CFD analysis for petrol overfilling incidents

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Presentation layout

- Introduction
- Experimental overview
- Computational model
- Model tuning
- Validation
- Sensitivity tests
- Further applications
- Conclusions

Introduction

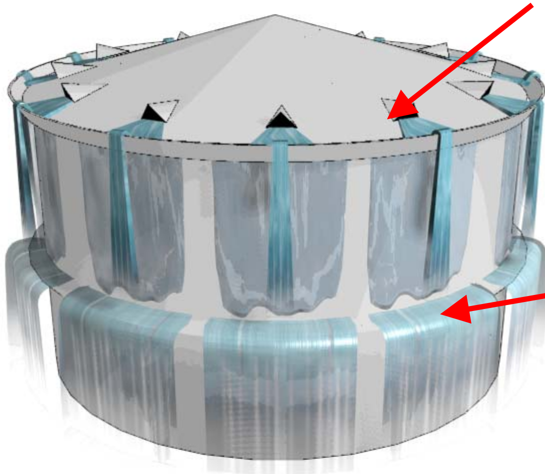
- Modelling the production of flammable vapour from tank overfilling involves a number of interacting processes
- These have been investigated experimentally
- The scope of the experiments is limited (timescales, geometries etc.)
- CFD modelling can be used to extend this scope

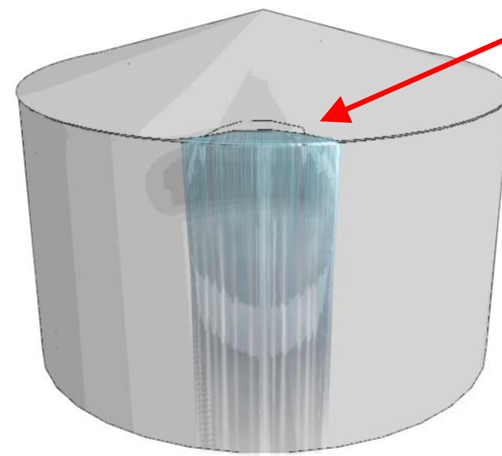
Aims

- To construct a CFD model of a liquid cascade and validate it using experimental data
- To use the validated model to explore other different timescales and geometries
- To inform the Vapour Cloud Assessment method (RR908)

Liquid cascade generation

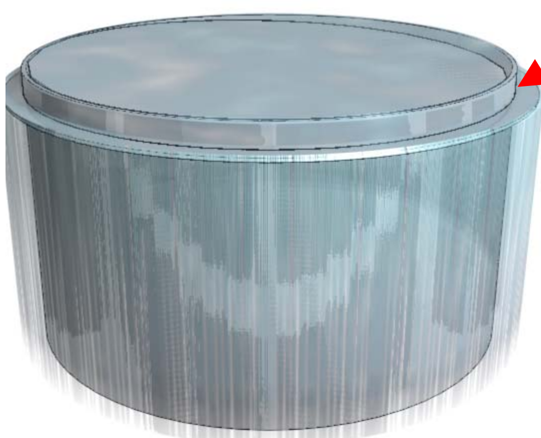
Fixed-Roof Tank with Vents (FRV)





Fixed Roof Tank with Pressure/Vacuum Valves (FRPVV)

Floating Deck Tank without Fixed Roof (FD)



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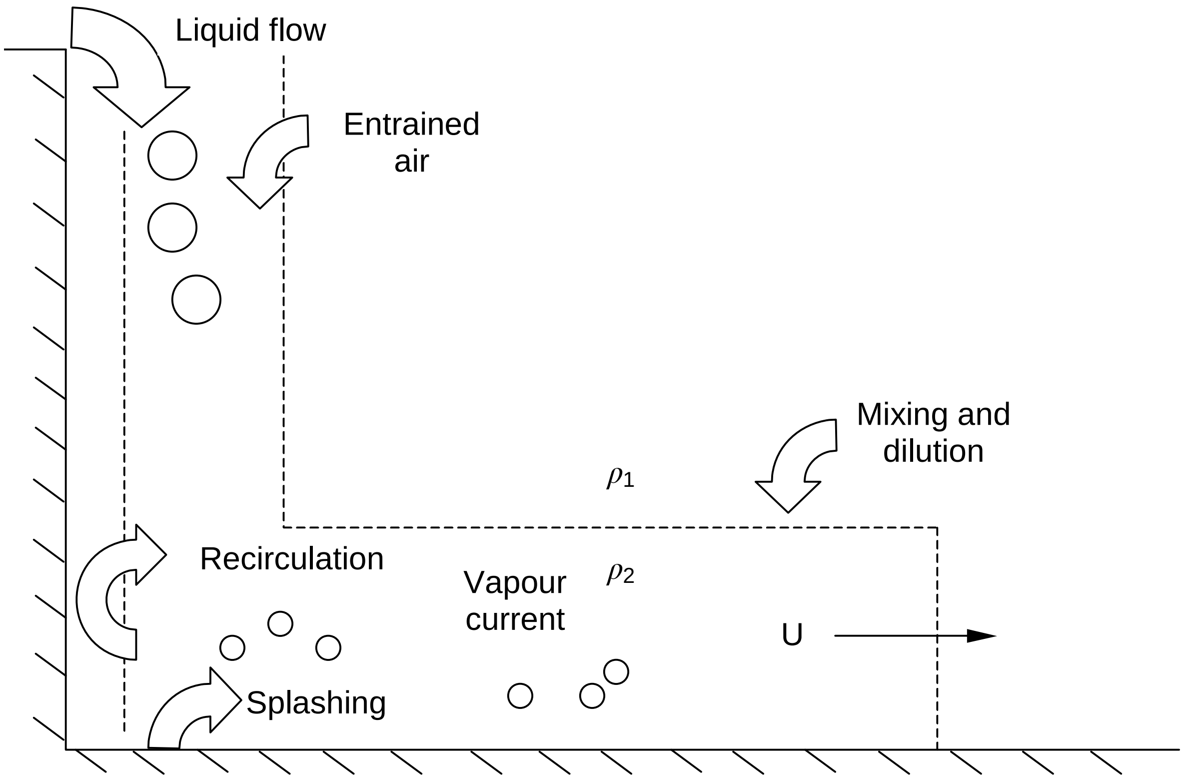
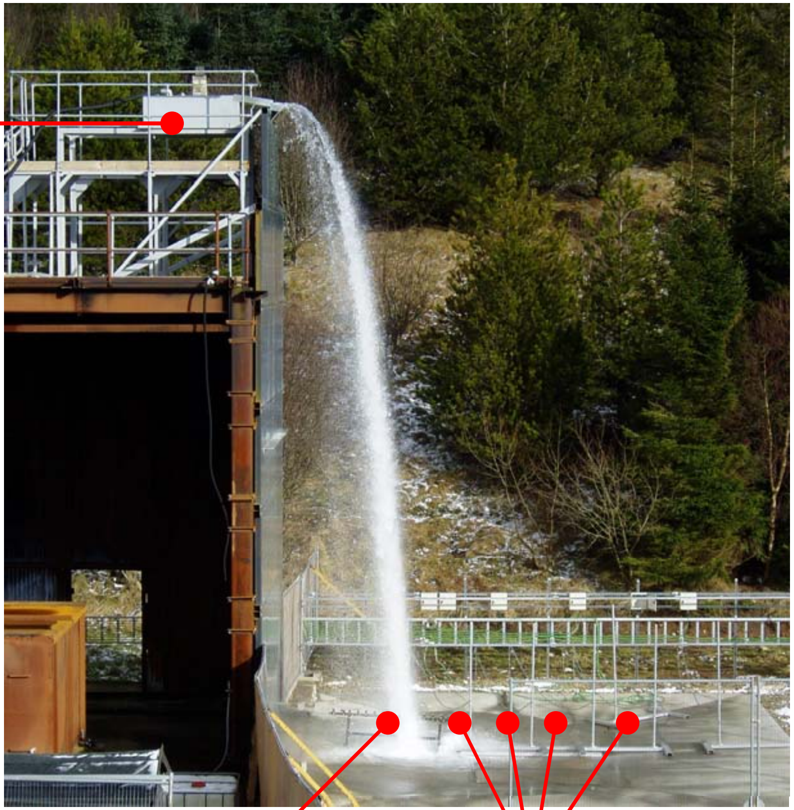
Cascade dynamics



Experimental overview

Liquid storage tank



Cascade thermocouples (liquid and vapour)

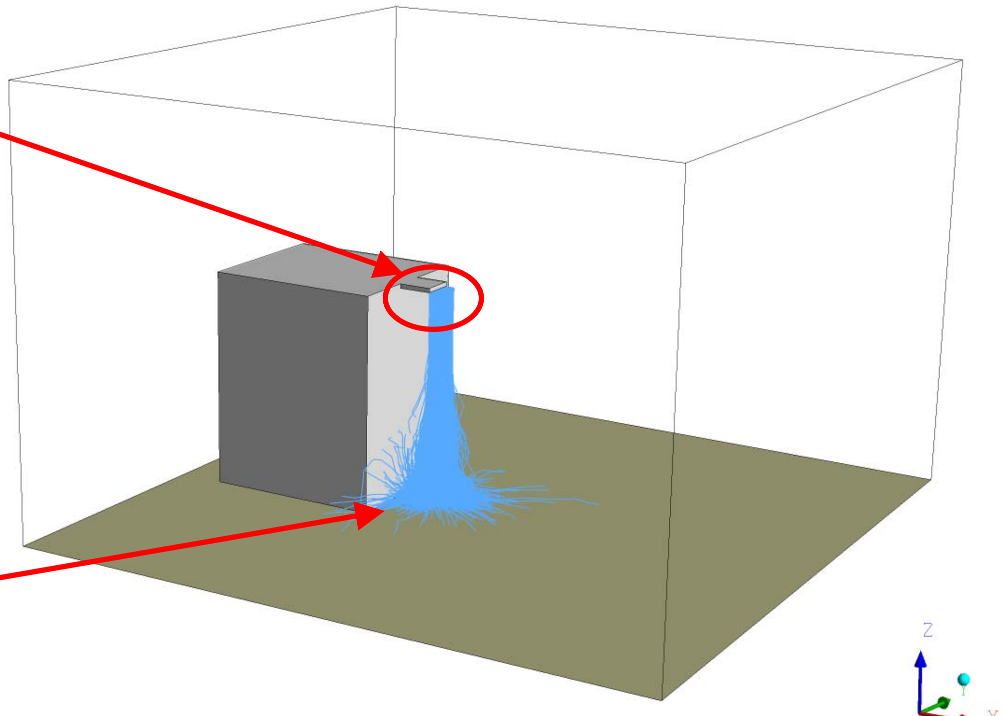
Vapour current thermocouples

CFD Model

- ANSYS CFX 12 software
- Air/vapour flow : Eulerian approach
- Liquid droplets : particle-tracking approach
- Model accounts for:
  - drag force on droplets (entrainment rate predicted)
  - heat and mass transfer (liquid evaporation)
- Model does not account for:
  - Liquid breakup (initial drop size prescribed)
  - Splashing (droplets re-injected from floor)
- Liquid released is hexane

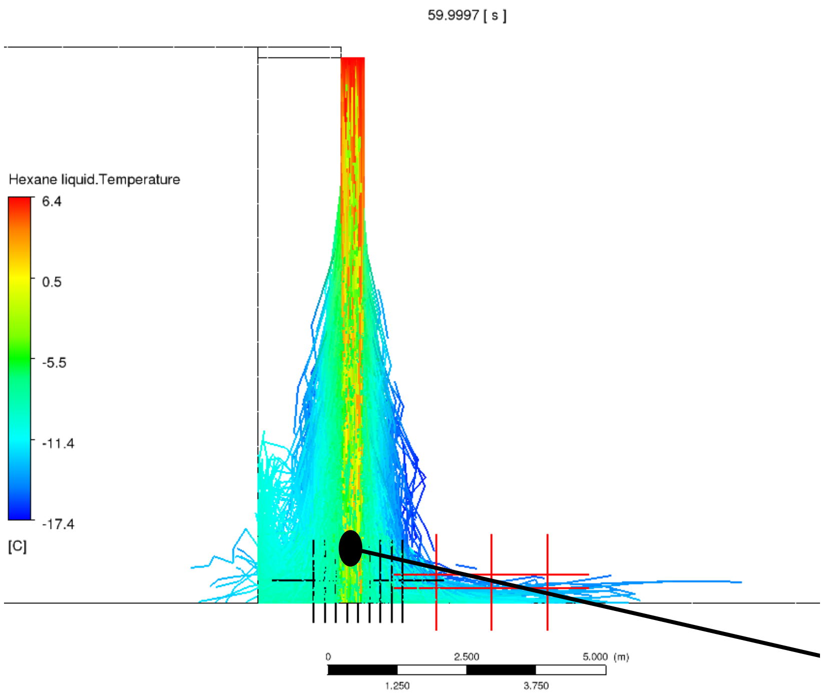
CFD Model

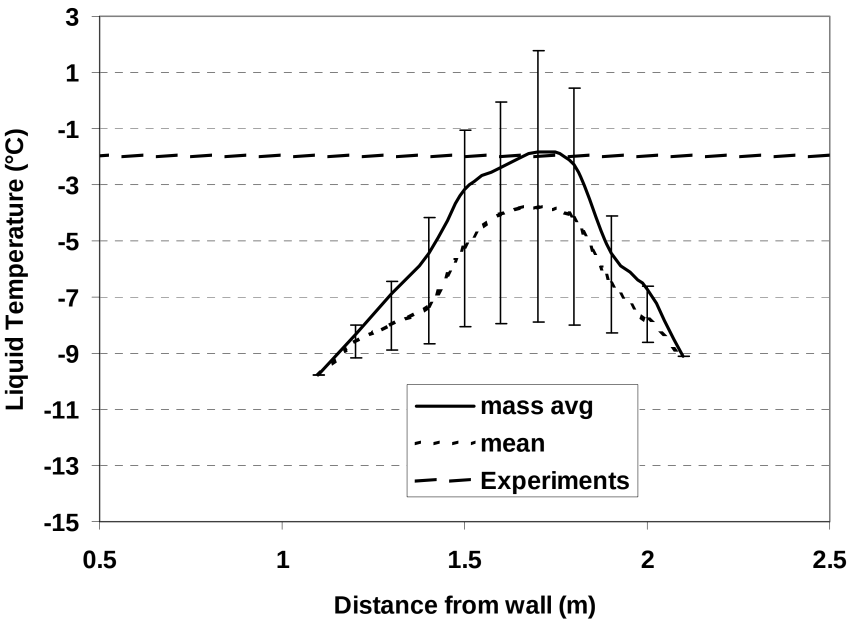
- Hexane droplets released from rectangular area
- Variable width, depth offset, mass flow and particle size
- Splashing particles (if present) injected from ground with prescribed conditions



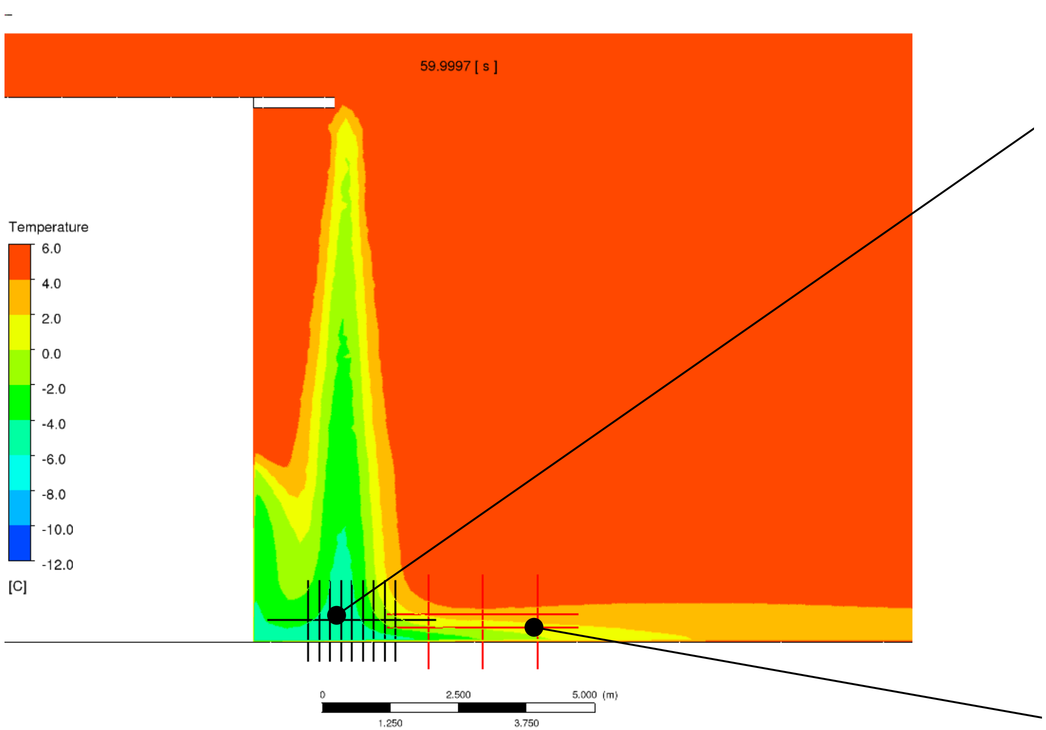
Liquid temperatures

- Droplets "collected" in post-processing
- Some droplets evaporate completely

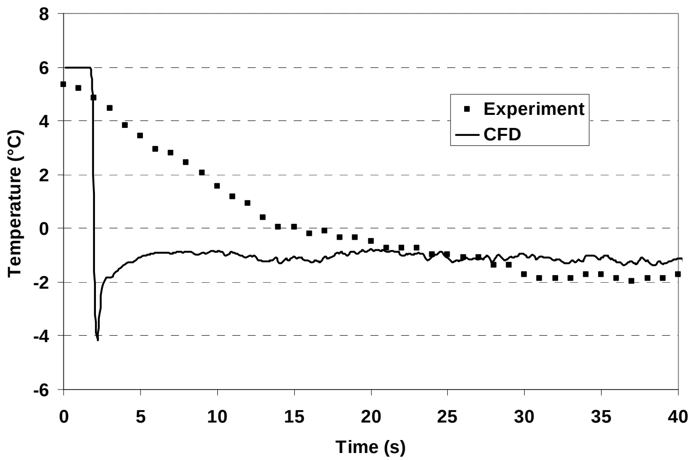




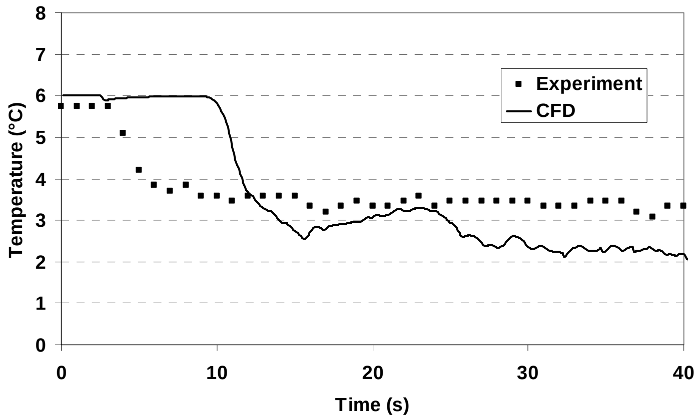
Vapour temperatures



Cascade



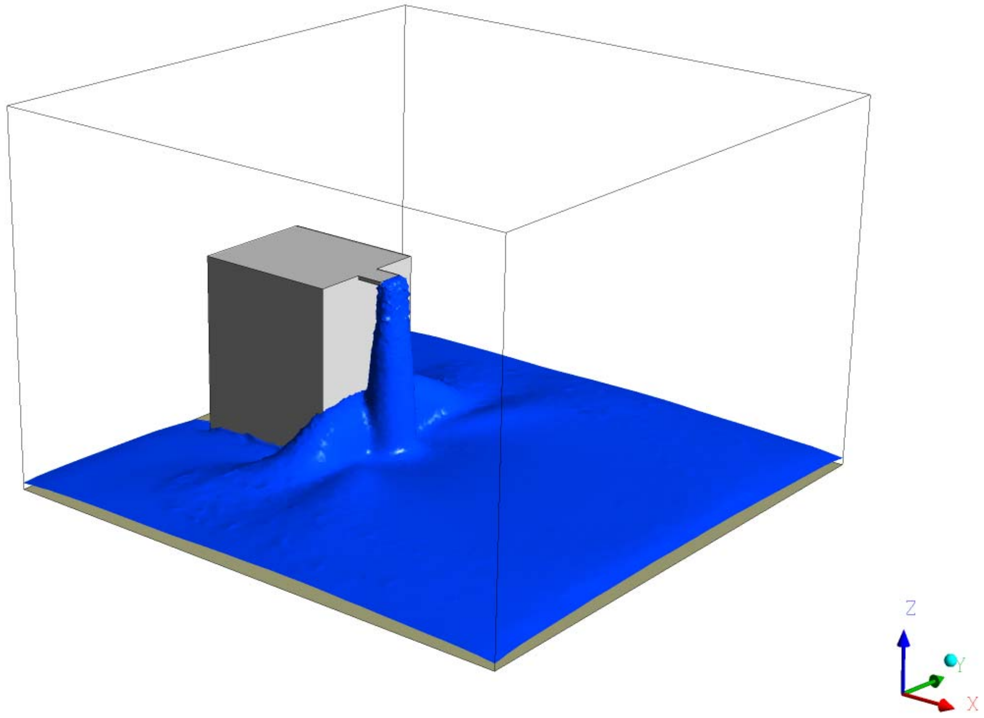
Vapour Current



Vapour volume

Total volume of vapour = Vapour in domain

$$+ \int \text{(rate of out flowing vapour)}.dt$$



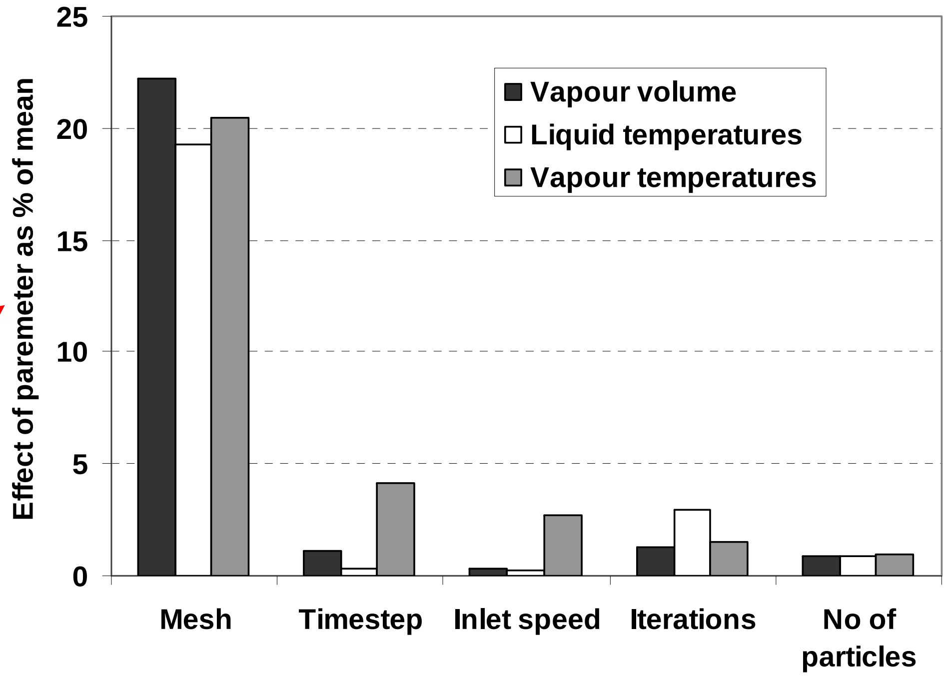
Sensitivity to Model Parameters

- Metrics:
  – Vapour volume
  – Liquid temp.
  – Vapour temp.

  Mean values in cascade

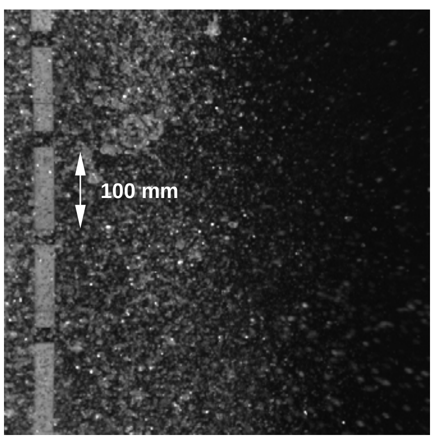
- Design of experiments

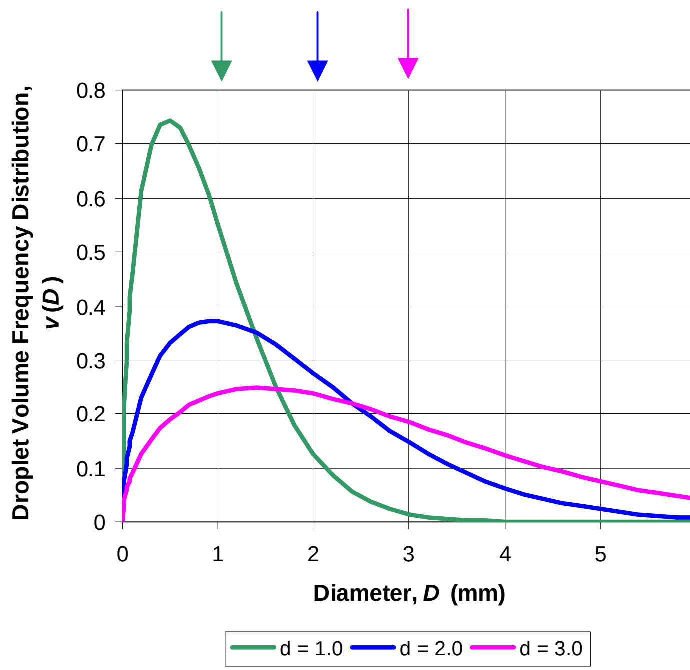
Difference between the high and low values for each input parameter, as a percentage of the mean over all eight simulations



Model Tuning

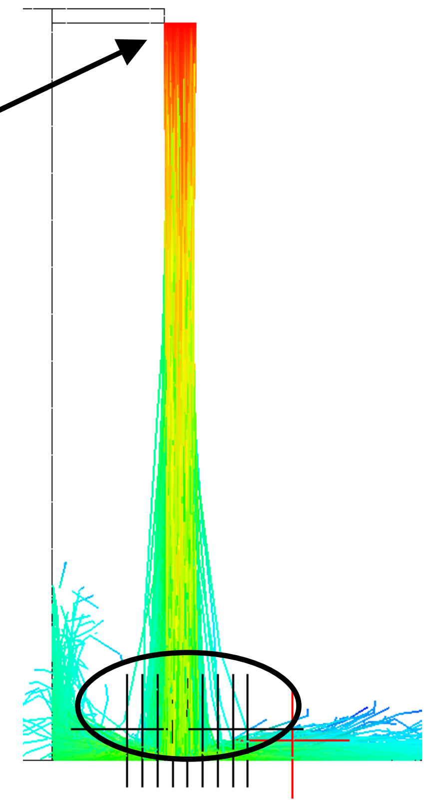
1. **Mean liquid temperatures** in cascade controlled primarily by average droplet size
   – Smaller droplets are more cooled





Rosin-Rammler Distribution

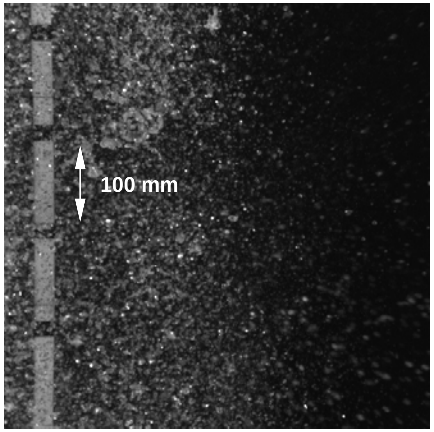
(3 different mean diameters)

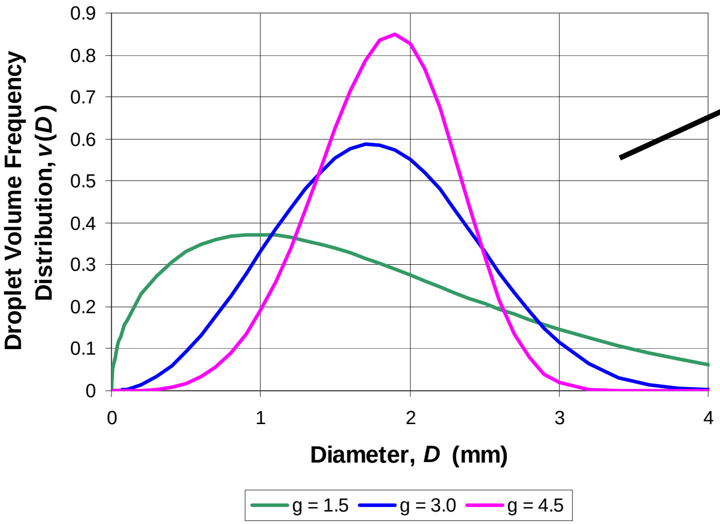


Model Tuning

2. **Vapour temperatures in cascade** can be controlled independently by size spectrum of droplets released

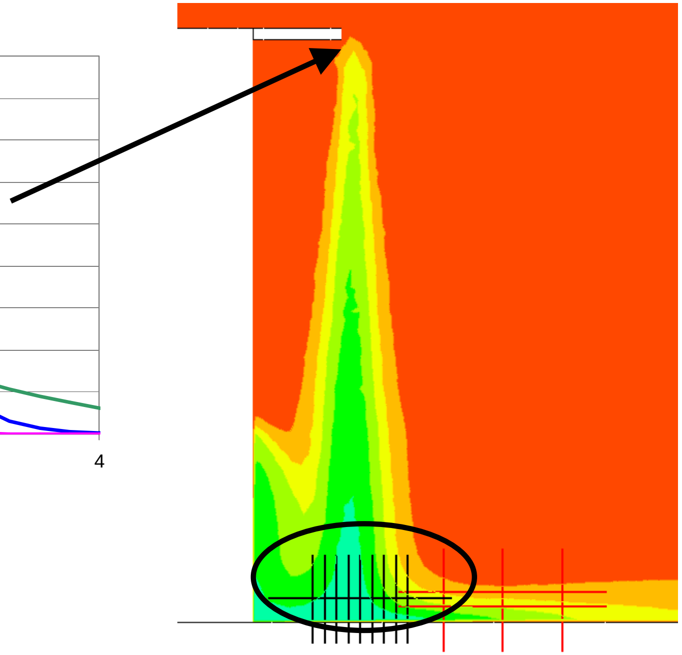
– Higher proportion of small droplets reduces vapour temperatures significantly but has little effect on bulk liquid temperatures





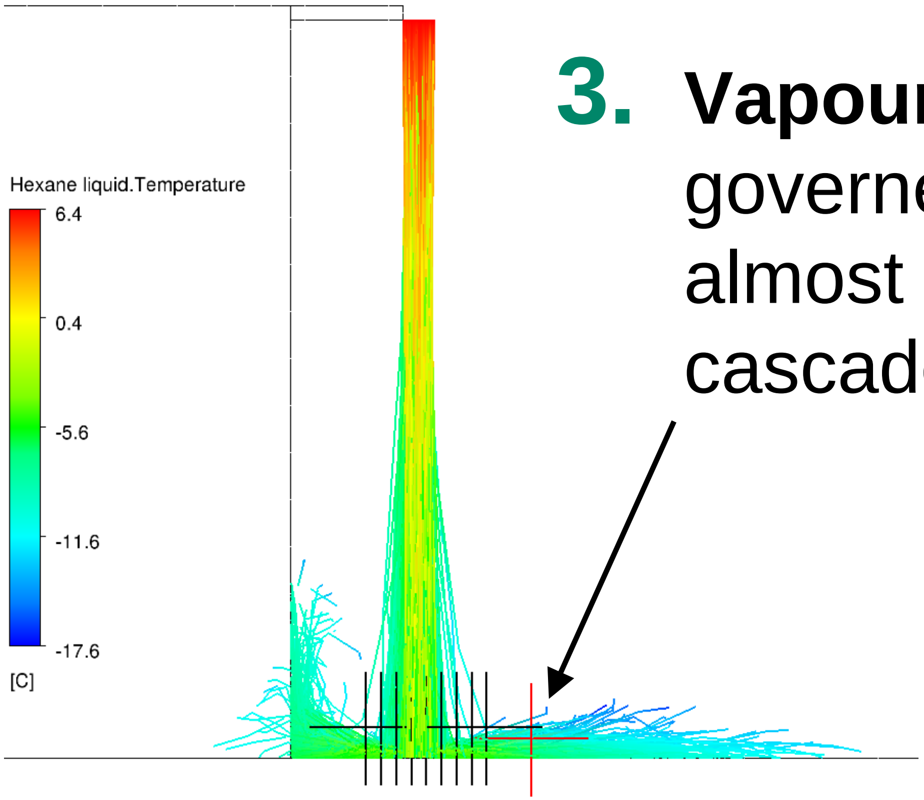
Rosin-Rammler Distribution

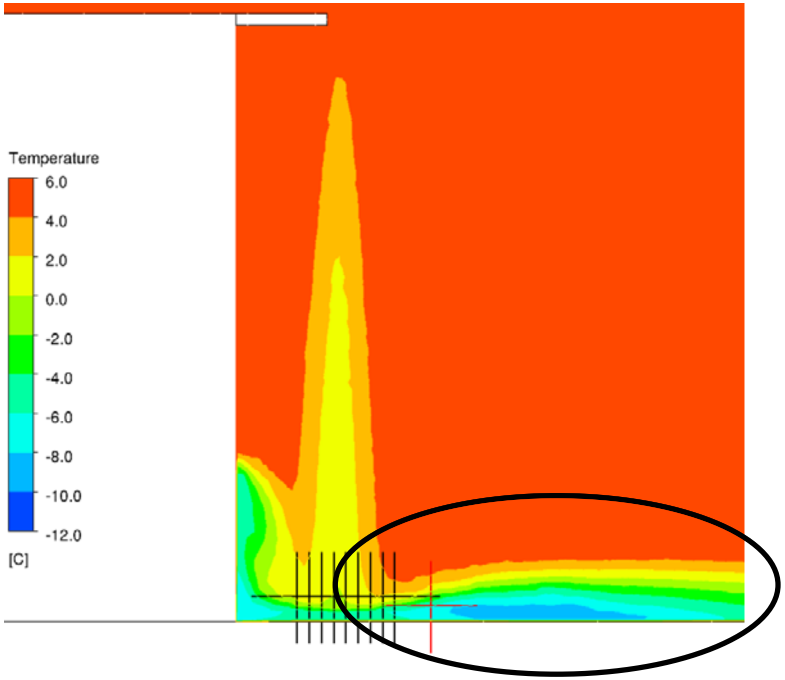
(Mean diameter = 2 mm in all three cases)



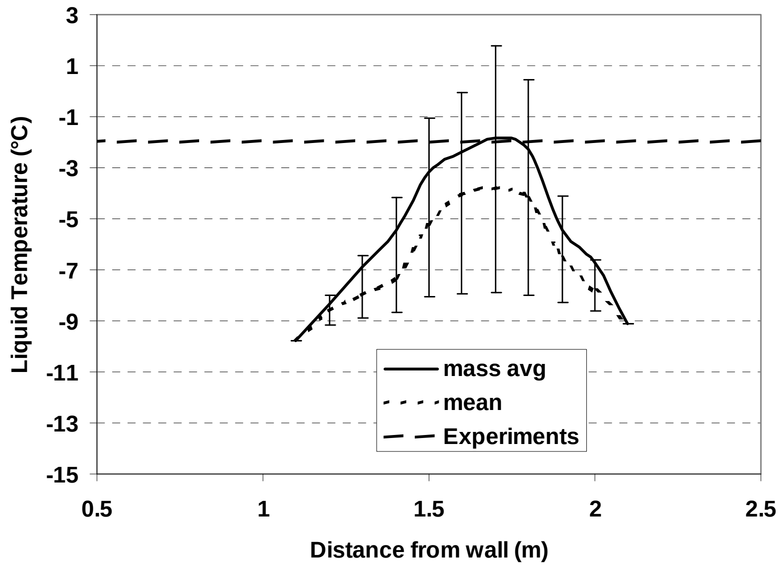
Model Tuning

3. Vapour current temperature governed by splashing droplets almost independently of cascade

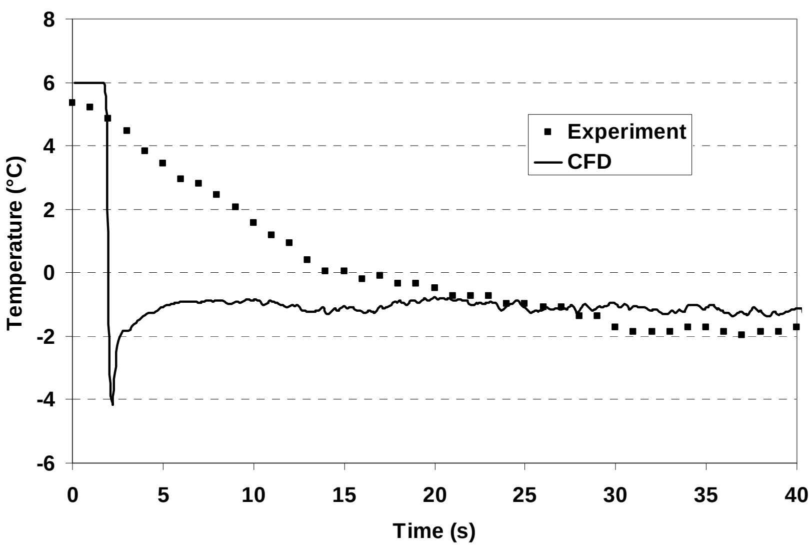




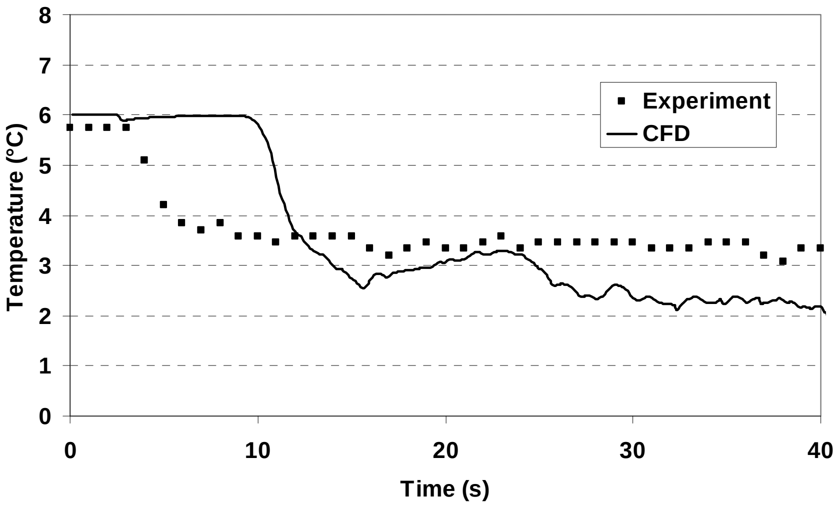
Model Tuning to Test 9



- Adjust droplet size distribution to match liquid and cascade vapour temperatures
- Adjust splashing droplets to match current temperatures

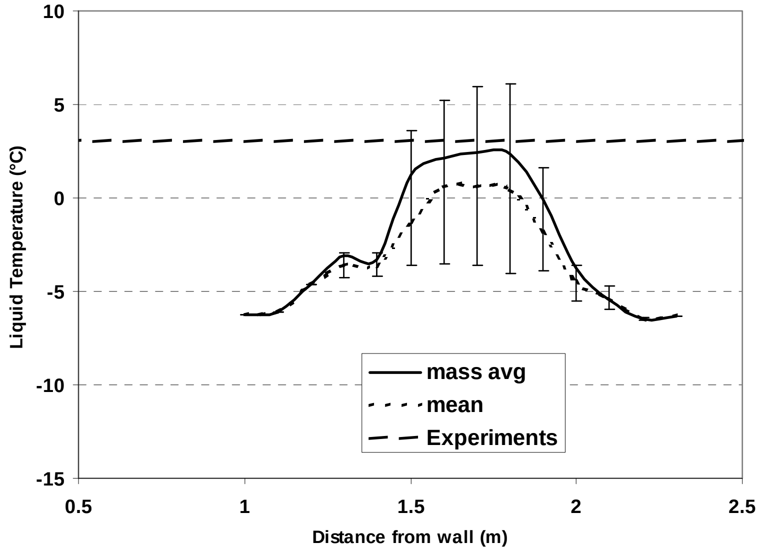


Cascade

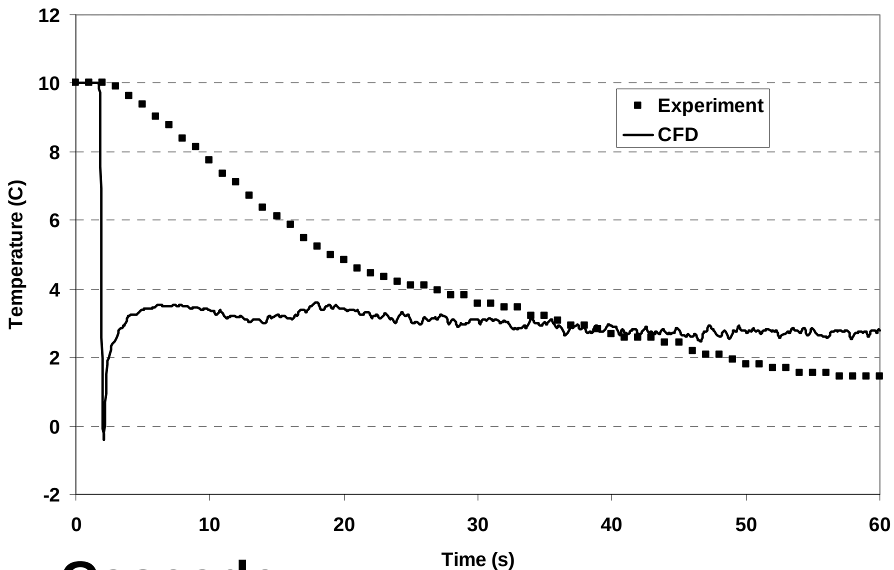


Vapour Current

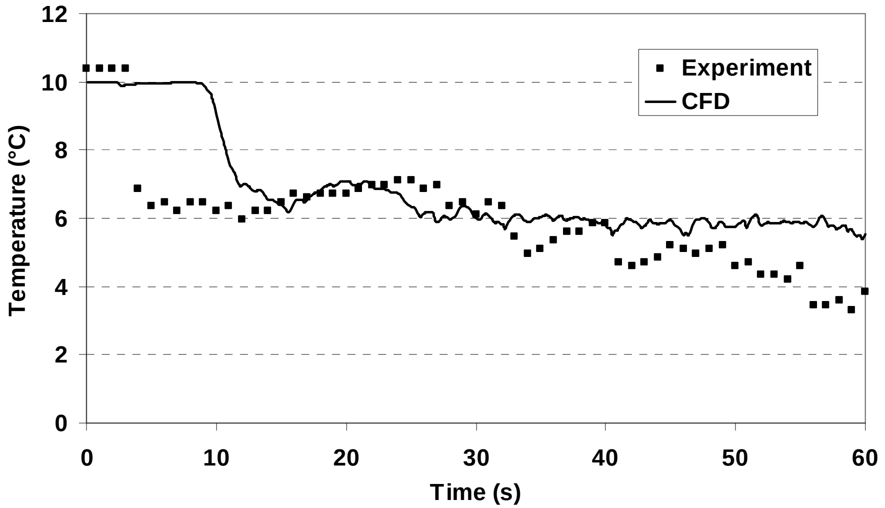
Model Validation with Test 12



- Same settings used as "tuned" model gives good predictions

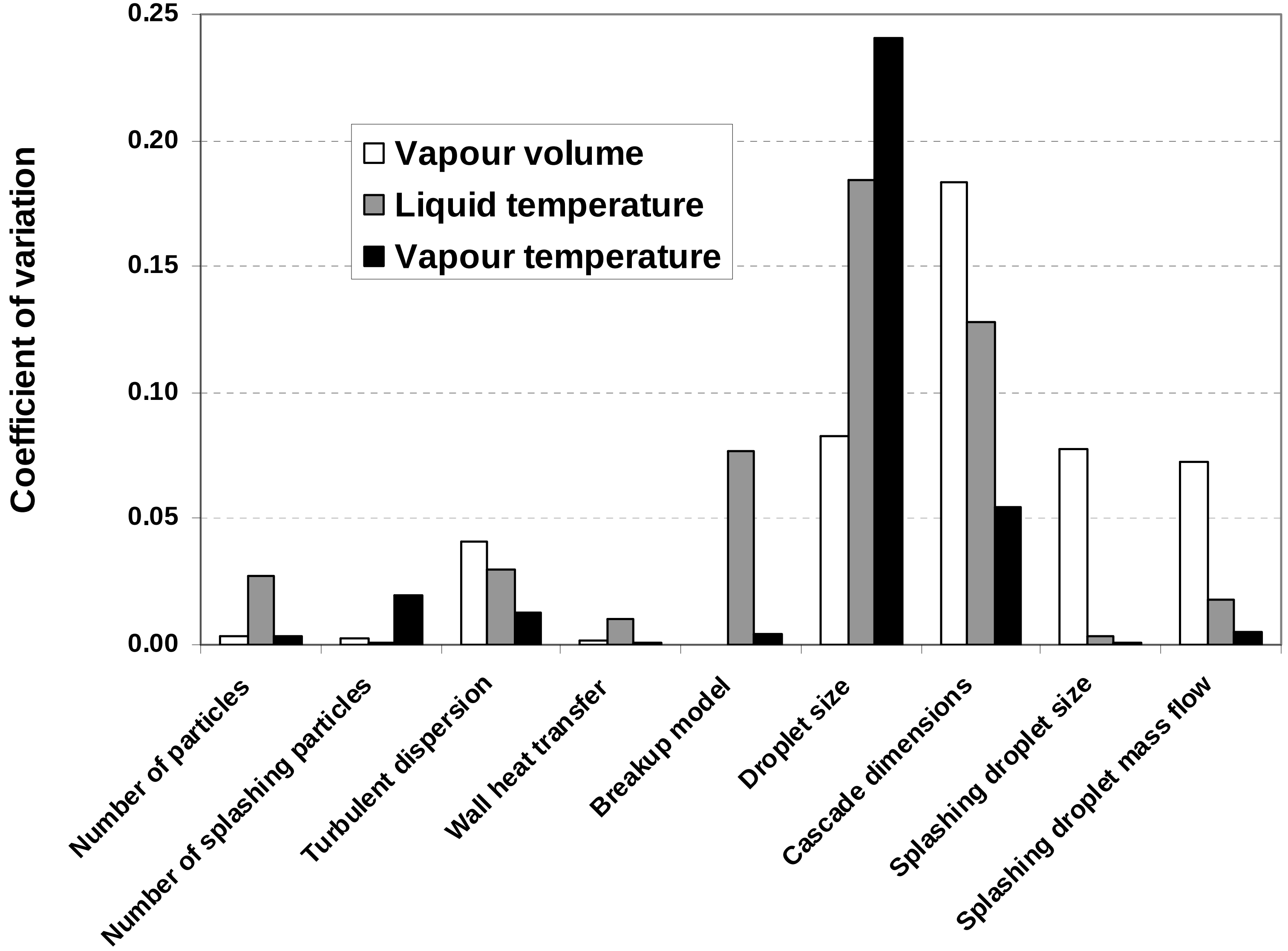


Cascade



Vapour Current

Sensitivity studies



Further Applications

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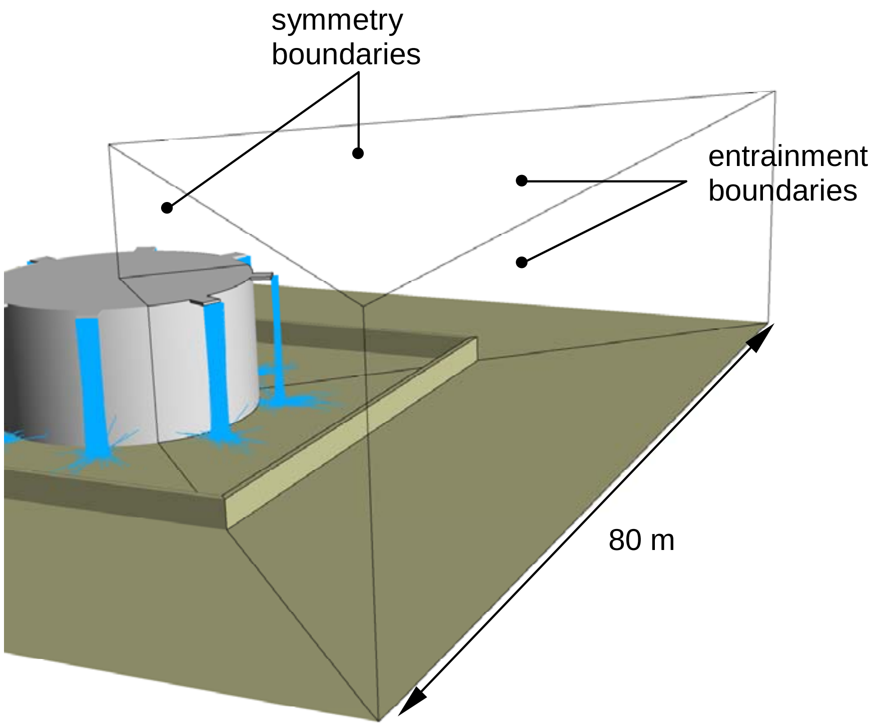
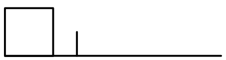
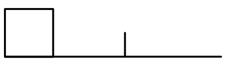
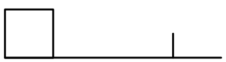
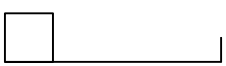
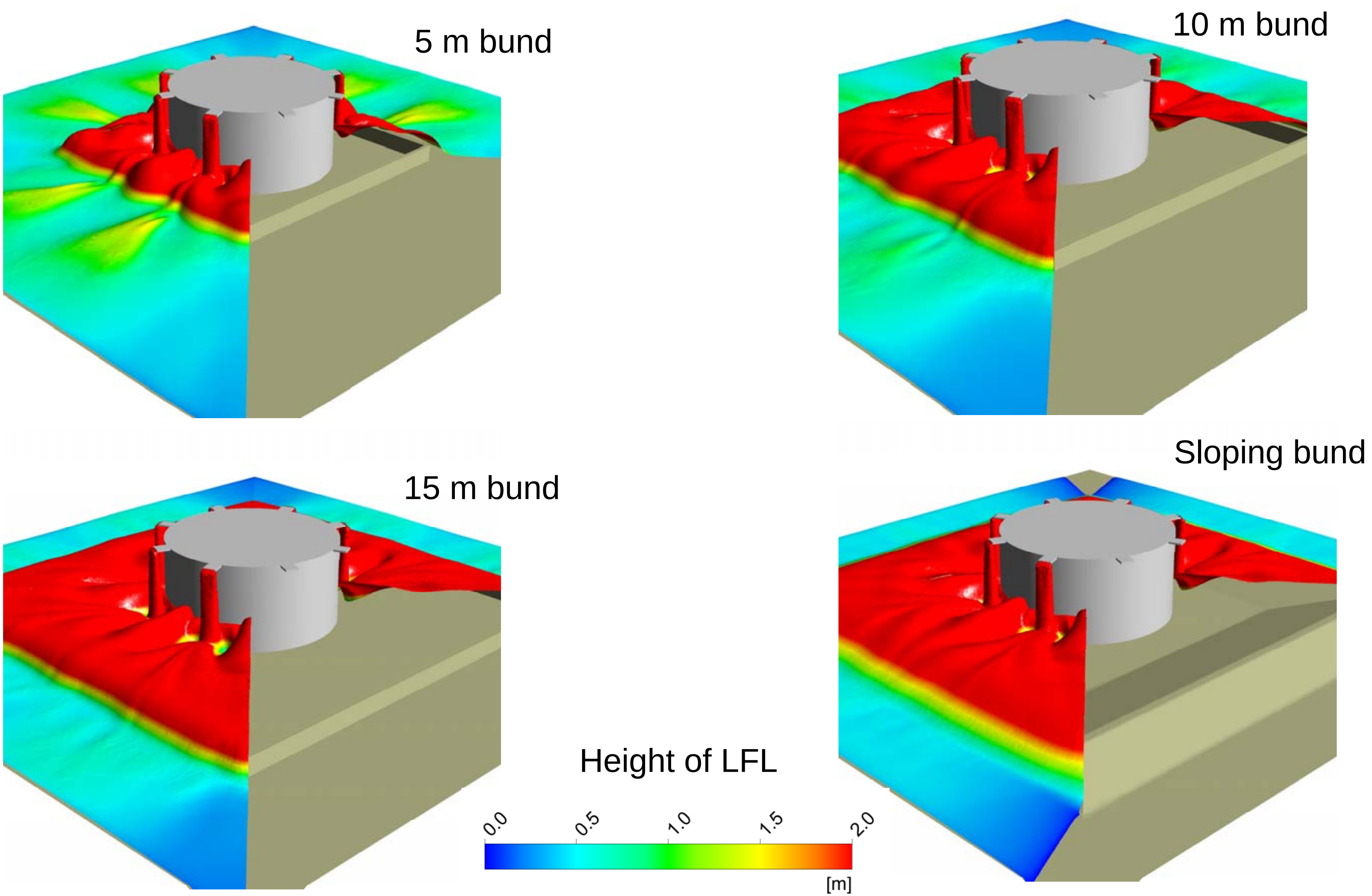
- Estimation of source term for vapour dispersion model
- Identification of key parameters for thermodynamic model
- Examination of different liquids and bund arrangements

Further Applications

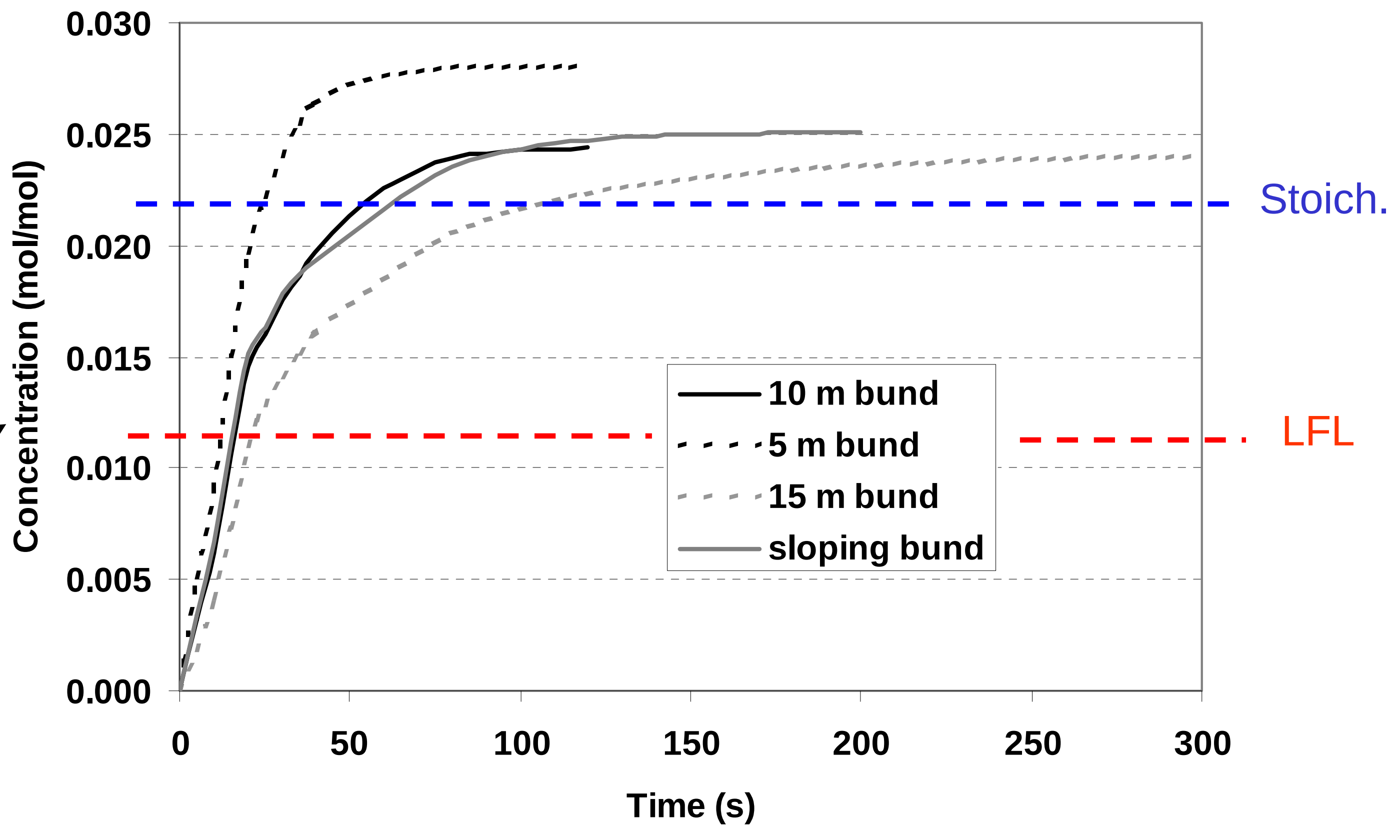


Case	Configuration	
D	Bund at 5m	
E	Bund at 10m	
F	Bund at 15m	
G	Sloping bund at 5m	
H	4 m wall	

Further Applications

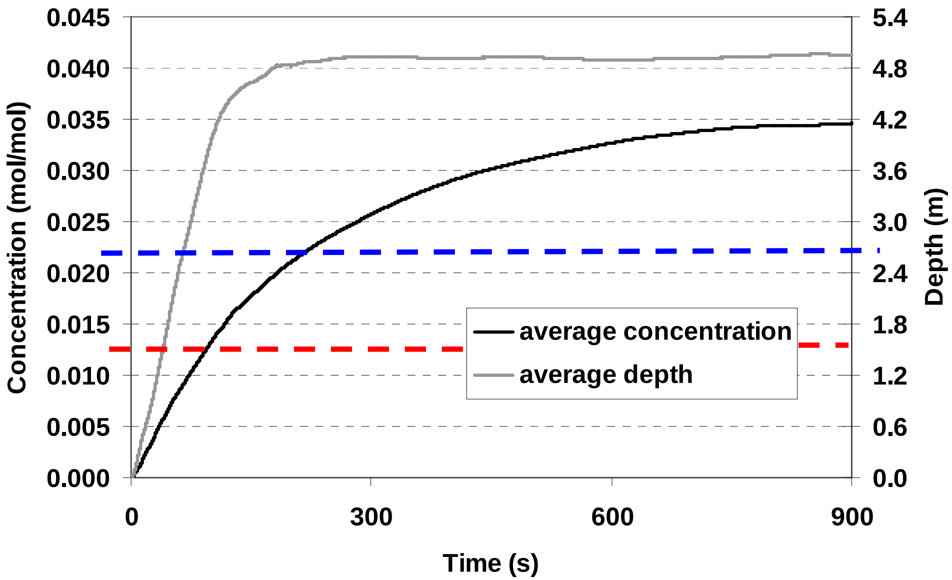


Further Applications



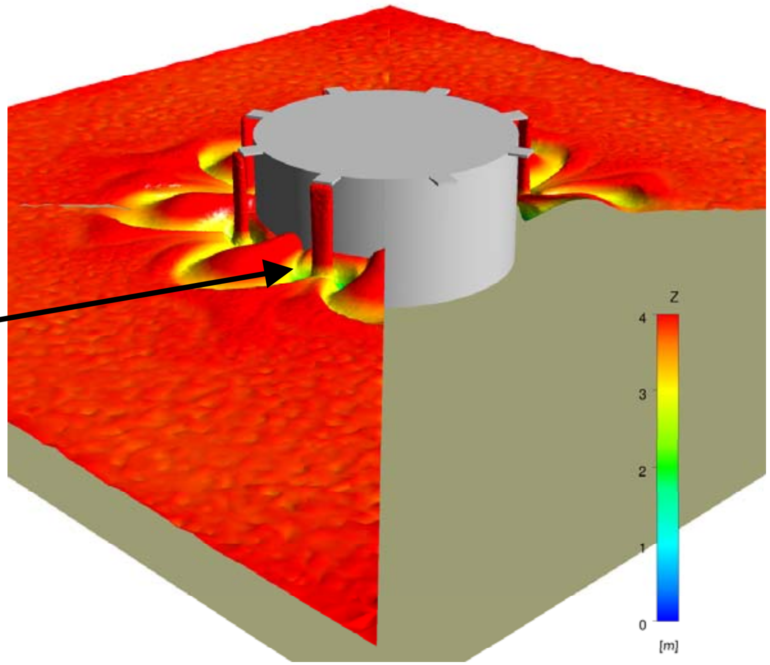
Average concentration inside bund to height of 2 m

Further applications



- Effect of accumulating vapour layer
- Increased concentration
- Within flammability limit

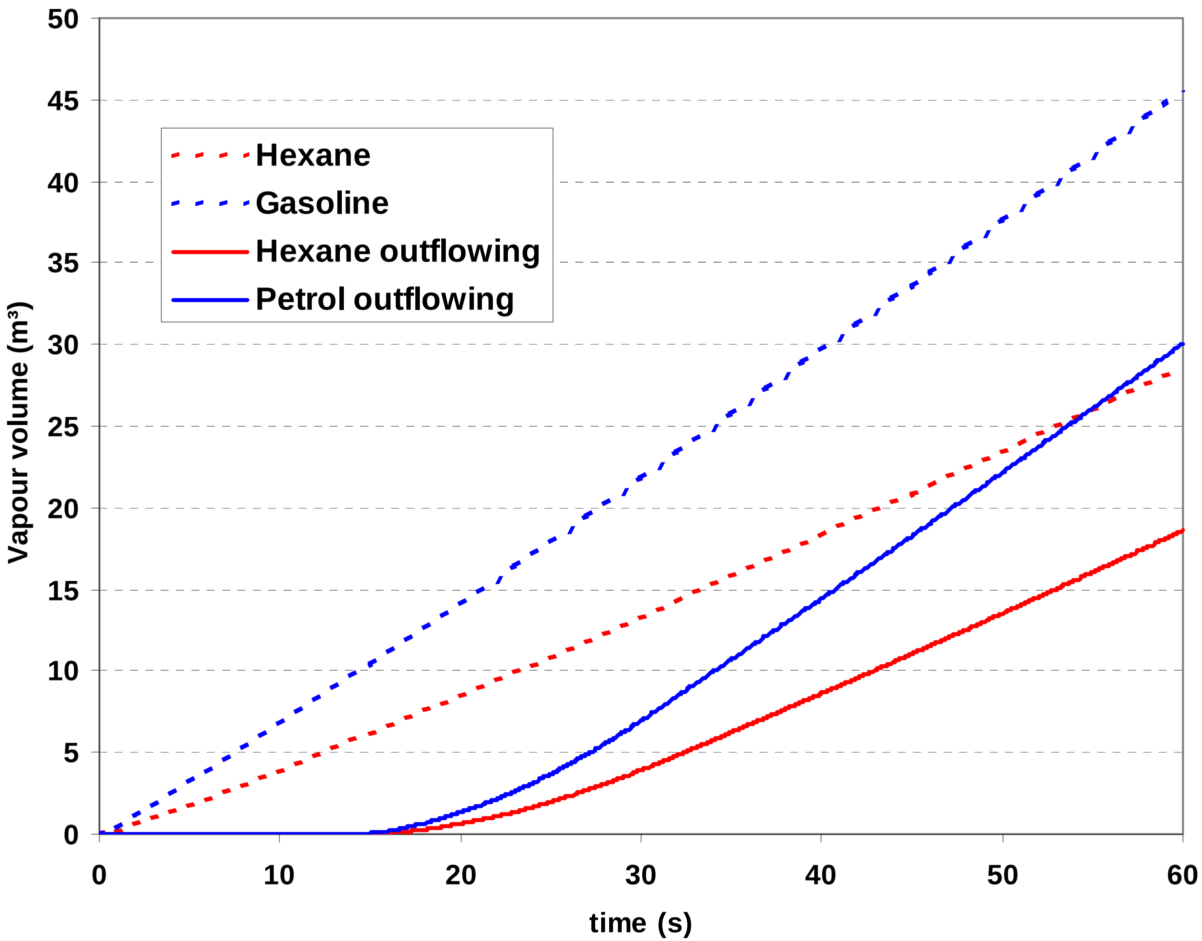
Fresh air drawn downwards limits concentration



Further applications

- Multicomponent cascade
  - Butane
  - Pentane
  - Hexane
  - Decane
- Multicomponent evaporation model applied

Multicomponent cascade



Conclusions

- CFD model has been developed and validated
- The important parameters governing vapour production have been identified
- The model has been used to explore configurations beyond the scope of the experiments
- Model outputs were used to inform the Vapour Cloud Assessment Method
- Modelling the splashing process needs further consideration