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A Simulation Study of Direct Injection Compressed Natural Gas Spark Ignition Engine Performance Utilizing Turbulent Jet Ignition with Controlled Air Charge

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Abstract : Compressed Natural Gas (CNG) mainly consists of Methane CH_4 and has a low carbon to hydrogen ratio relative to other hydrocarbons. As a result, it has the potential to reduce CO_2 emissions by more than 20% relative to conventional fuels like diesel or gasoline Although Natural Gas (NG) has environmental advantages compared to other hydrocarbon fuels whether they are gaseous or liquid, its main component, CH_4, burns at a slower rate than conventional fuels A higher pressure and a leaner cylinder environment will overemphasize slow burn characteristic of CH_4. Lean combustion and high compression ratios are well-known methods for increasing the efficiency of internal combustion engines. In order to achieve successful CNG lean combustion in Spark Ignition (SI) engines, a strong ignition system is essential to avoid engine misfires, especially in ultra-lean conditions. Turbulent Jet Ignition (TJI) is an ignition system that employs a pre-combustion chamber to ignite the lean fuel mixture in the main combustion chamber using a fraction of the total fuel per cycle. TJI enables ultra-lean combustion by providing distributed ignition sites through orifices. The fast burn rate provided by TJI enables the ordinary SI engine to be comparable to other combustion systems such as Homogeneous Charge Compression Ignition (HCCI) or Controlled Auto-Ignition (CAI) in terms of thermal efficiency, through the increased levels of dilution without the need of sophisticated control systems. Due to the physical geometry of TJIs, which contain small orifices that connect the prechamber to the main chamber, scavenging is one of the main factors that reduce TJI performance. Specifically, providing the right mixture of fuel and air has been identified as a key challenge. The reason for this is the insufficient amount of air that is pushed into the pre-chamber during each compression stroke. There is also the problem that combustion residual gases such as CO_2, CO and NOx from the previous combustion cycle dilute the pre- chamber fuel-air mixture preventing rapid combustion in the pre-chamber. An air-controlled active TJI is presented in this paper in order to address these issues. By applying air to the pre-chamber at a sufficient pressure, residual gases are exhausted, and the air-fuel ratio is controlled within the pre-chamber, thereby improving the quality of combustion. This paper investigates the 3D-simulated combustion characteristics of a Direct Injected (DI-CNG) fuelled SI en- gine with a pre-chamber equipped with an air channel by using AVL FIRE software. Experiments and simulations were performed at the Worldwide Mapping Point (WWMP) at 1500 Revolutions Per Minute (RPM), 3.3 bar Indicated Mean Effective Pressure (IMEP), using only conventional spark plugs as the baseline. After validating simulation data, baseline engine conditions were set for all simulation scenarios at λ=1. Following that, the pre-chambers with and without an auxiliary fuel supply were simulated. In the simulated (DI-CNG) SI engine, active TJI was observed to perform better than passive TJI and spark plug. In conclusion, the active pre-chamber with an air channel demon-strated an improved thermal efficiency (η_{th}) over other counterparts and conventional spark ignition systems.

Keywords : turbulent jet ignition, active air control turbulent jet ignition, pre-chamber ignition system, active and passive pre-chamber, thermal efficiency, methane combustion, internal combustion engine combustion emissions
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