Cavitation in High Pressure Fuel Systems and the Application of Methods for Erosion Prediction: Initial Investigations into the Occurrence of Cavitation in Injectors

CaFE Innovative Training Networks

HORIZON2020 Marie Skłodowska-Curie actions

1 Abstract

Cavitation cannot be avoided in parts of high pressure fuel systems. The occurrence of cavitation does not always lead to issues. Indeed, cavitation is a benefit in certain regions and can inhibit deposit formation, but cavitation does have potential to cause problems. Hence, understanding cavitation characteristics is important. In order to gain experience and insight, high-speed images were taken of a large scale model (LSM) of an injector. Corresponding CFD analyses were carried out at similar running conditions using RANS turbulence modelling. The simulation results were similar to those from the LSM, with cavitation occurring in the same areas.

2 Introduction

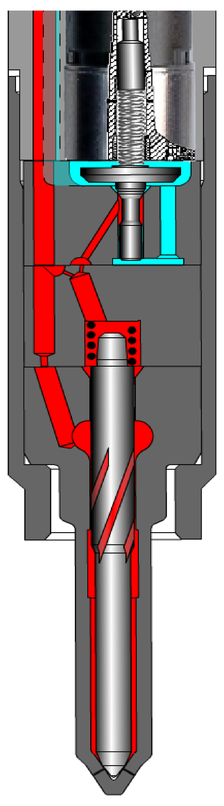

Fig. 1- Typical diesel injector. The red areas indicate HP fuel flow paths.

The fuel flow path out of the nozzle greatly effects diesel combustion. Understanding the upstream flow characteristics enables further optimization of this widely used system. Design optimisation is especially import as current designs are looking to increase injection pressure by 50%.

Potential issues arise at these higher pressures that are not only related to the mechanical stress in the components. With increased pressure comes increased flow velocities and pressure drops, resulting in increased potential for cavitation. Cavitation can lead to erosion if occurring and collapsing in the wrong location. Previous examples of cavitation erosion in high pressure fuel systems are known.[1,2,3]

Experimental results and CFD simulations are utilized to develop and design higher pressure fuel systems. LSMs, where both the Reynolds Number and Cavitation Number (CN) are matched to the actual injection conditions, were used by Bush et al[4], and provided excellent validation for LES CFD results. The initial research presented here, as part of the CaFE project, explores some details of cavitation characteristics. The project will later focus on the context of cavitation and subsequent erosion. The injector used here has no known cavitation erosion issue and provides baseline results, as well as experience.

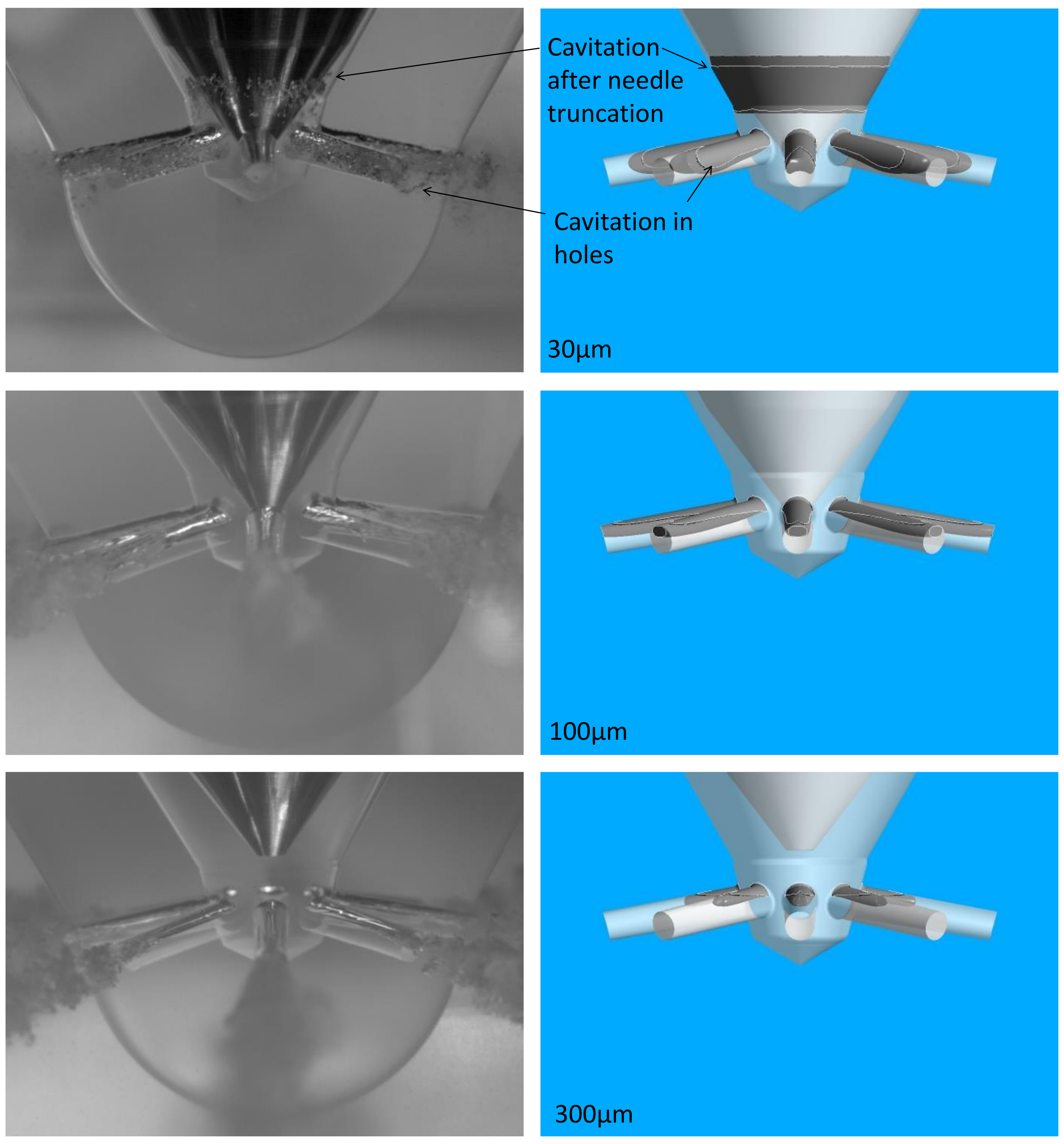

Fig. 2- LSM and equivalent CFD showing cavitation at three fixed valve lifts. 800 bar upstream and 50 bar downstream (equivalent). The CFD shows isosurface of 90% liquid volume fraction.

3 Methods and Materials

A LSM, representing the eight hole nozzle, as seen in Fig. 2, was machined to 20-times real-size. As this was baseline research and experience based work, only simple scaling calculations were carried out. This means that the up and downstream pressure were altered by a factor of 20^2 to achieve running conditions equivalent to the real-size. The LSM fluid, with comparable properties to diesel, was heated to a steady 35°C for consistent results in between runs.

The CFD simulations were run using the software ANSYS Fluent using incompressible RANS models. These simulations implemented Fluent's mixture model to simulate cavitation and k-epsilon with enhanced-wall treatment to simulate the turbulence and near wall physics, respectively.

For both the computer simulations and the LSM runs, the needle lift was set to 30, 100 and 300µm with upstream pressures at 800bar and downstream pressures at 50 bar, or equivalent. The values used resulted in a CN of 14.7.

4 Results and Discussion

Nozzle Holes

Results from the LSM experiment and the equivalent_CFD are seen in Fig. 2. The LSM images, shot at 15,000 fps, show that cavitation occurs in the holes for all three valve lifts and extends to the hole exit. The level of cavitation is greatly related to the hole taper and entry rounding. These holes were made with some degree of taper and rounding, without which the cavitation would be significantly increased.

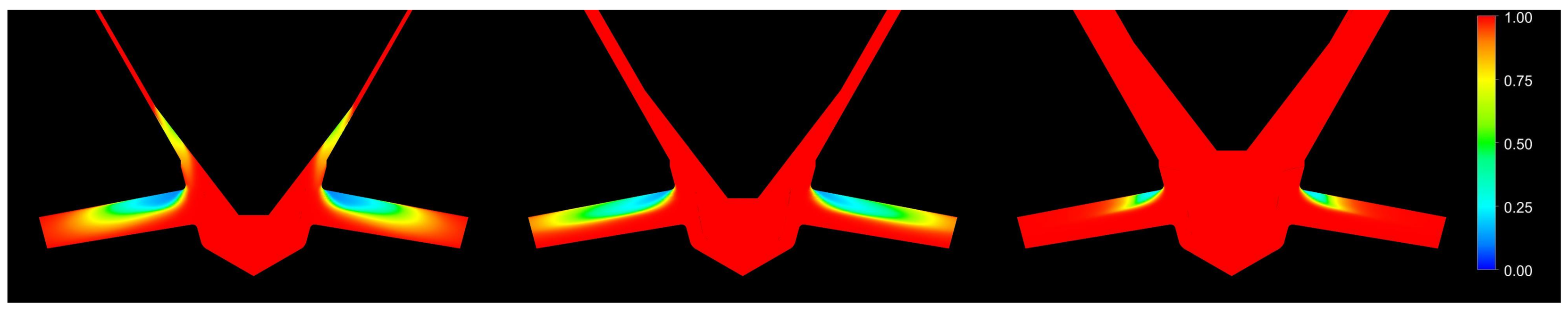

Fig. 3- Mid-plane view of the CFD at three fixed lifts. The scale shows liquid phase volume fraction. 800 bar upstream and 50 bar downstream.

The details of the cavitation in the LSMs differs between the three cases, which may be due to the level of turbulence upstream of the hole entrance.[5] The CFD results also show cavitation in the nozzle holes for all three lift cases. At high lift though, the cavitation collapses before the end of the hole and in a fairly rapid manner. This is further demonstrated in Fig. 3, where the cavitation is produced, but the vapour phase transport is underestimated when compared to the LSM, specifically at the 300µm lift. However, early and abrupt cavitation collapse is not uncommon with RANS models.[4,6]

Nozzle Needle

The 30µm (0.6mm for the LSM) lift cases show cavitation also occurs around the needle tip and extends to the hole entries. At this low lift, the minimum area for the flow through the nozzle tip occurs at the needle truncation diameter (Fig. 2). Almost all of the injection pressure is dropped by this point. The combination of high velocity and low pressure results in the formation of cavitation downstream of the needle truncation. The CFD results (Fig. 2 and 3) show similar characteristics, although estimates the cavitation initiating earlier on the flow.

5 Conclusions

The LSM results enables useful visualisation of the cavitating regions in the nozzle tip and provide the observer with an appreciation of the nature of the phenomenon. The CFD results show similar cavitation characteristics, within the known limitations of RANS modelling. Gaining an insight into these characteristics and establishing where the cavitation originates, and is likely to flow, is an important part in understanding the cavitation erosion potential.

Contact

Maxwell Brunhart
Delphi Diesel Systems
Maxwell.brunhart@delphi.com
http://cafe-project.eu/
(+44) 1634 585111

References

1.Gavaises, M. et al. *Link between cavitation development and erosion damage in diesel injector nozzles*. SAE 2007-01-0246.
2.Beban, B. et al. *On instationary mechanisms in cavitating micro throttles*. CAV symposium, Lausanne. 2015.
3.Koukouvins, F. et al. *Large eddy simulation of diesel injector opening with a two phase cavitation model*. CAV symposium, Lausanne. 2007.
4. Bush, D. et al. *Investigating hydraulic control components in high performance injectors*. IMechE Fuel Injection Conference, London. 2015
5. Soteriou, C. et al. *Further Studies of Cavitation and Atomization in Diesel Injection. SAE 1999-01-1486*
6. Giannadakis, F. et al. *Evaluation of the Predictive Capability of Diesel Nozzle Cavitation Models* . SAE 2007-01-0245

Innovation for the Real World