Evaluation of New Criteria for Cavitation Inception in Diesel Injectors

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Abstract

Modern diesel injectors are characterized by high injection pressures wherein the flow inside the orifice and sac becomes turbulent and cavitation patterns are observed at the orifice exit. Traditionally cavitation inception in diesel injectors is based on the condition that local pressure drops below the vapor pressure of the fuel. While this criterion is seen to predict cavitation inception reasonably well, recent studies have shown that normal viscous stresses should be considered in addition to pressure, since a fluid element experiences stresses rather than the local pressure. This theory is applied to high Reynolds number flows in diesel injectors. The differences between traditional and total stress criteria to predict cavitation inception was found to be insignificant. The total stress criterion which is based on molecular viscosity was modified to include the effect of turbulent viscosity. For high injection pressure when the flow inside the injector is turbulent this new criteria based on turbulent viscosity significantly influenced cavitation inception regions. There is, however, a lack of quantitative experimental data for determining and validating an effective criterion for cavitation inception.

Introduction

Combustion of injected liquid fuel in diesel engines is dependent on the effective atomization to increase the surface area of fuel and hence achieve higher rates of mixing and evaporation. The reduction in fuel droplet size leads to higher volumetric heat release rates, prompt ignition, increased flammability limits, and lower engine emissions. During the past two decades there has been tremendous growth of interest in understanding the fundamental injection and atomization processes. The key to model the atomization process effectively lies in understanding the primary breakup of the liquid jet. Fundamentally, primary breakup in the region close to the nozzle orifice is strongly influenced by aerodynamics, cavitation, and turbulence effects from inside the injector [1,2,3]. First step towards modeling primary breakup is to understand the flow inside the nozzle since it provides boundary conditions, including turbulence and cavitation intensity, for spray models.

Cavitation refers to the formation of bubbles in a liquid flow when the local pressure drops below the vapor pressure of the fluid. Liquid to vapor transition can occur by heating the fluid at a constant pressure, known as boiling, or by decreasing the pressure at a constant temperature, which is known as cavitation. Cavitation has also been defined as “the liquid continuum rupture due to excessive stress” by Franc et al. [4]. Modern diesel engines are designed to operate at very high injection pressures (upto 3000 bar) leading to high injection velocities. Therefore, in a diesel injector nozzle, high pressure gradients and shear stresses can lead to cavitation, or the formation of bubbles. This can be beneficial to the development of the fuel spray, since the primary breakup and subsequent atomization of the liquid fuel jet can be enhanced. In addition, cavitation increases the liquid velocity at the nozzle exit due to the reduced exit area available for the liquid. Cavitation patterns extend from their starting point around the nozzle orifice inlet to the exit where they influence the formation of the emerging spray. The improved spray development is believed to lead to more complete combustion process, higher fuel consumption efficiency, and reduced exhaust gas and particulate emissions. However, cavitation can also decrease the flow efficiency (discharge coefficient) due to its affect on the exiting jet. Also imploding cavitation bubbles inside the orifice can cause material erosion thus decreasing the life and performance of the injector. Clearly an optimum amount of cavitation is desirable and it is im-

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