CFD modelling of direct gas injection using a Lagrangian Particle Tracking approach

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The MAN Diesel & Turbo two-stroke GI engines can be operated on natural gas, which is injected directly into the cylinder at high pressure. An engine that can be run with multiple fuels is commonly known as a dual-fuel engine. The emission of SOx, NOx and CO2 are greatly reduced in the exhaust when the engine is operating on natural gas. The operating range is roughly between 0% to 97% natural gas which makes it possible to optimize the ratio depending on fuel prices and availability, and fulfil regulations in Emission Control Areas (ECA).

The gas injection could be simulated with standard CFD (Computational Fluid Dynamics) methods; however, this requires the area close to the nozzle to be fully resolved to capture all phenomena. This means that a high number of computational cells are necessary for the simulations which can be expensive both regarding time and computational power. An alternative method was desired to model the gas injection.

The aim of this thesis was to develop and implement a model for direct gas injection using a Lagrangian Particle Tracking (LPT) approach in the open source CFD package OpenFOAM, and evaluate it to fully resolved RANS (Reynolds Averaged Navier-Stokes) simulations. The LPT method is simply that particles are introduced to the domain and then interacts with the surrounding gas. The particles are solved within a Lagrangian coordinate system and the gas phase within an Eulerian. To get a better understanding of the coordinate systems an analogy could be used, where the Eulerian system is fixed in space, like a system of weather stations that record data, whereas the Lagrangian system is not fixed in space, similar to weather balloons that follows the wind and record data [1].

The LPT method is generally intended for liquid fuel sprays and solvers using this method are already present in OpenFOAM. With some care regarding the fuel properties and interaction between the particles and gas phase, this model could be used to model gas injection [2].

The first part of this thesis was to create a model to make the liquid fuel behave as a gas. In OpenFOAM, the liquid fuel is described by a number of constant properties which mostly consist of properties to describe the fuel specific phase diagram, shown schematically in Figure 1.

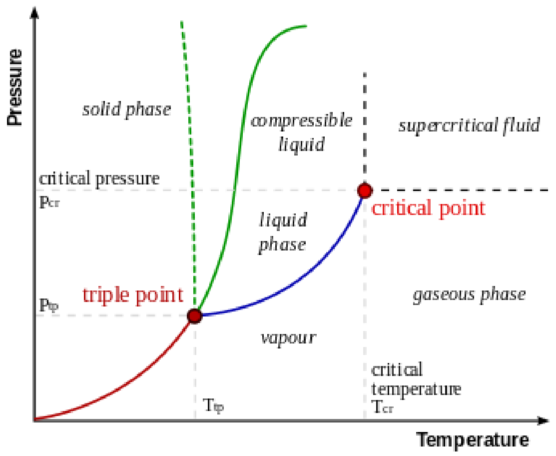

Figure 1 - Schematic phase diagram [3]

Additionally the liquid fuel is described by a number of pressure- and temperature dependent properties, e.g. density and viscosity. These properties are calculated with so-called thermophysical functions.

The constant fuel properties and the thermophysical functions were modified in order to make the fuel behave as a gas. Additionaly, the evaporation characteristics had to be modified. According to Hessel et al. [2], evaporation should occur after a certain distance from the nozzle to properly represent a physical jet.

The gaseous LPT model was then implemented in OpenFOAM 2.0.x and a few cases were set up in order to evaluate the method. Four cases with varying inlet velocities and chamber pressures were set up and simulated with both the gaseous LPT method and the fully resolved RANS method.

The method was evaluated by comparing vapour penetration length and radial spreading with the fully resolved method. Figure 2 shows the fuel mass fraction after the full injection duration for both methods where the white line represent a fuel mass fraction of 3%.

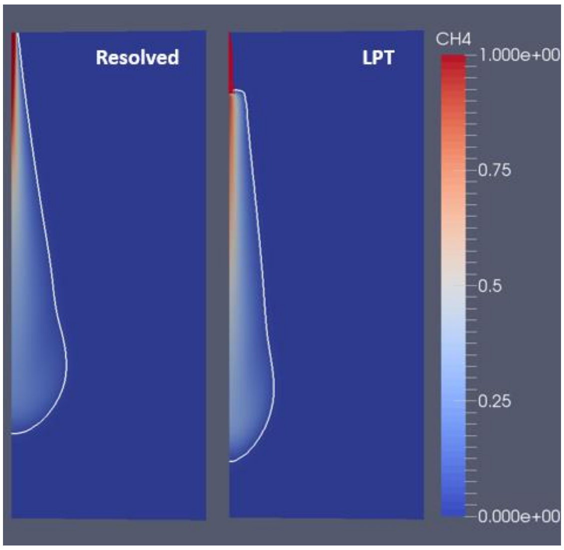

Figure 2 – Fuel mass fraction after the injection duration

The simulations showed that the gaseous LPT method generates a slightly longer vapour penetration and a lower radial spreading compared to the resolved method. However, all trends observed in the resolved simulations were also observed with the gaseous LPT method.

Despite the observations made, it was concluded that an LPT approach can be used in OpenFOAM to model direct gas injection with reasonable results.

References

[1] Lagrangian and Eulerian coordinate systems, https://dafeda.files.wordpress.com/2012/02/lagrangian_eulerian1.pdf. Accessed: 2015-05-22.

[2] Randy P. Hessel, Neerav Abani, Salvador M. Aceves and Daniel L. Flowers. Gaseous Fuel Injection Modeling Using a Gaseous Sphere Injection Methodology. *SAE Technical Paper 2006-01-3265*, 2006.

[3] Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Phase-diag2.svg. Accessed: 2015-05-07.