Superheated fuel injection modeling: An engineering approach

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A B S T R A C T

A liquid fuel undergoes a sudden decrease in pressure during an injection process. If the pressure outside the injector is below the saturation pressure of the fuel, superheated conditions are reached and the fuel undergoes a thermodynamic instability. Flash evaporation might take place inside or outside the injector nozzle, thus the liquid jet behaves following different mechanisms. Flashing conditions greatly influence atomization and vaporization processes as well as the mixture formation and combustion. This work presents a homogeneous one-dimensional model for the prediction of flash evaporation in superheated liquid fuel injections, able to deal with both internal and external flashing, useful for initializing 3D spray calculations in CFD codes. In this model a Volume Translated Peng–Robinson Equation of State (VTPR-EOS) is used to calculate thermodynamic properties of hydrocarbon fuels. A Homogeneous Relaxation Model (HRM) is used to predict the evaporation rate during internal flashing which may lead to effervescence atomization outside the nozzle. Standard thermodynamic analysis of the CJ-point is used instead for the evaluation of the evaporation rate outside the nozzle, when an unbroken meta-stable liquid jet is predicted under superheated conditions. Two different sets of numerical simulations have been carried out and the results have been compared versus experimental data in literature.

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1. Introduction

In recent years, injection processes involving superheated fuels are being extensively studied in aerospace and automotive sectors. Extensively investigated in nuclear engineering since the sixties, liquid flashing jets are not new in technical literature, but the complex physics behind them is still partially unclear. Superheated liquid jets are now the targets of new interest in modern aircraft and in internal combustion reciprocating engines, and other applications involving liquid fuel injection processes. In advanced aircraft engines a conventional hydrocarbon fuel is being considered for cooling the engine [1–3]. The increase in temperature of the fuel before it is injected and burned in the combustion chamber might lead to superheated conditions of the liquid jet. Flash vaporization might take place affecting the combustion performances and creating the danger of vapor lock within the fuel line [3].

Superheating conditions are likely to be found under partial load conditions in modern internal combustion reciprocating engines as well. In these engines the fuel goes through an increase in temperature due to the high pressure pump (i.e. GDI engines) and heat exchange within the fuel line or within the injector itself. In fact, in direct injection engines the fuel injector faces the combustion chamber undergoing high thermal stresses. Also in these cases the fuel works as a coolant, increasing its own temperature when injected. If the pressure inside the combustion chamber is lower than the saturation pressure of the fluid at the injection temperature, the enthalpy of the liquid exceeds the saturated value and might promote flash evaporation, which in turn greatly influences atomization and vaporization processes, as consistently reported from technical literature. Compared to mechanical break-up processes, evidences of enhanced atomization, increased cone angle of the spray, and decrease of intact jet length with increasing superheating degree are some of the correlations that have been found and investigated by Reitz [4], Park and Lee [5] and others. When thermal effects supersede hydrodynamic influences, the jet’s behavior will result thermally driven, thus thermal effects need to be considered. This is due to the different time scale at which heat transfer related phenomena are taking place, compared to inertia related phenomena.

Investigations in several working scenarios have shown that superheated fuels can alter mainly depending on nozzle geometry, pressure regimes, superheating degree and heat transfer. Oza and Sinnamon [6], identified two flashing modes in fuel injectors, described as internal and external flashing, depending on whether nucleation takes place within the nozzle or not. Nucleation was found to be promoted by the superheating degree and a high resident time of the fuel within the nozzle. Park and Lee [5]