Journal of Solid and Fluid Mechanics (JSFM), 15(2): 1-4, 2025

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2025.15947.3951

Manufacturing Engineering of Iran

Numerical investigation of different combustion chamber geometries and injection angles in a direct injection diesel engine

Javad Khadem[1*], Mohammad Shahkolayi[2], Ali Asadi[3] , Afshin Fahimi Rad[4]

[1] Assoc. Prof., Department of Mechanical Engineering, Faculty of Engineering, University of Birjand, Birjand, Iran.
[2] MSc, Department of Mechanical Engineering, Faculty of Engineering, University of Birjand, Birjand, Iran.
[3] Assist. Prof., Department of Mechanical Engineering, Faculty of Engineering, Bozorgmehr University of Qaenat, Qaen, Iran.
[4] MSc, Mechanical Engineering, Research and Development Department, Iran Heavy Diesel Plant

*Corresponding author: jkhadem@birjand.ac.ir

Received: 03/18/2025 Revised: 04/26/2025 Accepted: 06/06/2025

Abstract
Proper design of the combustion chamber geometry and selection of the optimal fuel injection angle are key factors in reducing fuel consumption and pollutant emissions in direct injection diesel engines. In this paper, a numerical study of different combustion chamber geometries and injection angles for the 16RK215 heavy-duty diesel engine has been conducted. Four different combustion chamber designs and four fuel injection angles, ranging from 130 to 160 degrees were examined. Using numerical simulations with the AVL-Fire computational code, the most suitable combustion chamber design and compatible fuel injection system were selected. An injection angle of 150 degrees and geometry number one showed the best overall performance. The highest NOx emissions were observed in geometry number one and the highest unburned hydrocarbons and soot emissions in geometry number four. The heat release rate, as a crucial parameter of combustion efficiency, reached its peak value in geometry number one. In all geometries, the highest peak temperature and average pressure were obtained at a 150-degree injection angle.

Keywords: Combustion Chamber, Diesel Engine, Injection Angle, Direct Injection, AVL-Fire.

1. Introduction

Today, internal combustion engines are widely used in human life. In these engines, chemical energy is released by burning or rapidly oxidizing fuel inside a combustion chamber. Internal combustion engines are generally divided into two categories: compression ignition and spark ignition engines [1, 2]. One of the methods for reducing particulate matter and other compounds produced in diesel engines is to improve the combustion process inside the combustion chamber. The first factor affecting combustion in these engines is the fuel injection system, which in new systems has evolved by increasing the injection pressure, better atomization of the fuel, and using intelligent management of the injection time and amount [3, 4]. Optimization of the fuel injection system is known as one of the basic ways to reduce emissions from heavy diesel engines and improve performance. Other effective factors in reducing emissions from diesels are the quality and composition of the fuel. Much research has been conducted on the effect of injection shape and timing in various diesel engines [5].

By studying previous research in the field of internal combustion engines, the importance of the geometry of the combustion chamber and the type of fuel injection is realized; therefore, a comprehensive and detailed study is needed in this field. The overall goal is to determine the optimal shape of the chamber and the fuel injection system to create a balance between reducing pollutants and increasing thermal efficiency. In this regard, in the present article, four combustion chambers with four different injection angles in the upgraded power of the 16-cylinder compression ignition engine model 16RK215, which plays an important role in the transportation industry, especially the railway industry, have been studied simultaneously. In the following, the important parameters of energy release rate, pollutant emission, and maximum pressure and temperature were investigated.

2. Simulation

In diesel engine design, to achieve maximum power without increasing emissions, it is of particular importance to carefully match the shape of the combustion chamber, the movement of the air flow into the chamber, and the fuel injection. Heavy-duty diesel engines, which often have large-diameter pistons, use high-pressure fuel injection systems. In these engines, there is little reliance on high rotation ratios and static chambers are often used. The shape of the chamber must be matched to the depth of penetration of the fuel spray and the amount of air circulation. Systems that use high fuel pressure require less air circulation, and high fuel pressure provides sufficient fuel penetration. Three different geometries were considered compared to the base geometry (Figure 1). It should be noted that to maintain comparability in this parametric analysis, all engine factors (such as compression ratio, etc.) except the combustion chamber shape and fuel injection angle are the same in all four designs, and the engine is considered for full load conditions and at a speed of 1000 rpm. The parameter affecting the process of fuel-air mixing, combustion and pollutant formation is the injection angle.

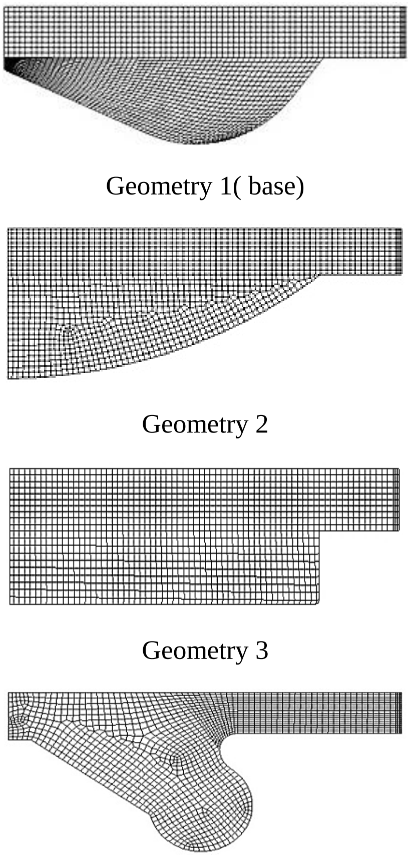

Figure 1. Four geometries studied in the present research for the combustion chamber

Figure 2, shows the four angles studied in geometry one. The high injection pressure in the engine is the main factor in creating vortex flows and turbulence and intensifies the mixture preparation rate. The injection angle will have a direct relationship with the amount of air entering the fuel injector. In this study, injection angles of 130, 150 and 160 degrees were studied in all four geometries compared to the base case injection angle of 140 degrees. The specifications of the engine used for simulation are given in Table 1.

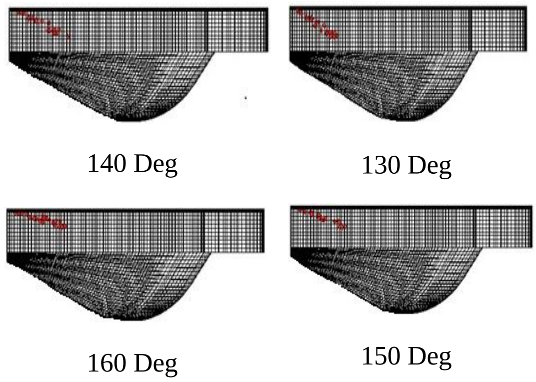

Figure 2. Four spray angles considered in geometry one

Table 1. Main parameters of diesel engine

Motor parameters	Description
Engine type	16 cylinders 4-stroke water-cooled
Bore x stroke length	275×215 mm
Connecting rod length	502 mm
Number of nozzles	9 pcs
Compression ratio	1 : 13.5
IVC	146 BTDC
EVO	121 ATDC
Intake air pressure	4.2 bar
Intake air temperature	370 K
Type of fuel used	DIESEL $C_{13.5}H_{27.6}$

3. Results and Discussion

Figure 3 shows the average temperature curve inside the cylinder of the studied engine in terms of crankshaft degrees in the upgraded mode (with a power of 3800 kW) compared to the base mode (with a power of 2952 kW). As can be seen in Figure 3, with the increase in the injected fuel flow rate, due to the delay of combustion in the expansion phase, the combustion temperature decreases at a slower rate and creates a higher temperature in the expansion phase. The temperature graph has the same trend until the start of combustion in all four geometries, but with the start of combustion, geometry number one shows a higher temperature and this advantage continues until the end of combustion. When the piston moves downward, the maximum temperature point decreases and the hot spots expand and thus occupy wider areas. At the injection angle of 150 degrees, the maximum value of the average temperature inside the cylinder in the first geometry is higher than all cases. This is due to the higher combustion rate in this case; also, as expected, the lowest average temperature was observed at the injection angle of 130 degrees.

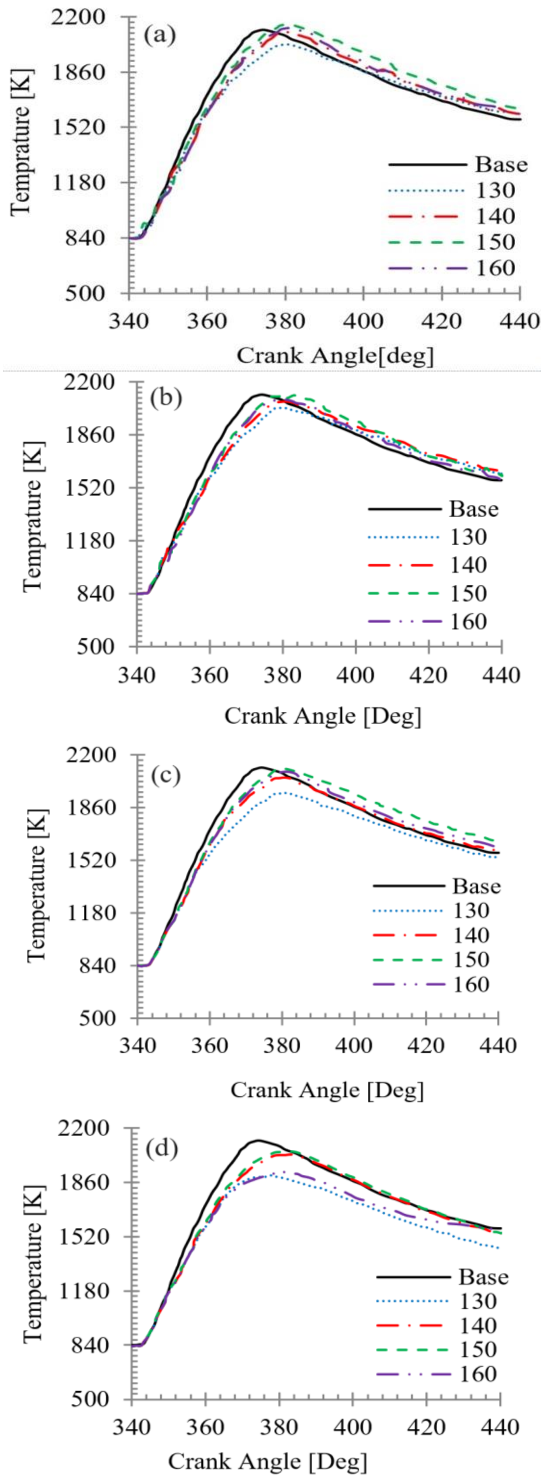

Figure 3. Average temperature variations with crank angle. a) Geometry 1, b) Geometry 2, c)Geometry 3 and d) Geometry 4

The average pressure inside the cylinder of the engine under study in terms of crankshaft degree in different geometries and injection angles in the improved state compared to the basic state is shown in Figure 4. As can be seen, with the increase in the fuel flow rate injected in each cycle, the maximum pressure inside the combustion chamber increased, which led to an increase in the area under the P-V diagram and increased work production.

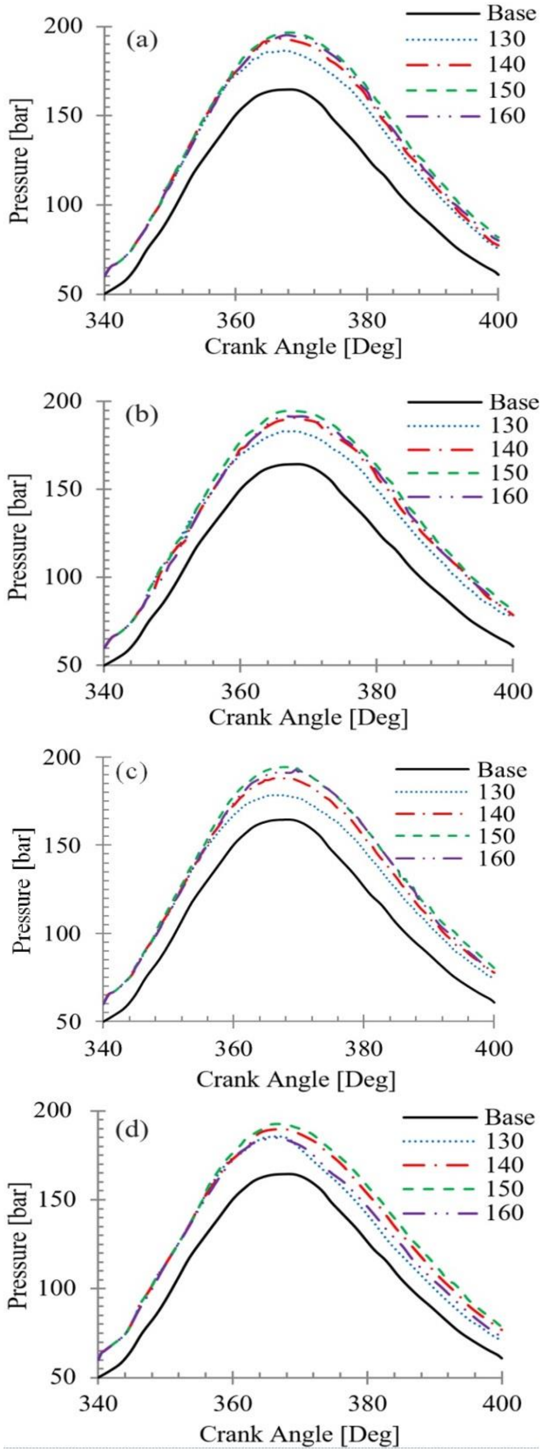

Figure 4. Average pressure variations with crank angle. a) Geometry 1, b) Geometry 2, c)Geometry 3 and d) Geometry 4

The pressure diagram showed similar behavior until shortly after the top dead center for all four geometries at a power of 3800 kW, which seems natural considering the same process of heat release up to this point. From this point on, due to the difference in the fuel distribution method, the combustion and subsequent heat release processes change. It should be noted that the difference in the fuel distribution method is due to the difference in the flow field created by the shape of the combustion chamber.

Also, the trend of changes in the pressure inside the cylinder shows that in all geometries, the lowest maximum pressure was observed at a spray angle of 130 degrees due to the collision of the spray with the combustion chamber wall and the suppression of the penetrating flame in these areas where the intensity of the vortex flow is also low; but in all geometries, the maximum pressure was higher at a spray angle of 150 degrees with a slight difference compared to the angles of 140 and 160 degrees, which is due to fuel injection in the area of intense vortex flow and better combustion distribution.

4. Conclusions

In this study, four different designs for the combustion chamber and four different fuel injection angles from 130 to 160 degrees were studied for the 16RK215 heavy diesel engine. Numerical simulation was performed using AVL-Fire software. After validating the results, the best combustion chamber design and fuel injection system were selected. The most important results of the present study are as follows.

• Geometry number 1 with a 150 degree injection angle provided the best overall performance in terms of combustion, pressure, and thermal efficiency. This combination produced stronger vortices and more uniform fuel distribution, improving the quality of mixing and more complete combustion.

• The maximum pressure and temperature inside the cylinder were also achieved in this combination. The reason for this was the proper spray penetration and energy concentration in the center of the chamber, which provided faster and more energetic combustion.

• In this case, the highest amount of NOx was also observed. This result is due to the formation of localized hot spots in the central area of the chamber, which indicates the need for complementary solutions such as exhaust gas recirculation to control emissions.

• The amount of soot and unburned hydrocarbons was minimized in geometry number 1 with an angle of 150 degrees. This indicates that combustion in this case was more complete and the formation of rich mixtures was prevented.

• At the spray angle of 130 degrees, despite the reduction in temperature and NOx, a significant increase in soot and HC was observed. This was due to the spray hitting the wall and the formation of cold and rich zones, which led to incomplete combustion.

• The vortex flow structure inside the cylinder was strongly influenced by the chamber geometry. Chambers with a deeper and more symmetrical design resulted in the formation of strong vortices and optimized mixing and increased uniformity in the heat release rate; While geometry number 4 caused combustion fluctuations and performance loss due to weakness in the vortex structure.

5. References

[1] Ghazikhani M and Shahab-Ahmadi M (2010) Investigation of the Exhaust Silencer Irreversibility and the Sound Intensity Emitted from the Exhaust in Diesel Engines. *J. Applied and Comput. Sci. Mech*., 21(1), 75-88 [In Persian].

[2] Talesh Amiri S, Shafaghat R, Jahanian O and Alamian, R (2024) Performance simulation of a reactivity controlled compression ignition (RCCI) engine fueled with waste cooking oil biodiesel (WCO) with a focus on consumption trends of fuel constituents. *J. Sol. and Fluid Mech*., 14(2), 1-13 [In Persian].

[3] Chamesara S and Mirsalim SM (2016) Investigation of the effect of air intake pressure and fuel injection parameters on upgrading power and emissions of heavy duty diesel engine. *J. Sol. and Fluid Mech*., 6(4), 239-247 [In Persian].

[4] Azarkhazin J, Aliakbari K, Sheykhi M and Delavari SMM (2025) Numerical investigation of combustion and intake valve timing on the performance of TU5 spark ignition engine. *J. Sol. and Fluid Mech*., 14(6), 19-32 [In Persian].

[5] Dastourani H, Mohammadian A and Ghazikhani M (2022) Evaluation of Changes in Soot Formation with Variation of Start Angle of Fuel Injection in Diesel Engine. *J. Engine Res.*, 24(24), 37-49 [In Persian].