**Thesis Title:** Spray, Laser Ignition, Combustion and Engine Investigations of Low Carbon Fuels

**Abstract**

Internal combustion engines (IC) have been crucial for human progress and economic growth. However, their dependence on fossil fuels has led to environmental issues, including greenhouse gas emissions and global warming. To address these concerns, there’s a growing interest in using low-carbon fuels as sustainable alternatives in the transport sector. This research focuses on assessing such fuels, including methanol, ethanol, hydrogen, and compressed natural gas (CNG), which are crucial for passenger vehicles, particularly in spark ignition (SI) engines. The experimental study on assessing was conducted in three phases. The research begins with investigating the spray characteristics of these fuels in engine-like conditions using many optical techniques. It explores factors like ambient temperature and pressure, highlighting differences in spray behavior among methanol, ethanol, and gasoline under different engine-like conditions. It was observed that an increase in ambient pressure decreased the spray penetration length, but increased fuel injection pressure (FIP) increased it. Also, the spray collapse was more prone to gasoline and methanol than ethanol. The gaseous fuels hydrogen and CNG underwent jet characterization studies, which found that the jet penetration lengths were similar despite significant differences in the physical properties of hydrogen and CNG. Hydrogen jets were also more sensitive to temperature changes than CNG. Laser ignition (LI) offers benefits such as low-temperature combustion, reduced NOx emissions, the ability to ignite leaner fuel-air mixtures, higher efficiency, precise ignition timing, and no quenching effect of the flame kernel. In the second phase of the study, a constant-volume combustion chamber (CVCC) is used to explore the fundamental aspects of LI for homogenous HCNG mixtures. Experimental investigations showed that hydrogen-air combustion had a significantly higher rate of pressure rise than stoichiometric CNG-air mixture combustion. Flame kernel images revealed faster growth for the Hydrogen-air mixture than the stoichiometric CNG-air mixture. The combustion duration for LI was considerably shorter, and centrally focused LI further accelerated the flame kernel propagation, resulting in an increased heat release rate and shorter combustion duration than conventional spark ignition. In the final phase of the study, three key investigations were conducted. The first was a feasibility study of methanol in a diesel engine, which demonstrated the successful use of port fuel injection of methanol in a diesel engine. It was found that methanol could displace 50% of diesel energy at all loads without significant engine hardware modifications. The second investigation examined the effect of spark timing sweep using pure methanol and ethanol and compared it with gasoline. It was found that as the timing advances, the in-cylinder pressure increases. Alcohols exhibited higher in-cylinder pressure than gasoline at mid and high loads due to their high flame velocity. Methanol and ethanol also showed lower EGT and higher BTE than gasoline. The third investigation was a comprehensive study of particulate characteristics of LI engines with hydrogen-enriched CNG fueling. The study found that hydrogen enrichment of CNG reduced the particulate number concentration. This research paves the way for more sustainable and efficient transportation systems by studying low-carbon fuel combustion characteristics and behavior and exploring innovative ignition methods such as laser ignition.

**Keywords:** Spray, Combustion, Laser Ignition, Hydrogen, HCNG, Methanol, Ethanol, SI Engine