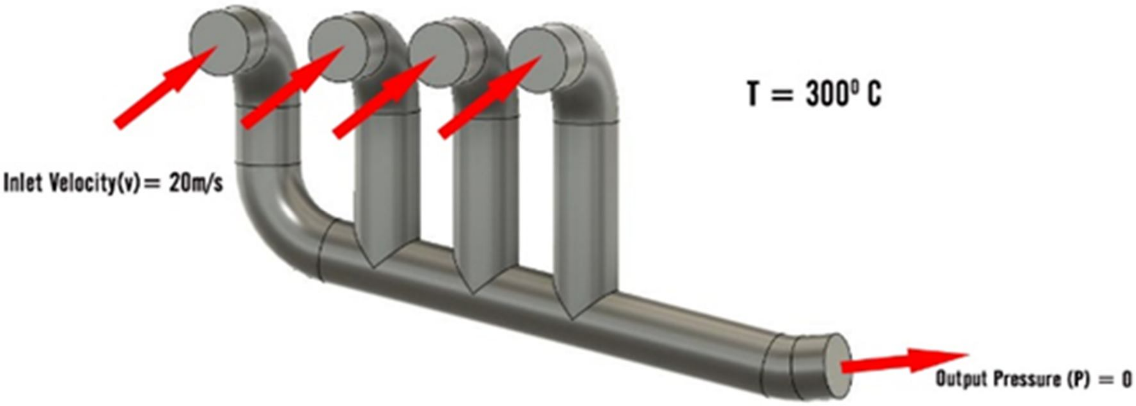


Figure 3. Boundary conditions applied on Engine exhaust manifold

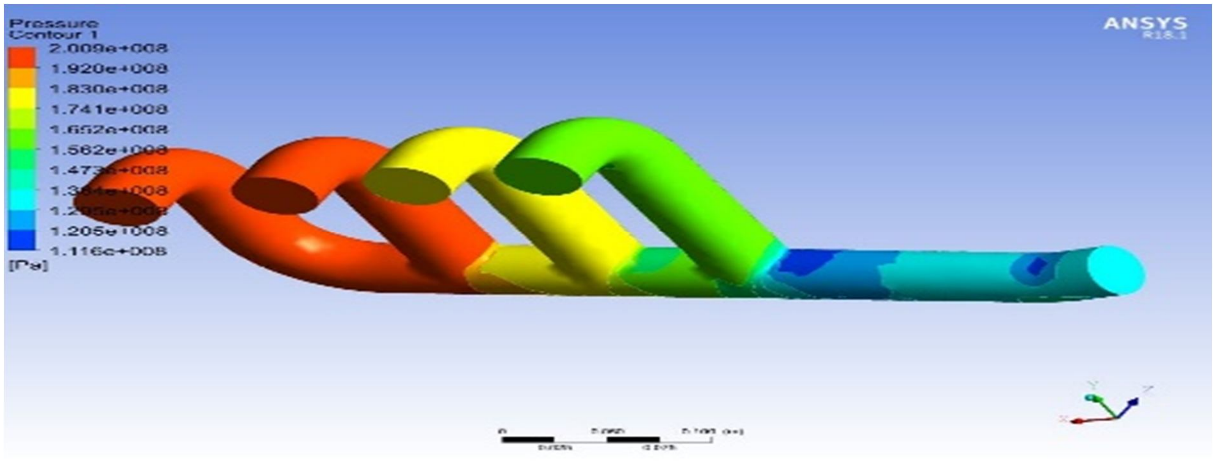
TABLE 3: Properties of Fuels used for the study.

Materials	Gasoline	Alcohol	LPG
Specific Heat (J/Kg-K)	1056.6434	1150.6	1138.40
Viscosity (Pa-s)	3.0927×10^{-5}	2.57×10^{-5}	2.57×10^{-5}
Thermal Conductivity (W/m-K)	0.0250	0.025	0.025
Density (kg/m^3)	1.0685	1.255	1.2631

III. RESULTS AND DISCUSSIONS

The CFD analysis was conducted using ANSYS software. An inlet velocity of 20 m/s was applied to both manifold models. The exhaust manifold was analyzed across four distinct regions of the outlet runner, while the exhaust manifold was evaluated in five separate regions.

A. The pressure distribution in the manifold was examined for three types of fuel: LPG, gasoline, and alcohol.



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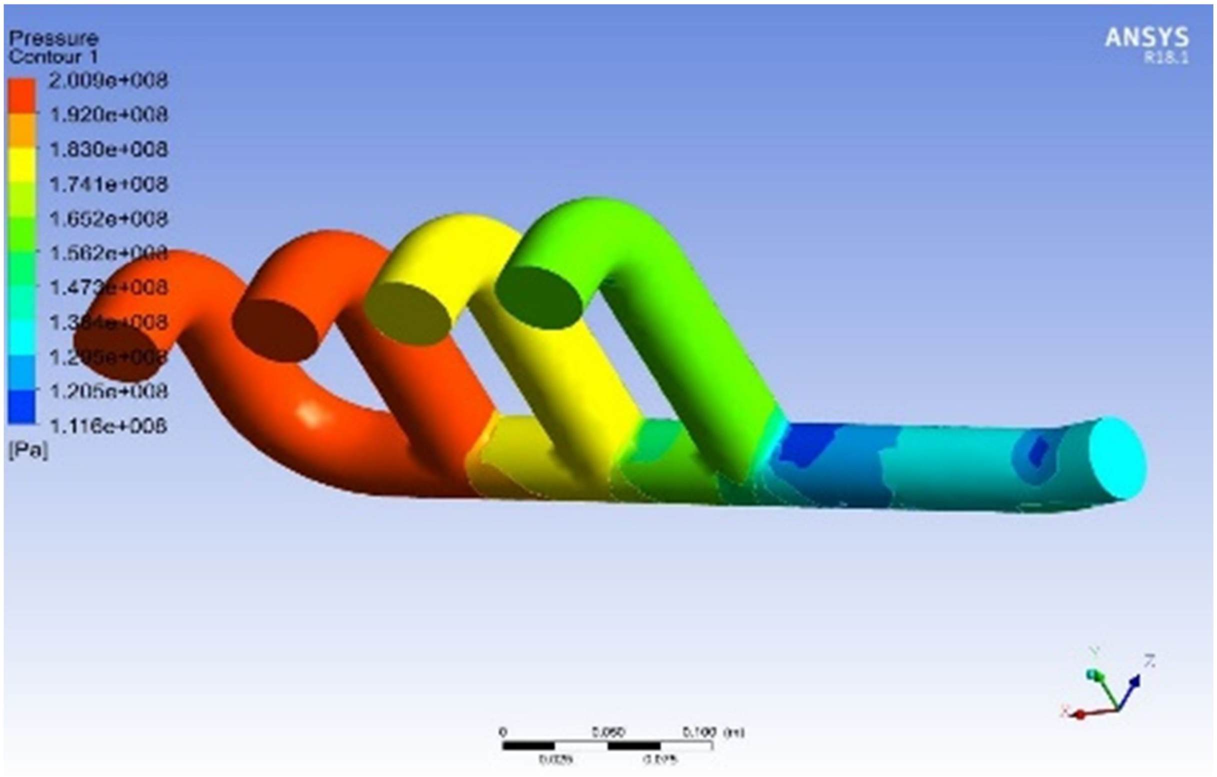

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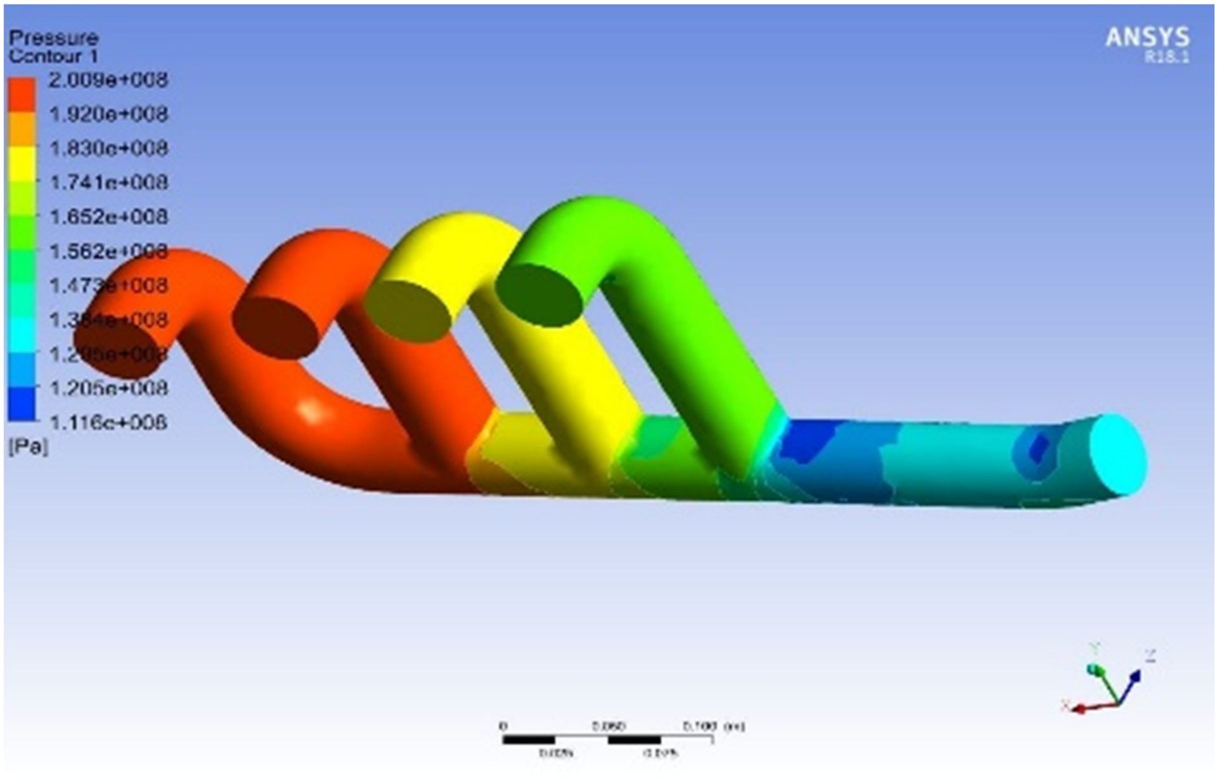

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Figure 4: The pressure distribution was studied for the manifold with three distinct fuels: LPG (a), gasoline (b), and alcohol (c).

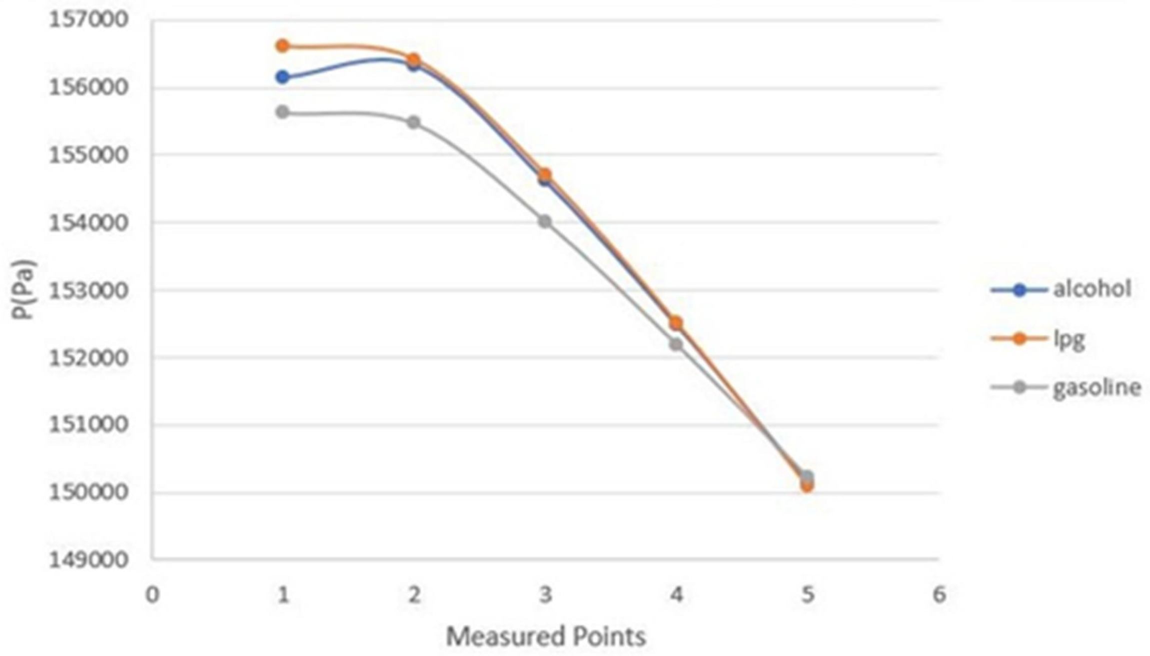
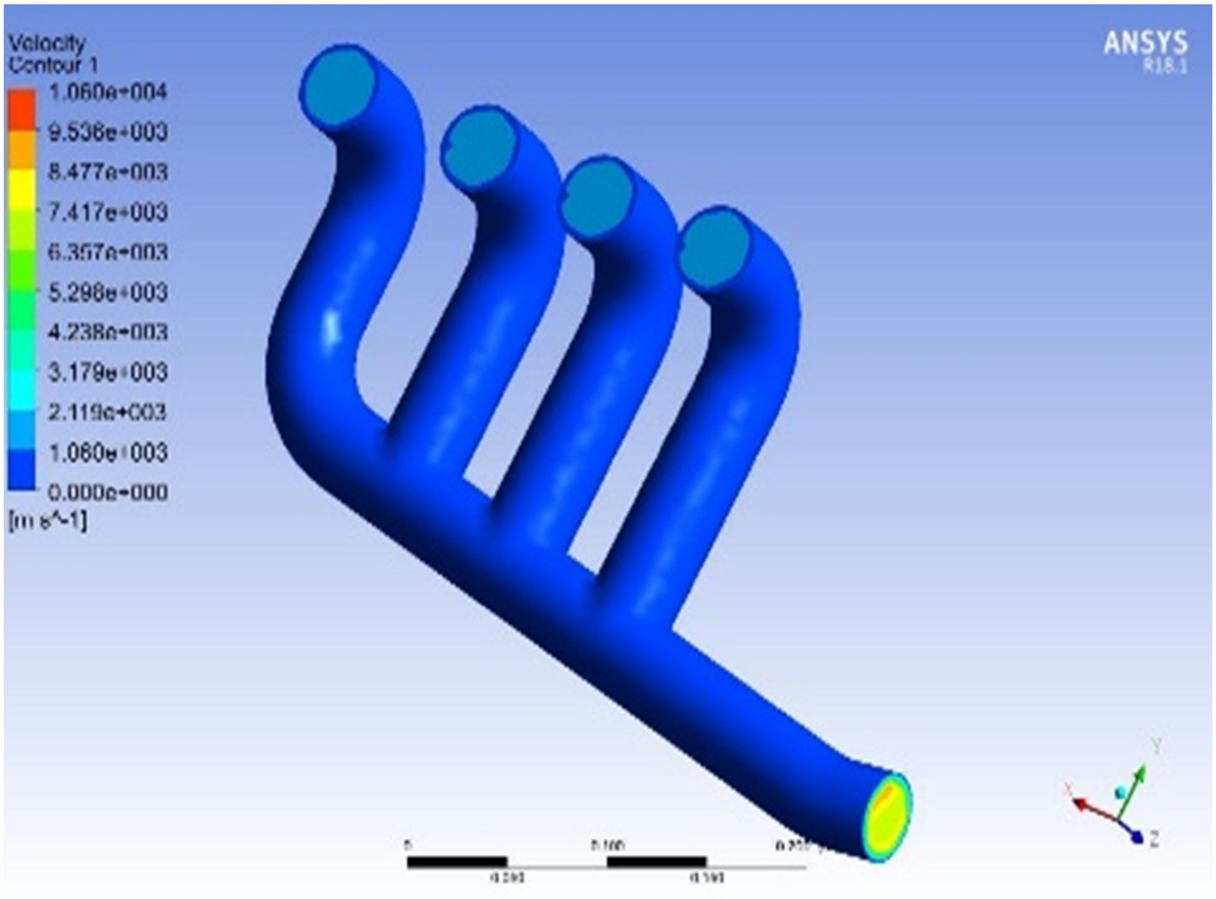


Figure 5. Pressure readings were taken at different points for each fuel type

B. The velocity distribution in the manifold was examined for three types of fuel: LPG, gasoline, and alcohol.



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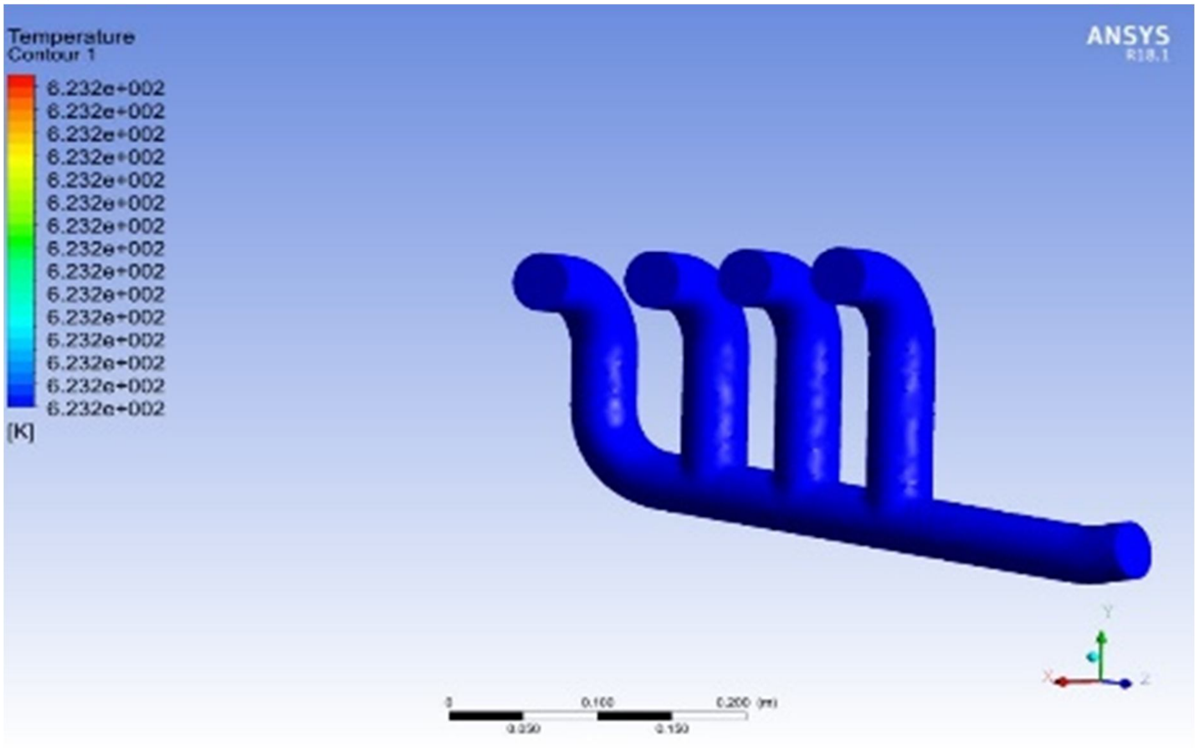

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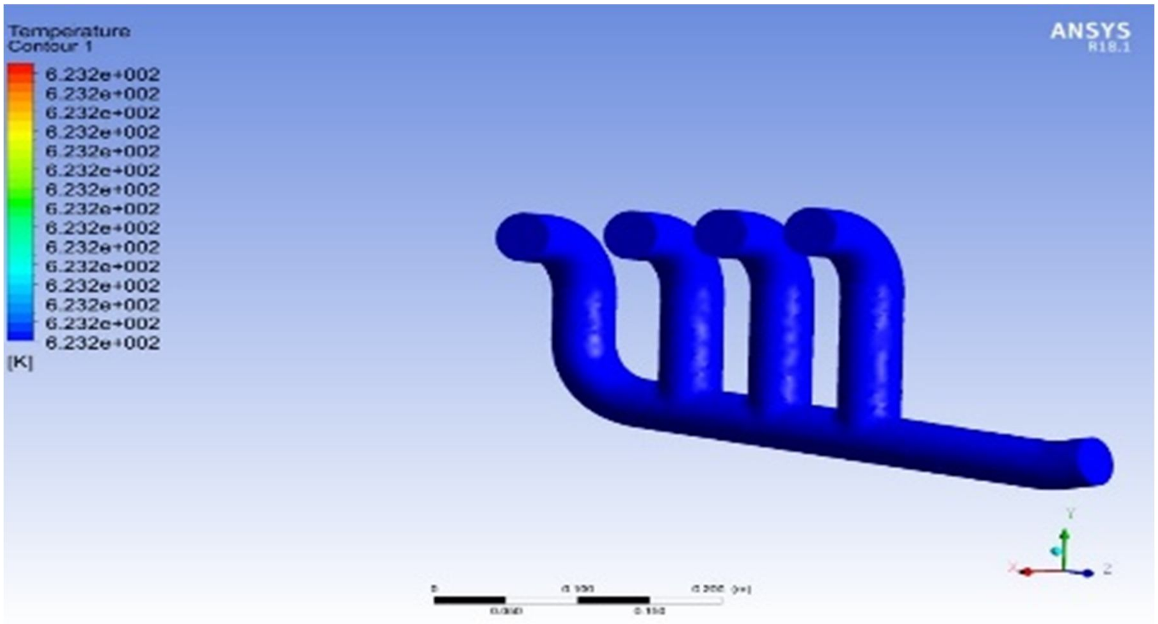


(c)

Figure 6: The temperature distribution in the manifold was assessed for three fuels: LPG (a), gasoline (b), and alcohol (c).

The temperature of gasoline and LPG remained stable at the specified points, whereas the temperature of alcohol fuel dropped between measurement points 1 and 2, then stabilized, as depicted in Figure 6. Likewise, The pressure for all fuels showed a similar pattern, remaining constant up to the third measurement point as shown in Figure 4 and Figure 5. Following a slight drop between the third and fourth points, the pressure increased after the fourth point. Additionally, it was noted that the pressure decreased from the inlet to the outlet.

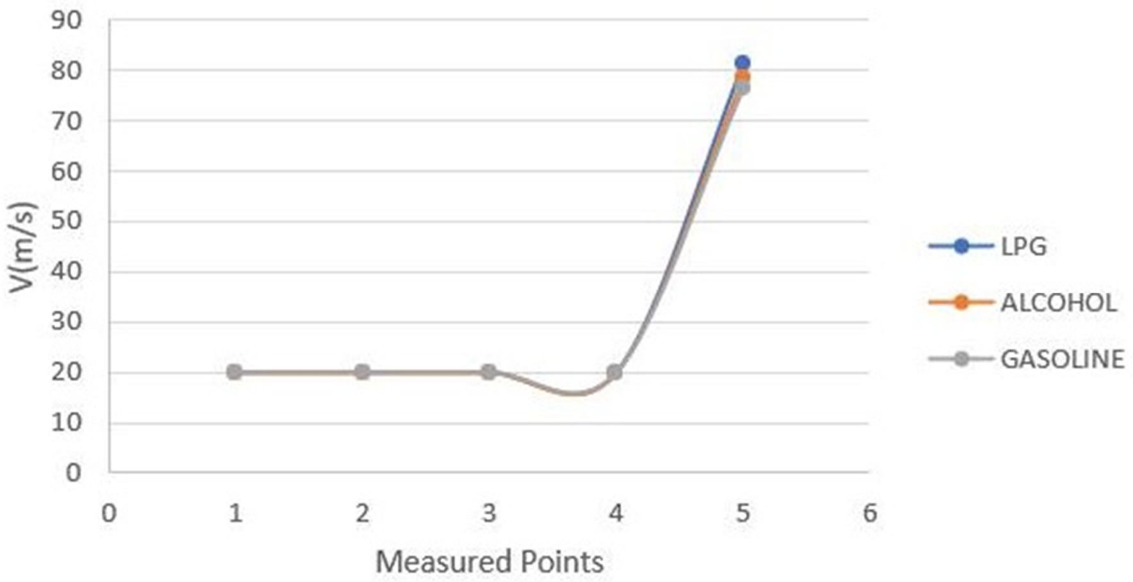
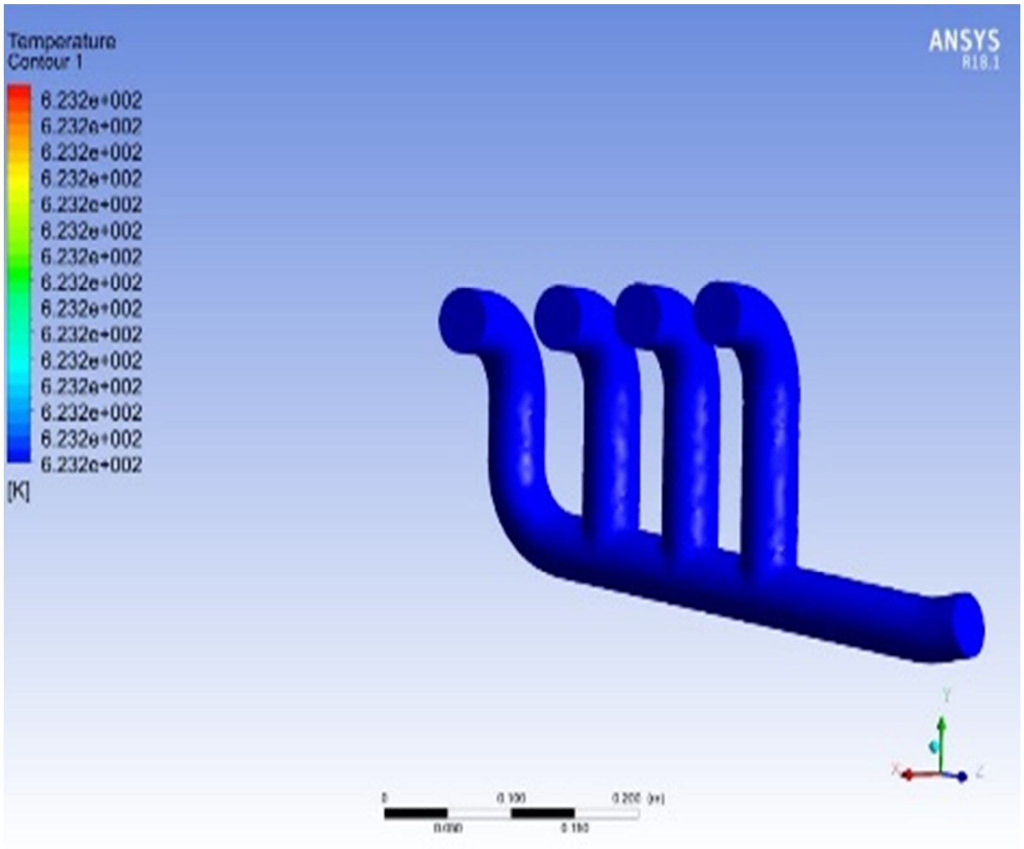


Figure 7. Velocity measurements for different fuels at the specified points.

In terms of velocity, it was noted that the speed dropped from measurement points 2 to 3, then surged quickly towards point 5. Points 2 and 3 were located closer to the exhaust outlet, where a decrease in the flow rate was observed in Figure 7 .

C. The temperature distribution within the manifold was analyzed for three types of fuel: LPG, gasoline, and alcohol:



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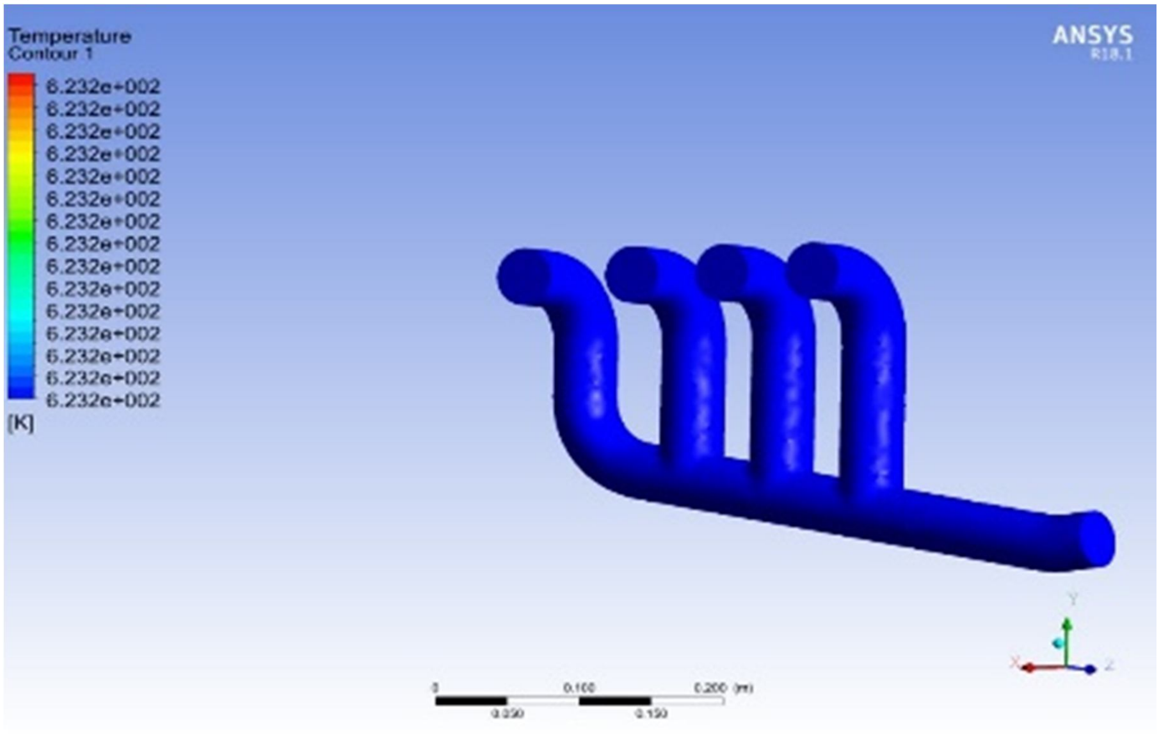

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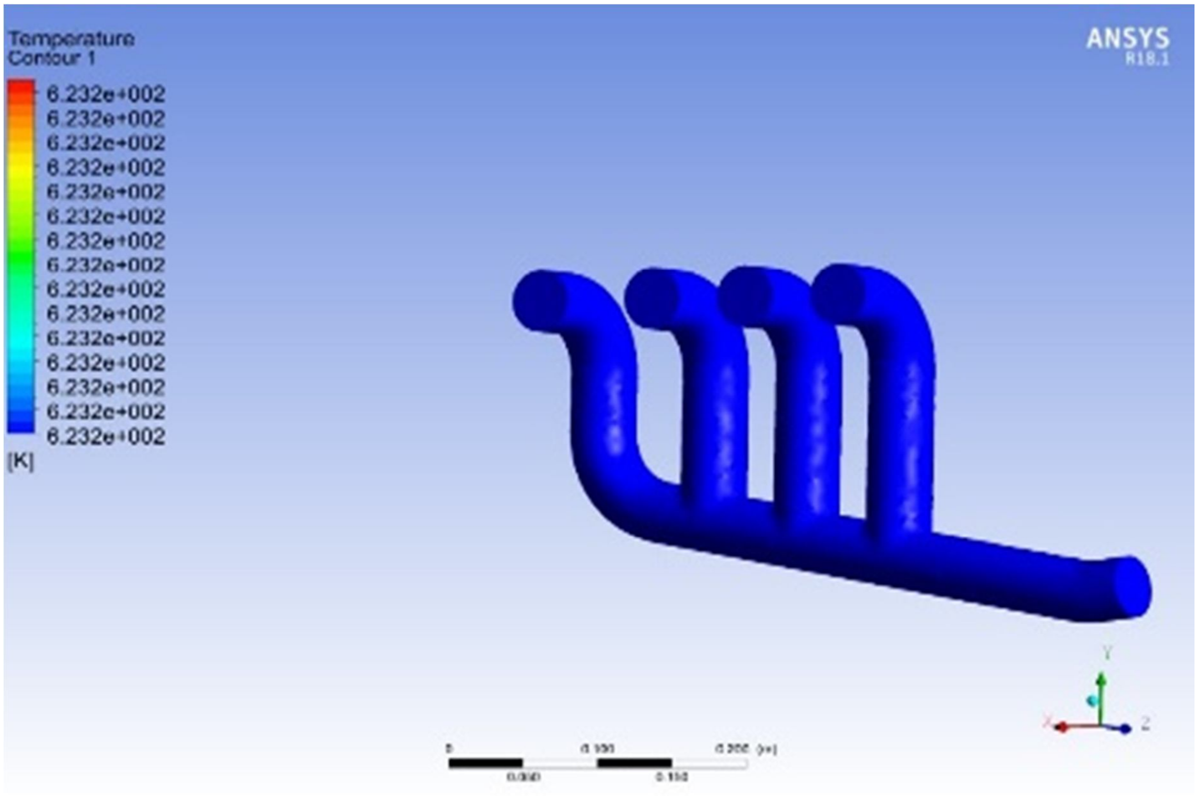

(c)

Figure 8: The temperature distribution of the manifold was evaluated for three different fuels: LPG (a), gasoline (b), and alcohol (c).

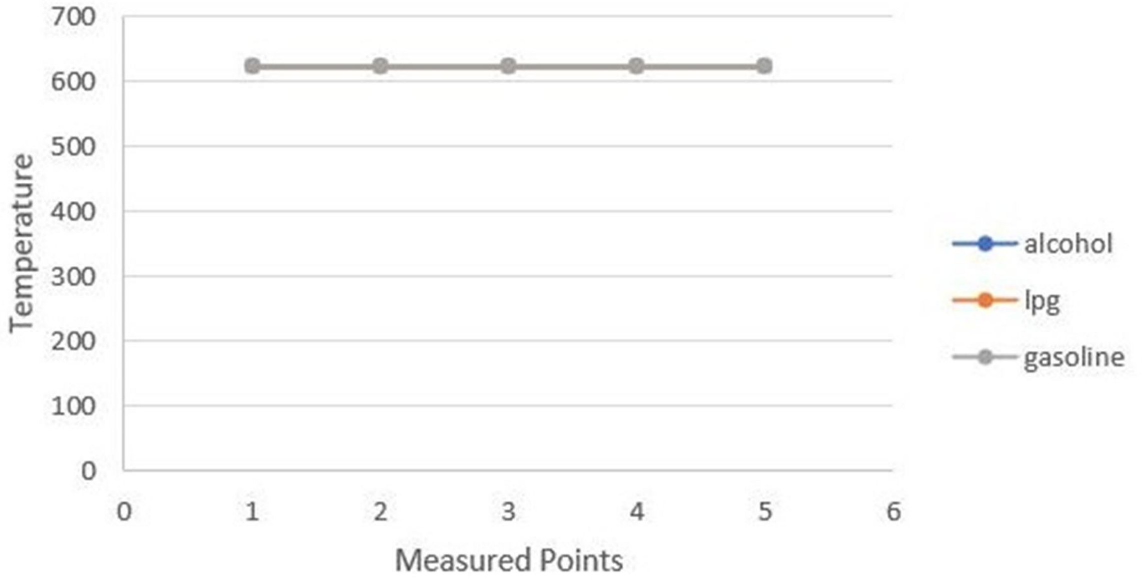

Figure 9. The temperature of each fuel was recorded at different points throughout the experiment.

The impact of various fuels on the pressure, volume, and temperature of design was examined, with the simulation results shown in the Figure 8 and Figure 9.

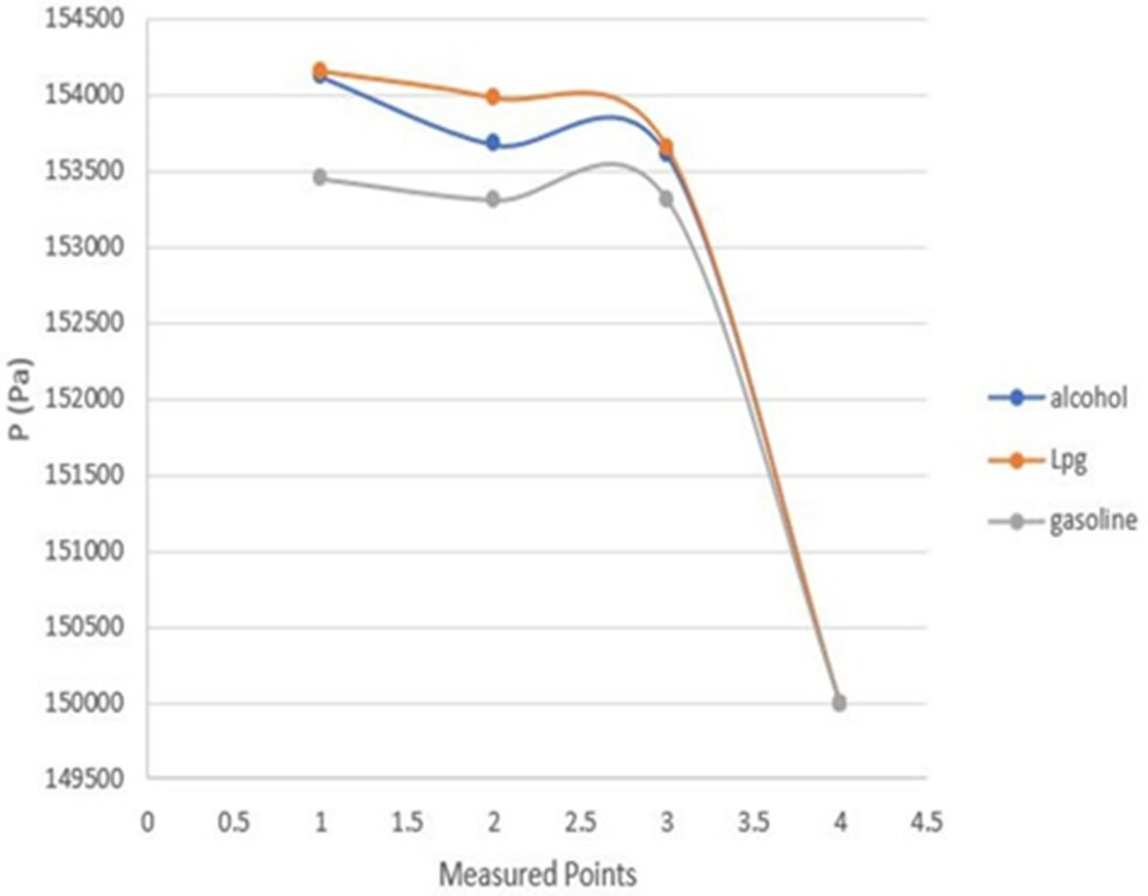

Figure 10. The pressure of different fuels was recorded at several points throughout the experiment.

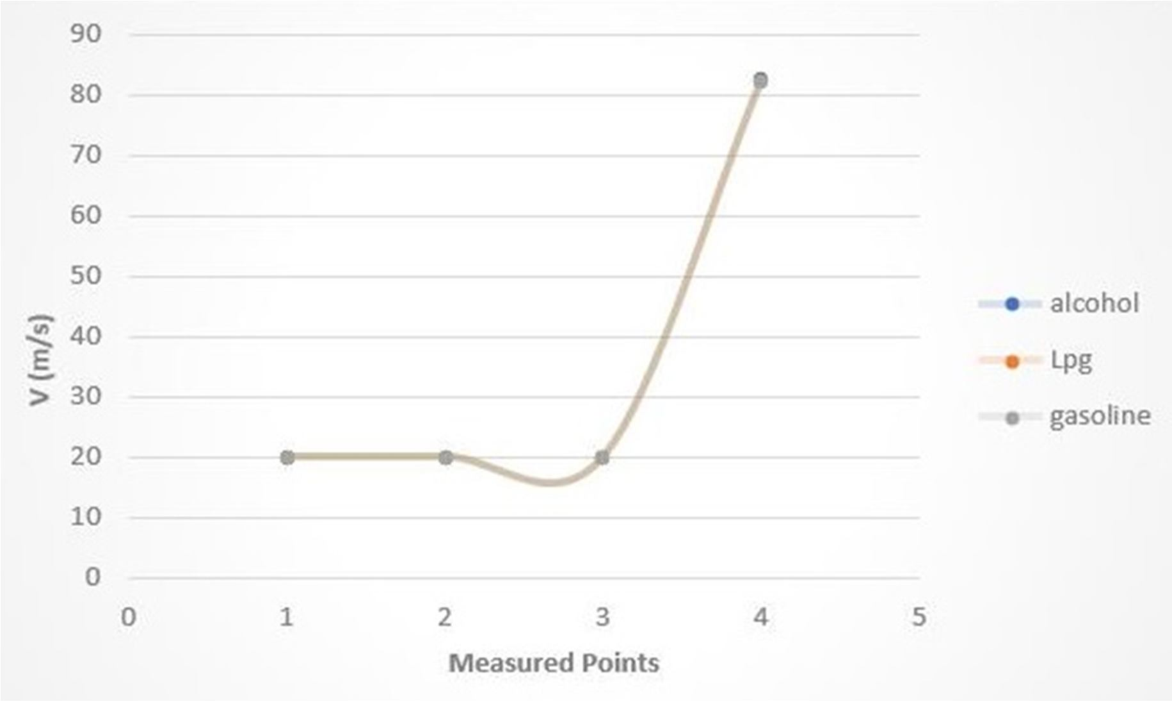

Figure 11. The velocity of each fuel was recorded at multiple points during the experiment.

When comparing the velocities of the different fuels, it was noted that the results were initially similar at the inlet. However, as illustrated in Figure 11, the flow velocities increased towards the exhaust source for all fuels. Moreover, the consolidation of all fuels into a single channel led to a sharp rise in velocity at the outlet. In terms of pressure, it was observed that pressure decreased towards the exhaust outlet, with gas fuel exhibiting lower pressure compared to alcohol and LPG. This difference can be explained by the distinct flow characteristics of gas, as shown in Figure 10. Regarding temperature, the temperature remained constant for LPG and gasoline, whereas for alcohol, it showed a decrease, as depicted in Figure 11.

IV. CONCLUSION

In this study, we conducted a comparative analysis of exhaust manifold models, assessing their performance using three types of fuel: alcohol, LPG, and gasoline. As the fluid flowed towards the outlet, the velocity increased while the pressure gradually decreased, and eventually reaching atmospheric pressure. Among the fuels tested, gasoline showed lower pressure and velocity values. In contrast, one of the manifolds exhibited higher pressure values, indicating better performance and efficiency compared to the other manifold. This paper presents the results of our initial analysis, and we are currently conducting experimental research on the same subject to further validate and expand our findings.

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