VSB2 model for diesel spray simulation and comparison of k-ε with Realizable k-ε turbulence model

Vignesh Pandian  (Chalmers University of Technology)
Anders Karlsson  (Volvo Group Trucks Technology)

November, 26, 2015 - Second Two-day Meeting on Internal Combustion Engine Simulations Using OpenFOAM® Technology - Politecnico di Milano
Overview

• Goal of the project
• Introduction to VSB2 model
• Previous work
• A short introduction to the goals of the current project
• Comparison of turbulence models
• Conclusion and Future work
Goal of the project

• Implementation of multicomponent / blended fuels in VSB2 spray model
  High demand in the automotive industry

• Supercritical effects of evaporation
  Recent works have suggested that no sprays exist at elevated pressure and temperatures

• LES of sprays
  For deeper insight into spray formation
Introduction to VSB2 Stochastic Blob and Bubble spray model

**parcel**
- collection of equal droplets

**blob**
- droplet size distribution
  - (based on local instantaneous We and Oh),
  - using break-up rate correlations by Pilch & Erdman*

```
Droplet size distribution
```

[Graph showing normalized blob mass distribution with different break-up scenarios]
Introduction to VSB2 Stochastic Blob and Bubble spray model

An attempt to reduce grid-size dependency
Maximum possible bubble size is the cell-size

Equilibrium

Unconditional robust - Rigorous thermodynamic equilibrium calculation preformed for each blob-bubble pair

\[ V_{bub} = \frac{\pi}{6} N_D \left[ (D_B + l_t)^3 - D_B^3 \right] \]

\[ l_t = \min \left[ C \frac{k^{3/2}}{\varepsilon}, V_{cell}^{1/3} \right] \]
Mesh Geometry: Same volume as Spray chamber at ECN, Sandia

Injection in the center, directed downward along the axis

3D view
Previous work – Anne Kösters, Anders Karlsson

Fuel: n-hexadecane

\( P_{\text{inj}}: 1370\text{bar, } T_{\text{gas}}: 727\text{deg celsius} \)

\( p_{\text{gas}} = 168 \text{ bar} \)

Experiment Siebers and Naber

Fuel: n-hexadecane

\( P_{\text{inj}}: 1200\text{bar, } T_{\text{gas}}: 500\text{deg celsius} \)

\( p_{\text{gas}} = 70 \text{ bar} \)

\( T = 500^\circ\text{C} \)

Experiment Chalmers HP/HT Rig
• Validation of the VSB2 spray model against spray A and spray H, A.kösters & A.Karlsson, Atomization and Sprays

• Previous implementation in OpenFoam 1.6.x

• Migration from 1.6.x to 3.0.x
Multicomponent fuel modeling

Continuing the work by visiting master student Francesca Pogliani from Politecnico di Milano

In case of a single component this is straightforward to coupling evaporation and heating/cooling of the surrounding gas and can be easily be implemented by an iterative procedure.

In case of multicomponent evaporation, substantial complexity increase due to the fact that each component has its own thermodynamical equilibrium, whereas the bubble temperature will depend on evaporation of all components.

The goal is to implement a direct numerical method for the coupling of evaporation and heating/cooling of multicomponent mixtures.
Super critical conditions of evaporation

• Research questions whether spray really exists at high pressure/high temperature conditions of modern diesel engines

• Alternative is a dense supercritical jet without droplet formation.

• This project investigates for possible supercritical phase transition in diesel sprays.
LES of sprays

• To obtain correct air entrainment in a fuel spray near the nozzle and accurate flame lift-off lengths

• LES is computationally expensive

• The approach of this project is to use LES to simulate the unsteady behavior of sprays and flame fronts.

• Use the results of LES to modify the standard k-epsilon models for industrial applications.
Comparison of $k$-$\varepsilon$ with Realizable $k$-$\varepsilon$ turbulence models for standard spray model

• Outcome of Realizable $k$-$\varepsilon$ is that it can be used for circular jets.

• Difference from standard $k$-$\varepsilon$ is that there is a new formulation for turbulent viscosity and a new equation for epsilon.
Comparison of Liquid penetration : $k-\varepsilon$ and Realisable $k-\varepsilon$

<table>
<thead>
<tr>
<th>Case</th>
<th>Spray H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Cylindrical Mesh</td>
</tr>
</tbody>
</table>

Liquid Penetration vs time

- Experiment
- Simulation-$k-\varepsilon$
- Simulation-Realizable $k-\varepsilon$
Summary

• Introduction to VSB2

• Previous work

• Comparison of turbulence models

Future work

• Implementation of VSB2 in OpenFoam 3.0.x

• Further development of VSB2: Implementation of multicomponent fuel
Research gap

• Standard spray models in openFoam and other commercial softwares require a lot of tuning and in most cases grid size dependent.

• The approach followed in this project ensures the above by employing rigorous thermodynamic calculation for the interaction between the gas and liquid phase.

• This ensures a robust model with minimal tuning parameters and grid size independence.

• Modify standard two equation k-epsilon turbulence models for industrial applications by using the results from LES simulations to capture fine details from unsteady spray simulations.