COMPARISON OF BREAKUP MODELS IN SIMULATION OF SPRAY DEVELOPMENT IN DIRECT INJECTION SI ENGINE

Przemysław Ćwikowski, Piotr Jaworski, Andrzej Teodorczyk

Warsaw University of Technology, Institute of Heat Engineering
Nowowiejska Street 21/25, 00-665 Warsaw
tel:+48 22 234 52 41 fax:+48 22 825 05 65
e-mail: pcwik@itc.pw.edu.pl
pjawor@itc.pw.edu.pl
ateod@itc.pw.edu.pl

Abstract

Nowadays the wide range of spark ignition (SI) engines with spray guided direct injection (SGDI) is in production. Spray development is playing a major role in advanced engine design with three-dimensional computational fluid dynamics (CFD). Nevertheless still there is a need for improvement in CFD injection simulations because of the high pressure injection. The high pressure injection influences the drop breakup, coalescence and evaporation which are critical for proper representation of simulated phenomenon.

Computer codes, like FIRE, give a possibility to simulate the process of injection with various types of breakup models. In spite of the importance of atomization, mechanisms of breakup are still not well understood. To obtain better understanding of breakup models simulations have been performed for the engine combustion chamber with inlet and outlet system and SGDI strategy. For that the model was at first constructed and then imported to the Fire code. After meshing process the model has 2 million cells. The engine is not boosted and as fuel the ethanol is used. The calculations were performed for 3500 rpm. The influence of different breakup regimes on the spray shape is presented in this study. Comparison is made for Wave, TAB (Taylor Analogy Breakup) and Reitz-Diwkar breakup models.

***Keywords**: direct injection, combustion, gasoline, breakup models, SGDI*

1. Introduction

Modern direct-injection gasoline engines have been in production for about ten years, moreover advanced gasoline engines equipped with turbo chargers are expected to remain competitive in vehicle applications for many years. Gasoline engines with direct in-cylinder injection can be categorized by the mixture formation process, wall-guides and spray guided. Engines with spray-guided combustion system are the most sophisticated to design, the centrally located fuel injector sprays along the cylinder axis towards closely spaced spark plug with electrodes carefully positioned at the edge of the spray.

Three-dimensional computational fluid dynamics CFD plays important role in advanced direct-injection gasoline engines development. This paper focuses on the influences of different spray breakup regimes on simulations results by modelling spray-guided combustion strategy. The model is based on combustion chamber from latest BMW engine with so called “high precision injection system” (Fig. 1) equipped with multi-hole piezo-injector, which offers good flexibility for fuel delivery.

The injector holes can be oriented asymmetrically to independently direct each spray plume. This allows optimization of the spray for good fuel-air mixing while avoiding impingement of liquid fuel on solid surfaces such as the intake valves, piston top or cylinder wall. Such impingement can lead to increased smoke emissions. However, multi-hole injectors in comparison to pintle injectors (Fig. 2) create sprays with relatively high penetration due to the high velocity jets issuing from the individual holes, by outward opening pintle-injectors the internal instabilities and cavitation, resulting in small spray-cone angle fluctuations that have been correlated with misfires. Penetration can be mitigated somewhat by creating more holes with smaller hole diameter.

Fig. 1. Combustion chamber SGDI engine

Because the petroleum-derived fuels are increasingly being replaced by renewable and more CO2-emissions- neutral fuels including ethanol and ethanol/gasoline blends, simulations had been performed for E100 fuel.

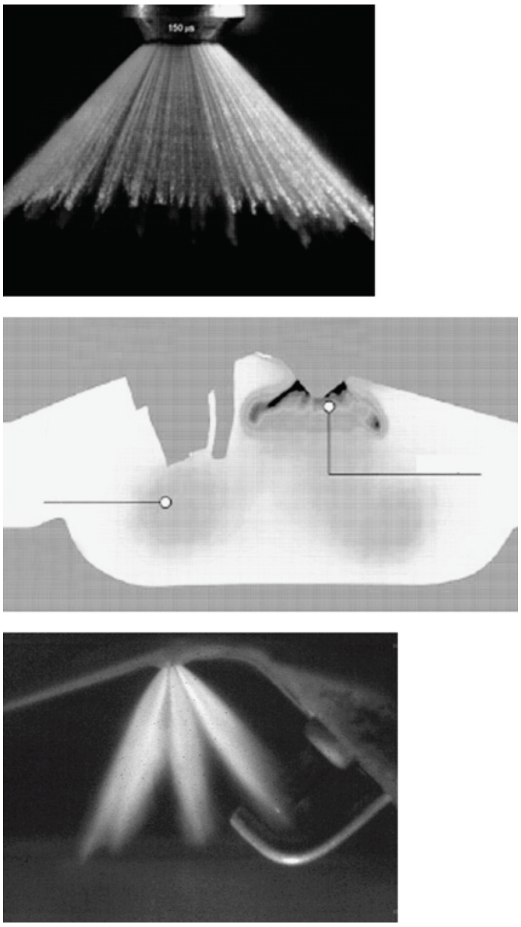


Fig. 2. Spray- and spray/spark-plug imaging for SGDI engines: from the top: near-injector-tip spray imaging of a piezoelectric outwardly opening pintle injector and MIE scattering image of a multihole injector spray

2. Spray simulation

Optimizing spray characteristics for multi-hole injectors with so many independent parameters is a tough work. Moreover complement experimental measurements is needed to set proper constants in breakup models.

Injector model is based on geometrical information and flow characteristics data of Bosch HDEV5 GDI injector with 6 holes. The injection starts from 430 up to 500 CA with initial fuel temperature 293K, injected fuel is ethanol.

Spray simulation study presented in this paper was carried out with focus on secondary breakup regimes, which are critical for spray shape. In last 20 years, a number of spray models have been used to model the injection process in a direct injection gasoline engine. Comparison was made for Wave (Kelvin-Helmholtz instabilities), TAB (Taylor Analogy Breakup) and Reitz-Diwkar breakup models. Despite none of these models completely capture spray behavior, they are included in AVL Fire computational fluid dynamic (CFD) code, which is widely used in the industry. Moreover the Wave model has been used for simulations study as a primary breakup, which is a default by this code.

2.1. Spray braekup regimes

Starting the analysis of the spray fragmentation problem is regime, when fuel is injected the different spray regimes are created. Three main zones, depending on the distance from the nozzle exit are visible (Fig. 3). Very dense so called "thick" in a direct vicinity of the injector hole, than "thin" as a result of primary breakup downstream the injector and finally in the certain distance from the injector appears "very thin" region as a result of secondary breakup and interactions with gaseous phase. It is important that the droplets in various regimes behave differently and are under influence of not the same phenomena.

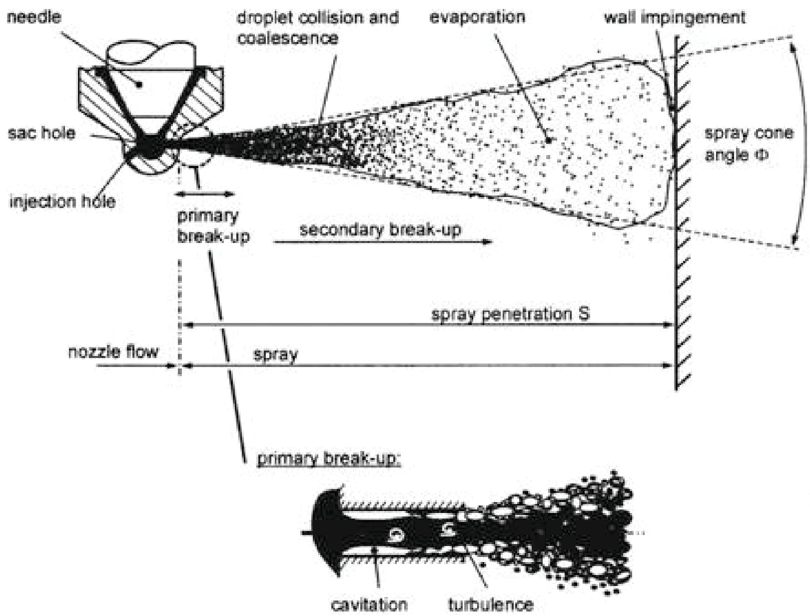


Fig. 3. Different flow regimes in high pressure diesel spray [Reitz,1994]

Concerning primary breakup, this process is a result of combination of three mechanisms, like turbulence within liquid phase, implosion of cavitations bubbles and aerodynamic forces acting on liquid jet. Secondary breakup regime occurs mainly due to the aerodynamic interactions between the liquid and the gaseous phase.

2.1.1. Wave model

Kelvin-Helmholtz instabilities were created in the consequence of the viscous forces caused by the relative tangential motion of two phases at the phase-dividing interface. The Wave breakup model had been developed by [Reitz, 1987] and it is based on [Reitz and Bracco, 1982] stability analysis of round liquid jets.

The stripping of the droplets from a round liquid jet is derived from a dispersion equation that relates the maximum growth rate of surface disturbance to its wavelength, and hence to the drop size of the newly formed drops. The Wave model is appropriate for very high speed injections where We>100 and is suitable not only for primary but also for secondary breakup regimes. This model considers the breakup of the injected liquid to be induced by the aerodynamically driven growth of surface disturbances that are direct result of the velocity between the gas and liquid phases.

2.1.2. Taylor analogy breakup (tab)

The TAB model is suitable for calculating droplet breakup and can be applicable to the engine injection systems. Model was developed based on Taylor's [Taylor, 1963] between an oscillating and distorting droplets and spring mass system.

The original parent droplet undergoes the breakup into a number of smaller child droplets, when the droplet oscillations grow to a critical value. As a droplet is distorted from a spherical shape, the drag coefficient changes. Since the TAB model is described by the spring mass analogy its application is limited for sprays with low Weber numbers. Applying the TAB model for extremely high sprays We numbers results in shattering of droplets.

2.1.3. Reitz-diwakar model

The authors R.D. Reitz and R. Diwakar [1986] distinguish between two break-up regimes, bag break-up for low and stripping break-up for high relative velocities. Drops with Weber number greater than 6 are supposed to be unstable and tend to break-up into smaller droplets. The authors also proved that in case of lack of any droplet breakup model the initial size of the drop has a very strong influence on the processes occurring downstream the nozzle exit.

2.2. Model preparation

Target of the calculation is to show a difference between models of spray breakup used in simulation. SGDI system of mixture preparation can be found already in various types of piston engines. For this investigation the geometrical model had been prepared (Fig. 4) based on latest BMW 3.0 l 6 cylinder gasoline engine with spray guided combustion system, where multi hole injector is centrally located in combustion chamber. Investigated phenomena allows to neglect the channels effect after the valves are closed so model includes also version without channels. After the work on CAD the models were imported to AVL Fire software and prepared for the meshing process in FEM+ (Automatic module for moving mesh generation).

Mesh consists of three different parts. For CA from 340 to 360 includes all ports open (Fig. 5), for CA from 360 to 560 only inlet ports are open (Fig. 6) and for CA from 560 to 750 all ports are closed (Fig. 7).

Number of cells differs from 2 000 000 for worst cases when the valves are closing (Fig. 7) to 600 000 when the ports are closed and only the cylinder volume is under investigation. Because of the sophisticate mesh one case was calculated more than two weeks period under 16 core computer.

Fig. 4. 3D model for BMW engine cylinder with inlet and outlet channels

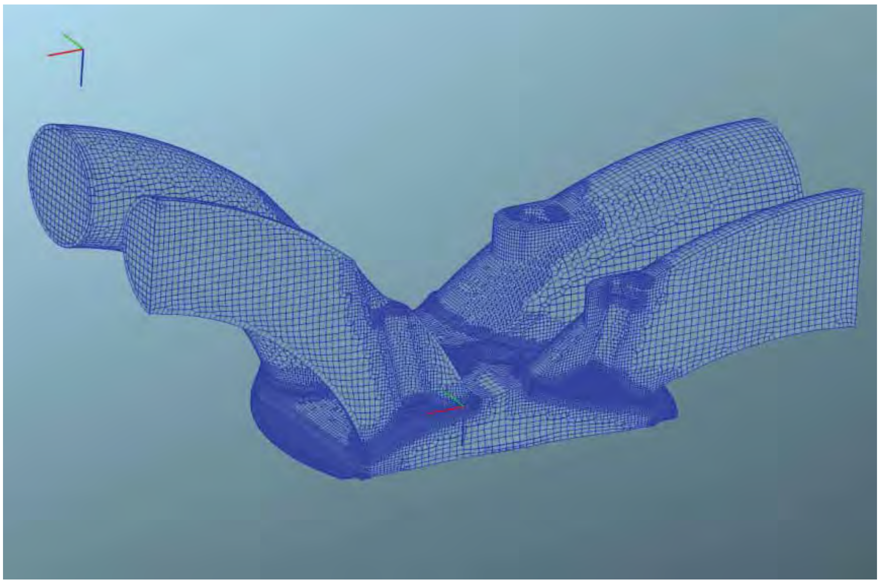


Fig. 5. Mesh model from 340 to 360 CA

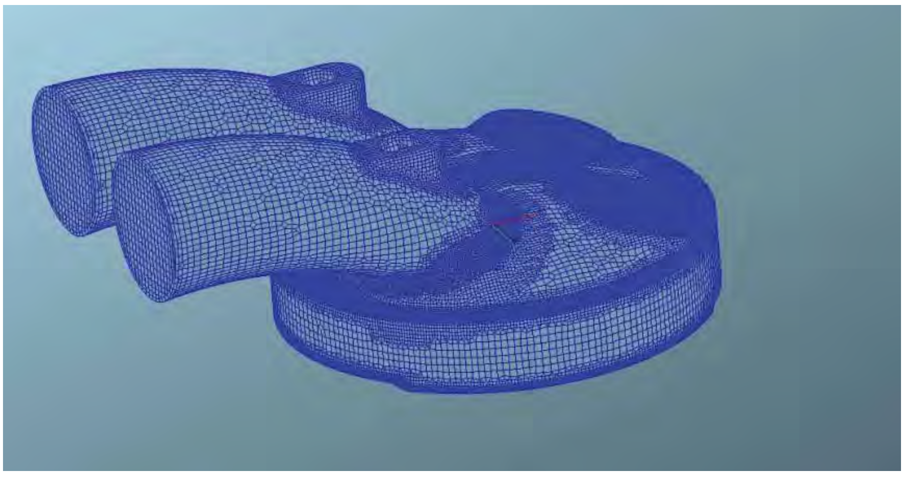


Fig. 6. Mesh model from 360 to 560 CA

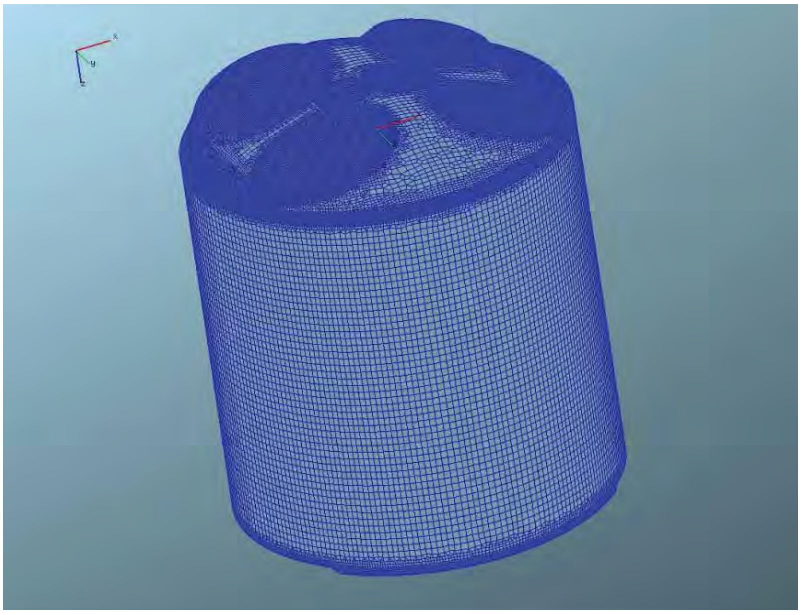
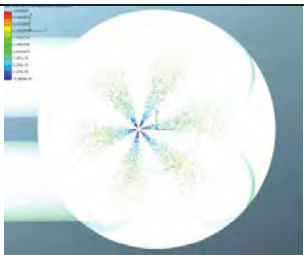
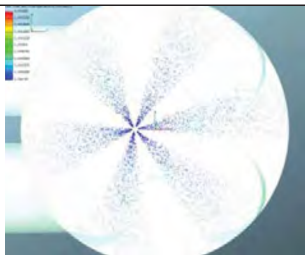
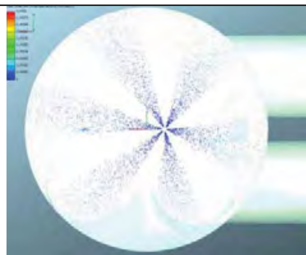
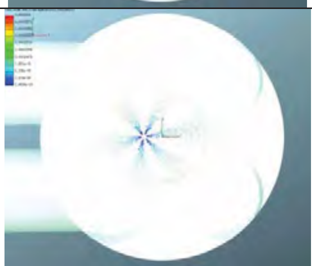
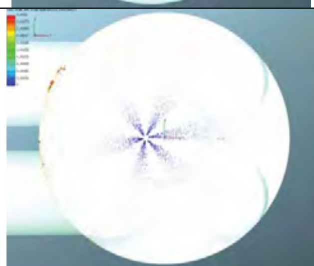
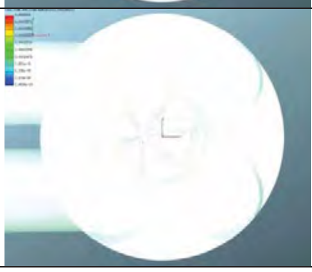
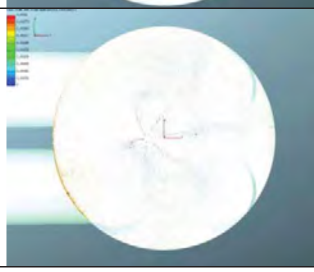


Fig. 7. Mesh model from 560 to 750 CA

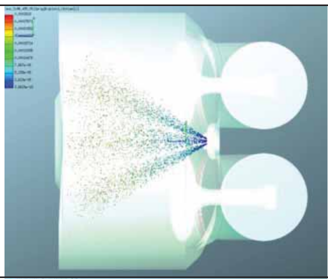
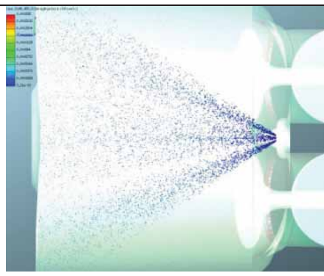
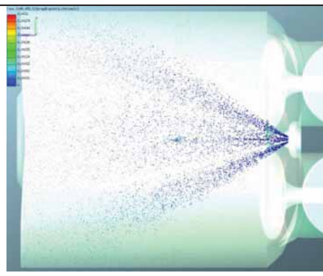
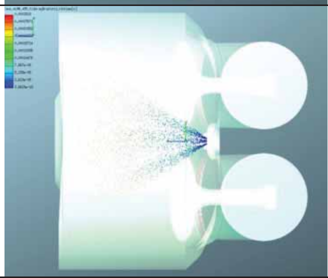
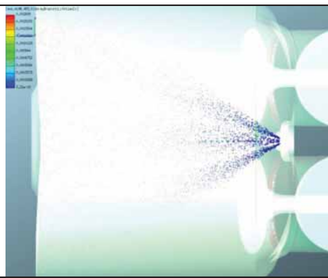
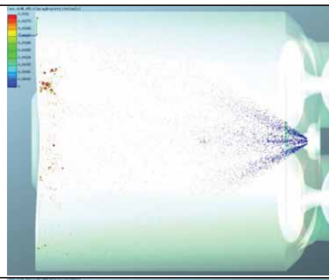
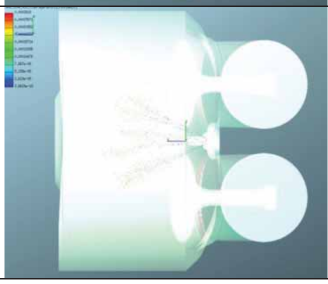
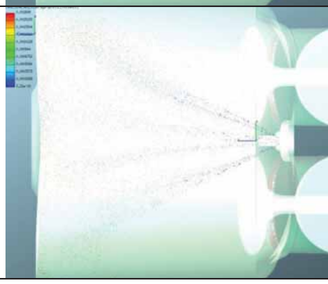
3. Results and discussion

Spray model results were post processed (Tab. 1-2) to observe droplet lifetime and penetration form injector nozzle exit and spray shape as well as wall wetting for each breakup model. The shortest droplets lifetime occurs for TAB model due to high sprays We numbers which take place in high pressure injection systems. It results in shattering of droplets, probably in case of TAB model should be use a Blob injection model as a primary barake-up, but unfortunately this model is activate in AVL Fire code only with so called spray file for proper injector.

Tab. 1. xy view on spray development. Color represent the lifetime of the droplet

	435°	465°	495°
Wave			
Reitz-Diwakar			
Tab			

Tab. 2. yz view on spray development. Color represent the lifetime of the droplet

	435°	465°	495°
Wave			
Reitz-Diwakar			
Tab			

Comparison of simulated SMD diameter (Fig. 8) penetration (Fig. 9) and mass evaporated (Fig. 10) has been presented. It can be seen from these figures that smallest SMD diameter result for TAB model what is not correct in compare with another breakup models and even to experimental results for n-heptane [1]. The experimental results for injected ethanol with multi hole GDI injectors are still not available.

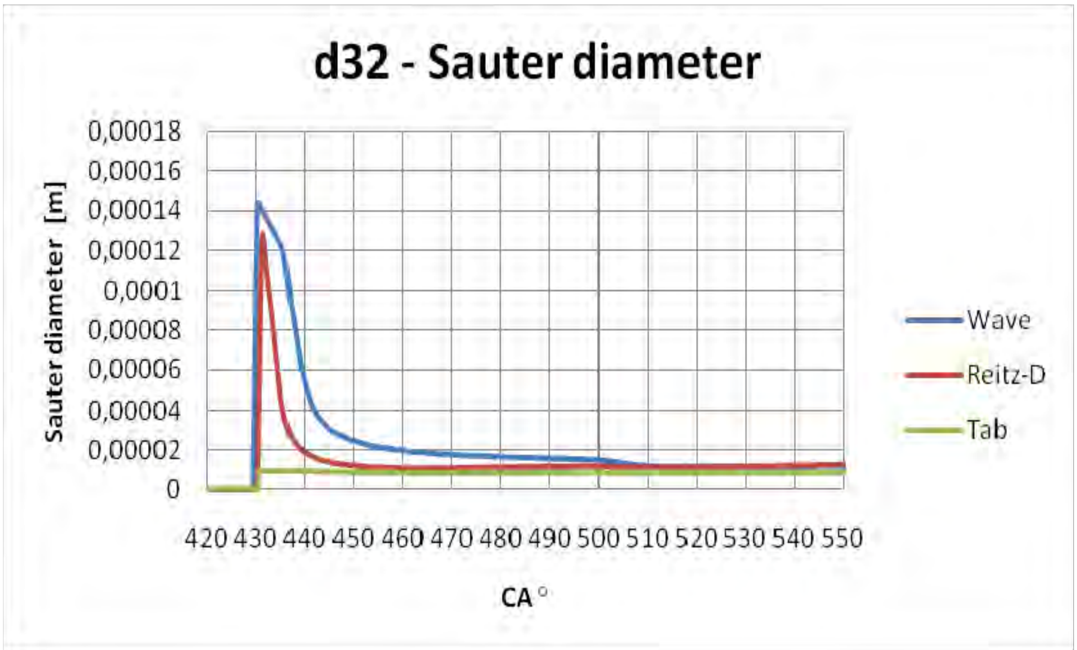


Fig. 8. SMD diameters as a result of different breakup models

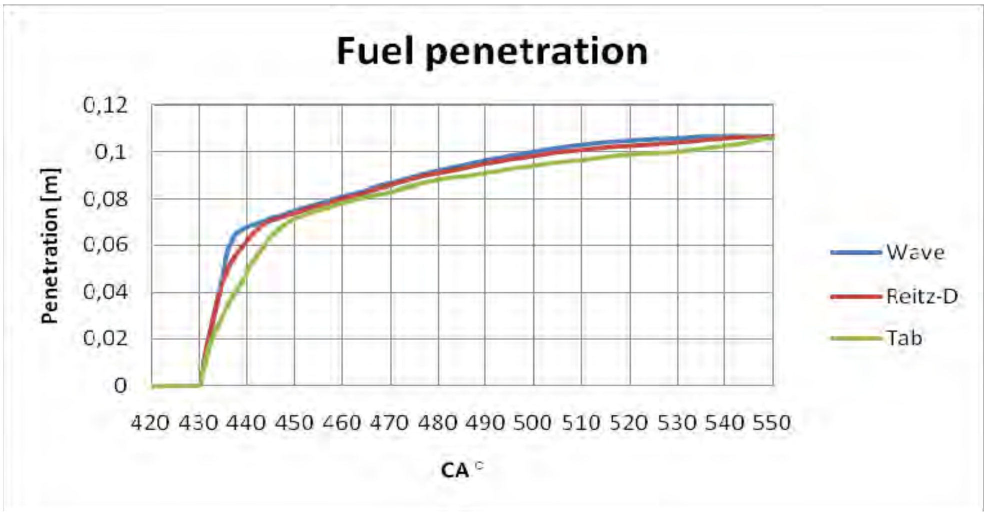


Fig. 9. Simulated fuel penetration

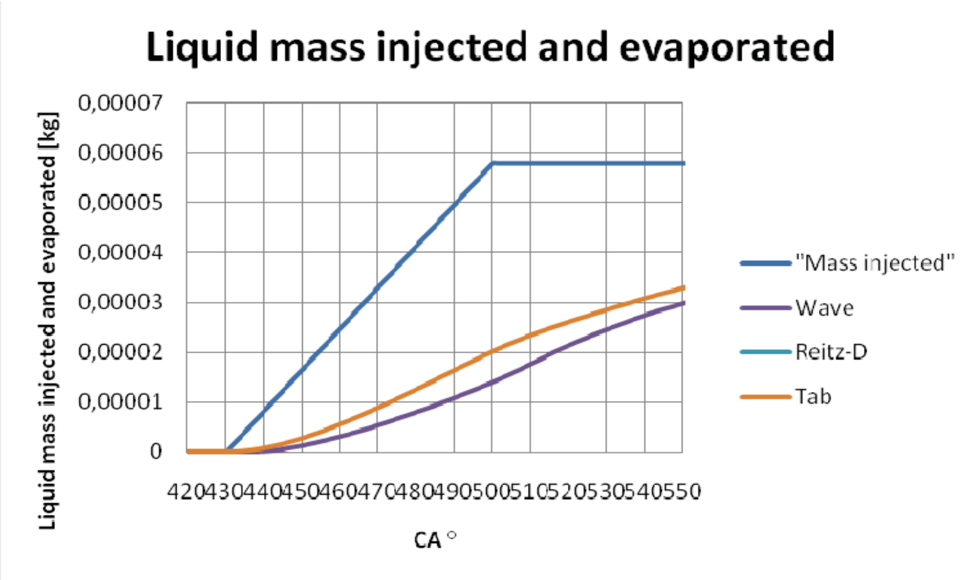


Fig. 10. Simulated fuel mass injected and evaporated

4. Conclusion

Further engine development will base on spray guided combustion strategy, where the spray characteristics are a key point. Proper models for GDI injection simulations need a validation during experiments for all type o fuels and blends. Moreover currently available breakup models had been developed in last decade and there is the need of validation to latest high precision injection systems.

References

[1] Das, S., Chang, S.-I., Kirwan, J., Spray Pattern Recognition for Multi-Hole Gasoline Direct Injectors Using CFD Modeling, SAE Paper 2009-01-1488, 2009.

[2] Drake, M. C., Haworth, D. C., *Advanced gasoline engine development using optical diagnostics and numerical modeling*, Proceedings of the Combustion Institute 31 99–124, 2007.

[3] Wojdas, O., *Numercial Simulations for Diesel engines*, Ph.D. Thesis Insa Lyon 2009

[4] AVL Fire CFD Solver v8.5.1 – *Spray modeling manual*.