

GENERAL ANALYSIS OF THE COMBUSTION PROCESS IN DIESEL ENGINES

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Abstract

This article analyzes the general characteristics of the combustion process in diesel engines, including fuel injection, fuel-air mixture formation, and the main stages of combustion inside the cylinder. The paper also discusses the key factors affecting the combustion process, such as compression ratio, injection pressure, temperature, and the quality of the air-fuel mixture. The possibilities of reducing fuel consumption, increasing engine efficiency, and decreasing harmful exhaust emissions through the organization of an effective combustion process in diesel engines are considered.

Keywords: diesel engine, combustion process, fuel injection, compression ratio, combustion chamber, air-fuel mixture, efficiency coefficient, environmental efficiency, thermal process, engine performance.

Introduction

At the modern stage of development of the automotive transport sector, serious requirements are imposed on vehicles. These requirements include the rationality of design solutions, safety, adaptability to various natural conditions, ease of technical operation and repair, ergonomics, mass indicators, simplicity of maintenance, economic efficiency, and environmental safety. At the same time, these advantages directly depend on the quality of diesel fuel mixing with air, the organization of the combustion process, design solutions, and production technologies [1].

It should be emphasized that, despite the ongoing policy of electrification of road transport and the development of alternative fuels, diesel trucks remained the main choice for buyers in the European Union in 2022. Their share accounted for 96.6% of newly registered trucks, while in 2021 this indicator was 95.9%. Although the market for electric trucks has grown significantly, they still accounted for only 0.6% of the European Union truck market. Vehicles with alternative powertrains made up 2.8% of all trucks sold [2].

The combustion process in a diesel engine is a complex combination of physical, chemical, and thermodynamic phenomena. In this process, fuel is injected under high pressure into compressed hot air, which causes self-ignition. Unlike gasoline engines, diesel engines do not prepare the air-fuel mixture in advance. Air is compressed inside the cylinder under high pressure, and as a result of compression, its temperature rises to approximately 700–900 °C. At this moment, diesel fuel injected through the injector under high pressure mixes with the heated air, ignites after a certain ignition delay period, and the combustion process begins.



Figure 1. Modern diesel engine

The figure shows a modern turbocharged diesel internal combustion engine. This type of engine is widely used in trucks, passenger cars, and special-purpose machinery. The design includes a high-pressure fuel injection system, a turbocharger, and electronic control elements, which help to increase engine power and improve economic efficiency.

In this diesel engine, fuel is injected into the cylinder under high pressure and ignites spontaneously under the influence of compressed hot air. The turbocharger supplies additional air to the cylinders and improves combustion efficiency. As a result, fuel consumption decreases, engine power increases, the efficiency coefficient improves, and the amount of exhaust gases is reduced.

Such engines operate on the basis of modern Common Rail technology and are adapted to EURO environmental standards.

The main components of a diesel engine are as follows.

The cylinder block is the main body of the engine. It contains the holes and cavities necessary for engine operation. A cooling jacket is located on the outer wall, which is filled with coolant in the assembled engine to cool the housing. The central part contains the main holes called cylinders, where fuel combustion takes place. In addition, the block design includes holes for connecting the cylinder head and the valve timing mechanism.

The pistons and connecting rods are similar in design to those of a gasoline engine. The main difference is that the piston and connecting rod of a diesel engine are made stronger in order to withstand higher mechanical loads.

The crankshaft converts the reciprocating motion of the pistons into rotary motion and transmits mechanical energy to the powertrain.

The balancing shaft is often used in small single-cylinder diesel engines, especially in small electric generators. Since a single-cylinder engine has only one piston, it can generate strong vibration during operation. In order to ensure smoother engine operation, the balancing shaft compensates for sudden increases in mechanical energy and reduces vibration.

The injector injects diesel fuel into the cylinder under high pressure. The fuel pump supplies fuel to the injector at the required pressure. The turbocharger sends additional compressed air into the cylinders and increases combustion efficiency. The valve mechanism controls the intake of air and the exhaust of burned gases. The cooling system prevents the engine from overheating. The lubrication system lubricates friction surfaces and reduces wear of engine parts.

In a diesel engine, air is first drawn into the cylinder and then compressed under high pressure. As a result of compression, the air temperature rises sharply. At this moment, diesel fuel is injected through the injector. Under the influence of heated air, the fuel ignites spontaneously, and a high pressure is generated as a result of combustion. This pressure moves the piston, and through the crankshaft, the energy is converted into mechanical work.

Today, diesel-powered vehicles are becoming more advanced due to the introduction of innovative technologies that meet environmental standards and the needs of modern drivers. In

the past, diesel engines were mainly used in trucks, but today many passenger cars are also equipped with such engines. Diesel engines are especially popular in Europe, where a significant proportion of vehicles use this type of power unit.

In the modern automotive industry, diesel engines are widely used because of their high economic efficiency, ability to produce high torque, and long service life. They are particularly important as the main power source in trucks, agricultural machinery, industrial equipment, and special-purpose vehicles. New-generation diesel engines are distinguished by environmental safety, fuel economy, and high power output. By improving the combustion process in diesel engines developed on the basis of modern technologies, it is possible to reduce the amount of harmful substances in exhaust gases and increase the efficiency coefficient.

The effective operation of a diesel engine is based on the interrelated performance of several main systems. These systems ensure the proper mixing of air and fuel, the complete realization of the combustion process, the conversion of thermal energy into mechanical energy, and the discharge of exhaust gases into the atmosphere.

One of the important parts of a diesel engine is the intake system. This system supplies the required amount of purified air to the cylinders and ensures the correct direction of airflow [3]. In modern diesel engines, the intake system consists of several valves and channels that create air swirl inside the cylinder. This helps diesel fuel mix well with air in the form of fine droplets. As a result, combustion efficiency increases and the amount of harmful substances in the exhaust gases decreases. When the engine operates at low rotational speed, some intake valves remain closed, and as the speed increases, they open automatically. This system helps reduce carbon monoxide and unburned hydrocarbon emissions.

One of the most effective methods of increasing diesel engine power is the use of a turbocharging system. The turbocharger operates by using the energy of exhaust gases. Exhaust gases rotate the turbine blades, and this motion is transmitted to the compressor section. As a result, additional air is supplied to the cylinders under pressure. Increasing the amount of air entering the cylinder ensures more complete fuel combustion, which increases engine power and reduces fuel consumption. Modern diesel engines use variable geometry turbochargers, which create optimal air pressure under different engine operating modes.

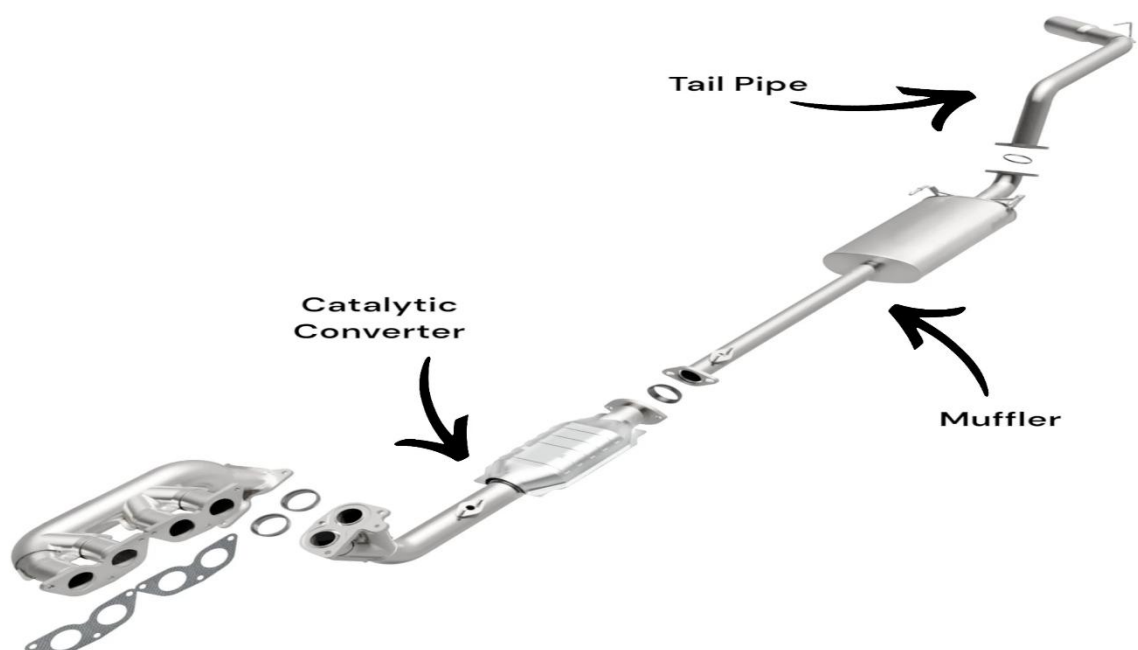


Figure 2. Exhaust system

From a technical point of view, the main difference between a diesel engine and a gasoline engine is determined by the method of air-fuel mixture formation. In gasoline engines, the mixture is prepared in advance, whereas in diesel engines only air is compressed, and fuel is injected directly into the cylinder. As a result of compression, the air temperature reaches 700–900 °C. At this moment, diesel fuel injected under high pressure mixes with the heated air and ignites spontaneously. The high-pressure gases produced by combustion move the piston and generate mechanical energy.

Method

The methodological basis of this article consists of a theoretical and analytical study of the combustion process in diesel engines. The research was carried out by analyzing scientific and technical sources related to internal combustion engines, fuel injection systems, air-fuel mixture formation, turbocharging, and environmental performance indicators of diesel engines.

During the study, the main structural elements of diesel engines were considered, including the cylinder block, piston group, crankshaft, injector, fuel pump, turbocharger, intake system, valve mechanism, cooling system, and lubrication system. Special attention was paid to the influence of these systems on the formation of the air-fuel mixture and the completeness of combustion.

The research method was based on the following approaches: analysis of the operating principle of diesel engines; comparison of diesel and gasoline engine combustion processes; study of the influence of injection pressure, compression ratio, air temperature, and turbocharging on combustion efficiency; and evaluation of the relationship between effective combustion, fuel economy, engine power, and exhaust gas emissions.

In addition, the article uses a descriptive-analytical method to explain the sequence of processes occurring inside the diesel engine cylinder. These processes include air intake, compression, fuel injection, ignition delay, rapid combustion, controlled combustion, and exhaust gas release. This approach makes it possible to understand the combustion process not only as a single event, but also as a complex thermodynamic process consisting of several stages.

Results and Discussion

The analysis shows that the combustion process in diesel engines is mainly determined by the quality of fuel injection and the proper organization of air movement inside the cylinder. Since the air-fuel mixture is formed directly in the combustion chamber, the injector, fuel pump, intake system, and combustion chamber geometry play a decisive role in ensuring efficient combustion.

One of the most important results of the analysis is that high injection pressure improves fuel atomization. When diesel fuel is injected into the cylinder in the form of very fine droplets, the contact surface between fuel and air increases. This accelerates evaporation, improves mixture formation, and contributes to more complete combustion. As a result, the engine produces higher power with lower fuel consumption.

The compression ratio also has a significant influence on the combustion process. A higher compression ratio increases the temperature and pressure of the air inside the cylinder. This creates favorable conditions for self-ignition of diesel fuel. However, excessively high pressure and temperature may increase mechanical and thermal loads on engine parts. Therefore, the compression ratio must be selected in accordance with engine design, fuel quality, and operating conditions.

The intake system also plays an important role in combustion efficiency. The creation of swirl and turbulence inside the cylinder improves fuel-air mixing. Properly organized air movement ensures that fuel droplets are distributed more evenly throughout the combustion

chamber. This reduces the amount of unburned fuel, improves thermal efficiency, and lowers harmful emissions.

The use of turbocharging significantly improves the performance of diesel engines. By supplying additional compressed air to the cylinders, turbocharging allows more fuel to burn completely. This increases engine power and torque without significantly increasing engine size. In addition, more complete combustion reduces smoke formation and improves fuel economy. Variable geometry turbochargers are especially effective because they can provide optimal boost pressure at both low and high engine speeds.

The analysis also confirms that the combustion process directly affects environmental indicators. Incomplete combustion leads to an increase in carbon monoxide, unburned hydrocarbons, soot particles, and other harmful substances in exhaust gases. In contrast, well-organized combustion reduces fuel consumption and decreases the amount of harmful emissions. Therefore, improving the combustion process is one of the main directions in the development of modern diesel engines.

Modern Common Rail injection systems are particularly important in this regard. These systems allow fuel to be injected at very high pressure and in several stages. For example, pilot injection can reduce ignition delay and noise, main injection provides the main energy release, and post-injection can help reduce soot and improve exhaust aftertreatment efficiency. This means that electronic control of fuel injection has become one of the key technologies for improving diesel engine performance.

Thus, the overall analysis shows that diesel engine efficiency depends not on one single factor, but on the coordinated operation of several systems. The injector must provide high-quality fuel atomization; the intake system must ensure sufficient air supply and turbulence; the turbocharger must increase the amount of air entering the cylinder; and the combustion chamber must provide favorable conditions for complete combustion. Only the correct combination of these factors makes it possible to achieve high power, low fuel consumption, long service life, and reduced environmental impact.

Conclusion

In conclusion, the combustion process in diesel engines is a complex physical, chemical, and thermodynamic process that determines the main performance indicators of the engine. The analysis shows that the efficiency of diesel engines largely depends on the quality of fuel injection, compression ratio, air temperature, air-fuel mixture formation, and the design of the combustion chamber.

Unlike gasoline engines, diesel engines operate on the principle of compression ignition. Air is compressed inside the cylinder until its temperature becomes high enough to ignite the injected fuel. This feature allows diesel engines to achieve high thermal efficiency and produce high torque, which is why they are widely used in trucks, agricultural machinery, industrial equipment, and special-purpose vehicles.

The study shows that the improvement of fuel injection systems, the use of turbocharging, the optimization of intake airflow, and the application of modern electronic control systems contribute to more complete combustion. As a result, fuel consumption decreases, engine power increases, the efficiency coefficient improves, and the amount of harmful exhaust emissions is reduced.

Therefore, the development and improvement of diesel engine combustion processes remain an important scientific and technical task. Further improvement of diesel engines should be aimed at increasing fuel economy, reducing emissions, improving reliability, and adapting

engines to modern environmental standards. The effective organization of the combustion process is one of the main conditions for ensuring the long-term competitiveness and ecological efficiency of diesel engines in the automotive industry.

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