Research Article

Effect of Fuel Injection Parameters on Engine Performance in A Conventional Single Cylinder Spark Ignition Engine

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ABSTRACT: In this study, a 1D model was created using the Ricardo-Wave program for a single-cylinder, spark ignition, four-stroke, direct injection engine with a stroke volume of 398 cc. Air-fuel ratio (AFR), mixture temperature (MT), and start of injection (SOI) were used as fuel injection parameters. Using these parameters, 343 different cases were created. Brake power, thermal efficiency, and fuel consumption were used as engine performance parameters. By holding one injection parameter constant, a contour plot was created to examine the effect of the other two parameters on the engine performance parameter. According to the results, the effect of MT and SOI on brake power is 1%, the effect of AFR on brake power is 9.6%, the effect of MT and SOI on thermal efficiency is 1%, and the effect of AFR on thermal efficiency is 12.8%. The effect of MT and SOI on fuel consumption is 0.04%, the effect of AFR on fuel consumption is 22.9%, and the effect of AFR on brake specific fuel consumption is 22.9%. These results indicate that the most significant effect is provided by AFR, while MT and SOI also have a slight impact on engine performance.

Keywords: Fuel injection, Internal combustion engine, Performance, Simulation

1. INTRODUCTION

One of the greatest inventions affecting humanity is undoubtedly internal combustion engines. Although many researchers have made significant contributions to the development of internal combustion engines, the historical achievements in the development of the spark-ignition engine (1876) and the compression-ignition engine (1892) have shaped the present of the global automotive industry [1]. These fossil fuel-powered internal combustion engines provide approximately 25% of the world's power. Significant technological advancements have been made in internal combustion engines, particularly in recent years. However, the reputation of internal combustion engines has recently taken a significant hit, primarily due to high-profile emission scandals like the Volkswagen diesel scandal. These scandals revealed that some manufacturers manipulated emissions testing to make their engines appear cleaner than they actually are. This deception has not only damaged trust in these engines but also raised doubts about their potential to contribute meaningfully to future emission reductions, as they have been shown to produce more pollutants under real-world conditions than previously claimed. Consequently, there have been developments aimed at replacing internal combustion engine vehicles with electric drives to further reduce fuel consumption and emissions and decrease vehicle greenhouse gas emissions [2]. For example, in the United Kingdom, internal combustion engine vehicles produced 23% of carbon dioxide emissions in 2010, compared to 14% in 1980 [3]. Although there has been a transition from internal combustion engine vehicles to electric vehicles today, significant work continues internal combustion engines. Society continues to rely heavily on integrated circuit engines for transportation, commerce, and energy production. This is why motor research, with over a century-long history, is still vibrant today. Internal combustion engines are used not only in the transportation sector but also in many areas such as pumps, lawnmowers, chainsaws, and power generators [4]. Changes in motor technology and transportation energy demand, driven by the need to increase the efficiency of internal combustion engines and reduce emissions, also affect future fuel characteristics. The increasing energy demand for transportation is shifting towards jet fuel compared to gasoline [5].

Various simulation programs are used to develop internal combustion engines. Through simulation, the impact of engine design parameters on performance can be observed [6]. 1D engine models are frequently preferred in engine analyses. Yontar and Doğu [7], in their study, created a 1D engine model alongside experimental work to observe the impact of CNG and gasoline fuels on engine performance. A 1D model was created for all test equipment and the engine using Ricardo-Wave software, and numerical engine analyses were performed. The same test parameters were

***Corresponding Author Email:** recepcagriorman@gmail.com
Submitted: 23.06.2024 **Revision Requested:** 13.08.2024 **Last Revision Received:** 25.08.2024
Accepted: 11.09.2024 **Published Online:** 30.09.2024

Burdur Mehmet Akif Ersoy University Press

Cite this article as: Orman, R. Ç. (2024). Effect of Fuel Injection Parameters on Engine Performance in A Conventional Single Cylinder Spark Ignition Engine. Scientific Journal of Mehmet Akif Ersoy University, 7(2): 1-7.
DOI: https://doi.org/10.70030/sjmakeu.1503849 https://dergipark.org.tr/sjmakeu

analyzed, and the same test outputs were calculated in the 1D engine model. Therefore, the test and 1D engine model were used to measure the effects of gasoline and CNG fuels on engine performance and emissions for a unique engine [7]. Claywell et al., in their study, used Ricardo-Wave software to investigate the performance of the three most common intake concepts for a naturally aspirated four-cylinder Formula SAE engine, as well as the performance of two variations of the basic concepts [8]. Deighan et al., in their study, presented an approach to model engine crankcase gas flow using Ricardo-Wave software. The model was developed and validated using pressure and leakage data during the design of a racing engine's dry sump version. The model was used to measure gas velocities, pressure fluctuations, and power loss resulting from the pumping of crankcase gas [9]. Youssef et al., in their study, created a computer simulation using Ricardo-Wave software to predict the performance and nitrogen oxide emissions of a diesel engine running on a diesel-biodiesel blend and diethyl ether as a fuel additive. The model created was validated with experimental data.

In 1D models, it is common to validate the engine operating conditions with experimental data. However, 1D models can also be created to examine the impact of engine parameters on engine performance. Due to the numerous variables in these models, it may not be possible to validate all obtained data. However, these models can be actively used to observe the impact of a parameter. The main aim of this study was to examine the impact of fuel injection parameters on engine performance in a conventional, single-cylinder, spark-ignition engine using a 1D model.

2. MATERIALS AND METHODS

In this study, a 1D model was created in the Ricardo-Wave program for a single-cylinder, spark ignition, four-stroke, direct injection engine with a stroke volume of 398 cc. The engine has two valves. The connecting rod/crank ratio is 3.66. The nozzle diameter of the injector is 0.2 mm and the working pressure is 2000 kPa. In the model, the case in which the engine operates at a constant speed of 5000 rpm is examined. For reference, the air/fuel ratio is 14.5, the fuel-air mixture temperature is 320 K, and the injection start is -100°CA.

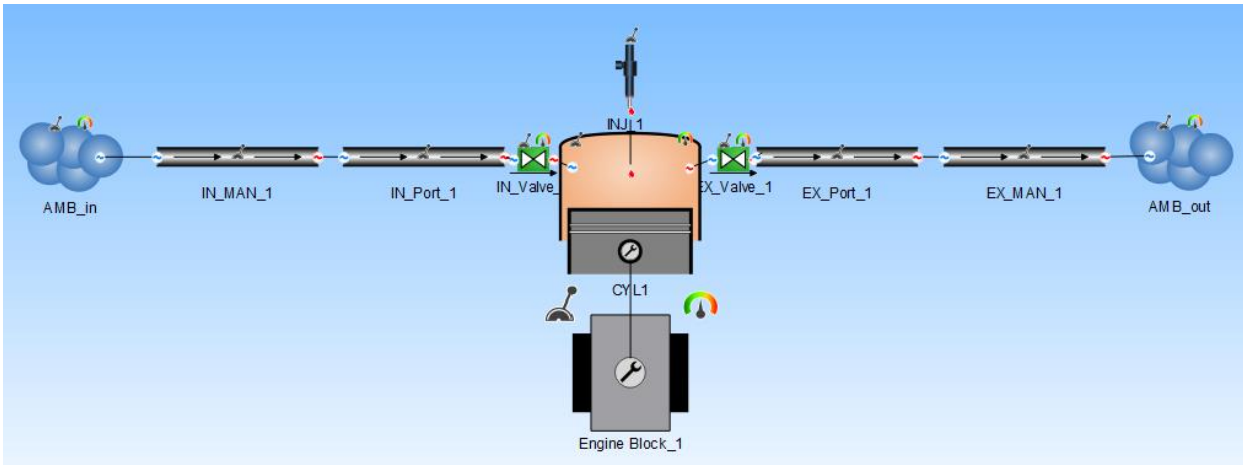


Fig 1. Model created for the engine

The change of in-cylinder pressure and temperature to the reference values of the engine is as shown in Fig. 2. The maximum pressure of the engine is 6300 kPa and the maximum temperature is 2650 K. The results of the engine according to these reference values are among the examples tested in the Ricardo-Wave program.

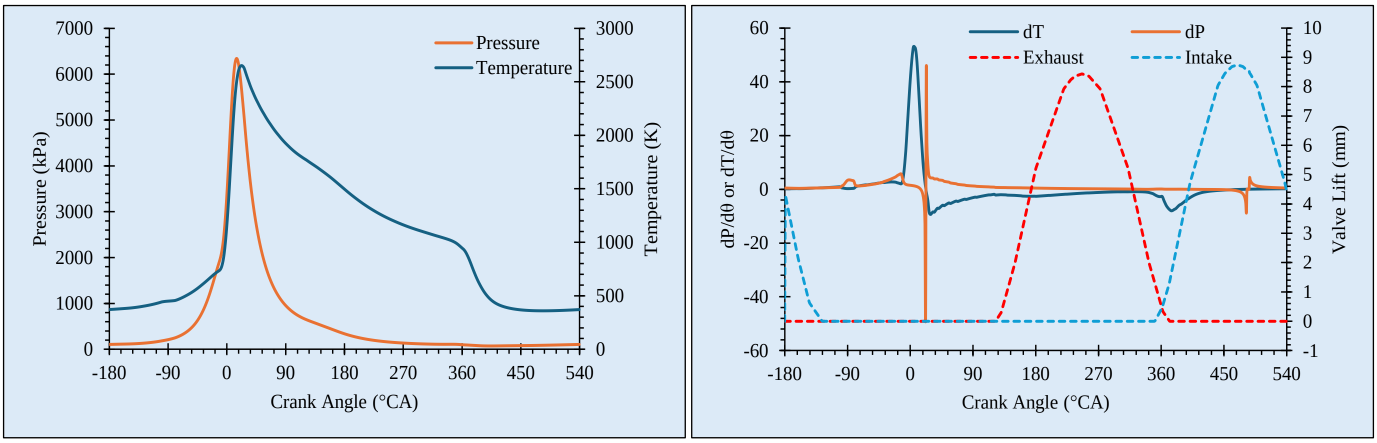


Fig 2. In-cylinder pressure and temperature change for reference case

For this study, the injection parameters were air-fuel ratio (AFR) (0.5 step between 13 and 16), mixture temperature (MT) (10 K step between 290 and 350 K), start of injection (SOI) (-130°CA to 10 steps between -70°C) are preferred. 343 full factorial cases were obtained for the parameters in the model. Accordingly, effective power, thermal efficiency and fuel consumption values at 5000 rpm were examined. The term “mixture temperature” here essentially corresponds to “fuel temperature”. The reason for insisting on using 'mixture temperature' instead of 'fuel temperature' is to align with the terminology used in the program. Since the program evaluates parameters for both port injection and direct injection, fuel temperature is referred to as mixture temperature. Actually, fuel temperature is a parameter that directly influences mixture temperature. When fuel is injected into the compressed air, the mixture temperature will decrease slightly due to the evaporation enthalpy of the fuel molecules. If the fuel is hot, some of the energy required for evaporation will be carried into the cylinder with the fuel, which can slightly affect performance. Although fuel temperature is not commonly used as a parameter in practice today, it is known that fuel temperature increases due to pressurization. However, the fuel may cool down in the distance between the pump and the injector. For this reason, mixture temperature has been deliberately considered a parameter in this study, and its impact has been examined.

3. MODEL OUTPUTS

The effect of the three determined injection parameters on engine performance was shown by creating contour plots while a certain injection parameter was at the reference value (AFR = 14.5, SOI = -100ºCA and MT = 320 K), and the effect of the other two parameters on engine performance was demonstrated.

The effect of injection parameters on braking power is shown in Figure 3. Low AFR and high MT values improve braking power. Figure 3a shows the effect of AFR and MT on braking power when SOI is constant. In this case, it can be seen that MT does not have a significant effect on braking power. However, it is seen that the brake power increases for the case where AFR is low. Figure 3b shows the effect of AFR and SOI on braking power when MT is constant. In this case, it appears that SOI has no significant effect on braking power. However, it is seen that the brake power increases for the case where AFR is low. Here it can be seen that AFR has a dominant effect on braking power. Figure 3c shows the effect of MT and SOI on braking power when AFR is constant. In this case, thermal efficiency increases when MT and SOI are low. A low SOI means the injection starts early. The effect of MT and SOI on braking power is 1%. The effect of AFR on braking power is 9.6%.

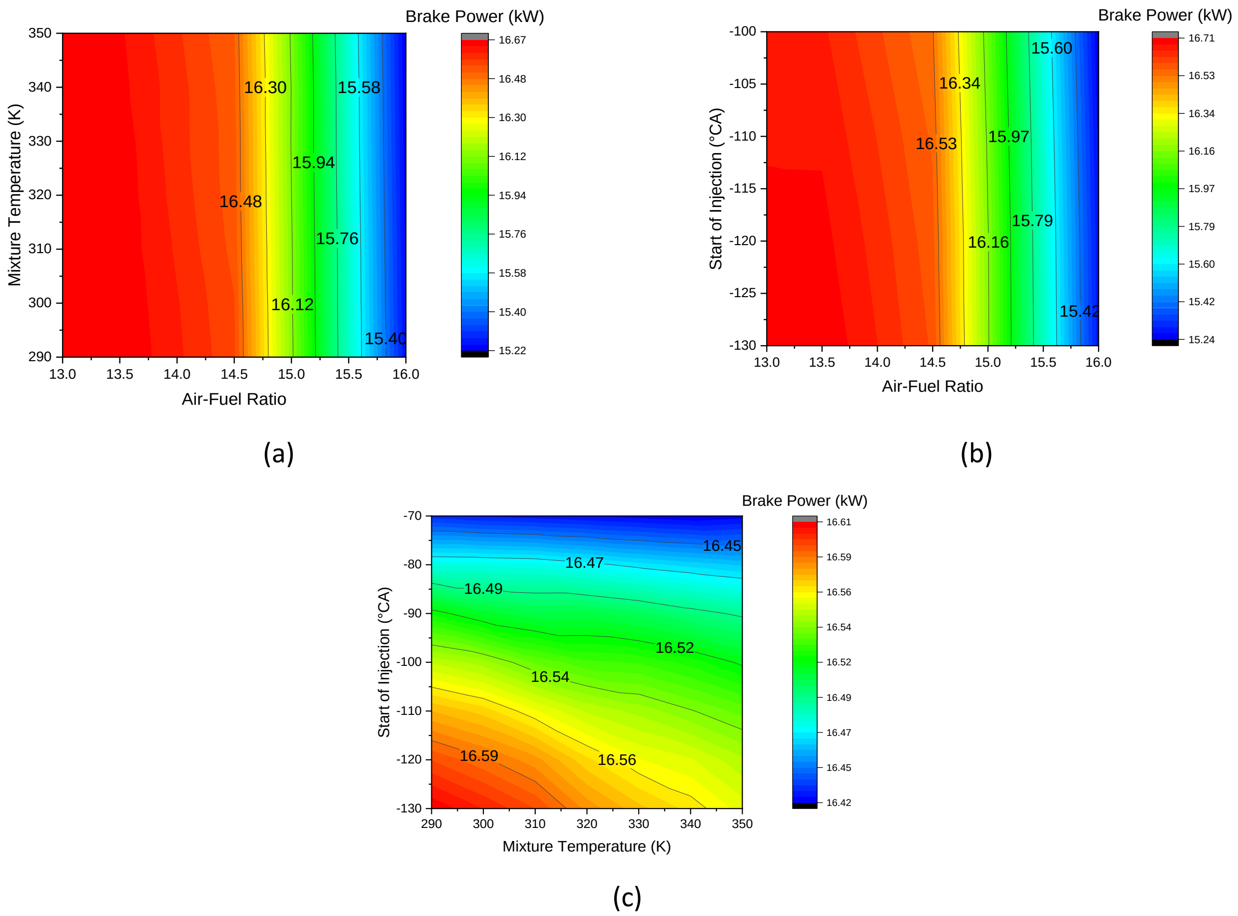


Fig 3. Effect of injection parameters on brake power

The effect of injection parameters on thermal efficiency is shown in Figure 4. High AFR and low MT values improve thermal efficiency. Figure 4a shows the effect of AFR and MT on thermal efficiency when SOI is constant. In this case, it appears that MT does not have a significant effect on thermal efficiency. However, it is seen that thermal efficiency increases for the case where AFR is high. Figure 4b shows the effect of AFR and SOI on thermal efficiency when MT is constant. In this case, it appears that SOI does not have a significant effect on thermal efficiency. However, it is seen that thermal efficiency increases for the case where AFR is high. Here it can be seen that AFR has a dominant effect on thermal efficiency. Figure 4c shows the effect of MT and SOI on thermal efficiency when AFR is constant. In this case, when MT and SOI are low, brake power increases. A low SOI means the injection starts early. The effect of MT and SOI on thermal efficiency is 1%. The effect of AFR on thermal efficiency is 12.8%.

The effect of injection parameters on fuel consumption is shown in Fig. 5. Low AFR and high MT values increase fuel consumption. Figure 5a shows the effect of AFR and MT on fuel consumption when SOI is constant. In this case, it can be seen that MT does not have a significant effect on fuel consumption. However, it is seen that fuel consumption decreases when AFR is high. Figure 5b shows the effect of AFR and SOI on fuel consumption when MT is constant. In this case, it appears that SOI does not have a significant effect on fuel consumption. However, it is seen that fuel consumption decreases when AFR is high. Here it can be seen that AFR has a dominant effect on fuel consumption. Figure 5c shows the effect of MT and SOI on fuel consumption when AFR is constant. In this case, when MT and SOI are high, fuel consumption decreases. A high SOI means that the injection starts late. The effect of MT and SOI on fuel consumption is 0.04%. The effect of AFR on fuel consumption is 22.9%.

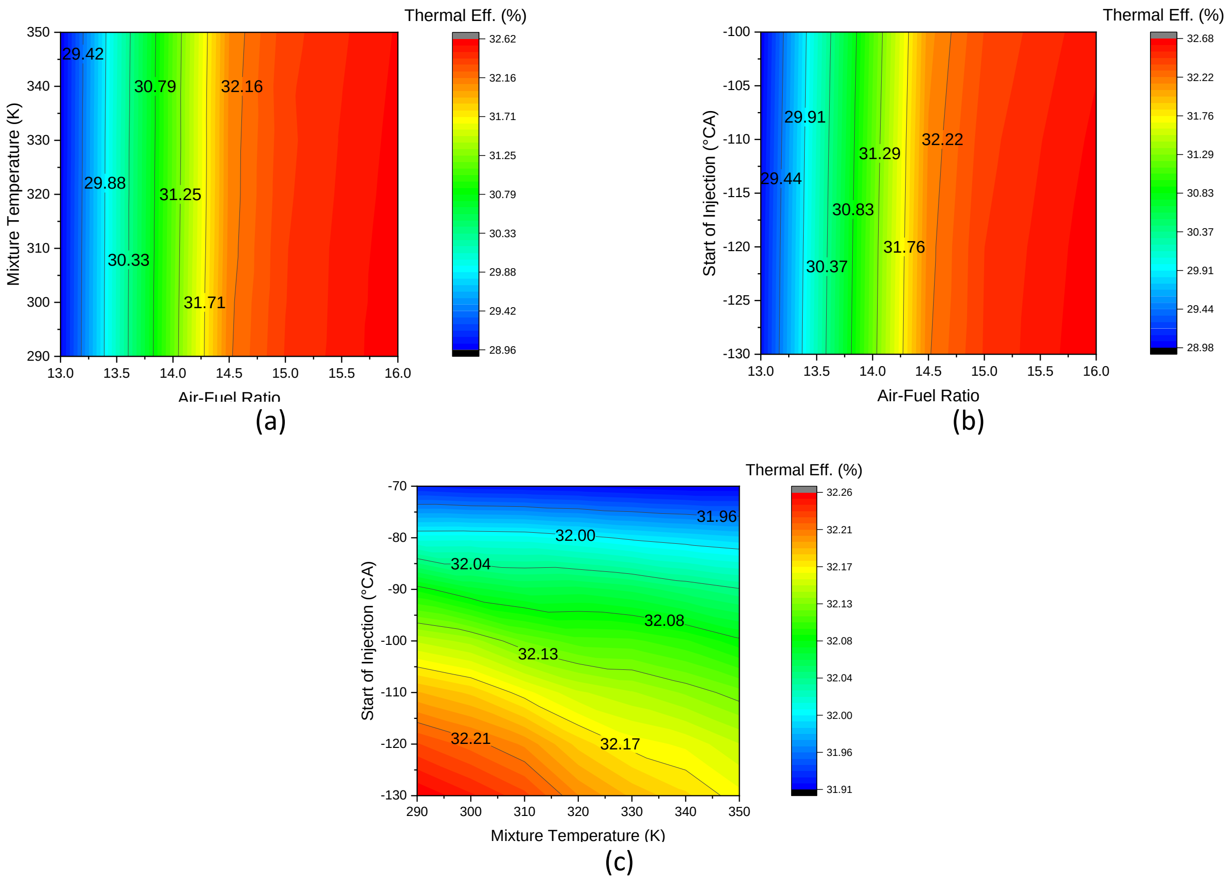


Fig 4. Effect of injection parameters on thermal efficiency

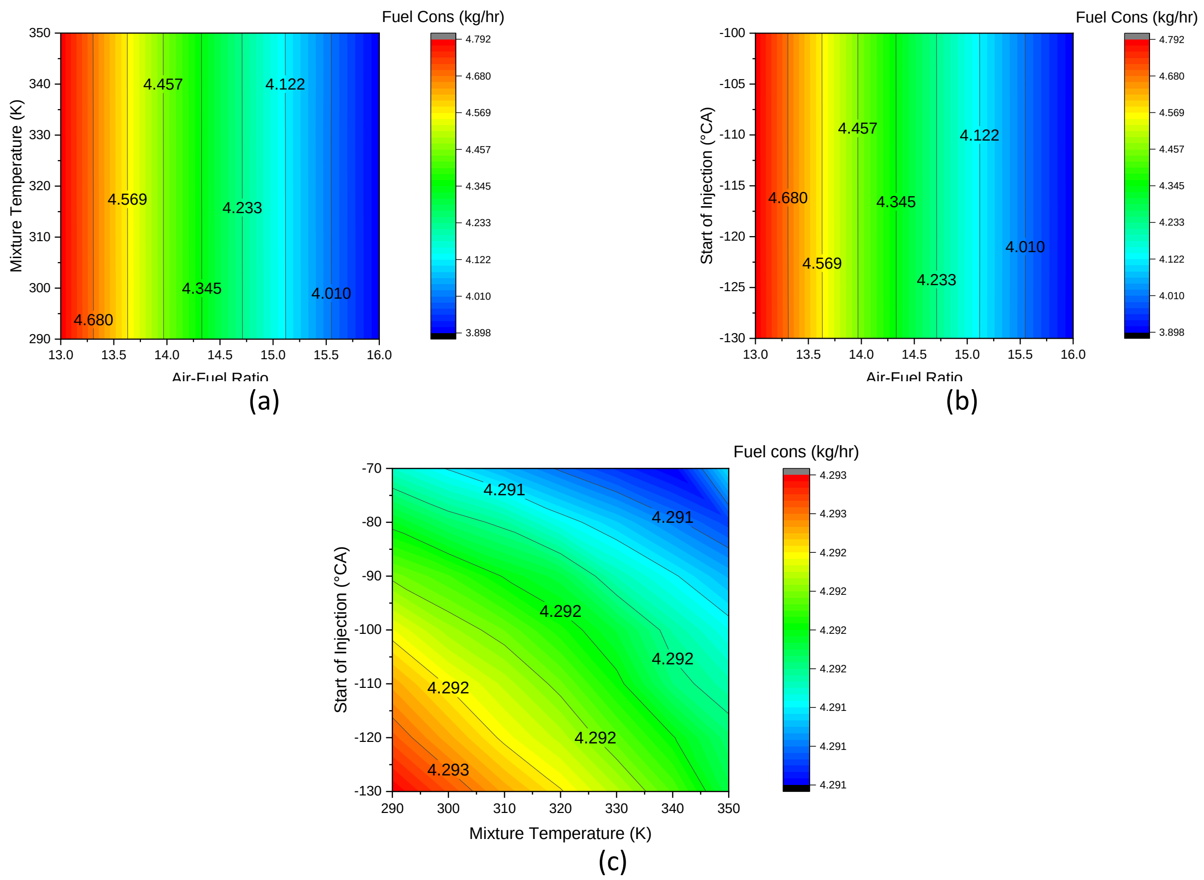
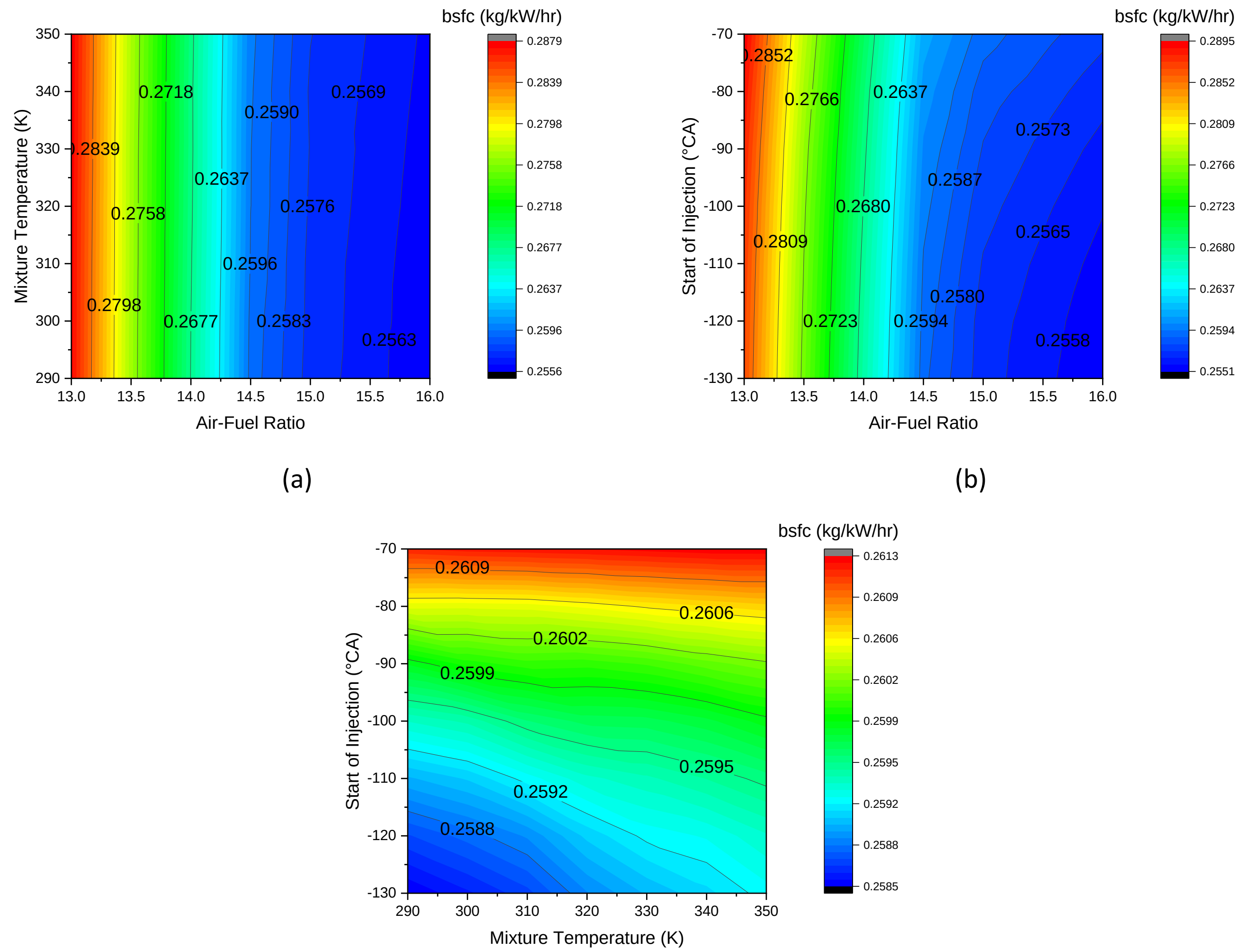


Fig 5. Effect of injection parameters on fuel consumption

The effect of injection parameters on brake specific fuel consumption is shown in Fig. 6. High AFR and low SOI values decrease fuel consumption. Figure 6a shows the effect of AFR and MT on brake specific fuel consumption when SOI is constant. In this case, it can be seen that MT does not have a significant effect on brake specific fuel consumption. However, it is seen that specific fuel consumption decreases when AFR is high. Figure 6b shows the effect of AFR and SOI on fuel consumption when MT is constant. In this case, it appears that SOI does not have a significant effect on brake specific fuel consumption. However, it is seen that brake specific fuel consumption decreases when AFR is high. Here it can be seen that AFR has a dominant effect on brake specific fuel consumption. Figure 6c shows the effect of MT and SOI on fuel consumption when AFR is constant. In this case, when MT and SOI are low, fuel consumption decreases. A low SOI means that the injection starts early. The effect of MT and SOI on brake specific fuel consumption is 0.04%. The effect of AFR on brake specific fuel consumption is 12.6%.



(c)

Fig 6. Effect of injection parameters on brake specific fuel consumption

4. CONCLUSIONS

In this study, a 1D model was created in the Ricardo-Wave program for a single-cylinder, spark ignition, four-stroke, direct injection engine with a stroke volume of 398 cc. Air-fuel ratio (AFR), mixture temperature (MT) and start of injection (SOI) were used as fuel injection parameters. Using these parameters, 343 different cases were created. Brake power, thermal efficiency and fuel consumption were used as engine performance parameters. By leaving any injection parameter constant, a contour plot was created in which the effect of the other two parameters on the engine performance parameter could be examined. According to the results, the effect of MT and SOI on brake power is 1%, the effect of AFR on brake power is 9.6%, the effect of MT and SOI on thermal efficiency is 1%, the effect of AFR on thermal efficiency is 12.8%, the effect of MT and SOI on thermal efficiency is 12.8%. The effect of AFR on fuel consumption is 0.04%, the effect of AFR on fuel consumption is 22.9%, and the effect of AFR on brake specific fuel consumption is 12.6%. Here it can be seen that the biggest effect is provided by AFR. However, MT and SOI are also slightly effective on engine performance.

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Techno-Science *Paper ID: 1503849*