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Numerical Simulation of a Heavy-duty Diesel Engine to Evaluate the Effect of Fuel Injection Duration on Engine Performance and Emission

B. Alizadeh Kharkeshi, R. Shafaghat*, M. Mohebbi, S. Talesh Amiri, M. Mehrabiyan

Sea-Based Energy Research Group, Babol Noshirvani University of Technology, Babol, Iran

P A P E R I N F O	*A B S T R A C T*

Due to limited space in transport vehicles, compression ignition (CI) engines with high power density have always been a priority. In heavy-duty diesel engines, direct injection results creation of the lean region in the space of the combustion chamber. Increasing the fuel penetration by changing injection duration is an effective solution to achieve a homogenous mixture. In this paper, the impact of changing injection duration in upgraded MTU-4000-R43L diesel engine on power characteristics, rate of heat release (RoHR), combustion phasing, emission and, most importantly, the gradient of pressure changes as a characteristic of the vibration and knocking of the engine, has been studied numerically. Numerical simulation is performed in AVL Fire which is coupled with reduced detail chemical kinetics. The fuel injection duration was varying from 14.6 to 35.6 ºCA, the in-cylinder mean pressure, the IMEP decreases, and the ISFC increases; however, as the fuel injection duration decreases, the pressure gradient rises; from the range of 30.6 degrees onwards, the reduction of the fuel injection duration leads to a severe knock of the engine and as a result reduces its engine life. Emission results also showed that CO_2 and NOx increased and CO reduced with decreasing fuel decreasing injection duration.

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NOMENCLATURE

3D	Three Dimensional	IMEP	Indicated Mean Effective Pressure
aBDC	After Bottom Dead Center	ISFC	Indicated Specific Fuel Consumption
aTDC	After Top Dead Center	IVC	Intake Valve Closing
BDC	Bottom Dead Center	LHV	Low Heating Value
CAD	Crank Angle	PFI	Port Fuel Injection
CFD	Computational Fluid Dynamics	RoHR	Rate of Heat Release
EVO	Exhaust Valve Opening	TDC	Top Dead Center

1. INTRODUCTION

Diesel engines can be used in a variety of applications due to their high power density and efficiency; also, among the types of internal combustion engines, diesel engines have a high compression ratio; therefore, mentioned engines have the highest heat efficiency among internal and external combustion engines [1]. Therefore, diesel engines are applicable in different sizes and applications [2]. One of the most important

*Corresponding Author Institutional Email: rshafaghat@nit.ac.ir (R. Shafaghat)

applications of heavy diesel engines is their applicant as the driving force of transportation systems [3]; however, it is important to note that in heavy diesel engines, due to the high volume of the combustion chamber, a homogeneous air-fuel mixture of fuel and air is not normally formed before the combustion process begins; This creates lean areas inside the combustion chamber, and by reducing the combustion quality, part of the fuel is exhausted from the engine unburned. This will reduce the thermal efficiency of the engine in different operating conditions [4]. Different methods have been proposed to solve this problem, all of which are based on increasing the level of homogenization of the fuel-air

mixture by earlier fuel injection [5]. The main problem of implementing this type of strategy is the impossibility of precise control of the start of combustion and, of course, control of engine performance at different speeds and high loads [6]. On the other hand, changing the injection duration may cause a change in the flow regime and collide the fuel spray with the edge of the piston bowl rim edge [7]. Therefore, this set of scientific strategies for internal combustion engines have so far been used only in laboratory conditions and light applications. In addition, focusing on fuel injection characteristics can greatly help improve the performance of compression ignition engines in injection duration conditions. In evaluating engine performance, it is necessary to consider the fuel injection strategy to control combustion. It is noteworthy that the momentary change of fuel injection along with the momentary change of combustion start will have different effects on engine power and performance [8-10]. The use of the EUI (Electronic Injector Control Unit) system is one of the significant advances in diesel engines that has had a remarkable impact on fuel consumption, durability as well as emission standards. EUI technology, with better performance than traditional technologies, allows precise adjustment of fuel injection in terms of fuel injection duration, pressure and injection volume [8, 11]. Homogenization of fuel-air mixture in a heavy diesel engine depends on two characteristics of fuel penetration and diffusion in the combustion chamber [12]. Various factors such as fuel type and physical properties, nozzle hole diameter, in-cylinder pressure during the injection process, fuel droplet diameter, and fuel evaporation rate on fuel permeability in air mass inside the cylinder have an effect [12-14]. But the most effective factor on fuel penetration is the spray interval and pressure. At a constant mass flow rate, as the fuel injection duration decreases, it is predicted that the penetration into the combustion chamber will increase due to the rise in droplet velocity [15]. Vamankar and Morgan investigated the effect of fuel injection scheduling on the performance of a direct-injection (DI) single-cylinder diesel engine with a combined fuel. In this study, synthetic fuel with a volume composition of 10% CB and 90% diesel (Carbodiesel10) was applied. Studies have shown that with the consume of Carbodiesel10, the thermal efficiency increased by about 6.4% in some injection times and the specific fuel consumption decreased by about 11.9%; also, NOx emission increased by about 23% and smoke decreased by about 13.5% at 26° CA bTDC injection [16]. Malbec et al. [17] showed that, compared to conventional diesel combustion, abnormal operating conditions can cause further combustion delays. If these long delays are longer than the injection time, the combustion quality is significantly affected by the end of injection (EOI).

Ignition delays were investigated through cylinder pressure analysis and lamp chemistry imaging. At TDC temperature of 850K or higher, injection time is longer than combustion delay. Therefore, EOI has no effect on combustion delay. At TDC temperature of 800K or lower, for a short injection time, ignition occurs after EOI, and combustion delay decreases as injection time decreases [17]. Koten and Paralagit [18] investigated the effect of diesel engine parameters on ignition delay. They showed that although there are many parameters that affect each other such as fuel consumption, greenhouse gas emissions and engine noise, the results are more related to the quality of combustion. In this regard, control of combustion start and ignition delay should be well analyzed. Turkan et al. [19] studied the fuel injection time in a diesel engine. They showed that injection time is a parameter that directly affects engine performance and emissions. Injection time can be varied by considering fuel characteristics, inlet air pressure and temperature, compression ratio, injection systems, engine speed, and combustion chamber design. In a numerical study using GT-POWER software, Abu Ahmad et al. [20] investigated the effect of instantaneous fuel injection on engine performance and emissions and found the optimum operating point for a six-cylinder diesel engine by the turbocharger. The simulations were performed at four separate injection times (5, 10, 20 and 25°CA bTDC) and constant engine speed (1800 rpm). Delay in injection time along with reduction of NO_2 and CO_2 pollutants increased HC and CO_2 emissions. The results also showed that early injection time (20◦ CA bTDC and 25◦ CA bTDC) reduces CO_2, emissions of unburned hydrocarbons and also increases the thermal efficiency of the engine. Biramoglu and Nouran [21] studied the effect of fuel injection duration (injection duration) on diesel engine performance and emissions. In their study, the effects of different injection times on diesel engine performance and exhaust emissions were investigated using computational fluid dynamics (CFD). Numerical study was performed on a four-stroke single-cylinder engine. In this study, combustion chamber velocity profiles, fuel mass change, temperature, pressure, heat release rate were determined for standard operating conditions. Rosa et al. [22] used a single-cylinder research engine to experimentally determine the effect of different strategies and fuel injection duration on combustion, emission characteristics and engine performance. They found that advanced injection time increased the RoHR in the early stages of combustion. by decreasing SOI and BMEP increased and BSFC and exhaust gas temperature decreased significantly; also, the emissions of carbon dioxide and unburned hydrocarbons were significantly reduced. Long et al. [23] conducted a study on knock intensity due to non-uniform temperature distribution in the engine in the form of two and three-

dimensional simulations with regular temperature changes. Gikwad et al. [24], in the form of an experimental and numerical study of a piston engine, investigated the effects of peak pressure on the occurrence of knock in the engine. They showed that with increasing peak pressure values, the potential for knock occurrence increases. In heavy-duty diesel engines, due to the high volume of the cylinder, the fuel does not fully combine with the air inside the cylinder; earlear fuel injection is one of the new methods to increase the homogenization of the fuel-air mixture. However, considering this strategy in heavy diesel engines, it is not possible to control the engine at different loads. In the present paper, the possibility of increasing engine efficiency by increasing the amount of fuel penetration in the air mass in the cylinder has been investigated. In this regard, an attempt has been made to carry out investigations during a combustion cycle by constantly considering the mass of the injection fuel by changing the fuel injection duration. For this purpose, the fuel injection duration at maximum speed and load in the upgraded MTU4000 R43L heavy diesel engine as the target engine has been numerically evaluated. Numerical simulation in the AVL Fire software environment is performed in the form of a coupling with a detailed chemical kinetics code. The important point in this study is to consider the engine performance limitation by changing the fuel injection duration, which can cause knocking and the possibility of damage to the engine.

2. METHODOLOGY

2. 1. Governing Equations and Solution Method
AVL Fire software is applied to numerically simulate the closed cycle of the engine. The governing equations in this section include the equation of continuity, momentum, energy, and equations of the turbulence model by k-ζ-f model have implemented [25]. In studying the performance of an internal combustion engine, solving chemical equations is necessary to evaluate fuel oxidation and heat release. During the fuel oxidation process, in addition to the temperature and pressure of the combustion chamber, it is crucial to be aware of the production and consumption of some species, including free radicals of hydrogen [26]. According to the objectives of this study, the accuracy of calculations is very important to investigate the effect of fuel injection duration on the combustion process. Therefore, in this work, detailed chemical kinetics code has been used to solve chemical equations and raise the accuracy of the results. The flowchart shown in Figure 1 shows the simultaneous simulation steps of AVL Fire software as a coupling with chemical coupled kinetics code. According to the figure, after executing and

checking the geometry and mesh, considering the boundary conditions and thermodynamic conditions in the software, a numerical simulation based on mass and momentum survival equations is performed. Kelvin-Helmutz and Riley-Taylor models were applied to simulate fuel injection. After completing the calculations related to computational fluid dynamics, combustion calculations are carried out. Suppose the computational cell temperature is above 600 K. In that case, the data from the kinetic code of combined combustion of diesel and gasoline fuels, which include 77 species and 457 reactions, were applied to modify data such as species concentrations and heat release. These steps were repeated until the crank angle reaches the moment of opening the exhaust valve. It should also be noted that the Zeldovich method was implemented to calculate the amount of NOx in the chemical coupled kinetics code (Figure 1) [7].

2. 2. Validation
The engine studied in this research is MTU-4000 R43L, the specifications of which are presented in Table 1. In this engine, a common rail system is applied for the direct injection of fuel into the combustion chamber. Table 2 summarizes the specifications of the direct fuel injection system. For validation, numerical results are compared with experimental data. In this regard, the performance of MTU4000 R43L engine was studied in an experimental test. Figure 2 shows a schematic diagram of the engine and other equipment required in the experimental test room.

According to the objectives of the present study, experimental tests were performed at 1800 rpm and maximum load. To apply the defined load, the HORIBA hydraulic dynamometer model DT3600-2 is used (Table 3). The pressure inside the cylinder is also measured by the piezoelectric pressure sensor KISTLER 6613CA and
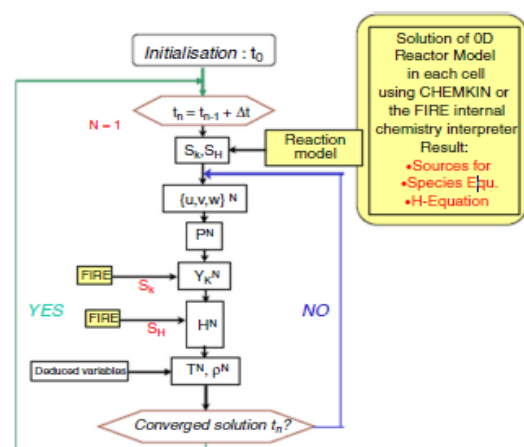

Figure 1. The strategy of coupling AVL fire and detailed chemical kinetics [7]

TABLE 1. Engine Characteristics [27]

Item	Specification
Type	Heavy-Duty Diesel Engine MTU4000-R43L
Bore (mm)	170
Stroke (mm)	190
Displacement (cc)	51.7
Compression ratio	18
Intake valve closing (CAD aBDC)	5
Exhaust valve opening (CAD bBDC)	50
Number of cylinders	16

**TABLE 2.** Specifications of the direct fuel injection system and fuel injection in port [27]

Items	Common-rail injection system
Number of holes	8
Hole diameter (mm)	3.5
Spray angle	6
Injection pressure (bar)	1600
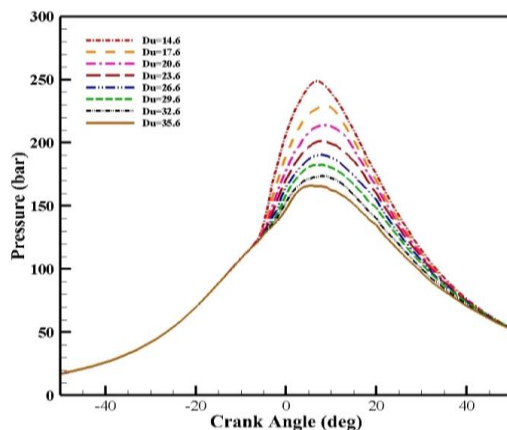
Figure 2. In-cylinder mean pressure change by engine crank angle

the amplifier KISTLER 5018. The measured pressure data were compared with similar numerical results In order to validate the simulation. To derive numerical results, the MTU4000 R43L heavy-duty diesel engine is first simulated in a closed cycle between the time the air valve closes and the smoke valve opens. According to the available information from the laboratory study and considering the number of nozzle holes, for numerical simulation in AVL fire software environment, one-eighth of the piston geometry has been used for modeling and meshing. According to the size and geometry of the solution field, the number of computational cells was considered to be about 31,400 (Figure 3).

TABLE 3. Specifications of HORIBA DT3600-2 hydraulic dynamometer

Item	Unit	Specification
P_{nom}	kW	3600
Maximal Speed n_{max}	1/min	3000
Rated Torque M_{nom}	Nm	30000
max. Share of Coupling Mass at n_{max} /Distance from the coupling flange	Kg	280/114
Θ Rotor	kgm^2	18.4
Torsion-spring constant up to middle of dynamometer	10^6 Nm/rad	11.9
Weight	kg	3200
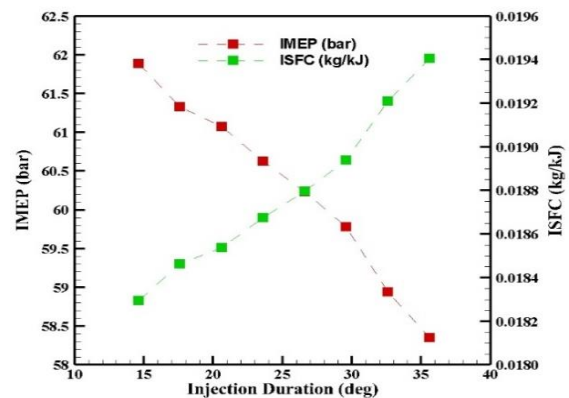
Figure 3. Varying IMEP and ISFC by injection duration

It is observed that the mean pressure inside the cylinder is very well coordinated with the experimental data. In practice, numerical simulation and solving the problem by computational fluids dynamics reached a good agreement with experimental data. Port and diesel fuel characteristics are shown in Table 4.

3. RESULTS AND DISCUSSIONS

One of the key characteristics that significantly affect the performance of a CI engine is the fuel injection

TABLE 4. Diesel fuel charactristics [7]

Items	Diesel
Chemical formula	C12-C25
Cetane number	52.1
Octane number	-
Density (gr/mL)	0.845
Low Heating Value (Mj/kg)	42.8
Latent heat of vaporization (kJ/kg)	301
Viscousity (Mpa.s)	3.995

strategy. In CI engines, to increase the level of homogenization, the reduction of lean areas in the combustion chamber is implemented in different strategies, which are based on increasing fuel penetration and more diffusion, and thus, enriching the mixture. Fuel and air enter the engine cylinder in different areas. Increasing fuel penetration is possible by increasing the velocity of the fuel droplets sprayed from the injector. It is necessary to raise the fuel injection pressure. Therefore, in this research, by keeping the mass of the injection fuel constant in a heavy diesel engine, the effect of changes in the fuel injection duration is investigated. Figure 2 shows the changes in the average pressure inside the combustion chamber at different fuel injection duration. As the fuel injection duration decreases, so do the maximum pressure inside the engine cylinder, since as the fuel injection duration declined, the fuel penetration naturally increases, and as the leaner areas decrease, a better homogeneous mixture of fuel and air is formed, which causes more mass of fuel to participate in the combustion process, therefore at each stage, with decreasing fuel injection duration, the maximum average pressure inside the cylinder is increased. One of the important points in studying the pressure inside the cylinder is to study the trend of maximum pressure changes in different fuel injection duration. As can be seen in Figure 2, the step of increasing the maximum pressure in the injection duration less than 20.6 CA is significantly more than the injection duration less than this value, so that by reducing the fuel injection duration from 26.6 degrees to 14.6 CA, the maximum pressure has increased by about 11.5 percent, if this characteristic reduced from 35.6 to 32.6 CA around it has increased by 6.3%.

Figure 4 shows the indicated mean effective pressure (IMEP) change rate with respect to the change in fuel injection duration. As can be seen, with decreasing fuel injection duration from 14.6 to 35.6, the amount of IMEP has been continuously increasing.

Considering that reducing the fuel injection duration, if fuel mass keeps constant increases the penetration of fuel droplets in the combustion chamber during the fuel injection process, which results in a reduction of lean areas and the participation of more mass of fuel in the combustion process. It is also worth noting that the reduced the fuel injection duration, the more volume of fuel is injected in a shorter period of time, the combustion process will start at a smaller volume of the combustion chamber. This will increase the indicator mean effective pressure value, which is one of the characteristics of the output power.

Indicator-specific fuel consumption is one of the efficient characteristics of the internal combustion engine. This characteristic shows how much output power is generated in relation to the fuel consumed. As can be seen in Figure 2, by decreasing the fuel injection

duration, the value of this characteristic has reduced, which is due to the constant mass of the fuel in the injector and the increase of the maximum pressure inside the cylinder and, consequently, the output power by reducing the fuel injection duration.

Figure 4 shows the changes in the heat release rate; in this figure, the starting of heat release rate and its process for different injection duration is shown. According to the marked part of the figure, it can be seen that the combustion conditions in different duration are divided into two parts; in the injection duration, less than 23.6° CA, heat release rate at the starting point is much more than the others. At injection duration greater than 29.6° CA, is heat release rate has lower gradient, but one of the most thought-provoking points in this figure is the injection duration of 26.6 °CA. As can be seen, the heat release rate gradient is similar to the other durations up to 70 Joules, but it can be seen that in the continuation of the heat release process, the gradient of the same heat release increases with injection duration. In fact, Du = 26.6 is an injection duration of transition between two combustion processes. Also, in Figure 5,
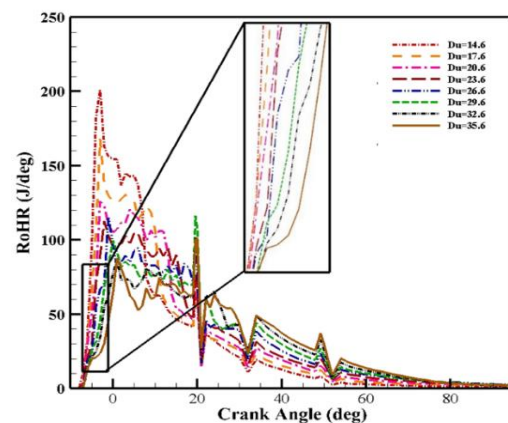

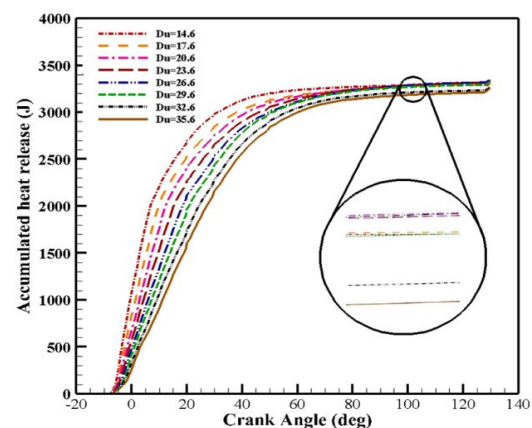**Figure 4.** Varying RoHR by crank angle

Figure 5. Varying cumulative heat release rate by the crank angle

the accumulated heat release is shown. In this figure, the total accumulated of heat released in the injection duration of 32.6º CA and 35.6 º CA is less than other fuel injection duration, which injection duration, that by reducing the injection duration, more fuel mass participates in the combustion process due to the reduction of lean areas.

Combustion duration (CD) is the duration which 5 to 90% of the total heat release. Ignition delay is also characterized by the duration between the fuel injection and 5% of the total heat release. One of the most important performance characteristics of CI engines is ID and CD, on the basis of which the fuel injection duration is set. As can be seen in Figure 6, as the fuel injection duration decreases, the ignition delay rate decreases continuously, since as the fuel injection duration reduced, the start of fuel injection is considered fixed. The whole mass of fuel is injected into the engine closer to the start of injection, which causes combustion to start earlier due to the higher volume of fuel and reduce the ignition delay; but according to the diagram of changes in the combustion duration, a different process takes place. In the injection duration between 35.6 to 29.6 degrees, as the injection duration decreases, the fuel is injected in a shorter duration, so the total combustion process takes less time; however, in the injection duration of 26.6, the combustion duration is suddenly decreased. As shown in Figure 4, it was observed that this injection duration is in fact, a transition between different combustion processes. In low injection durations, the combustion process started with a larger gradient due to the higher volume of fuel compared to other injection durations, and then the combustion process gradient has decreased since the injection penetration velocity is lower than the combustion development. On the other hand, the greater portion of the fuel participated in combustion; therefore, combustion duration increased in comparison with the injection duration of 29.6 CA, then combustion duration decreased as the injection duration reduced.

Figure 7 shows the CA50 (the moment which half of the heat of the entire combustion process is released). As the fuel injection duration decreases, the CA50 reduced continuously. This means that as the fuel injection duration decreases, the entire fuel combustion process takes place at a distance closer to the TDC and naturally in a smaller volume of the combustion chamber. This will have two consequences; the first consequence is an increase in engine power due to the increase in maximum pressure inside the combustion chamber, which leads to an increase in thermal efficiency, as shown in Figure 8, the ISFC reduced. But, the second consequence of this event is the early formation of combustion and start of combustion before the TDC and the application of negative work in the piston and combustion chamber. Due to the fact that in
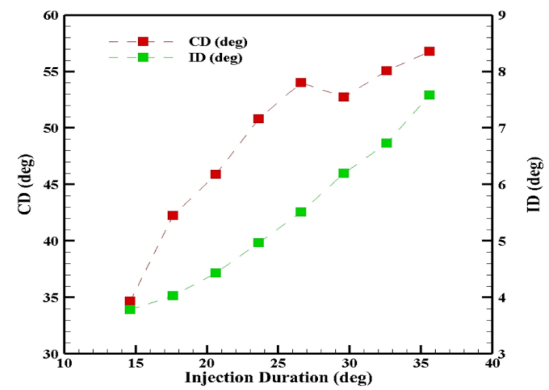

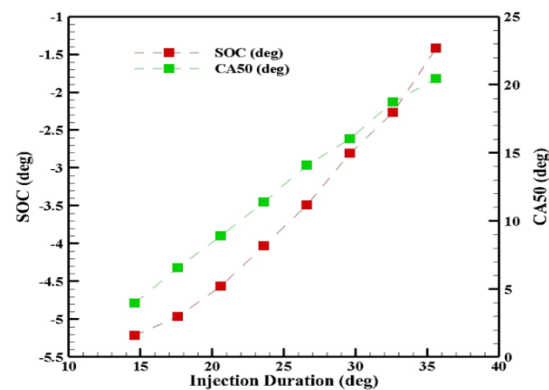**Figure 6.** Varying ID and CD by injection duration

Figure 7. Varying start of combustion and CA50 by injection duration
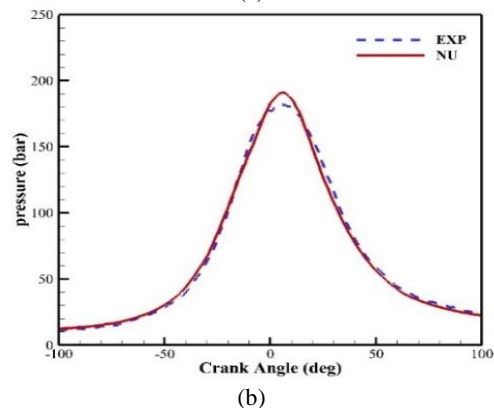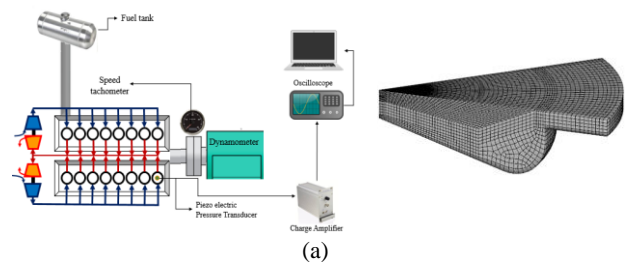

(a)

(b)

Figure 8. Validation of numerical simulation process by considering the diagram of the mean pressure inside the chamber

this particular engine, the start time of fuel injection is 9 degrees before the TDC, so the second consequence does not have a significant impact on the engine power and the total work.

Figure 9 shows the maximum gradient of the pressure diagram and the moment of maximum pressure increase in the combustion chamber. The maximum gradient of the actually injection durationicates the vibration and noise of the engine which cause serious damages to the cylinder body, cylinder head, connecting rod and engine crankshaft. According to the figure, the maximum gradient of the pressure diagram decreases with increasing fuel injection duration. In the duration range of 35.6 to 32.6, the maximum gradient of the pressure diagram does not increase slightly, but from Du = 32.6 to Du = 35.6 because a larger portion of the fuel is involved in the combustion process, the value of this characteristic increases dramatically. In the injection duration of 26.6, which was introduced as a transition mode in the previous sections, up to the duration of 20.6, the maximum gradient of the pressure diagram has not increased significantly. In the injection duration between 20.6 and 14.6 degrees, the value of this characteristic has increased sharply. As can be seen in these cases, the point at which the amount of pressure reaches its maximum change is 4 degrees before the TDC, which means that in addition to the fact that the pressure suddenly increases, the volume of the combustion chamber is decreasing. This causes a sudden increase in pressure inside the cylinder, and in fact, the reason for the change in the maximum pressure changes mentioned in Figure 8 is the occurrence of this phenomenon. This event, which is an injection duration of knocking process, will cause severe damage to the engine, as well as increase the noise and vibration of the engine, so reducing the fuel injection duration is not so desirable, but to increase power and efficiency can be reduced the duration to 20.6 degrees.
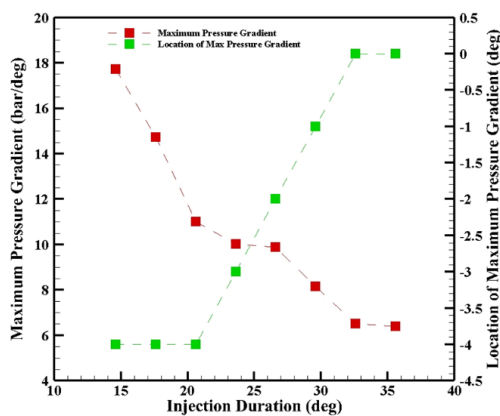
Figure 10 shows the effect of fuel injection duration on carbon monoxide and carbon dioxide greenhouse gas emissions. The more homogeneous a mixture of fuel and air is formed, and the more oxygen is introduced into the chemical process, the lower amount of carbon monoxide. By reducing the fuel injection duration, the fuel penetration increases, and in different areas of the combustion chamber space, the fuel-air composition becomes more homogeneous. It can be said that the lean areas are reduced, participates in the combustion process, and causes the combustion process of the fuel to move towards complete combustion, which increases CO_2 (which is in fact the product of combustion and a sign of complete combustion). At injection duration of fewer than 35.6 degrees, the value of these two species does not change significantly, which injection duration that in this case, the mixture has reached its most homogeneous state, and as shown in Figure 11. The most amount of fuel has participated in the combustion process, which injection duration the high condition of combustion conditions and increased engine efficiency. It can also be seen in Figure 11 that the amount of NOx pollution has increased continuously with decreasing injection duration. This is studied in Figure 8; however, in increasing the injection duration from 32.6 to 35.6, the increase in this pollution is very significant, because in this interval. According to Figure 9, the sudden increase in pressure coincides with a decrease in volume and causes an excessive increase in pressure and its nature. The temperature has risen, which is the most important reason for the increase in NOx. On the other hand, by reducing the fuel injection duration, the unburned hydrocarbon in the engine decreases to the injection duration of 23.6.6 degrees, which injection duration increase in IMEP and engine temperature due to the reduction of the fuel injection duration. Up to this point, due to better penetration and distribution of fuel and reduction of lean areas in the engine. But, by reducing the fuel injection duration to less than 23.6 degrees, and the reason for increasing performance
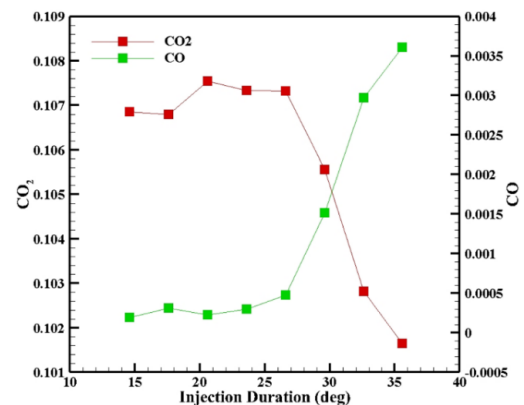

Figure 9. Varying the pressure gradient maximum and the location by injection duration

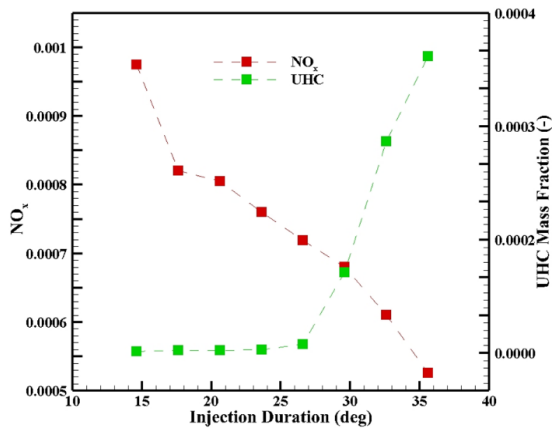**Figure 10.** Varying CO_2 and CO by injection duration

Figure 11. Varying NO$_x$ and UHC by injection duration

parameters is not better and more fuel consumption, it should be considered in the engine phase change of combustion.

Table 5 shows the concentration of diesel fuel in a different piston position for different fuel injection duration. Studying the trend of changing the contours in the position 4 degrees before the TDC, it is clearly seen that by reducing the fuel injection duration, the penetration and diffusion of fuel has increased, and even more volume of fuel has been injected up to that point. As can be seen, when the piston is at the TDC, it is evenly distributed over the entire dead volume in the shortest injection duration, and this results in the condition that the combustion chamber has its lowest volume, the volume of lean areas reaches its lowest

TABLE 5. Fuel concentration contour inside the chamber at different positions

Injection Duration	-4˚CA	0˚CA	10˚CA
14.6			
17.6			
20.6			
23.6			
26.6			
29.6			
32.6			
35.6			
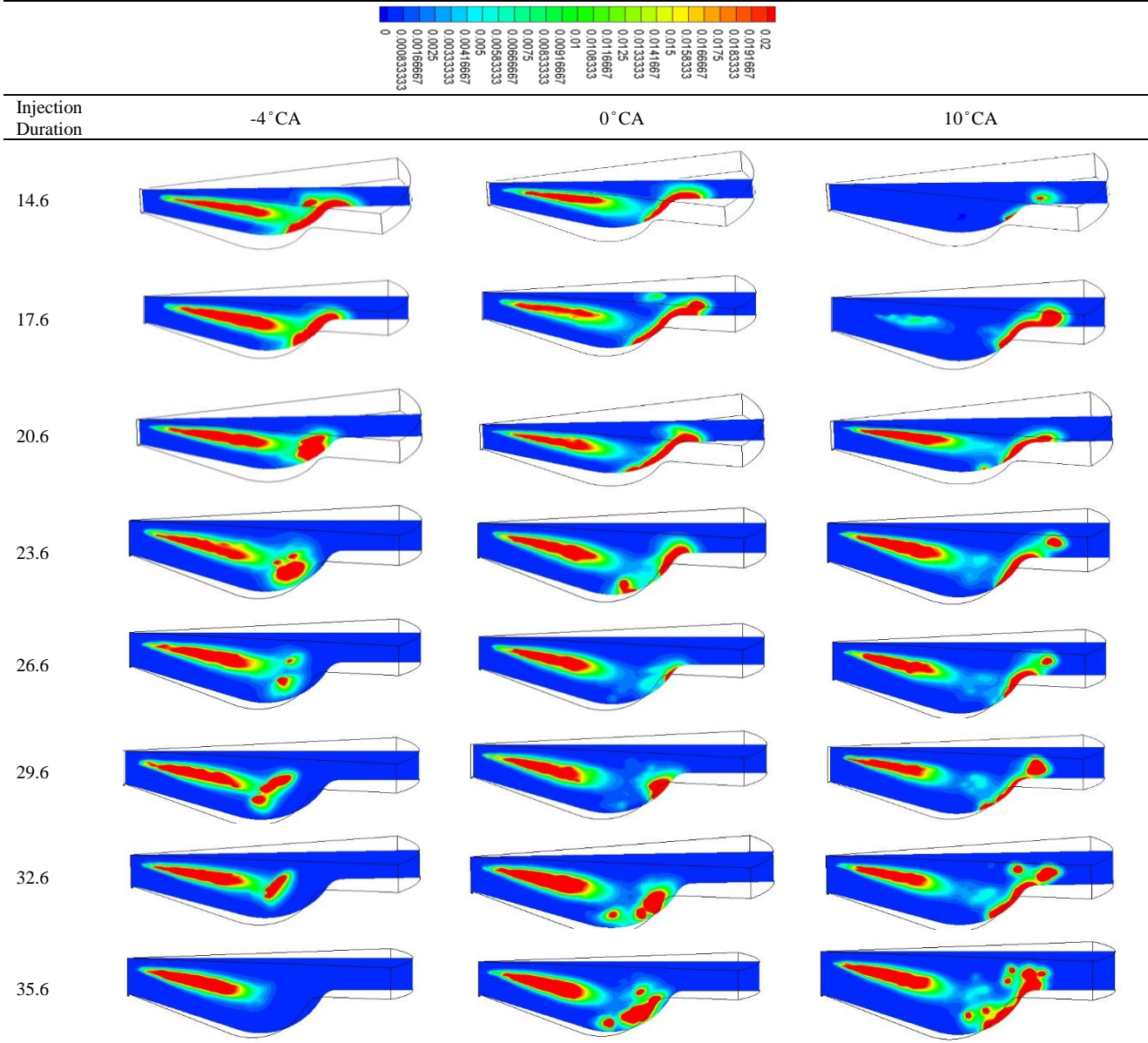
level. On the other hand, in the position of 10 degrees after the TDC in the lowest fuel injection duration, a large volume of fuel is consumed. Gradually, with increasing the fuel injection duration, the volume of the unconsumed fuel has increased increases.

4. CONCLUSIONS

An upgraded version of the MTU-4000 R43L engine has been used to investigate the feasibility of increasing the power density of the heavy diesel engine (with the set of changes that have been made in the study phase, it has the ability to provide more power than the base engine). In this study, the effect of changing the fuel injection duration on the performance of an upgraded, heavy-duty 16-cylinder MTU4000-R43L diesel engine was numerically studied. In this regard, to numerically simulate the engine, AVL Fire software was implemented by coupling with chemical joint kinetics code. In order to evaluate the effect of these conditions on combustion, important parameters such as in-cylinder pressure, temperature, released heat rate, IMEP, ISFC, combustion duration, combustion delay, combustion start, and pollutants have been investigated. The results obtained show:

- Reducing the duration of fuel injection leads to an increase in pressure and temperature of the combustion chamber, and also the gradient of this increase in temperature and pressure increases with decreasing fuel injection duration. Increasing the fuel injection duration also reduces the rate of heat released into the chamber.

- Increasing the duration of fuel injection duration leads to a decrease in the pressure inside the chamber, and the IMEP and an increase in the injection duration ISFC, or in other words, it can be said power increase by reducing injection duration.

- As the fuel injection duration decreases, the pressure gradient increases, which can cause the knock and vibration of the engine, so that the duration decreases from 20.6 °CA fuel injection will result in severe engine knock and thus reduce its service life.

- Increasing the fuel injection duration can increase the lean areas inside the chamber. However, the better the fuel penetration, the more complete the combustion. The results showed that the higher

- The carbon dioxide (Injection duration better combustion) increases with decreasing fuel injection duration decreases carbon monoxide (injection duration incomplete combustion). The temperature of the combustion chamber increases so does the production of NO_x.

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Persian Abstract

چکیده

با توجه به فضای محدود در وسایل نقلیه حمل و نقل ، موتورهای احتراق تراکمی (CI) به‌علت چگالی قدرت بالا همیشه در اولویت بوده اند. در موتورهای دیزلی سنگین، تزریق مستقیم باعث ایجاد ناحیه‌ی فقیر در فضای محفظه احتراق می شود. افزایش نفوذ سوخت با تغییر مدت زمان تزریق یک راه حل موثر برای دستیابی به مخلوط همگن است. در این مقاله ، تأثیر تغییر مدت تزریق در موتور دیزلی MTU-4000-R43L ارتقا یافته بر ویژگی های قدرت ، نرخ آزاد سازی حرارت، فاز احتراق ، آلایندگی و مهمتر از همه ، شیب تغییرات فشار به عنوان ویژگی ارتعاش و ضربه موتور، به صورت عددی مورد مطالعه قرار گرفته است. شبیه سازی عددی درنرم افزار AVL Fire با کوپل سینتیک شیمیایی کاهش یافته صورت پذیرفته است. مدت زمان تزریق سوخت از ۱۴.۶ تا ۳۵.۶°CA تغییر داده شده است. با کاهش مدت زمان تزریق سوخت، IMEP کاهش می یابد و ISFC افزایش می یابد. با این حال، با کاهش مدت زمان تزریق سوخت ، گرادیان فشار افزایش می یابد. از محدوده ۳۰.۶ درجه به بعد، کاهش مدت زمان تزریق سوخت منجر به ضربه شدید موتور و در نتیجه کاهش عمر موتور می شود. همچنین نتایج انتشار آلایندگی نشان داد که با کاهش مدت زمان تزریق، CO_2 و NOx افزایش یافته و CO کاهش می یابد.