SIMULATION OF DIRECT INJECTION, MIXING AND COMBUSTION OF CNG FUEL IN A SINGLE-CYLINDER ENGINE WITH DIFFERENT INJECTOR ORIENTATIONS USING CFD

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Abstract

The direct injection system is widely used in the automotive industry, especially for performance enhancement and cleaner emissions. The study proposed a direct injection system in a small, single-cylinder compressed natural gas engine. However, its compactness provides a minimum space for direct injector installation. Therefore, a suitable injector orientation that meets space availability and is practically effective must be determined. The main objective is to determine the best injector orientation for the direct injection process using computational fluid dynamics by analysing the effect of top and side injection on the cylinder flow pattern, in-cylinder pressure and temperature. The analysis was performed by using Ansys Fluent. The dynamic mesh strategy is utilised to ensure a realistic solution of in-cylinder flow, gaseous injection, mixing and combustion. Based on the visualisation results, it is found that the injector orientation affects the overall injected mass of fuel by deteriorating the injection penetration, injection velocity and spray cone, as demonstrated by the top injection case. As a result, the methane mass fraction in the cylinder is reduced. The plotted results showed the side injection has a higher cold flow and combustion pressure and temperature with values of 112.38 bar and 3834.3 K, while the top injection has 98.99 bar and 2381.1 K. Even though the simulation overpredicted the pressure and temperature for both cases, because of inaccurate convective heat transfer solution, the resultant pressures and temperatures provide a valuable indication of how the injector orientation affects the overall direct injection of natural gas engine's performance. In the current study, the side injection performed better than the top injection. The side injection produced a higher pressure and temperature because the higher mass was transferred during the side injection. The study provided valuable insights into the ideal direct injection of compressed natural gas.

1 Introduction

Compressed natural gas (CNG), primarily composed of methane (CH_4), is the most promising alternative fuel due to its environmentally friendly and economic advantages [1]. Using turbocharging can boost the CNG engine's performance and lower the gasoline engine's power gaps [2]. Direct injection (DI) of CNG improves thermal efficiencies comparable to diesel engines while maintaining smoke-free emissions such as spark ignition (SI) engines and slightly lower NOx emissions. [3]. The direct injection (DI) systems can increase the mixture's absolute heating value and turbulence intensity for better mixing. Hence, it improves combustion efficiency to increase torque and power, minimise pumping and heat losses, and precisely control the engine's air-fuel ratio [4].

Based on the fundamental aspects of combustion, the in-cylinder pressure during the engine processes varies and reaches its maximum value at the top dead centre (TDC) during the compression stroke. In this period, the pressure increment is due to the pumping work and is considered negative work or boundary-work of the engine [5]. In the event of firing, the heat is released as the combustion is initiated, and the pressure increment is driven by the heat release process. Higher combustion pressure is desirable to generate more torque. The pressure is proportional to the force acting on the piston and the torque acting on the crankshaft [6]. Instead of the heat release, the in-cylinder temperature, the heat losses through the wall, and the boundary work mentioned above also affect the maximum cylinder pressure [7]. Even though the pressure is proportional to temperature, the higher temperature is unnecessary as it positively correlates with NOx emission and is limited by the material properties [8]. The temperature increase inside the cylinder during the combustion process can reach a maximum (adiabatic) flame temperature of around 3900 K [9], indicating the burned mixture in specific locations within the engine cylinder.

Based on technological advances, Direct injection spark ignition (DISI) CNG engines were developed and studied intensively worldwide [10]–[15]. Previous work showed that the CNG-DISI engine's torque improved due to the improved combustion pressure inside the cylinder