Çukurova Üniversitesi Mühendislik Fakültesi Dergisi, 36(1), ss. 71-77, Mart 2021
Cukurova University Journal of the Faculty of Engineering, 36(1), pp. 71-77, March 2021

Numerical Investigation of Effects of Different Injection Pressure on Diesel Engine Performance and NO_X Emission

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Geliş tarihi: 02.01.2021 Kabul tarihi: 31.03.2021

Abstract

Favourable efficiency of diesel engines makes them the most abundant type of internal combustion engines. However, diesel engines are also primary sources of particulate matter (PM) and nitrogen oxides (NO_X) emissions formed as a result of the combustion process. There are many variables to affect the performance of diesel engine. One of them is injection pressure. Combustion process has a crucial effect on emission formation of diesel engines and this process is highly affected by fuel atomization. Injectors are one of the most important components of diesel engines that control the atomization of fuel. Today’s modern injectors provide high injection pressures to improve fuel atomization. To reduce exhaust emissions and fuel consumption, the effect of high-pressure fuel injection was investigated in four-cylinder engines numerically. Increased injection pressure improves smoke and fuel consumption, especially at low and medium speeds. However, some variables can be adversely affected by pressure increases. In this study, variables affecting engine performance were observed at different injection pressures for 500-800 bar and 800-1000 bar, and the results were shared.

Keywords: Diesel engine, Injection pressure, High pressure, Fuel consumption

Farklı Enjeksiyon Basıncının Dizel Motor Performansı ve NO_X Emisyonu Üzerindeki Etkilerinin Sayısal Olarak İncelenmesi

Öz

Dizel motorların avantajlı verimleri onları en yaygın içten yanmalı motor türü yapmaktadır. Bununla birlikte, dizel motorlar aynı zamanda yanma işlemi sonucunda oluşan partikül madde (PM) ve nitrojen oksit (NO_X) emisyonlarının birincil kaynaklarıdır. Dizel motorun performansını etkileyen birçok değişken vardır. Bunlardan biri enjeksiyon basıncıdır. Yanma sürecinin dizel motorların emisyon oluşumunda çok önemli etkisi vardır ve bu süreç yakıt atomizasyonundan büyük ölçüde etkilenmektedir. Enjektörler, yakıtın atomizasyonunu kontrol eden dizel motorların en önemli bileşenlerinden biridir. Günümüzün modern enjektörleri, yakıt atomizasyonunu iyileştirmek için yüksek enjeksiyon basınçları sağlar. Egzoz emisyonlarını ve yakıt tüketimini azaltmak için dört silindirli motorlarda yüksek basınçlı yakıt enjeksiyonunun etkisi sayısal olarak incelenmiştir. Artan enjeksiyon basıncı, özellikle düşük ve orta hızlarda duman ve yakıt tüketimini iyileştirir. Ancak bazı değişkenler basınç artışlarından olumsuz etkilenebilir. Bu çalışmada, 500-800 bar ve 800-1000 bar için farklı enjeksiyon basınçlarında motor performansını etkileyen değişkenler gözlemlenmiş ve sonuçlar paylaşılmıştır.

Anahtar Kelimeler: Dizel motor, Enjeksiyon basıncı, Yüksek basınç, Yakıt tüketimi

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1. INTRODUCTION

Diesel engines are widely used in various applications such as power generation, agriculture, transportation, and personal vehicles. Diesel fuel has been used for a long time and different studies are carried out to use this fuel effectively. Many studies in the literature are carried out on bio-fuels, blends of diesel and biodiesel-like fuels or different fuel types [1-8]. Besides, testing different operating conditions and different fuel mixtures is a different way to improve diesel engine performance [9-12]. Researchers also consume effort to reduce the negative effects of diesel engines on nature and to use the existing fuels efficiently [13-14]. Also, exhaust emissions from petrol-powered diesel engines fuel have caused environmental pollution and global warming, so rigorous emission regulations have been made necessary for reductions in particulate matter (PM) and nitrogen oxide (NO_X) emissions in recent years. Therefore, diesel engine manufacturers and researchers focused to create commercial diesel engines with high performance and low emissions [15-19]. High efficiency with low pollution is becoming an important request for diesel engines, and the requirement will be significant. In particular, reducing the NO_X emission emerges as a problem to be overcome. To reduce smoke and exhaust emissions and fuel consumption, the other parameters should be investigated. Furthermore, some improvements can make better the motor performance such as the relationship between fuel injection characteristics and exhaust emissions or fuel consumption performance. Turbo-charging, exhaust gas recirculation (EGR), diesel particulate filter (DPF) are some well-known methods that provide improved combustion accompanied by low emissions. Some of the studies were also carried out to explore the effects of advanced injection parameters on combustion process [20-25]. Therefore, this study focuses on the effects of different injection profiles on diesel engine characteristics. The effect of injection pressure has been studied from a wide perspective and the effects of varying pressures on different outputs of the engine have been discussed in detail. Therefore, the performance values of diesel engines at different injection pressures of diesel fuels were studied numerically in this study.

Nomenclature

BMEP	Break mean effective pressure
BOSCH/SM	Smoke number
ICE	Internal combustion engine
IP	Injection pressure
KW	Brake power
NM	Torque
NO_X	Nitrogen oxide
PM	Particulate matter
RPM	Rotation per minute
SFC	Specific fuel consumption

2. MATERIALS AND METHOD

Diesel-RK software was developed for simulation and modeling of internal combustion engines. It is mainly used to simulate and optimize the working processes of any internal combustion engine. Also, the software can provide useful knowledge by estimating the performance of diesel engine properties such as torque curves, motor performance, fuel consumption, emission analysis, optimization of the fuel injection profile, sprayer design, and bowl shape optimization. Furthermore, the modern models of combustion and emission simulations by arrangement optimization allow optimal emission control corresponding with the actual emission regulations [26-27]. Diesel-RK simulation software interface is given in Figure 1.

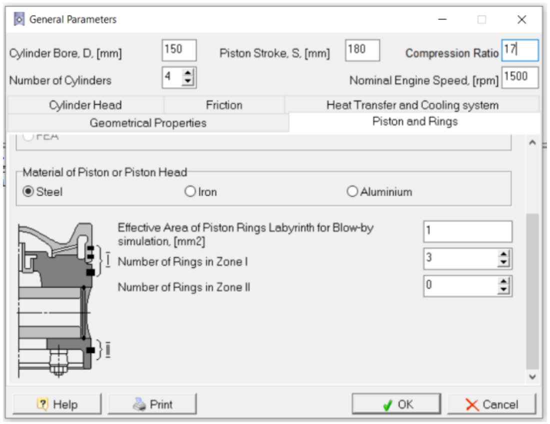

Figure 1. Diesel-RK simulation software interface

Diesel fuel has specific properties such as density, dynamic viscosity, lower heating value, saturated vapour pressure and specific vaporization. Diesel fuel properties are given in Table 1.

Table 1. Properties of diesel fuel

Density (kg/m^3)	830
Dynamic viscosity at 323 K (Pa.s)	100
Lower heating value (MJ/kg)	42.5
Saturated vapour pressure at 480 K (bar)	0.048
Specific vaporization (kJ/kg)	250

In this study, DIESEL-RK software was used that helps to simulate and optimizes combustion operating processes for internal combustion engines [26-31]. The diesel engine is four-cylinder, water-cooled, four-stroke, and 3298 cc. Engine properties are explained in more detail in Table 2. The numerical results were carried out for constant compression ratio (17:1) and at different injection pressures (pressure ranges of 500-800 bar and 800-1000 bar).

Table 2. Properties of diesel engine

Cylinder configuration	In-line 4 cylinders and two valves
Engine Volume (cc)	3298
Bore (mm)	100
Stroke (mm)	105
Engine power (kW)	95.6 @3500 rpm
Max. torque (Nm)	294.2 @ 2000 rpm
Cooling system	Water cooling
Brand	Mitsubishi canter 4D31

3. RESULTS AND DISCUSSION

In this study, a diesel engine was investigated numerically at various injection pressures 500-800 bar and 800-1000 bar ranges. Power, torque, specific fuel consumption (SFC), NO_X, particular matter (PM) graphs and break mean effective pressure (BMEP) were compared according to the different injection pressures. The performance and NO_X emission of the diesel engine was investigated at 500-800 bar and 800-1000 bar injection pressures. The diesel engine power output curves are given in Figure 2. It can be seen that as the injection pressure increases, the power output values also increase. Improved atomisation accompanied by increased injection pressure may be the reason for brake power increment.

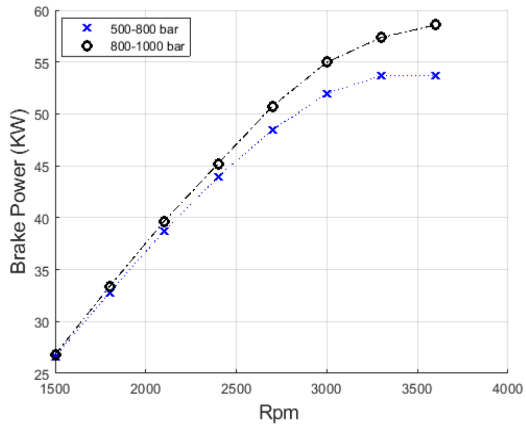

Figure 2. Power-engine speed with different injection pressure values

According to Figure 3, the torque values of the diesel engine have been improved by higher injection pressures. This improvement in torque values may have resulted from enhanced combustion performance at higher injection pressures. Also, the peak point of torque values is at 2100 rpm for both injection pressure values.

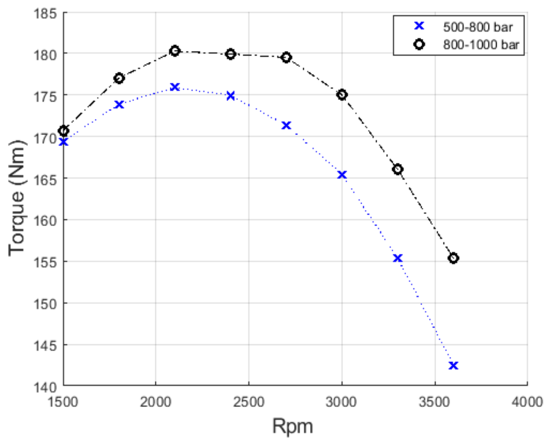

Figure 3. Torque-engine speed with different injection pressure values

Figure 4 shows that the lower injection pressure values have higher specific fuel consumption rates and the ratio of SFC gets higher after 2100 rpm. Also, the most efficient engine speed range for SFC values is 2100 rpm for the tested diesel engine. Enhanced fuel economy is one of the most important evidence that shows improved combustion process.

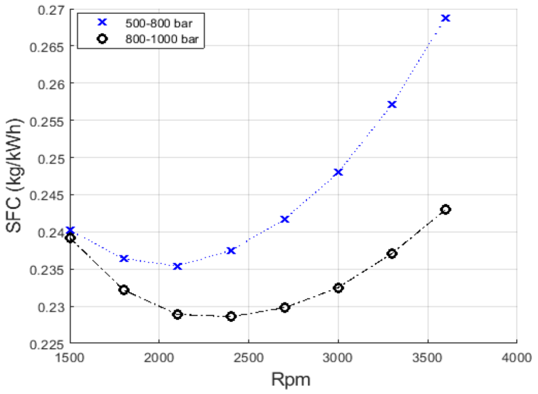

Figure 4. SFC-engine speed with different injection pressure values

The NO_X value starts nearly at the same levels for both different injection pressures. While engine speed gets higher, the values of injection pressures separate for different injection pressures. The lower injection pressure value has lower NO_X emission. This condition can be seen in Figure 5. Elevated temperatures are obtained as a result of improved combustion obtained at high injection pressures. NO_X emissions formed at high temperatures (above 1500ºC) are the main reasons for increasing trend.

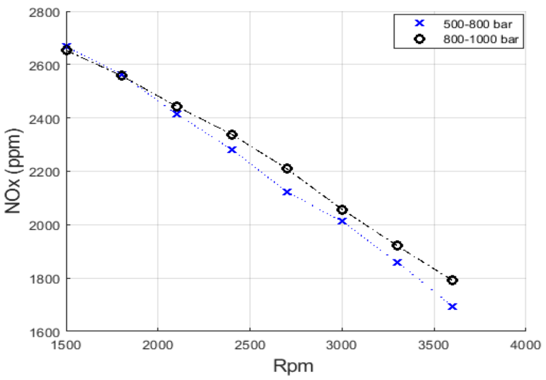

Figure 5. NO_X-engine speed with different injection pressure values

Figure 6 show particular matter emissions of two different injection pressure values. PM graph shows that the PM emissions slightly decrease with increased engine speed values. Injectors volumetrically adjust necessary amount of injected fuel per one cycle. Increased amount of injected fuel at high injection pressures resulted in higher amount of PM emissions. Therefore, at high injection pressures PM values are increased.

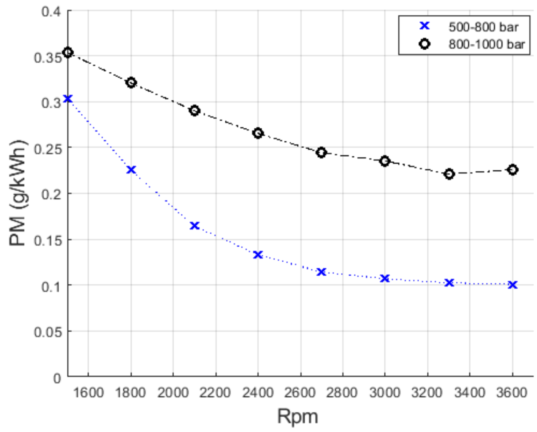

Figure 6. PM-engine speed with different injection pressure values

It can be seen in Figure 7 that the BMEP value reaches its peak at 2100 rpm at both injection pressures. BMEP values have increased up to 2100 rpm. But after 2100 rpm, BMEP started to decrease.

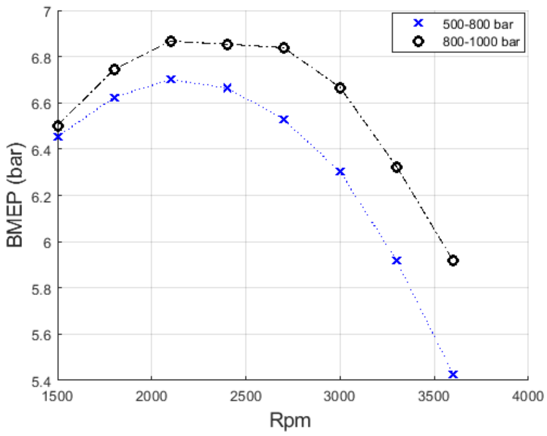

Figure 7. BMEP-engine speed with different injection pressure values

4. CONCLUSION

This study presents an investigation of the performance and emission characteristics of the diesel engine. The effects of injection pressure on engine performance and exhaust emissions are discussed in detail. Two different injection pressure ranges 500-800 bar, 800-1000 bar, were utilized respectively and their effects on certain engine performance parameters were investigated numerically. When comparing the injection pressures increased for 500-800 bar and 800-1000 bar, the values of power, torque, NO_X emission, particular matter (PM), and break mean effective pressure (BMEP) were affected by changing injection pressure. At 800-1000 bar injection pressure, the variables were higher than variables of 500-800 bar. But, as the injection pressures increased specific fuel consumption (SFC) decreased. High NO_X emission value is not desired to contribute to global warming negatively. For this reason, reduction of NO_X emission studies should be done.

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