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A numerical study of the effects of pressure fluctuations inside injection nozzle on high-pressure and evaporating diesel spray characteristics

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ABSTRACT

Effects of injection pressure fluctuations on high-pressure and evaporating spray behaviour, especially under the representative modern diesel engine injection conditions, were carefully evaluated by using a well validated two-stage modelling approach. The numerical results indicate that as the injection pressure fluctuates more drastically both liquid and gas phase motions in the spray field will be more intensively disturbed. Furthermore, the injection pressure fluctuations have strong potential to enhance fuel/gas mixing processes inside high-pressure and evaporating diesel spray field.

1. Introduction

Most modern direct-injection diesel engines employ the common rail injection systems, and more recently advances in the common rail fuel injection strategies have included flexible multiple injections, increased injection pressure (more than 300 MPa), and nozzles with smaller discharge holes (less than 100 μm). In realistic diesel injection cases corresponding to the above new fuel injection strategies, the internal flows of injector nozzle become very complicated. Besides occurrence of cavitation [1–4], high-frequency fluctuations of pressure inside injector nozzles are unavoidable because of fast opening and closing of the needle valve during very short injection intervals and the propagation of pressure wave through narrow fuel passages [5,6]. To further optimize the fuel injection strategies and obtain a better combustion with lesser emissions in direct-injection diesel engines, it is quite important to deeply evaluate the effects of both cavitation and pressure fluctuations in an injector nozzle on spray behaviour at realistic diesel injection conditions.

In the past few years, most of the related studies have examined the separate effects of cavitation on the characteristics of spray and atomisation [7–11]. Accordingly, the effects of cavitation on near-nozzle spray behaviour have been well clarified. So far cavitation has been shown to have a significant impact on macroscopic fuel spray characteristics in the near-nozzle field and it is usually expected to enhance the fuel atomisation process. However, the effects of injection pressure fluctuations on diesel spray behaviour have only been highlighted by a few studies. Though the studies of Ubertini [12] and Pontoppidan et al. [13] have provided evidence that the impact of injection pressure fluctuations on injected fuel mass flow rate and spray characteristics

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Nomenclature

A	amplitude of pressure fluctuation
$C_1, C_2, C_3, C_B, C_\mu$	model constants
C_D	drag coefficient
C_E	Egler coefficient
C_{TD}	turbulent dispersion coefficient
C_R	condensation reduction factor
d	nozzle hole diameter
$\mathbf{F}^D$	drag force
$\mathbf{F}^{TD}$	turbulent dispersion force
$\mathbf{g}$	gravitational acceleration
k	turbulent kinetic energy
l	nozzle hole length
l_m	maximum of needle lift
L	length scale
m	cavitation bubble mass
$\dot{M}$	break-up rate
$\mathbf{M}$	momentum interfacial exchange
N'''	bubble number density
p	pressure
p_{avg}	average inlet pressure
p_{sat}	saturation pressure
r	hole inlet rounding radius
R	mean bubble radius
R_{core}	radius of liquid core
R_{drop}	radius of droplet
S	source term
t	time
$\mathbf{T}^t$	Reynolds stresses
V	velocity
$\mathbf{V}$	velocity vector

Greek symbols

α	volume fraction
ρ	density
σ	surface tension
υ	viscosity
ε	turbulence energy dissipation
λ	shear stress
$\mathbf{\Gamma}$	mass exchange

Subscripts

1	vapour
2	continuous liquid
amb	ambient gas
A	atomisation
k, l	phase index
T	Turbulence
W	Wave

increase with increasing injection pressures, and moreover, controlling the injection pressure fluctuations inside injector nozzles may be an effective way of governing the spray formation/mixing process, up to now the effects of strong pressure fluctuations on realistic diesel spray behaviour have not been thoroughly evaluated.

The present study aims to further evaluate the impact of high-frequency pressure fluctuations inside injection nozzles on high-pressure and evaporating spray behaviour, especially under typical diesel engine injection conditions. Because most current experimental techniques can provide few reliable quantitative flow data for thoroughly exploring the correlation between diesel nozzle flow and spray behaviour, the use of computational fluid dynamic (CFD) simulations for this research topic is not only practical but even necessary. Up to now, Arcoumanis and Gavaises [14], Bianchi et al. [15], von Berg et al. [16,17], Som and Aggarwal [9], and Mohan et al. [8] have presented different strategies for coupled simulation of nozzle flow and diesel spray. In