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Analysis of the effect of the number of injector nozzles on the pressure and heat transfer coefficient in a hydrogen-diesel mixture diesel engine

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Highlights

- Increasing the number of injector holes reduces the pressure in the cylinder.
- Adding hydrogen to diesel fuel increases the heat transfer coefficient.
- Adding hydrogen to diesel fuel increases engine power and NOx.
- Increasing the number of nozzle holes reduces the depth of fuel penetration into the combustion chamber.

Abstract

In reciprocating internal combustion engines, the calculation of the heat transfer coefficient (HTC) is essential to estimate the heat transfer during combustion in the combustion chamber. The HTC calculation takes into account fluid flow and combustion processes and varies as a function of crank angle and location within the chamber. The mean HTC value is commonly used to calculate the thermo-mechanical analysis of various combustion chamber components. In this study, dynamic grids for the intake port, exhaust port and chamber are created in the chamber modelling section of the AVL-Fire software. The intake and combustion processes are then simulated and the calculated pressure data are compared with experimental data at 2800 rpm with 1, 3 and 6 hole injectors. Finally, the distribution of HTC over the chamber walls was evaluated using a time step method. The research also included verification of the HTC results with theoretical data obtained by Woschni and Hohenberg. In addition, with the decreasing availability of fossil fuels and the need for lower exhaust emissions from diesel engines, the use of blends of diesel and hydrogen fuel has become widespread. In this engine, a mixture of 10% hydrogen and 90% diesel fuel is used. The final results show that the heat transfer coefficient increases by approximately 1.72% when hydrogen is added to diesel fuel due to the number of collisions between hydrogen and other fuel components.

Introduction

About a third of the total energy input into the engine is lost to the environment through heat transfer. Temperatures in the combustion chamber of an engine can rise to around 2700 K and the materials used [1] to build the engine cannot withstand such high temperatures for long periods of time. Proper heat transfer is essential to maintain the function and durability of the engine and to prevent degradation due to excessive heat.

To maintain engine efficiency and structure, heat dissipation is crucial and it is essential to run the engine at the highest possible temperature without causing damage [2,3]. To better study heat transfer, an engine is divided into subsystems [4,5], including the intake system with the intake port, intake valve and intake manifold. During the intake process, the temperature of the fuel and incoming air is typically lower than the cylinder wall temperature and their velocity is higher, resulting in heat transfer from the wall to the fluid inside the chamber [6,7]. During the compression stroke, the gas temperature exceeds the cylinder wall temperature and decreases [8,9], and heat is transferred from the gas in the cylinder to the combustion chamber wall. At the point of combustion [10], the gas temperature rises significantly and the gas expands, increasing in velocity and decreasing in temperature [11,12]. This is when the rate of heat transfer to the walls is at its highest. Finally, a small amount of fuel and air in the cylinder passes through the piston rings to the ports, resulting in additional heat transfer [13,14].

Heat transfer occurs when some of the fuel and air in the cylinder passes through the piston rings into the crankcase. As the gas expands, its temperature decreases and so does the heat transfer rate [[15], [16], [17]]. During the exhaust process, as the exhaust valves open, heat is transferred from the exhaust gases to the exhaust pipes, increasing the temperature of the exhaust pipes and decreasing the temperature of the exhaust gases [18].

Calculating heat transfer in a cylinder requires information on cylinder pressure, temperature of the burned and unburned gases, combustion chamber surface area, gas temperature and average gas velocity. Accurate prediction of heat transfer is essential for optimum engine design [19,20]. Heat is transferred by convection and radiation; once it passes through the wall, it is transferred to the surroundings. The heat transfer to the wall varies, from negative values during the suction process to positive values at the beginning of the expansion process, up to several megawatts per square metre [21,22].

The researchers found that delaying the ignition time reduces the instantaneous heat transfer coefficient, while increasing the engine speed increases it. Broekaert et al. proposed a fuel-independent model in 2016 by conducting experiments with a heat flux sensor to determine the factors affecting heat transfer and classifying them into three categories: fixed, manageable and unmanageable. The researchers used root cause analysis to thoroughly investigate the contribution and impact of each factor on heat transfer [[23], [24], [25]].

Blending hydrogen with diesel fuel can change the composition and potentially affect the performance and exhaust emissions of a diesel engine [26,27]. The effects depend on the blend ratio, engine design and operating conditions. These effects include increased power output, reduced exhaust emissions and reduced engine wear [[28], [29], [30], [31], [32], [33], [34]].

The impact of different injector orifice configurations on diesel engine performance and emissions varies. Spray pattern, fuel dispersion and combustion efficiency are all affected, which affects engine performance, emissions and efficiency [35,36]. The use of hydrogen-diesel fuel blends and specific injector nozzles can have a significant impact on engine performance and emissions, depending on the blend ratio, engine design and operating conditions.

In this study, a 4-cylinder single-hole injector diesel engine is investigated to analyses the effect of the number of injector nozzles on the pressure in the cylinder and the distribution of the convective heat transfer coefficient (HTC). The chamber modeler section of the AVL-Fire software is used to create dynamic meshes for the intake port, exhaust port and chamber. The intake and combustion processes are then simulated and the calculated pressure data compared with experimental data at 2800 rpm with 1, 3 and 6 hole injectors. The distribution of HTC over the chamber walls is evaluated using a time step method. The results are compared with experimental data obtained by Woschni and Hohenberg.

Section snippets

General studies of governing equations

General studies show that the temperature and velocity of the gas in the combustion chamber fluctuate greatly, causing the heat flux distribution on the chamber walls to be non-uniform. Equation (1) represents the stable, one-dimensional heat transfer through the combustion chamber of the cylinder. This equation correlates the heat flux ($\dot{q} = \frac{\dot{Q}}{A}$) with the measured temperature ($T_{w.g}$) [37].$q = \dot{q_{cv}} + \dot{q_r} = h_{c.g}\left(\overline{T_g} - T_{w.g}\right) + \sigma\varepsilon\left(\overline{T_g^4} - \overline{T_{w.g}^4}\right)$
$\dot{q} = q\dot{_{CN}} = \frac{k(T_{w.g} - T_{w.c})}{t_w}\dot{q} = q\dot{_{CN}} = h_{c.c}\left(T_{wc} - \overline{T_c}\right)$

Radiation usually has…

Combustion chamber geometry

The geometric specifications and working conditions of the simulated engine are according to Table 1.…

Model validation

Fig. 4 shows the pressure and temperature inside the chamber and the pressure results obtained are compared with the experimental pressure results of the engine at 2800 RPM. The results before ignition are in good agreement with the experimental values, with a difference of less than 1%. Even after the initial pre-injection, the pressure changes remain in agreement with the experimental values. However, the difference increases during combustion and expansion. The difference at this time seems …

Heat transfer coefficient

The maximum pressure in the chamber occurred at an angle of 724° (4°CA aTDC), when the expansion stage began, reducing the pressure and converting it into torque on the crankshaft. Fig. 8 shows the local heat transfer coefficient at different crank angles. The exhaust and intake valves had the highest heat transfer coefficient of approximately 9000W/m^2K, probably due to the high velocity of the gases around them and their high Reynolds number. The exhaust valve has a slightly higher…

Conclusions

In this study, an AVL-Fire software network of air intake, exhaust outlet and combustion chamber for a 4-cylinder diesel engine was created using a dynamic and structured gridding method. The simulation of the intake and combustion processes was performed at 4000rpm and full load. In addition, the combined use of hydrogen and diesel fuel was investigated. The results are as follows.

- The maximum heat transfer coefficient for the components and their average are obtained at an angle where the…

…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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