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Experimental Investigation of Intake Manifold Design Effect on Diesel Engine Performance

Usame Demir[1], Ozan Cetinkaya[2], Anil Can Turkmen[3*] and Cenk Celik[3]

0000-0001-7383-1428[1], 0000-0002-5783-3308[2], 0000-0002-3916-2854[3], 0000-0002-2918-3635[4]

[1] *Mechanical Engineering Department, Bilecik Şeyh Edebali University, Bilecik, 11000, Turkey*
[2] *Stellantis, Izmir, 35090, Turkey*
3 Mechanical Engineering Department, Kocaeli University, Kocaeli, 41000, Turkey

Abstract

Intake port geometry is the most significant parameter for air supply of engines into combustion space. Especially because only air is supplied into combustion spaces of diesel engines and the fuel is sprayed over the air, intake port geometry should form a specific horizontal turbulence ratio in formation of fuel-air mixture. In this study, the impact of cylinder heads of intake port of a single cylinder compression ignition engine produced with 3 different geometries on performance and emissions of the engine was analysed experimentally. Additionally, the impact of intake port geometry produced with old and new moulds on 3 different geometries was researched. As a result of the study; power, torque, specific fuel consumption, exhaust gas temperatures, intake air flow and soot emission were measured. It was found out that the different intake port designs had impact on performance parameters, specific fuel consumption and soot emission following the study. Moreover, it was shown that the change of intake port didn't have any impact on the flow of the air intake in low speed. It was observed that the cylinder heads produced with old and new mould cores had a significant impact. It is predicted that the main reason for the poor performance of the port geometry, which is called Y-type and creates a wider auger around the intake valve, may be due to the low turbulence intensity it creates in the cylinder. X and Z type ports gave better results by about 15% in power and torque values. Z type intake port gave the best performance in terms of exhaust gas temperature and soot emission.

Keywords: Engine performance; Intake port; Single cylinder diesel engine; Soot emission

Research Article

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* Corresponding author

Anil Can Turkmen

anilcan.turkmen@hotmail.com

Address: Mechanical Engineering Department, Kocaeli University, Kocaeli, 41000, Turkey

Tel:+903122028653

1. Introduction

The rapid decrease of the world's oil reserves, an increase of such fuels in terms of supply-demand balance, and price inconsistency are especially causing serious problems for economies of developing countries. Due to such reasons, there have been various studies regarding the use of such fuel more economically. Essentially, all studies on internal combustion engines show that the progress is not towards the mechanical direction, but towards the improvement of combustion for better use of the energy generated by the fuel used in the cylinders. Therefore, the majority of the studies made to increase the performance of internal combustion engines and decrease fuel consumption were aimed at increasing the combustion quality. Air intake into the cylinder and direct injection into the cylinder are performed in diesel engines. The mixture in the cylinder is formed by the geometry of the piston and the turbulence effect on the air intake. A good formation of the mixture in the cylinder of diesel engines directly affects emission and combustion performance. For this reason, improving the volumetric and thermic performance of the engine under any operating conditions, and decreasing friction losses to levels close to the minimum level that is possible with the current technology are current issues studied [1].

In the studies, the impact of increasing the turbulence in the intake manifold on the engine performance. As a result, it was observed that the increase in turbulence resulted in a 1.1% increase in engine power and a 4.4% decrease in specific fuel consumption [2].

Hiticas et al. [3] analyzed the impact of the intake manifold system on performance in BMW N52 vehicles through experiments. They succeeded in optimizing the intake manifold with the help of CFD software and were successful in terms of filling temperature, hydraulic resistance, pressure decrease, and temperature.

Y. L. Qi et al. [4] observed vortex formation on the upper parts of the intake port in their studies on intake port design and that the rotation rate and volumetric performance decreased over the intake period. Vortex formation was eliminated with a small modification and it was observed that the rotation ratio increased. Additionally, it was observed that the new design increased fuel evaporation by 20%.

Zeng and Wang [5] used three different intake manifolds in their study on adjustable intake manifold control of dual-loop EGR engine air-orbit system and tried to find out the one with the best control and fastest reaction during the transition process. In this study, the fuel performance improved and emission values decreased.

Ceviz [6] analyzed the impact of intake plenum volume and its effect on the engine performance, cycle efficiency, and emission. As a result of the study, it was observed that the plenum volume improved the engine performance and diminished pollutant emission. Additionally, it was determined that increasing the plenum volume between 1700 rpm and 2600 rpm improved the brake torque and therefore the performance. In addition to those results, it was observed that increasing plenum volume also increased intake air pressure, formed a better mixture, increased cycle efficiency, and interestingly, decreased the mean effective pressure (COVimep).

Jemni et al. [7] studied the impact of an intake port design that operates with the acoustic wave filling principle and another intake port design that wasn't specified on diesel and LPG heavy machinery. In this study, it was observed that the fuel mixture was more efficient and that it improved burning qualities when the first manifold was used. The reason for that was suggested as the proper homogeneity and expansion of the mixture in the cylinder depending on the diminishing loss of head.

Green and Moumtzis studied airflow behavior on the upper side and air distribution of combustion equipment via mathematical methods and observed that the decrease in pressure of volumetric flow distribution was due to variables such as manifold shape, length, and flow area. Therefore, these results are also supporting the previous studies [8].

Chen et al. studied the turbulence model to analyze flow in a distribution manifold. Standard k-ε model (KF), renormalized group k-ε model (RNG), and realizable k-ε model (REAL) turbulence models were analyzed for the flow in the same manifold. It was determined that the model that best fit the experimental results in the said geometry (manifold) was the realizable k-ε model [9].

Ceviz and Akın [10] conducted a study analyzing the impact of entry plenum length/volume effects on the performance of a spark-ignition engine with electronic fuel injectors. The engine with electronic fuel injectors and multiple fuel injection systems has only one intake manifold containing airflow, and the fuel is injected through the intake valve.

Supercharge effects of the entry plenum with varying lengths would be different than the carburetor engine especially when the intake manifolds transfer air. They conducted the engine tests to have a primary study for the intake manifold plenum design with varying lengths. Engine performance factors such as break torque, brake power, thermal efficiency, and specific fuel consumption were taken into consideration to assess the impacts of change in entry plenum length. As a result, they observed that the change in plenum length improved the engine performance factors, especially in the case of low engine speed and fuel consumption with a high head that is seen on city highways. According to test results, it was determined that the plenum size should be extended at low engine speed and diminished as the engine speed increases.

Karthikeyan et al. highlighted that a properly designed intake manifold was a prerequisite for the optimal performance of an internal combustion engine in their studies. The airflow in the intake manifold is one of the significant factors conducting engine performance and emissions. Therefore, the flow in the intake manifold should be optimized to generate more engine power with better combustion and to decrease emissions. In this study, pressure waves of the intake manifold were simulated via 1D AVL-Boost software under temporary conditions to analyze the internal airflow characteristics of a 3-cylinder diesel engine during the process of producing new engines.

Based on the results of the 1D simulation, the intake manifold design was optimized using 3D CFD software under stable state circumstances. In this 3D CFD analysis result, the unstable flow of the air within runners was determined and the pressure within the runner was analyzed experimentally on the engine test bench. Additionally, the engine smoke level was analyzed for the initial and optimized manifold using the engine test bench. As a result of the study, they found out that the pressure within the runners for the optimized intake manifold design while the smoke level diminished [11].

Lee and Yoon conducted a study on the change of factors affecting volume efficiency such as the volume of pressure room to determine the best design for the entry system. they attempted to determine the lengths of the intake manifold and pipes and lengths of equalizing tank and the pressure room. they conducted experiments to obtain intake manifold exceeding various engine speeds and the pressure history in the volume efficiency. The best sizes were determined for the test engine's entry system: The intake pipe was 140 cm long; the pressure room volume was 2000 cc and the intake manifold was 90 cm. The best intake system and engine's volume efficiency in this study is approximately 4% higher than the operation of the original system [12].

Jemni et al. found out that the diesel engines caused various economic and ecological problems for especially trucks and busses. Diesel exhaust emissions are a significant source of pollution mostly in the city centers around the world. Additionally, the price of petroleum keeps increasing rapidly. The use of alternative fuels (liquefied petroleum gas, LPG, compressed natural gas, CNG) and combustion optimization provide effective results. Considering all these, they suggested that the improvement of combustion is related to the improvement of the intake aerodynamic movements induced by the entry system and especially by the intake manifold. In this study, the impact of two intake manifolds' geometry on flows within a cylinder was analyzed both computationally and experimentally. The two manifolds were mounted on a six-cylinder, fully equipped, 13.8 l displacement, heavy load, IVECO engines of busses in Sfax. This engine was tried with dual fuel spark-ignition engine oil and gas fuels. The first manifold provides an uncertain geometry, while the second one provides the most appropriate filling geometry. 3D computational modeling of turbulent flow within the cylinder was carried out with two manifolds. The model is based on solving Navier Stokes and energy equations using 3D CFD code FloWorks with standard k-e turbulence model. This modeling can also be used to analyze the best fitting manifold and inward flow structures. Experimental measurements are also conducted to verify this manifold through the measurement of significant engine performance indicators. Break power (BP), break torque (BT), and brake thermal efficiency (BTE) is increased by 16%, 13.9%, and 12.5%, respectively, using the best manifold. Break specific fuel consumption (BSFC) is decreased by 28%. Simulation and test results verified the benefits of optimized manifold geometry on cylinder inward flow and engine performance [13].

Martinez-Sanz et al. aimed at developing a new high-performance intake manifold via CAD and FEM combination in their study. FEA model was applied at first. This model includes full thermal and structural analyses of the new intake manifold produced using CATIA, ANSYS, WORKBENCH, MATHCAD. Thereafter, some combined prototypes were made and analyzed. Other research and analyses were conducted to model an intake manifold using new material. Finally, aluminum was decided to be used considering the characteristics for thermal efficiency when mixed with materials such as steel and low weight factors. A new problem occurred when an interconnection was added for wheels. The correct solution to the problem was found as the connection of both parts with an adhesive agent. It was concluded that the tension in the connection would be minimum and the fatigue value would be optimal for use in such a case [14].

Gocmen and Soyhan performed the geometry optimization of the intake manifold of a four-cylinder diesel engine in their study. They tried to equalize the pressure drop in all four combustion chambers by designing a new manifold[15].

Hemanandh et al. In their study, they studied the effect of helical and tangential port geometry on air flow parameters in a diesel engine by combining 1D and 3D simulation software. By having the obtained new geometry produced, a volumetric efficiency test was performed on the vehicle. It was observed that 95% volumetric efficiency and 0.1 bar pressure drop were achieved[16].

Arjunraj et al. In their study, they experimentally studied the effect of using different fuels for different intake manifold designs on engine performance and emissions in a diesel engine. In particular, it has been observed that alternative fuels have more effect than the intake manifold. However, they found that the helical geometry in the intake manifold has an effect on emissions[17].

Chandekar and Debnath have determined the gas distribution in the manifold by simulating the air flow and velocity parameters in the manifold with the Ansys Fluent software in the bio-CNG injection in the intake manifold. They found that as the ratio of the radius of the R/D manifold bend to the manifold diameter increased, a more uniform air-fuel mixture was achieved. They emphasized that it is especially important for dual-fuel engines.[18].

In this study, 3 different cylinder heads for which different intake port geometries were designed and molds were made, and fuel consumption, torque, power, intake airflow, exhaust gas temperature, and obscureness/smut value were measured with different speeds. Additionally, separate tests were conducted with the new mold and the mold used for production to analyze the impact of mold differences and the impact of renewal of molds, the process of production was also studied.

2. Material and Method

The experimental study conducted was performed at the engine test workshop of the R&D Department under Anadolu Motor Üretim ve Pazarlama A.S. Technical specifications of the engine used in the experimental study were given in detail in Table 1.

A schematic view of the test apparatus is seen in Figure 1. Engine parts and sections such as cylinder walls, piston surfaces, segments, cylinder heads, and injectors were checked to prepare the engine to test conditions. While preparing the engine to test conditions, no changes except factory settings were made. These tests aimed to obtain engine performance, fuel consumption, and smut values at different speeds with different types of intake port designs. The parameters directly measured during the test were a force, power, engine speed, fuel consumption, air consumption, air intake pressure decrease, room (atmosphere) temperature, pressure, and relative humidity, oil temperature, and pressure, exhaust gas temperature, and exhaust gas smoke density. The test engine was connected to a dynamometer as it is seen in the figure. The engine's torque in the crankshaft is transmitted to the dynamometer with a group of couplings and is seen as a load on the lever arm of the dynamometer. And the engine speed was measured with the tachometer fixed on the engine dynamometer. The surrounding temperature was measured with a basic thermometer during the measurement of intake temperature. Exhaust temperature was measured with a thermocouple placed near the exhaust manifold. Intake and exhaust pressure values were measured with the help of an oblique manometer. Because the fuel consumption is high when the engine starts, the measurements were made after a fixed regime was achieved. The consumed fuel amount was measured volumetrically. Smut measurement was performed with Bosch BEA 150 emission measurement device.

The old intake port core used in the production, the prototype intake port core that is the new version of the old core and the new intake port core with changed geometry, the old cylinder head mold used in the production and the new cylinder head mold renewed and cylinder heads cast were tested to analyze the impact of geometric shape change in intake port on engine power and torque, on the flow of intake air and specific fuel consumption, and the temperature of exhaust gas formed and soot emission (Fig. 2).

As a result of this geometric change in the intake port, a more curved and smooth intake port design that will facilitate airflow was aimed.

Table 1: Technical specifications of Antor 3 LD 510 engine

Parameter	Value
Cylinder Qty	1
Cylinder Volume	510 cm³
Cylinder Diameter	85 mm
Stroke	90 mm
Compression Rate	17.5:1
Engine Speed	3000 rpm
Engine Power	12 HP
Maximum Torque	3.35 Nm/1800RPM
Fuel Tank Capacity	5.5 L
Specific Fuel Consumption	190 gr/HP.hour
Oil Consumption	10 gr/hr
Crankcase Oil Capacity	1.75 lt
Dry (Empty) Weight	60 kg

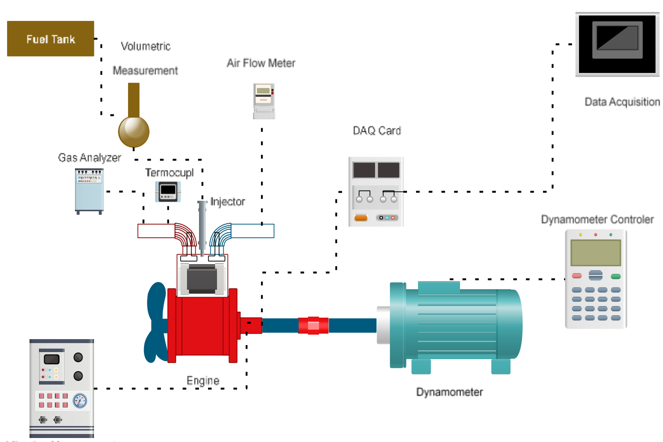

Fig. 1. Schematic View of Test Apparatus

Fig. 2. The appearance of X, Y, and Z-type intake port cores

The positive impact on the majority of the data was aimed at the change of intake manifold in a diesel engine. The most significant data that is intended to be changed is an increase in engine power. In the study, the impact of different cylinder heads of intake port geometries cast with the new and old molds on engine power was analyzed. Values obtained at 2000-3000 rpm and 6 different speeds from the engine where 6 different cylinder heads were mounted were analyzed on the test apparatus.

3. Experimental Results

The values obtained as a result of the tests conducted were classified according to the categories below and analyzed. It was given as it is in Table 2.

Values of 3 separate designs called X type, Y type, and Z-type were shown here. The design differences here were due to the difference in cores used in the production process. All types of designs were first produced with the old mold, their values were taken 5 separate times and then their means were obtained via software.

Additionally, the mold was renewed to contribute to the reliability of the results obtained, and X type, Y type, and Z-type designs were reproduced by casting, and also the impact of renewal of molds was analyzed. This way, the impact of mold difference on the intake manifold's performance was analyzed. Data obtained with the new mold were given in the graphics as X' Type, Y' Type, and Z' Type.

Table 2. Production details of tested cylinder heads

X	Old Mould – Old Core
Y	Old Mould – New Core
Z	Old Mould – Prototype Core
X'	New Mould – Old Core
Y'	New Mould – New Core
Z'	New Mould – Prototype Core

In Figure 3, the impact of 3 different intake ports produced with new and old mold on the engine's power parameter is seen. When the figure is scrutinized, it was seen that the highest power was achieved with C type design. While the Z-type design provided fairly close values, the Y-type design led to significantly lower values compared to the other two. It was observed that the designs produced by casting in the new mold provided a power increase. It was seen that the highest power was achieved with the X-type design when it was cast in the new mold. When it's considered that the change of mold made a positive impact on power increase, it was seen that such impact was negative in terms of Z design and that the Z design cast in the new mold had a lower performance than the one cast in the old mold.

Another significant point to be suggested is the torque value graphics change according to speed, and it was given in Figure 4. When torque curves are considered, the highest torque values were reached with C type design when produced with the old mold. Z-type design provided fairly close values while producing less torque compared to X-type when the rpm increased. Y type design provided significantly low values compared to the other two designs. When the designs cast with the new mold were considered, X and Y type designs provided significantly higher torques, while the torque decreased in Z-type. Power parameter analyses match the results obtained.

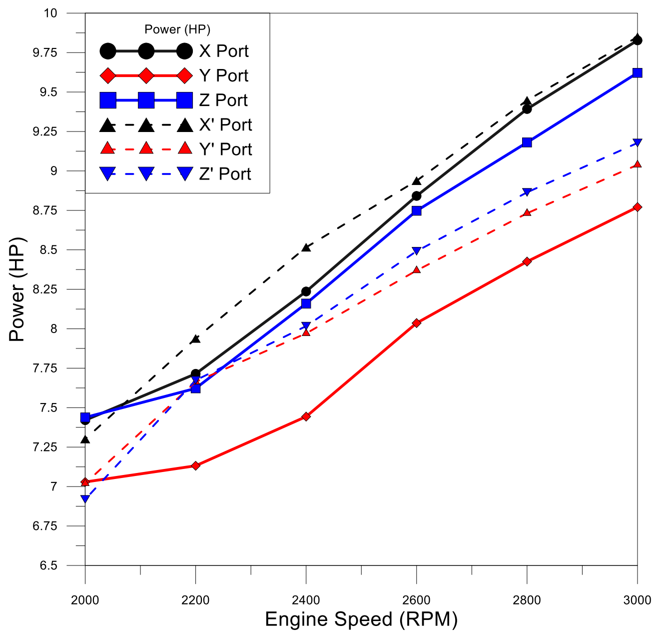

Fig. 3. Power graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

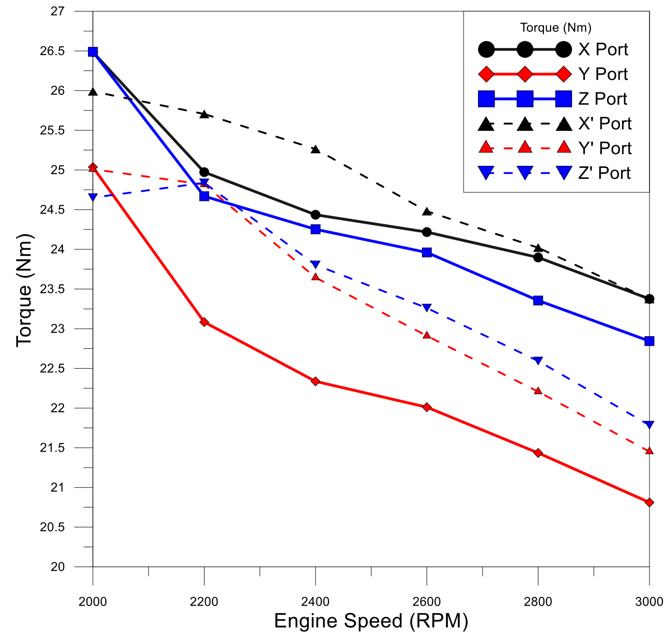

Fig. 4. Torque graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

Exhaust temperature curves were analyzed since they provide us with information about the specific fuel consumption and decalescence from the cylinder. Exhaust gas temperature was measured with a thermocouple placed in the exhaust manifold.

In Figure 5, a change in exhaust gas temperature with revolution is seen. In the Y-type intake port design, the highest exhaust gas temperatures were obtained with old and new molds. As this might have many reasons, the most significant one, as we know thanks to thermodynamics, is that the energy generated by the fuel leaves the system with a high energy level leading to lower enthalpy values and therefore the thermal efficiency decreases.

When exhaust gas temperatures were analyzed, it was seen that the lowest values are provided by the Z-type design cast with the old mold. This is followed by X and Y type designs produced with the old mold.

In Figure 6, a change of intake air flow by revolution is seen. Since it would affect the volumetric efficiency, analysis of intake airflow was decided and it was measured with an oblique manometer connected to the intake manifold. When the intake air flow is analyzed, close values were obtained from 3 types of designs cast with old and new molds. Therefore, different intake port geometry doesn't have a significant impact on the flow of intake air. Although there are no significant effects, a difference of almost 10 kg/h was observed with higher revolutions. While X type consumed more in lower revolution numbers, the situation changed with higher numbers of revolution. After 2700 rpm, the Z-type design consumes higher amounts.

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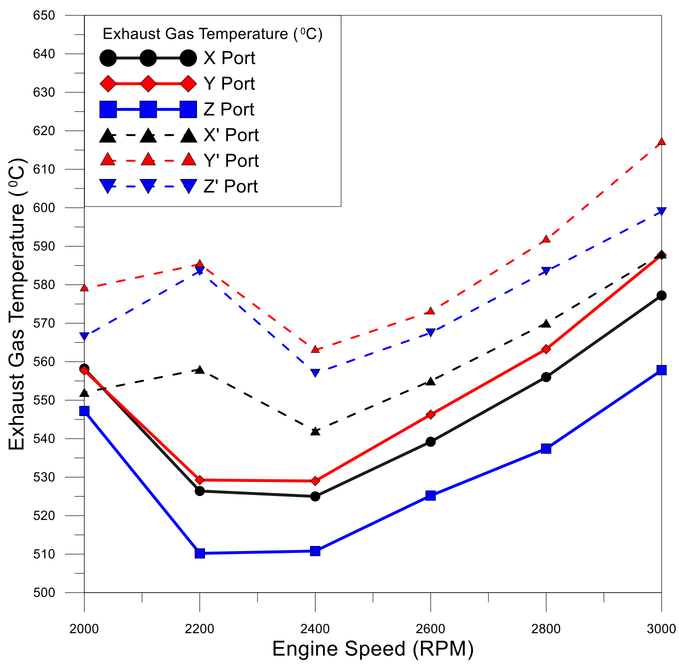

Fig. 5. Exhaust gas temperature graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

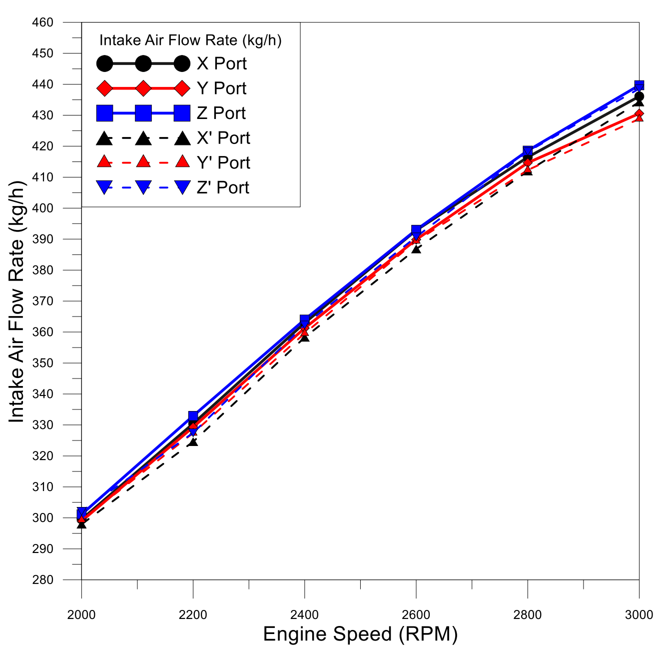

Fig. 6. Intake airflow graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

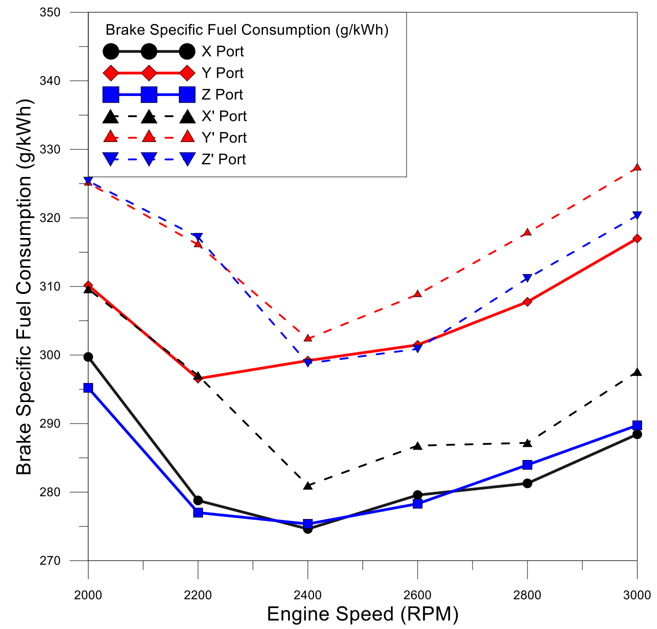

Fig. 7. Brake specific fuel consumption graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

In Figure 7, a change in specific fuel consumption values by revolution is seen. When the graph is analyzed, it's seen that the specific fuel consumption reaches the optimal level at 2400 rpm in general and then increases. It is understood that the X and Z-type intake ports produced with the old mold have the lowest specific fuel consumption value. The highest consumption was by the Y' intake port produced with the new mold. The highest increase was in Y-type ports produced with old and new molds and the rate of increase was approximately 10-15%. According to this data, it may be concluded that mold has a significant impact on specific fuel consumption. It was observed that the X-type port design was the one that was the least affected by the fuel consumption increase due to mold change.

In Figure 8, a change in soot emission values by revolution is seen. When the graph is analyzed, it is observed that the soot emission increases especially at 2200 rpm, and decreases in general as the revolution increases. Additionally, it was observed that the old mold increased the soot emission compared to the new one. It is understood that the X and Z-type intake ports produced with the old mold had the lowest formation levels. It was seen that the Y-type intake port produced with old and new molds provided the highest soot emission values. While the value was low in the Z-type intake port produced with the old mold, it almost doubled with the new one.

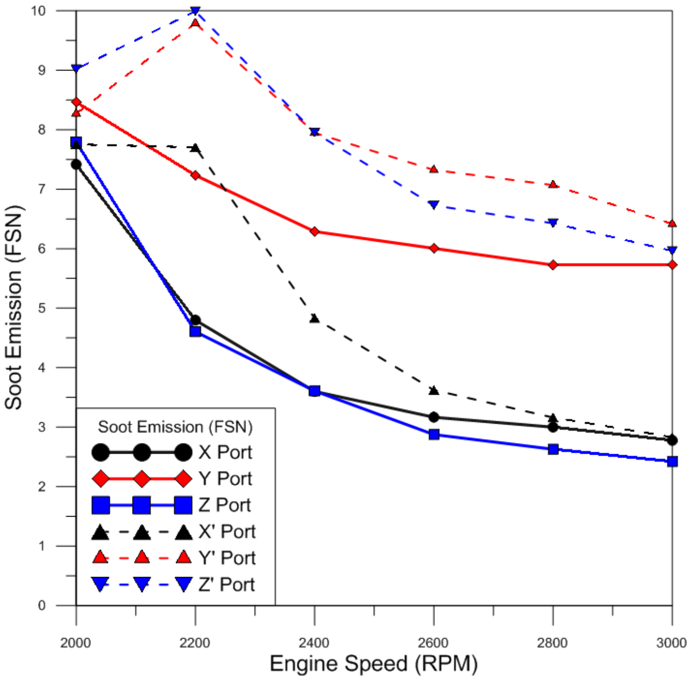

Fig. 8. Soot emission graphics of X, Y, and Z-type intake manifold designs produced in old and new molds

4. Conclusions

Studies on single-cylinder diesel engines' intake port geometry are quite limited and don't provide enough content. Because the inward mixture process of cylinders is very important in diesel engines, intake port geometry directly impacts the combustion efficiency. There are usually simulation studies in the literature and this study was conducted experimentally. It is believed that it might light the way for future studies and engine designs with higher performance, lower fuel consumption and that is environment friendly.

As a result of the performance tests on the engine where X type, Y type, and Z-type designs produced with old and new molds were used;

The highest power value was provided by the X' type design produced with the new mold. The lowest, in this case, was provided by the Y-type design.

It was observed that the new mold increased power values. However, power values decreased with a reverse effect in the case of the Z-type design.

The lowest fuel consumption was achieved with Z-type and X-type designs produced with the old mold.

It was observed that the new mold increased the specific fuel consumption compared to the old one.

The designs with the best performance in terms of soot emission were X and Z-type designs produced with the old mold.

No significant impact was seen on intake airflow about the manifold and intake port design.

It was observed that the best values in terms of thermal efficiency were seen in the Z-type design with the old mold and it was followed by the X-type design produced with the old mold.

Additionally, the direct impact of the intake port geometry on combustion efficiency is understood by the specific fuel consumption values in this study. The reason for this is that the turbulence inside is affected more by the intake port geometry and therefore leads to improvement or degradation.

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Cenk Celik: Conceptualization, Supervision,
Usame Demir: Conceptualization, Writing-original draft, Validation,
Anıl Can Turkmen: Conceptualization, Writing-original draft, Validation,
Ozan Cetinkaya: Data curation, Formal analysis

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