# Marine engine fuel injection

## Objectives

This project aims to correlate the fuel flow inside a marine injector with spray formation dynamics, droplet mixing, vaporization and combustion.

## Background

Much of the ongoing marine engine development is focused on meeting the requirements of the IMO Tier III legislation which will first go into effect in 2016. Tier III dictates an 80% reduction in NOx engine out levels. Engine manufacturers are investigating engine internal NOx reduction methods such as Miller/Atkinson timing, water in a fuel emulsion, and EGR. The development of these methods requires that engine manufacturers have a good understanding of all the internal engine processes, including fuel injection. The challenge to computational fluid dynamics (CFD) modelling of such engines is to achieve better predictability. A weak link in that problem has been detailed understanding of the flows in the interior of the nozzle and their effect on fuel spray formation (primary breakup). Primary breakup is the least understood part of the spray combustion process [1], and that is the topic of this project.

It is becoming clear that cavitation plays a large role in the development of such a spray. It can occur as “geometric cavitation” (located at the corner and wall of the nozzle hole and caused by the sudden reduction of static pressure as the flow enters the passages) or as “string cavitation” (sometimes called “vortex cavitation”, appearing transiently within the core of strong vortices that can build up in these geometries (see e.g. Andriotis et al. [2]). It appears that both types of cavitation can occur in the kind of injector under study. It is not clear how switching from one type of internal flow to another will affect spray formation and thus spray breakup, mixing and combustion in a real marine engine during one cycle.

Winterthur Gas&Diesel Ltd. (Win G&D) is a Swiss company that provides advanced 2-stroke marine engine designs that are then constructed by various contractors and installed in ships at various locations in Asia. Their main products are the designs that are driven by intellectual capacity within the company; much of it driven by CFD. One of the greatest impediments to next generation designs is the ability to predict coupled spray formation, mixing, and combustion. The goals of this project are therefore to deliver the experimental observations required to develop new models and then to validate them.

The student will investigate interior flows for a selection of optically transmissive nozzles developed in collaboration with Win G&D. The interior flows will be correlated with spray formation in the spray near field using methods discussed just below. After several years at Chalmers, the student will then study the far field and combustion in the spray chamber at Win G&D using metal versions of the same injector tips.

## Methods

The Chalmers team has recently developed optically transmissive injector tips that can withstand higher fuel pressures than former designs (see Falgout and Linne [3]). The tips are modified to match Win G&D geometries and used for the in-nozzle flow investigations. The spray formation in the near field can be observed using ballistic imaging, a technique developed by the Chalmers team.

Unfortunately, rebounding fuel jets inside the chamber produced streams of large drops that filled the space between the jet and the window. Ballistic imaging can minimize image corruption by small drops that scatter light off axis. Large drops in the geometric regime refract light without scattering, and so when present in high number density and when out of focus, they simply attenuate light. Moreover, the same jets then coated windows and caused further attenuation. In this work, we will develop a room temperature, pressurized chamber designed specifically for marine injectors. It will minimize the fuel jet rebound problem and improve the quality of the images. Room temperature will be used here so that transparent tips can be used in coordination with ballistic imaging. In the near field, the density ratio and cavitation number matter much more than temperature, and it will be possible to match important density ratios and cavitation numbers at room temperature.

The far field of the spray under combusting and non-combusting conditions will be investigated using the high pressure and temperature spray chamber in Winterthur [4]. This chamber has the same inner bore as a small Win G&D marine two-stroke engine. The swirl number of the engine is also emulated by the jet of hot gas that enters the chamber from the heater section. In this device, the gas pressure can peak at 200 bar with peak temperatures around 900 °C. This device has windows that can be placed at various locations allowing investigators to view different regions of the spray. High-speed planar laser diagnostics are available for Mie scattering from drops, Rayleigh scattering from molecules, and selected laser induced fluorescence. Injector concepts that have been investigated in optical layouts at Chalmers will subsequently be investigated as metal injectors at Win G&D for a full accounting of spray performance from inside the injector all the way out to a burning tip.

## Results

The latest measurement series acquired used the previously developed transparent nozzle holder (based on [3]) that allows using real-sized, single-orifice injector nozzle designs matching WinGD's nozzles. Three different nozzle geometries were investigated: a centrically arranged 90° orifice, a centrically arranged 75° orifice and an eccentrically arranged 90° orifice. All the orifice diameters used were 0.75 mm and the rail pressure applied was 50 MPa. The in-nozzle flow and the spray formation were simultaneously acquisitioned using two high-speed cameras. In addition, the nozzles were hydro-erosive ground using the previously developed hydro-erosive grinding rig. The flow grinding using a highly viscose, non-Newtonian fluid that contains small abrasive particles allows the introduction of inlet radii between the nozzle main bore and the orifice. Different levels of hydro-erosive ground nozzles were investigated.

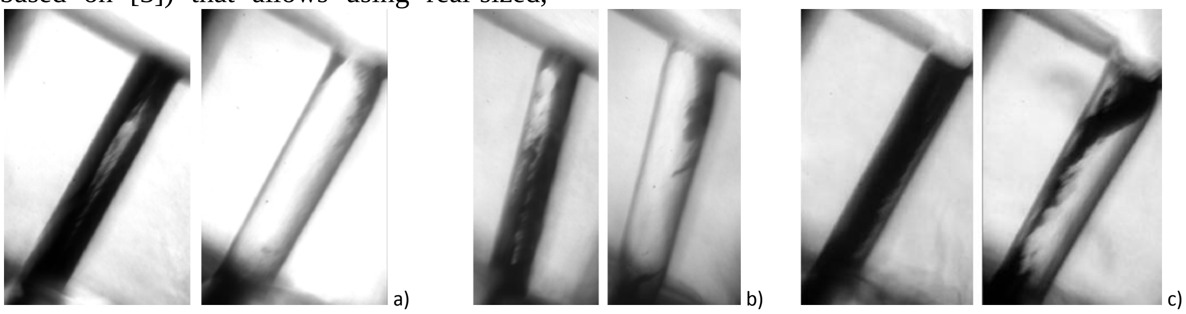


*Figure 1: In-nozzle flow visualization for three different nozzle designs: centrically arranged 90° orifice (a), centrically arranged 75° orifice (b) and eccentrically arranged 90° orifice (c). The left image shows the sharp edge and the right image shows the hydro-erosive ground configuration. Dark areas indicate cavitation.*

Figure 1 depicts the in-nozzle flow visualizations of the three nozzle variations with different levels of hydro-erosive grinding. The selected field of view is set on the orifice while on top of the images, the nozzle main bore is slightly visible. The fuel flows through the main bore from the top left corner and then enters the orifice and leaves the nozzle at the bottom. Dark areas indicate cavitation while bright areas show non-cavitating flow. The wall of the main bore is slightly visible as the refractive index of the Diesel fuel used and the optically transparent material of the nozzles (PMMA) are not perfectly identical.

The in-nozzle flow visualizations in Figure 1 clearly show how the hydro-erosive grinding affects the level of cavitation and how the different nozzle designs alter the cavitation patterns. The simultaneously acquired spray visualizations matching the in-nozzle data from Figure 1 are depicted in Figure 2. The spray formations were acquired using a line-of-sight optical measurement technique. Note that the bottom of the sprays are cut-off due to optical limitations of the spray chamber.

The spray axes are corrected with regard to the orifice orientation. While the spray morphology differences for the centrically arranged 90° orifice with and without hydro-grinding (see Figure 2 a)) seem minimal, they are significant for the other two nozzle designs (see Figure 2 b) & c)). The centrically arranged 75° orifice (see Figure 2 b)) changes the spray axis and angle significantly and the spray formation of the eccentrically arranged 90° orifice (see Figure 2 c)) is massively wider with hydro-erosive grinding compared to all other nozzle configurations.

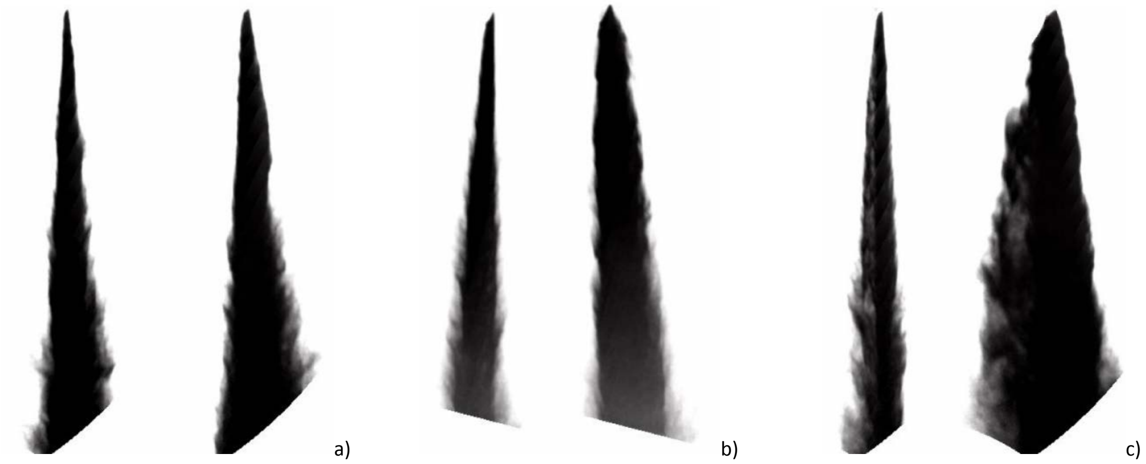


*Figure 2: Spray visualization matching the in-nozzle flow depicted in Figure 1: centrically arranged 90° orifice (a), centrically arranged 75° orifice (b) and eccentrically arranged 90° orifice (c). The left image shows the spray formation from the sharp edge nozzle and the right image from the hydro-erosive ground nozzle configuration. The lower part of the sprays is cut-off due to the optical limitations of the spray chamber.*

Although the spray formations were acquired under ambient temperature and back-pressure conditions, the significant impact of the nozzle configuration on the spray, especially the influence of the hydro-erosive grinding process of the nozzle are clearly visible.

## Conclusions and ongoing work

The in-nozzle flow of large marine two-stroke Diesel engine injector nozzle geometries has successfully been visualized using the newly developed transparent nozzle holder together with the developed hydro-erosive grinding rig. The nozzle geometry variations show significant influence on the spray formation and the current data is in evaluation and will shortly be disseminated.

Based on the acquired measurements, selected nozzle designs were manufactured from metal to continue with combustion experiments on the combustion and spray chamber at WinGD. The metal nozzles will match the transparent nozzles geometries to continue evaluating the influence of the in-nozzle flow on the spray formation and combustion of Diesel fuel under realistic conditions.

The data gathered in this project will be disseminated and used for validation of CFD cavitation models.

## References

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