The present work deals with experimental and numerical analysis of natural gas fueled SI engines with particular focus on the gas fuel injection and air-fuel mixing processes. In general, control of mixture quality plays a critical role in setting course for the proximate combustion and emission formation characteristics. Specifically, as a result of its constant gas state and low density, the operation of gas injector and gas-phase mixing bear peculiar differences from conventional liquid-fueled engines and therefore warrant detailed insight. Both PI and DI systems have been studied.

A general introduction is provided in the first chapter, justifying the promising viability of natural gas as an alternative transport fuel from the technical, as well as social and economic, perspectives. In particular, the potentials and limitations of combustion system technologies accessible to natural gas fuelling are pinpointed in brief and generic terms. The main body of the present dissertation consists of three parts, described respectively in chapter two, three and four.

The first part presents a numerical study on a port-injection spark-ignition CNG engine. The numerical model adopts the source-cell approach for the simulation of underexpanded gas jet from a single-hole injector, and the modeling sensitivity and validity are thoroughly investigated. The proposed approach, albeit simplifying the grid construction by omitting the complicated internal fluid passage of an injection, provides faithful description of the underexpanded jet structure and proves adequate for the intended gas fuel injection and mixing study. The numerical model is then applied as a diagnostic tool to explain the experimental observations. Fuel induction and mixing characteristics peculiar to port-injected gaseous fuel are revealed with respect to fuel distribution and turbulence. The influence of injection timing and the necessity of including fuel injection model are highlighted by comparisons with a conventional premixed homogeneous simulation case under the same conditions.

The second part presents a detailed experimental and numerical study on the jet structure and development of a highly underexpanded jet issuing from an outward-opening poppet valve injector that is intended for direct CNG injection application. The results from high-speed schlieren imaging technique and numerical modeling agree with each other and allow for the understanding of jet formation mechanism and consequent development stages. The hollow cone jet significantly differs from widely studied circular jet and features bluff body wake-like flowfield, von Kármán vortex patterns, circularly distributed potential core and high, early unsteadiness. The implications of the resultant fundamental deviation of jet morphology from axisymmetry, commonly neglected in numerical works, are also demonstrated.

The third part presents an analysis of the direct gas injector implementation in an optically accessible engine by means of tracer-LIF visualization experiment and numerical modeling. The injection characteristics are investigated by considering jet interaction with walls and intake air flow at different engine operating points with distinct injection windows, VVA profiles and engine speeds. The resultant in-cylinder coherent flow motion, turbulence level and mixture quality are discussed and compared with combustion measurement. The side-mounted configuration that takes advantage of the Coandă effect proves an effective design to overcome the usually problematic jet penetration and mixing capabilities of low-density gaseous fuels for homogeneous-charge combustion systems.

The experimental and numerical techniques applied in the present dissertation are specific to the investigation into gaseous fuel injection and air-fuel mixture formation process, with the purpose of establishing a set of appropriate predictive and diagnostic methodologies for the development of gas-fuelled internal engines.