





The Effect of Injector Nozzle Opening Pressure and Cetane Number on Fuel Consumption in Single-Cylinder Diesel Engines at Various Engine Speeds

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Abstract

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The ability of diesel injectors to spray fuel greatly affects the homogeneity of the mixture and its penetration power in the combustion chamber. The research method used is an experiment with data presented descriptively. The objectives of this study are to determine the effect of nozzle opening pressure on fuel consumption, to identify the nozzle opening pressure at which fuel consumption is lowest, and to determine the effect of cetane number on fuel consumption in diesel engines. The results of this study indicate that the nozzle opening pressure of the injector in a diesel engine significantly affects fuel consumption, regardless of whether the engine is operating at low, medium, or high RPM. The lowest fuel consumption in a diesel engine occurs at a nozzle opening pressure of 10 MPa. The cetane number of the fuel does not significantly affect fuel consumption in a diesel engine, specifically a single-cylinder indirect injection diesel engine.

Keywords: *Injector Pressure, Fuel Consumption, Diesel.*

Abstrak

Kemampuan injektor diesel dalam menyemprotkan bahan bakar sangat berpengaruh terhadap campuran homogen dan daya penetrasi dalam ruang bakar. Metode penelitian yang digunakan ialah eksperimen dengan data disajikan secara deskriptif. Tujuan penelitian ini adalah mengetahui pengaruh tekanan bukaan nozzle terhadap konsumsi bahan bakar, mengetahui pada tekanan bukaan nozzle berapakah bahan bakar paling rendah dikonsumsi, mengetahui pengaruh kadar cetane number pada bahan bakar terhadap tingkat konsumsi bahan bakar pada motor diesel. Hasil penelitian ini adalah tekanan bukaan nozzle injektor pada motor diesel sangat berpengaruh terhadap konsumsi bahan bakar, baik pada rpm rendah, menengah dan tinggi. Tekanan bukaan nozzle yang paling rendah mengkonsumsi bahan bakar pada motor diesel adalah pada tekanan 10 MPa, kadar cetane number pada bahan bakar tidak terlalu berpengaruh terhadap tingkat konsumsi bahan bakar pada motor diesel, dalam hal ini adalah diesel satu silinder berjenis indirect injection.

Kata-kata kunci: *Tekanan Injektor, Konsumsi bahan bakar, Diesel.*



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1. Introduction

Fuel is a factor that must always be available for the survival of internal combustion engines. ICEs work by converting the chemical energy in fuel into heat energy through combustion. Diesel engines are one example of ICEs. Diesel engines utilize the heat of compressed air to trigger fuel combustion in the combustion chamber. According to data from the Central Statistics Agency (BPS) in 2019, the total number of motor vehicles of various types up to 2019 exceeded 133 million units [1]. Of that number, 231,000 units are buses and 5 million units are freight vehicles, both of which are diesel-powered [2]. Hundreds of millions of motor vehicles inevitably produce exhaust emissions. Among these emissions are gases that are harmful to living creatures and have a negative impact on the environment. Motor vehicle exhaust contains hazardous substances such as nitrogen oxides (NO_x), sulfur oxides (SO_x), lead (Pb), carbon monoxide (CO), and hydrocarbons (HC) [3].

The effect of air pollution on the environment is an increase in the greenhouse effect or global warming due to excessive carbon emissions from human activities. The transportation sector also plays a significant role in contributing to global carbon production. The Earth produces carbon emissions in the form of CO₂ at an average rate of 5.8–8.7 million tons per year, with nearly 89% of these emissions originating from motor vehicles that consume fossil fuels, including land, air, and sea transportation [4]. The greenhouse effect can accelerate the melting of polar ice, which over time will cause sea levels to rise, rendering previously habitable land uninhabitable as it may be submerged by seawater or tidal flooding. Specifically for diesel engines, exhaust emissions that are often feared to have a negative impact on the environment and human health are particulate matter or suspended particulate matter (SPM). Particulate matter is the exhaust gas from the combustion of diesel fuel, in this case diesel fuel, that is emitted from the exhaust in the form of ash or soot [5]. If these particles enter the body in large quantities through breathing, they can cause cancer [4].

As long as there are still many internal combustion engines (ICE) in use, it will be impossible to completely eliminate pollution. Efforts can be made to respond to this phenomenon by implementing measures aimed at minimizing gas emissions, including those produced by ICE. Efforts to minimize emissions include automotive technology approaches to reduce gas emissions from motor vehicles [6], an example of this is the use of catalytic converters in vehicles. Another effort can be made by improving fuel quality. In this case, diesel engines require diesel

fuel with low sulfur content [7]. The last thing you can do is to regularly maintain and repair your motor vehicle. Motor vehicles with relatively long service or tune-up intervals produce higher exhaust emissions than vehicles that are regularly and routinely maintained [8].

Diesel engines utilize heat from air compression to generate compression heat, which is then used to burn the mixture of air and fuel sprayed by the injector nozzle. The injector nozzle in a diesel engine is responsible for measuring and distributing fuel to the combustion chamber. The injector nozzle converts liquid diesel fuel into a mist or small droplets, so that when the fuel is sprayed into the combustion chamber, it can burn easily [9]. Another task of the injector nozzle is to spray fuel at the right time so that the ignition timing also matches the specifications. In gasoline engines, there is a carburetor to measure fuel and a spark plug to regulate ignition timing, but in diesel engines, both of these roles are replaced by the injector nozzle. The injector nozzle is responsible for measuring the fuel entering the combustion chamber and regulating the ignition timing [10]. Over time, diesel engines that operate continuously require injector nozzle adjustment. Injector nozzles that have never been adjusted and calibrated will cause changes in the shape of the fuel atomization from its original form. Originally, the fuel spray formed small droplets due to carbon deposits blocking the orifice holes, causing the fuel droplets being sprayed to become larger. These larger droplets result in poor evaporation within the combustion chamber, causing the fuel-air mixture to not mix homogeneously during the compression stroke. This factor leads to thicker and more abundant black exhaust smoke from the exhaust pipe. Improper adjustment of the injector nozzle opening pressure also causes a decrease in the power output of the diesel engine. Another possibility is that the power output remains the same while fuel consumption increases. This clearly cannot be considered efficient engine operation, as power does not increase while fuel consumption rises. This phenomenon can be described as the engine being fuel-inefficient. Therefore, the above explanation necessitates calibration or adjustment of the valve opening pressure to achieve environmentally friendly exhaust emissions, high power output, and low fuel consumption.

This study aims to find data related to the effect of injector nozzle opening pressure variations on diesel engine fuel consumption. The injector nozzle opening pressure in diesel engines is varied using a diesel injector tester and then tested at various engine speeds, after which fuel consumption is calculated. The experiments in this study will determine the optimal injector pressure setting to achieve the lowest fuel consumption. Injector opening pressures that

result in low fuel consumption tend to produce lower exhaust emissions as well. The data obtained from this research can serve as a reference for diesel engine mechanics and technicians in determining the optimal injector nozzle opening pressure for diesel engines. This study will focus on the issue of diesel vehicles that have never undergone regular maintenance tend to consume more fuel.

2. Method

The research method used in this study is an experimental model. There are several variables in this study, namely: a) Independent variables (X), which are variations in injector nozzle opening pressure, including X1, X2, and so on up to Xn. b) Dependent variables (Y), which are diesel engine fuel consumption in units of volume (milliliters) within a certain period of time. Additionally, several types of fuel were varied, namely Y1 = bio solar CN 48, Y2 = dexlite CN 51, and Y3 = Pertamina dex CN 53. Data collection in this research and development study was carried out in three stages. The two stages are as follows: a) Collecting data on the fuel consumption of bio-diesel with a CN of 48 in relation to variations in nozzle opening pressure at a specific RPM. b) Collecting data on the fuel consumption of dexlite with a CN of 51 in relation to variations in nozzle opening pressure at a specific RPM. 3) Collecting data on the fuel consumption of dex fuel with a CN rating of 53 in relation to variations in nozzle opening pressure at a specific RPM.



Figure 1. Steps For Preparing to Collect Research Data



Figure 2. research data collection steps

The data analysis in this research and development study was processed and presented in the form of descriptive data. The data presented in this study is as follows: a) The effect of injector nozzle opening pressure on the consumption of CN48 biosolar fuel in diesel engines. b) The effect of injector nozzle opening pressure on the consumption of CN51 dexlite fuel in diesel engines. c) The effect of injector nozzle opening pressure on the consumption of CN53 dex fuel in diesel engines. d) Comparison of the use of the three types of fuel on diesel engine fuel consumption.

The object used to conduct this research was an 8hp single-cylinder diesel engine with the code R180, manufactured by Inda. The specifications of the diesel engine used are as follows.

Table 1. The Specifications of the Diesel Engine Used

Number	Specifications	Size
1	Type	R180
2	Brand	Inda
3	Engine power/RPM	8HP/ 2600 rpm
4	Cooling system	Hopper
5	Piston diameter x stroke	80x80 mm
6	Engine oil type	SAE 40 Diesel
7	Engine capacity	402cc
8	Engine combustion system	Indirect injection
9	Compression ratio	21 : 1
10	Number of cylinders	1



Figure 3. Single Piston Diesel Engine

3. Results and Discussion

3.1 Data on the variation in injector nozzle opening pressure in relation to fuel consumption

The table below shows the fuel consumption of biosolar with a cetane number of 48 consumed by a diesel engine during 2 minutes of operation with variations in injector opening pressure from the highest 20 MPa to the lowest 6 MPa. In addition to variations in injector pressure, changes were also made to engine speed at 1000 rpm, 1500 rpm, and 2000 rpm.

Table 3. Fuel Consumption Data with Biosolar Cetane Number 48 at 1000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1000	2	9
18 Mpa	1000	2	8
16 Mpa	1000	2	8
14 Mpa	1000	2	7
12 Mpa	1000	2	7
10 Mpa	1000	2	8
8 Mpa	1000	2	11
6 Mpa	1000	2	12

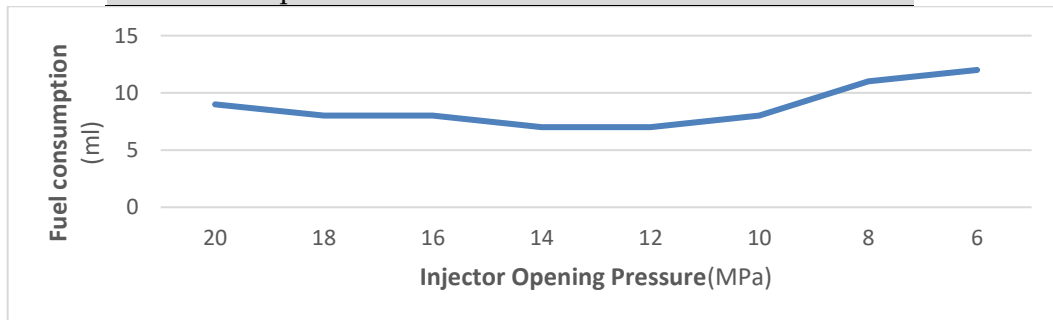


Figure 4. Bio Solar Fuel Consumption Chart at 1000 RPM

Table 4. Fuel consumption data with biosolar Cetane Number 48 at 1500 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1500	2	10
18 Mpa	1500	2	10
16 Mpa	1500	2	11
14 Mpa	1500	2	11
12 Mpa	1500	2	11
10 Mpa	1500	2	9
8 Mpa	1500	2	11
6 Mpa	1500	2	12

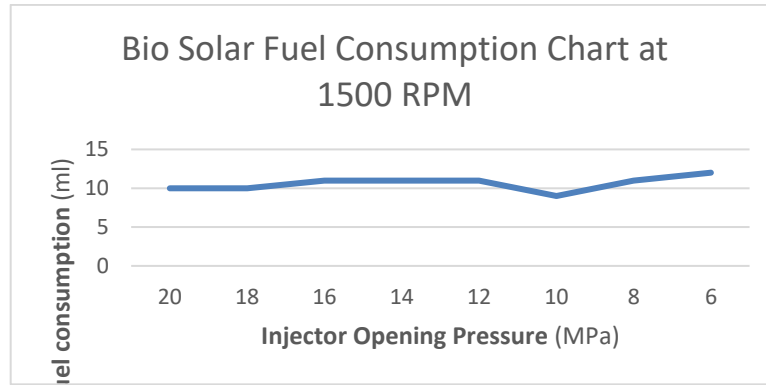


Figure 5. Bio Solar Fuel Consumption Chart at 1500 RPM

Table 5. Fuel consumption data with biosolar Cetane Number 48 at 2000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	2000	2	11
18 Mpa	2000	2	13
16 Mpa	2000	2	13
14 Mpa	2000	2	13
12 Mpa	2000	2	13
10 Mpa	2000	2	11
8 Mpa	2000	2	13
6 Mpa	2000	2	14

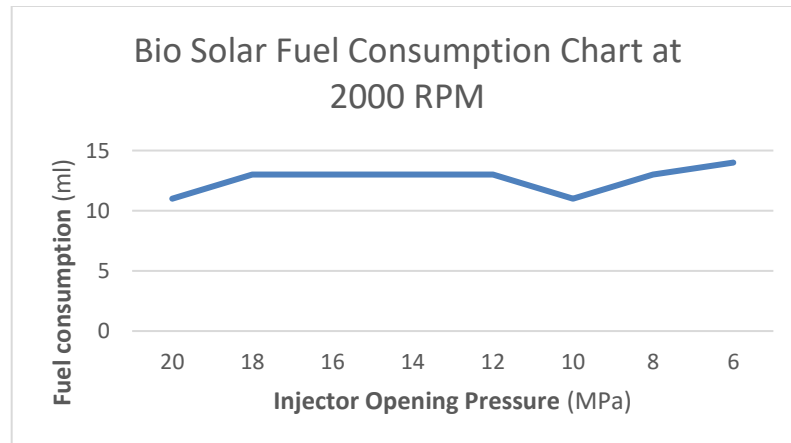


Figure 6. Bio Solar Fuel Consumption Chart at 2000 RPM

3.1.1.1 Fuel consumption data with dexlite Cetane Number 51.

Below is a table showing the fuel consumption of Dexlite with a cetane number of 51 consumed by a diesel engine during 2 minutes of operation with variations in injector opening pressure from the highest 20 MPa to the lowest 6 MPa. In addition to variations

in injector pressure, changes were also made to engine speed at 1000 rpm, 1500 rpm, and 2000 rpm.

Table 7. Fuel consumption data with dexlite Cetane Number 51 at 1000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1000	2	10
18 Mpa	1000	2	9
16 Mpa	1000	2	11
14 Mpa	1000	2	14
12 Mpa	1000	2	13
10 Mpa	1000	2	9
8 Mpa	1000	2	10
6 Mpa	1000	2	11

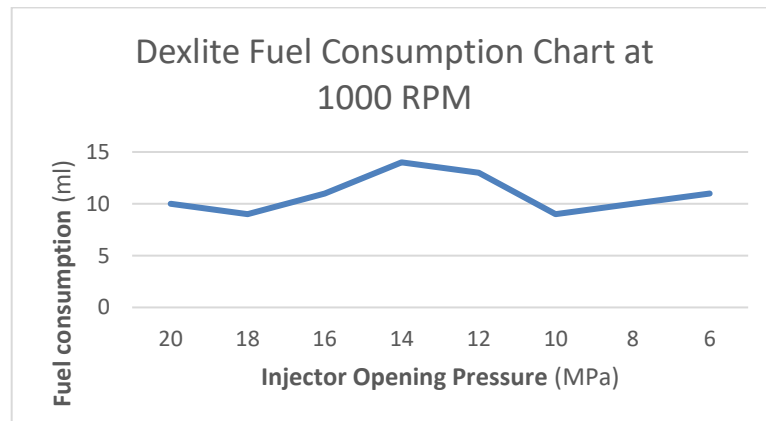


Figure 7. Dexlite Fuel Consumption Chart at 1000 RPM

Table 8. Fuel consumption data with dexlite Cetane Number 51 at 1500 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1500	2	12
18 Mpa	1500	2	14
16 Mpa	1500	2	14
14 Mpa	1500	2	15
12 Mpa	1500	2	14
10 Mpa	1500	2	12
8 Mpa	1500	2	14
6 Mpa	1500	2	15

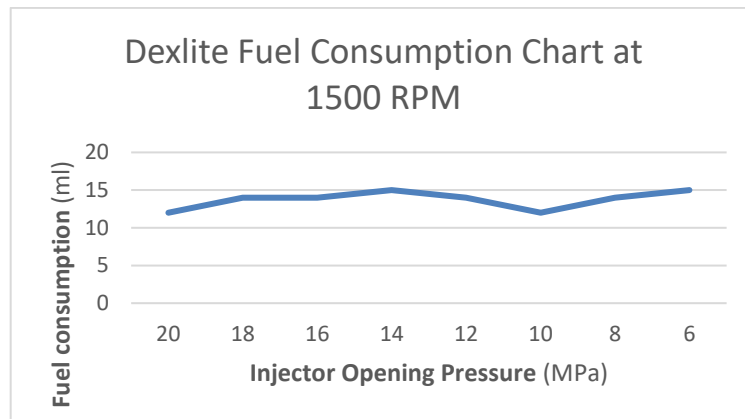


Figure 8. Dexlite Fuel Consumption Chart at 1500 RPM

Table 9. Fuel Consumption Data with Dexlite Cetane Number 51 at 2000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	2000	2	14
18 Mpa	2000	2	14
16 Mpa	2000	2	19
14 Mpa	2000	2	18
12 Mpa	2000	2	17
10 Mpa	2000	2	15
8 Mpa	2000	2	16
6 Mpa	2000	2	17

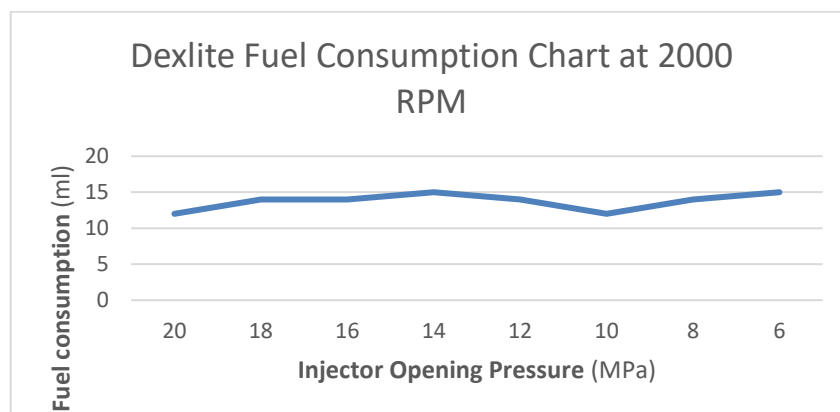


Figure 9. Dexlite Fuel Consumption Chart at 2000 RPM

3.1.1.2 Fuel consumption data with Dex Cetane Number 53.

Below is a table showing the fuel consumption of Dex fuel with a cetane number of 53 consumed by a diesel engine during 2 minutes of operation with variations in injector opening pressure from the highest 20 MPa to the lowest 6 MPa. In addition to variations

in injector pressure, changes were also made to engine speed at 1000 rpm, 1500 rpm, and 2000 rpm.

Table 11. Fuel consumption data with Dex Cetane Number 53 at 1000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1000	2	11
18 Mpa	1000	2	9
16 Mpa	1000	2	11
14 Mpa	1000	2	14
12 Mpa	1000	2	13
10 Mpa	1000	2	9
8 Mpa	1000	2	10
6 Mpa	1000	2	11

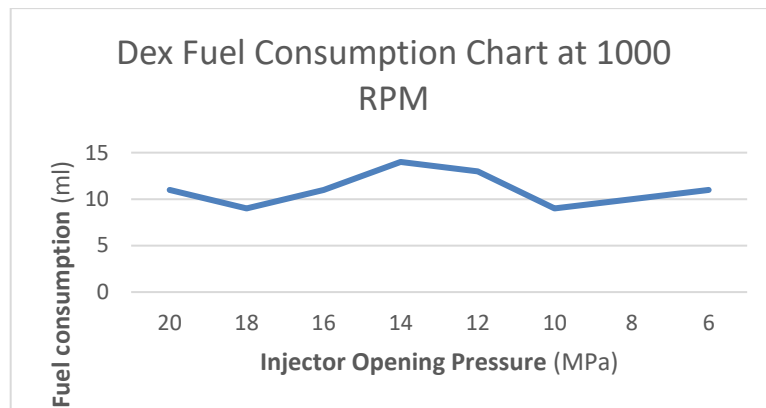


Figure 10. Dex Fuel Consumption Chart at 1000 RPM

Table 12. Fuel consumption data with Dex Cetane Number 53 at 1500 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	1500	2	12
18 Mpa	1500	2	13
16 Mpa	1500	2	14
14 Mpa	1500	2	15
12 Mpa	1500	2	14
10 Mpa	1500	2	12
8 Mpa	1500	2	13
6 Mpa	1500	2	14

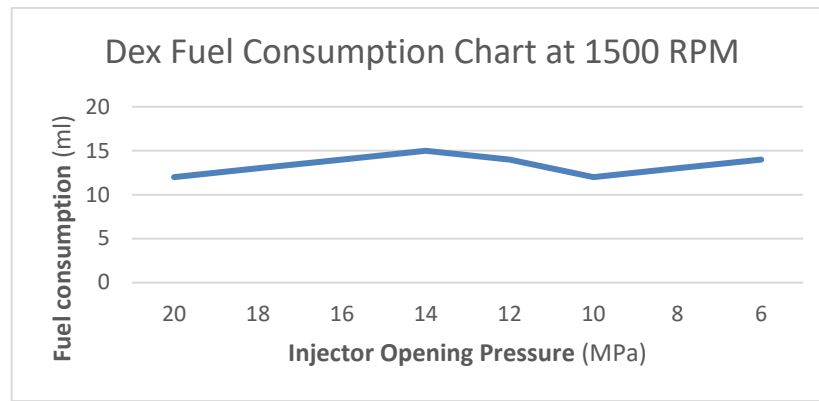


Figure 11. Dex Fuel Consumption Chart at 1500 RPM

Table 13. Fuel consumption data with Dex Cetane Number 53 at 2000 rpm.

Injector Opening Pressure	Engine Speed (rpm)	How long the motor runs (minute)	Fuel consumption (ml)
20 Mpa	2000	2	15
18 Mpa	2000	2	14
16 Mpa	2000	2	18
14 Mpa	2000	2	18
12 Mpa	2000	2	17
10 Mpa	2000	2	15
8 Mpa	2000	2	16
6 Mpa	2000	2	17

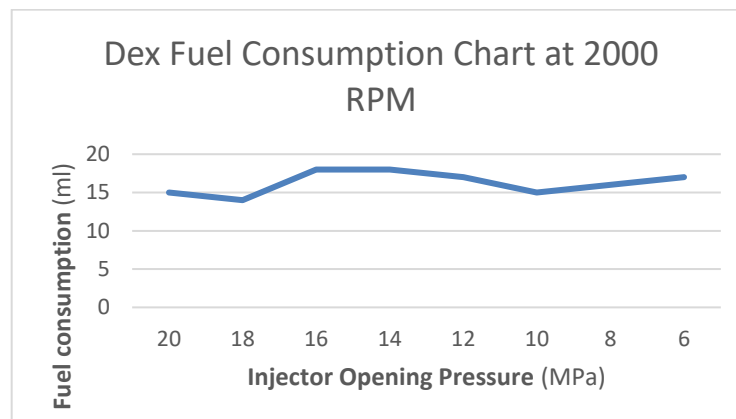


Figure 12. Dex Fuel Consumption Chart at 2000 RPM

3.2. Discussion

3.2.1. The effect of nozzle opening pressure on atomization

In a diesel engine fuel injection system, one of the key components that affects combustion efficiency is the injector nozzle. Nozzle opening pressure plays a crucial role in the fuel atomization process. The higher the pressure when the nozzle opens, the finer the size of the fuel

particles sprayed into the combustion chamber [11]. This results in more even fuel distribution and increases the surface area of contact with air, enabling more complete and efficient combustion. Low opening pressure tends to produce larger fuel particles [12], which can be propelled far enough to reach near the cylinder walls, allowing combustion to occur not only near the nozzle/injector but also in the farthest areas, maximizing combustion pressure. However, this also increases exhaust gas emissions. Conversely, excessively high opening pressure can also cause issues, such as premature wear on injector components or fuel overpenetration, where the spray creates soft fuel particles that prevent the fuel from penetrating the combustion chamber wall before optimal combustion pressure is achieved.

3.2.2. The effect of nozzle opening pressure on fuel consumption

Nozzle opening pressure in a diesel engine injection system plays an important role in determining fuel efficiency [13]. This pressure determines how quickly and how finely the fuel is sprayed into the combustion chamber. When the nozzle opening pressure is at an optimal level, fuel atomization becomes finer and more uniform, resulting in more complete mixing of fuel with air. This leads to more efficient combustion and directly reduces fuel consumption. Conversely, if the nozzle opening pressure is too low, atomization becomes less optimal [14]. Larger fuel droplet sizes result in suboptimal mixing with air, causing some fuel to burn incompletely and be expelled through exhaust gases. This forces the engine to inject more fuel to achieve the same power output, ultimately increasing fuel consumption.

On the other hand, excessively high nozzle opening pressure is not always advantageous. Although it produces very fine atomization, excessive injection pressure can cause fuel to spray too quickly and lack penetration into the combustion chamber, which can also reduce combustion pressure. Additionally, high pressure requires more energy from the injection pump, thereby increasing engine workload and potentially reducing overall efficiency.

3.2.3. Homogenization vs. penetration in diesel engine injectors and their impact on diesel engines:

In diesel engine fuel injection systems, two important aspects that significantly influence combustion quality are the homogenization and penetration of the fuel spray emitted through the injector [15]. These two factors directly relate to how fuel mixes with air inside the combustion chamber, ultimately determining combustion efficiency and overall engine performance.

a. Homogenization

Homogenization refers to how evenly the fuel is dispersed in the air within the combustion chamber after being sprayed by the injector. The better the homogenization, the more evenly the fuel and air mixture is distributed, resulting in more complete combustion. Good homogenization can reduce fuel consumption, lower exhaust emissions, and improve engine thermal efficiency [16]. This is particularly important in modern engines with strict emission controls.

b. Penetration

Penetration refers to how far the fuel spray can reach into the combustion chamber. Sufficient penetration is necessary for the fuel to reach all parts of the combustion chamber, which is very important because it affects the combustion process that will occur throughout the combustion chamber, including the walls and piston tips [17]. If the fuel can penetrate and reach the cylinder walls and piston tips, the combustion pressure generated will be greater. However, if penetration is too deep (overpenetration), the fuel may directly adhere to the cylinder walls or piston without mixing with air. This can cause incomplete combustion, increased particulate emissions, and energy loss.

3.2.3. Relationship and Balance

There must be a balance between homogenization and penetration [18]. Sufficient penetration without sacrificing homogenization will produce an ideal air-fuel mixture. Injectors designed with the right spray pressure, nozzle shape, and spray pattern play a key role in achieving this balance. If the spray is too strong (pressure too high), homogenization can be achieved well but penetration is reduced. Conversely, if the pressure is too low, homogenization is poor but the spray can reach the entire combustion chamber area.

3.2.4. The Effect of Fuel Cetane Content on Fuel Consumption

The cetane number of diesel fuel is an important indicator of combustion quality in diesel engines [19]. The cetane number describes how quickly the fuel begins to burn after being injected into the combustion chamber. The higher the cetane number, the faster the fuel ignites after injection (shorter ignition delay) [20]. When the ignition delay is shorter, the combustion process becomes more stable and controlled, allowing the energy from the fuel to be utilized optimally. This directly impacts combustion efficiency and reduces fuel consumption, as no fuel

is burned too late or wasted. Conversely, diesel fuel with a low cetane number tends to have a longer combustion delay [21]. As a result, some of the injected fuel has not burned at the right time and instead explodes in large quantities after ignition occurs. This condition causes inefficient combustion, increases fuel consumption, and causes knocking (loud explosions in the combustion chamber), which can damage the engine over the long term. The engine must work harder to produce the same power, resulting in increased fuel consumption.

Therefore, the use of diesel fuel with an appropriate or higher cetane number is highly recommended to achieve efficient combustion, optimal engine performance, and lower fuel consumption. Vehicle manufacturers and diesel engine operators should pay attention to the cetane specifications of the fuel used to ensure compatibility with the characteristics of the engine being operated.

4. Conclusion

Based on the discussion above, the following conclusions can be drawn: a) The opening pressure of the injector nozzle in a diesel engine has a significant effect on fuel consumption, whether at low rpm (1000 rpm), medium rpm (1500 rpm), or high rpm (2000 rpm). b) The lowest fuel consumption in a diesel engine occurs at a nozzle opening pressure of 10 MPa, followed by 20 MPa. However, at 20 MPa, it is still unclear whether power and torque decrease or remain unchanged. c) The cetane number of the fuel does not significantly affect fuel consumption in a diesel engine, specifically in a single-cylinder indirect injection diesel engine.

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