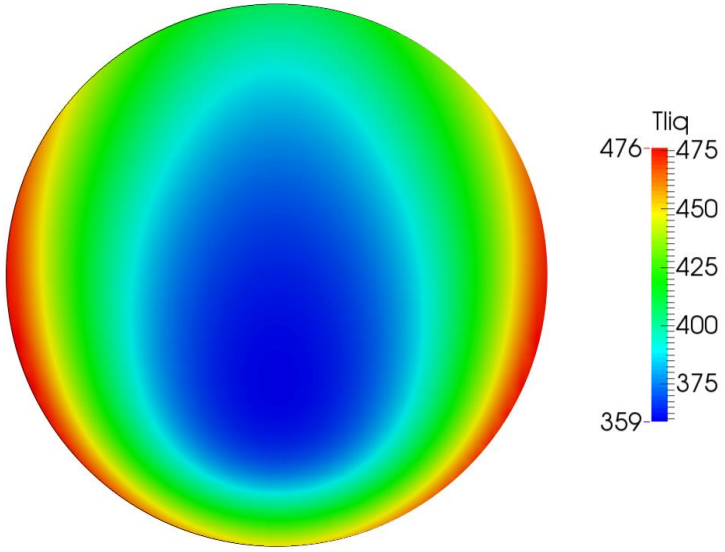
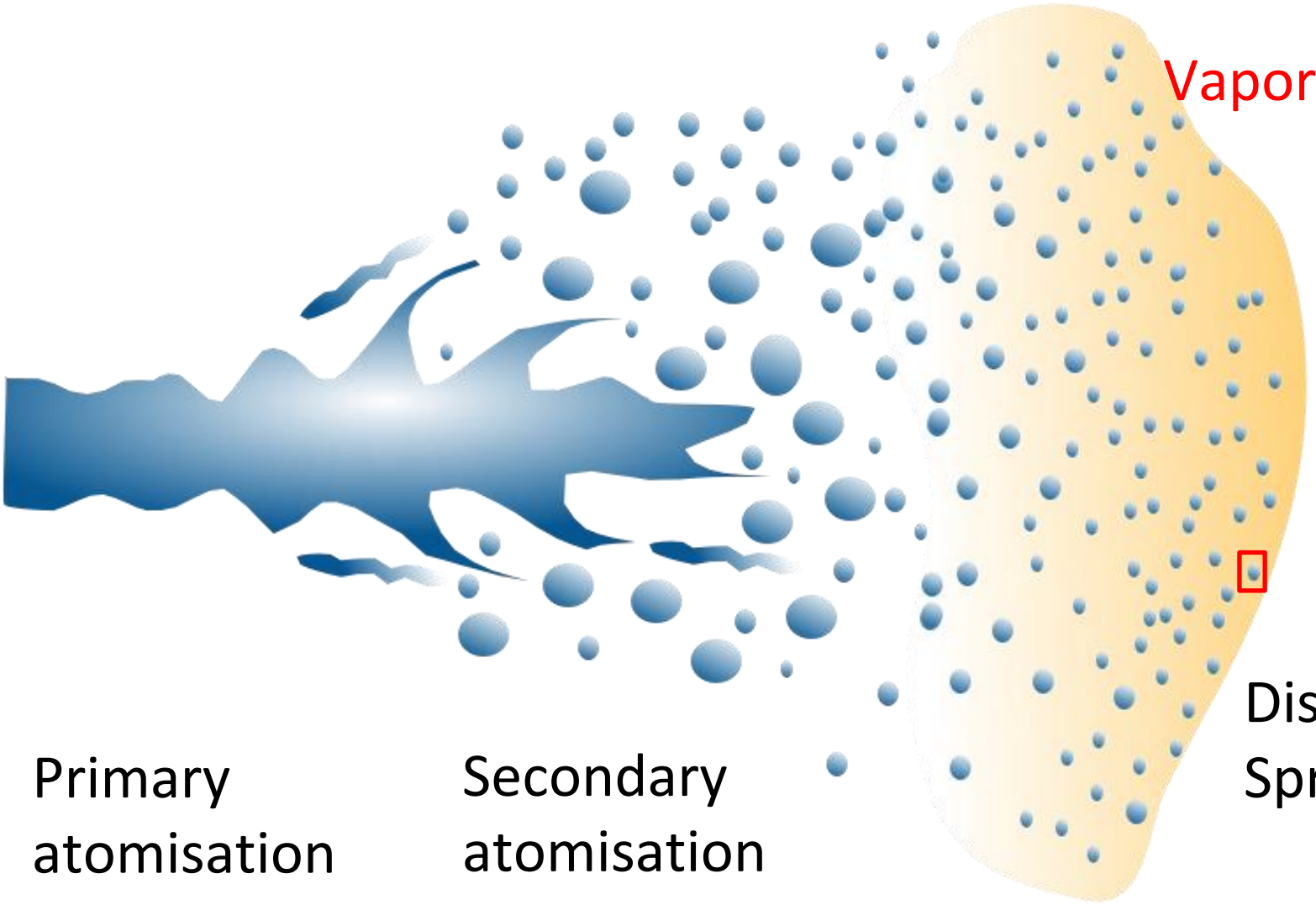
Evaporating droplets : comparisons between DNS and modelling

B. Duret, S. Sazhin, M. Al Qubeissi, C. Crua

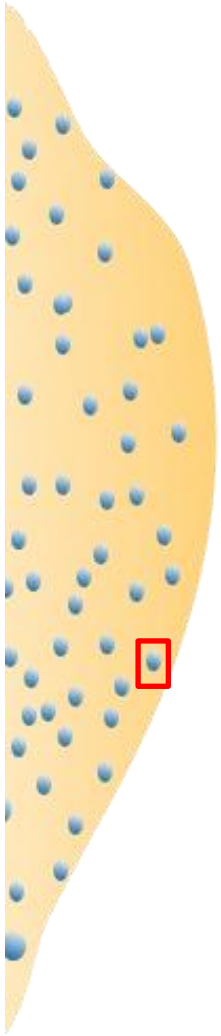


bp
EPSRC
The Sir Harry Ricardo Laboratories

Background

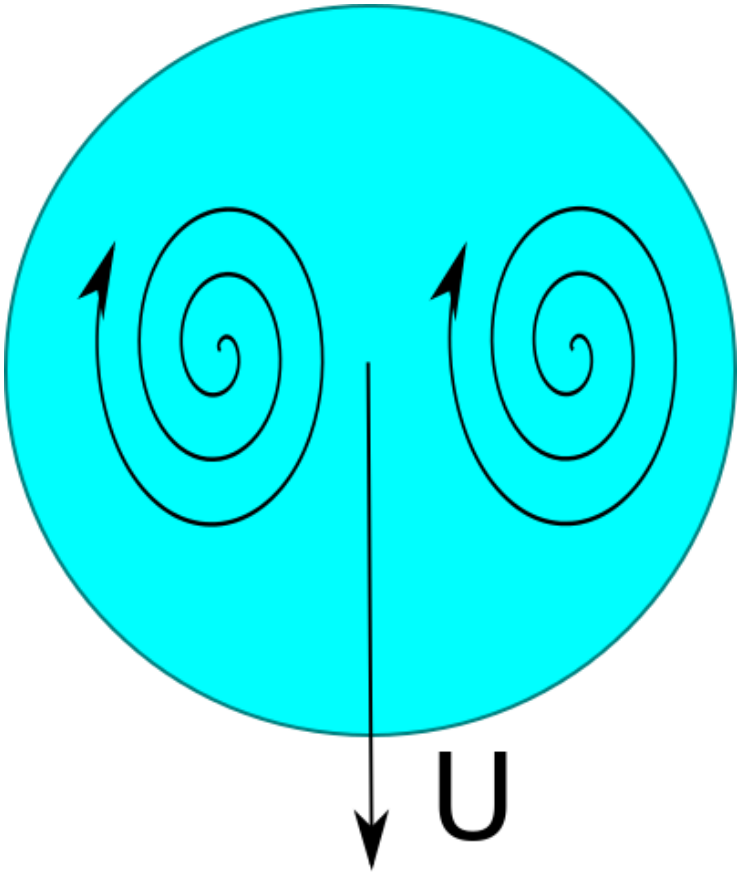

Vaporisation
Primary atomisation
Secondary atomisation
Dispersed Spray

Objective



Investigate the heating and evaporation of a moving droplet

Moving droplet

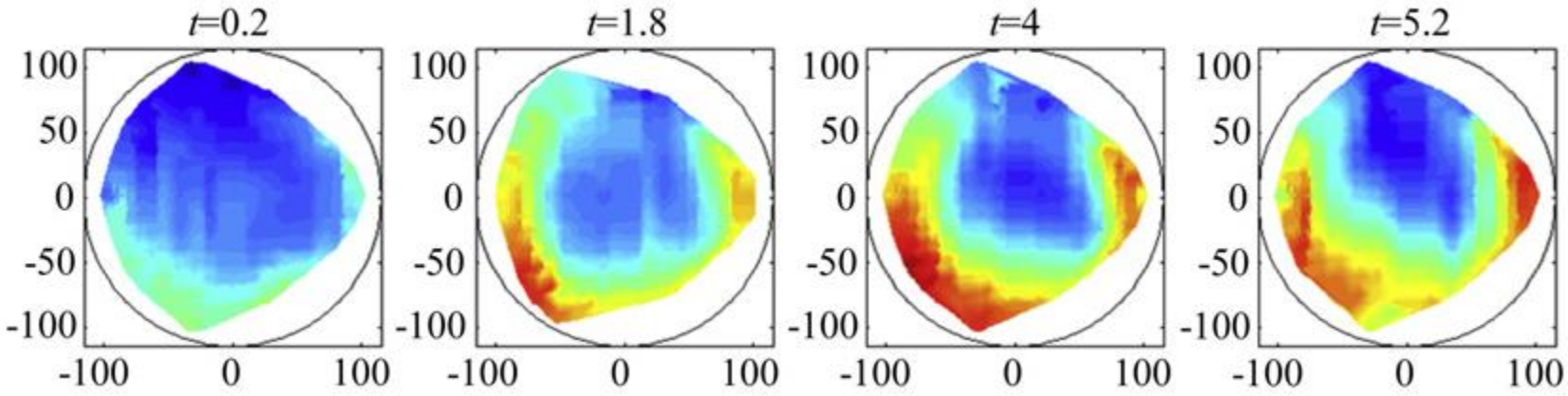


Creation of a vortex structure inside the droplet

Impact of the vortex on the temperature distribution

Moving droplet

Experiments are difficult [2]



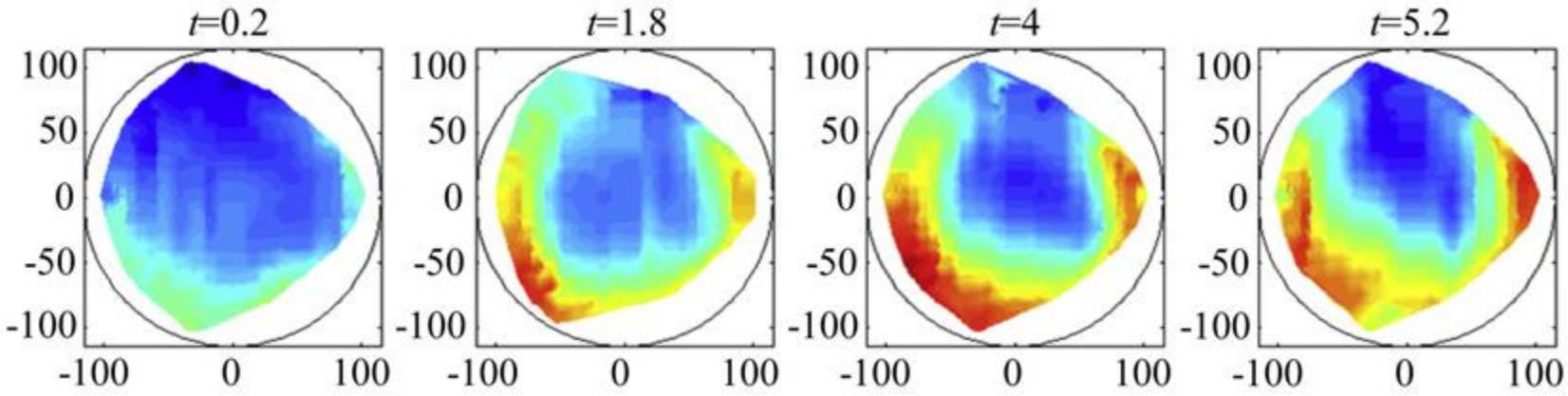
CFD modelling is based on the Effective Thermal Conductivity (ETC) model [1]

[1] Abramzon, B. and W. A. Sirignano, Droplet vaporization model for spray combustion calculations, IJHMT Vol 32(9):1605-1618, 1989.

[2] Castanet, G. et al, Internal temperature distributions of interacting and vaporizing droplets, IJTS Vol 50:1181-1190, 2011.

Moving droplet

Experiments are difficult [2]

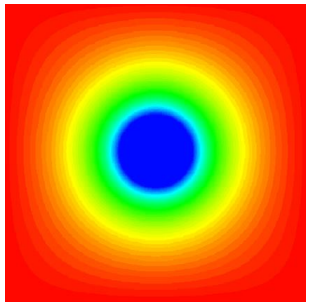


CFD modelling is based on the Effective Thermal Conductivity (ETC) model [1]

Lack of reference data … use DNS!

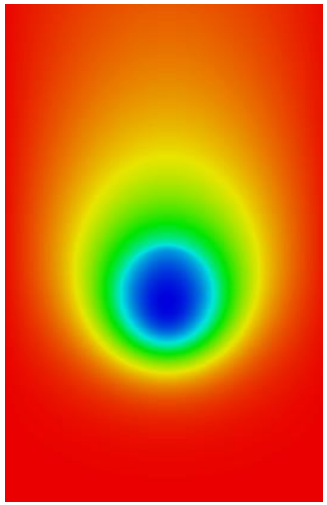
Numerical method

Tanguy et al. [1]



Level set method
2D axisym
Implicit resolution of diffusives terms + BC
Aslam Extrapolation
Adams bashford/WENO5
Sequential
Ghost Fluid
Projection Method

Duret, 2013 [2]



3D, Parallel
Explicit resolution of diffusive terms + BC
RK3/WENO5

[1] Tanguy, S. et al, A level set method for vaporizing two-phase flows, JCP Vol 21(2):837-853, 2007.
[2] Duret, B., Simulation numérique directe des écoulement liquide-gaz avec évaporation : application à l'atomisation, Phd thesis, Université de Rouen.

Moving droplet : methodology

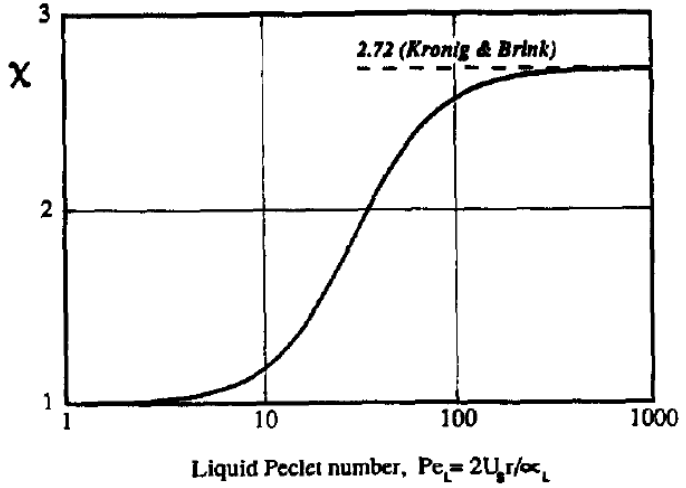
Benchmark of the model :

- Use the effective conductivity $k_{eff} = k_l \chi$
- $\chi = f(Pe)$

Perform DNS computations for a large range of Peclet number

Study vortex formation, heating and vaporization process

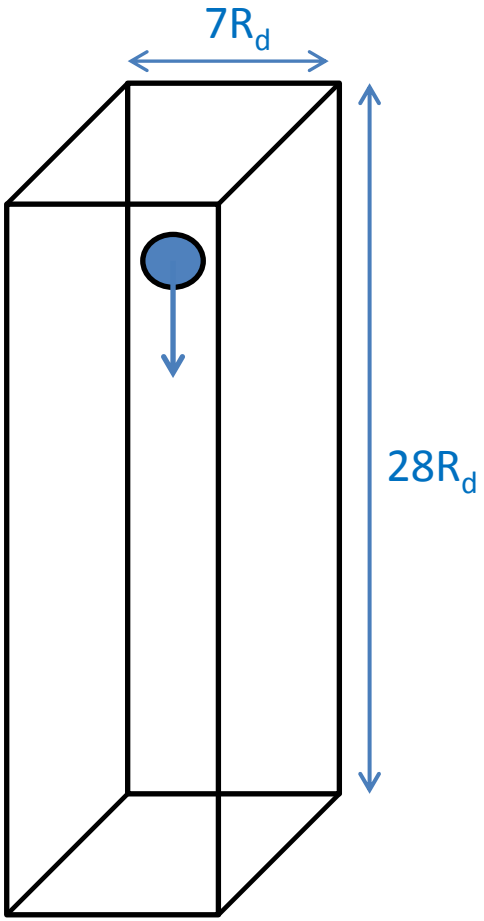
Possible improvements?



[1] Abramzon, B. and W. A. Sirignano, Droplet vaporization model for spray combustion calculations, IJHMT Vol 32(9):1605-1618, 1989.

Numerical configuration

Create a database to study the convectively heated droplet :



Computed @ BP, Houston

128x128x512 mesh

R_d = 50 µm

T_g = 800K

T_l = 350K

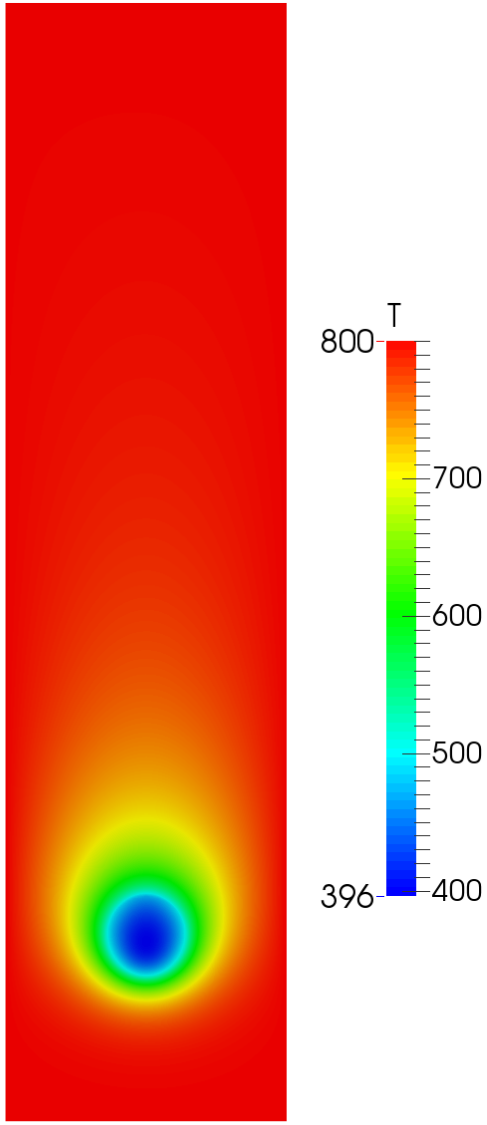
U_d = 0.1 m/s to 3 m/s

Pe = 143 to 4000

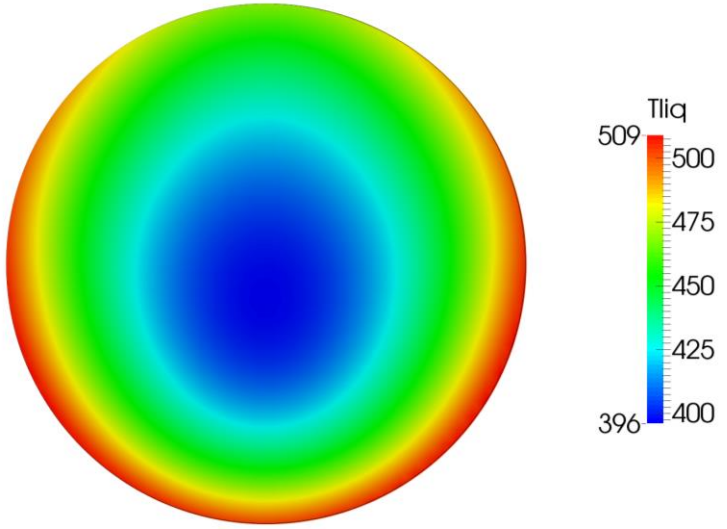
Only heating for now

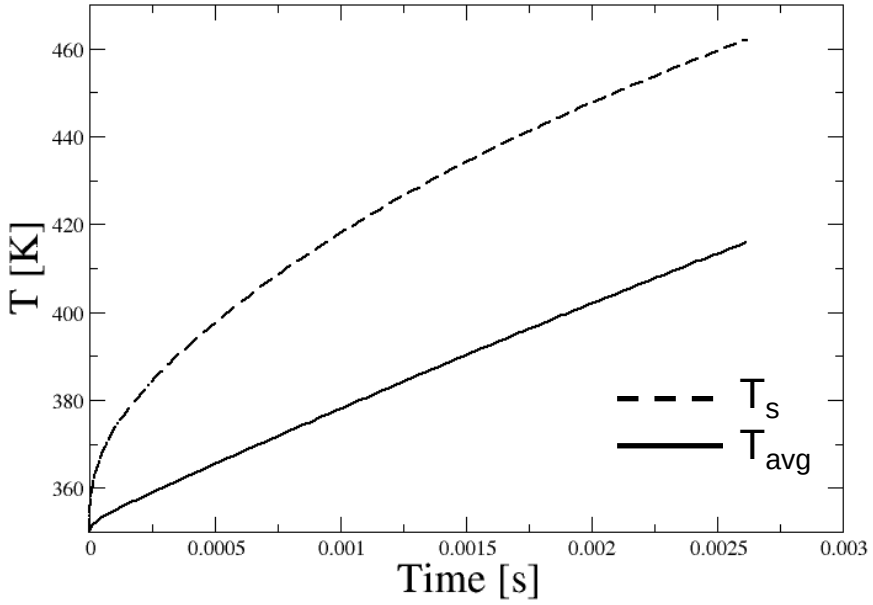
bp

Results : 0.2 m/s

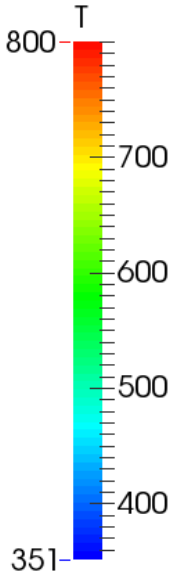


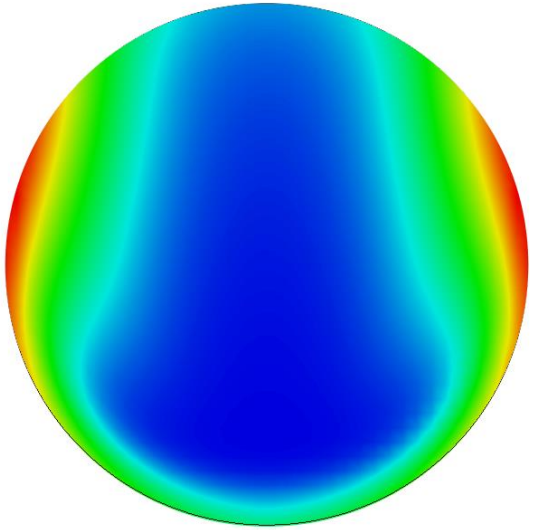
Pe = 286

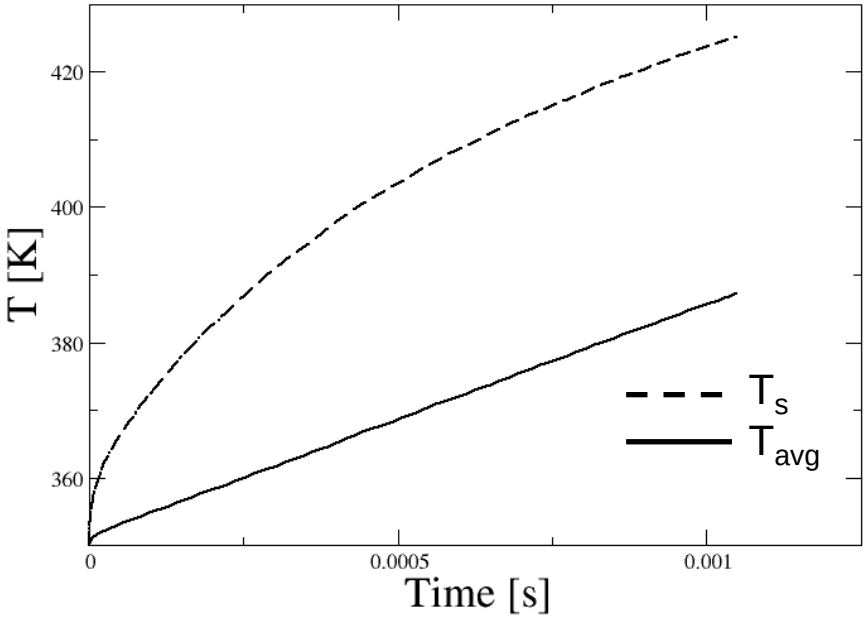




Results : 1 m/s

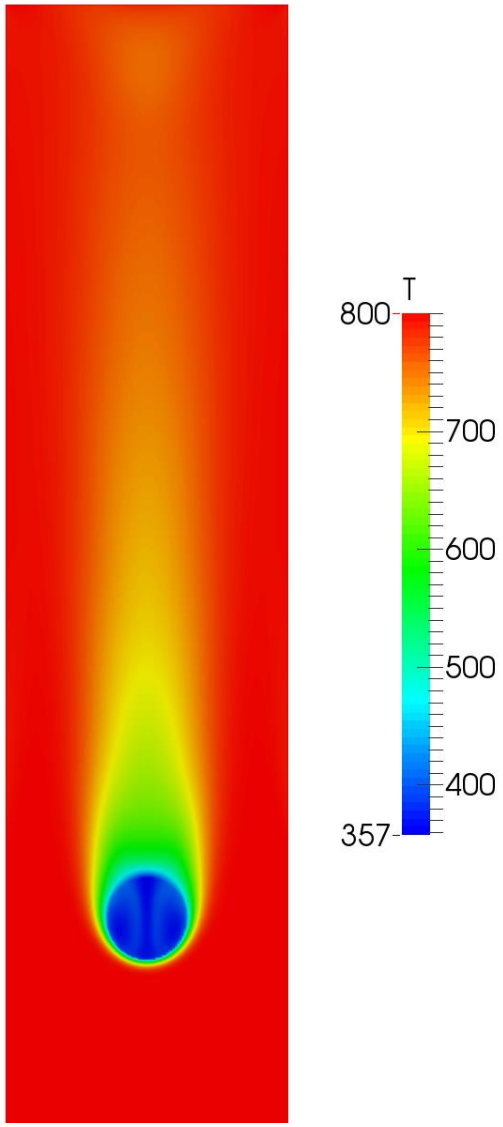




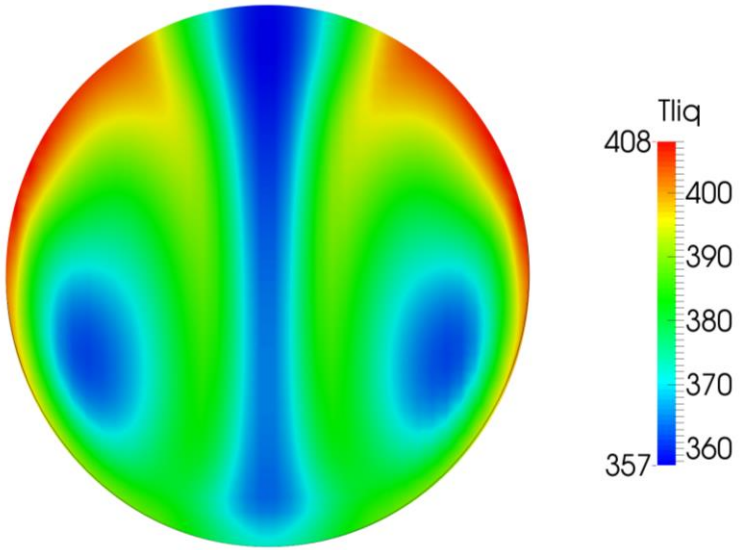


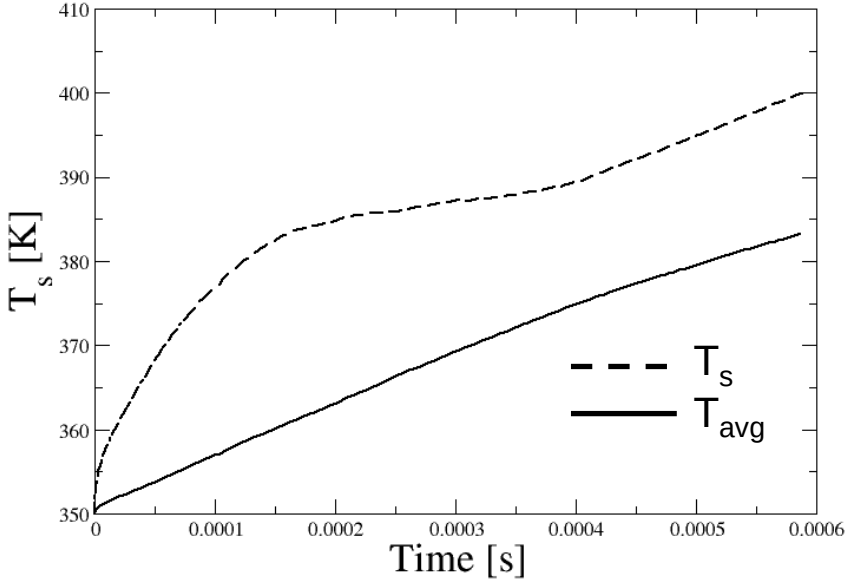
Pe = 1332

Results : 3 m/s



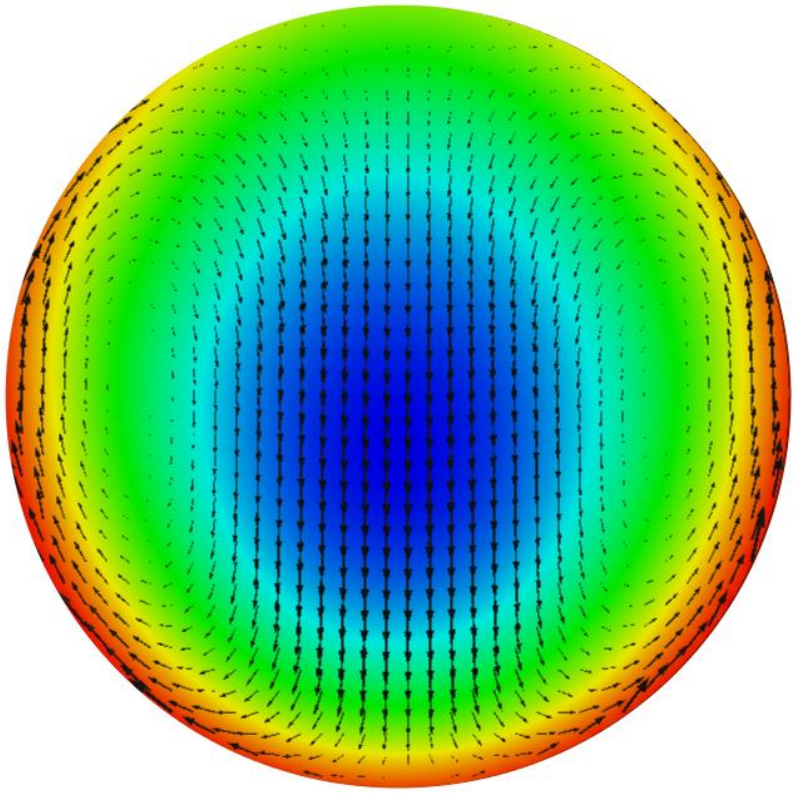
Pe = 4000





Internal Recirculation

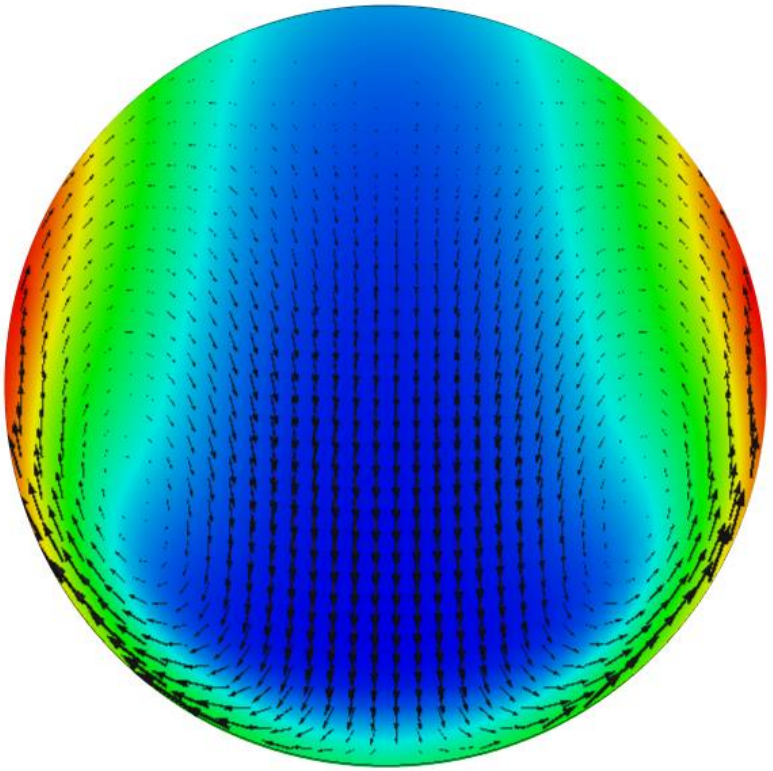
$\uparrow u'$



$U_d = 0.2$ m/s

Internal Recirculation

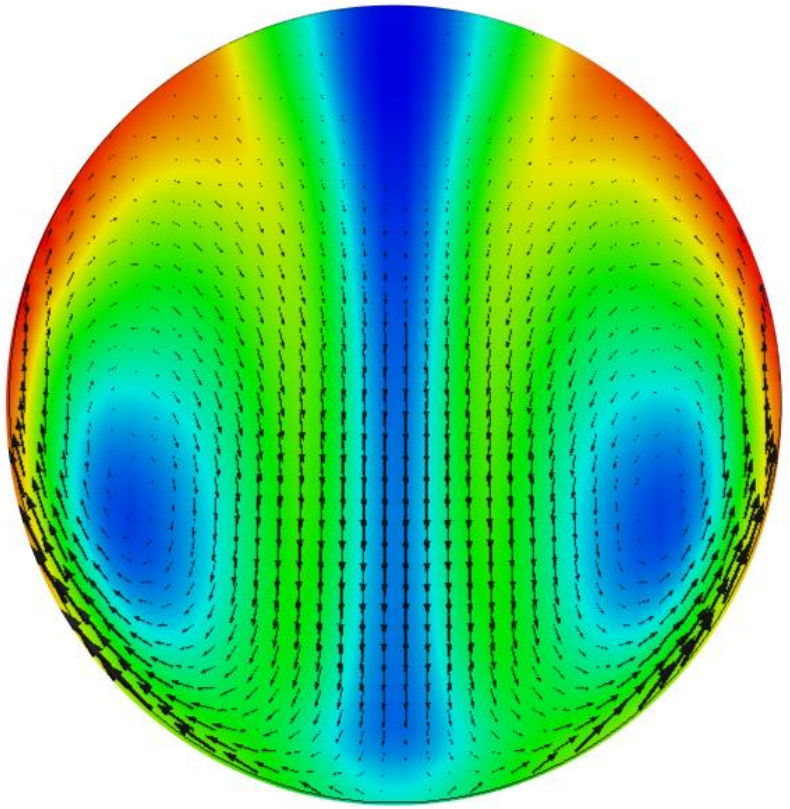
$\uparrow u'$



U_d = 1 m/s

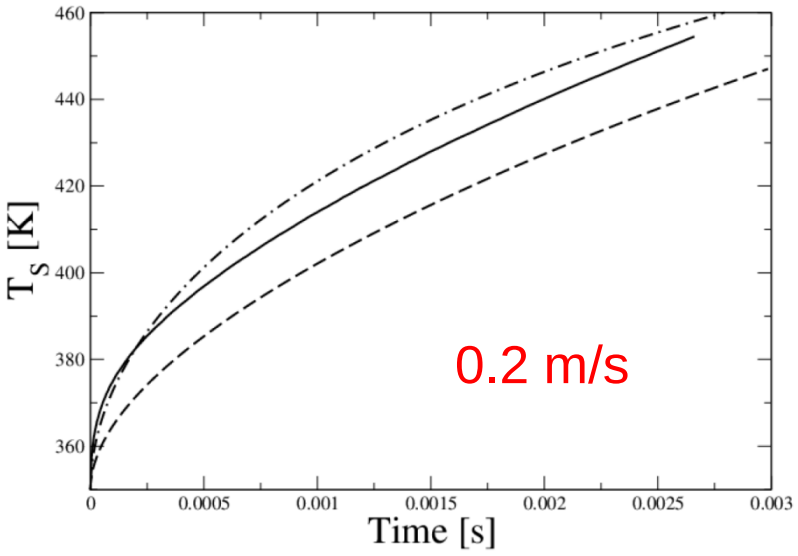
Internal Recirculation

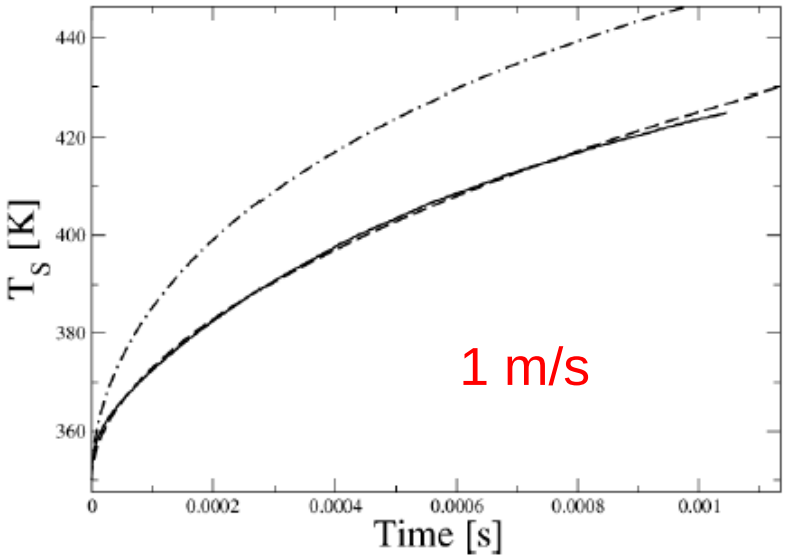
$\uparrow u'$

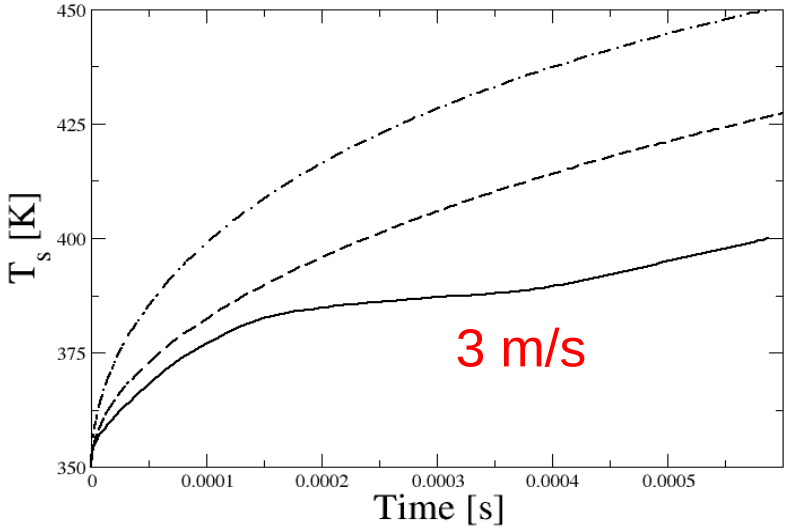


$U_d = 3$ m/s

Comparisons





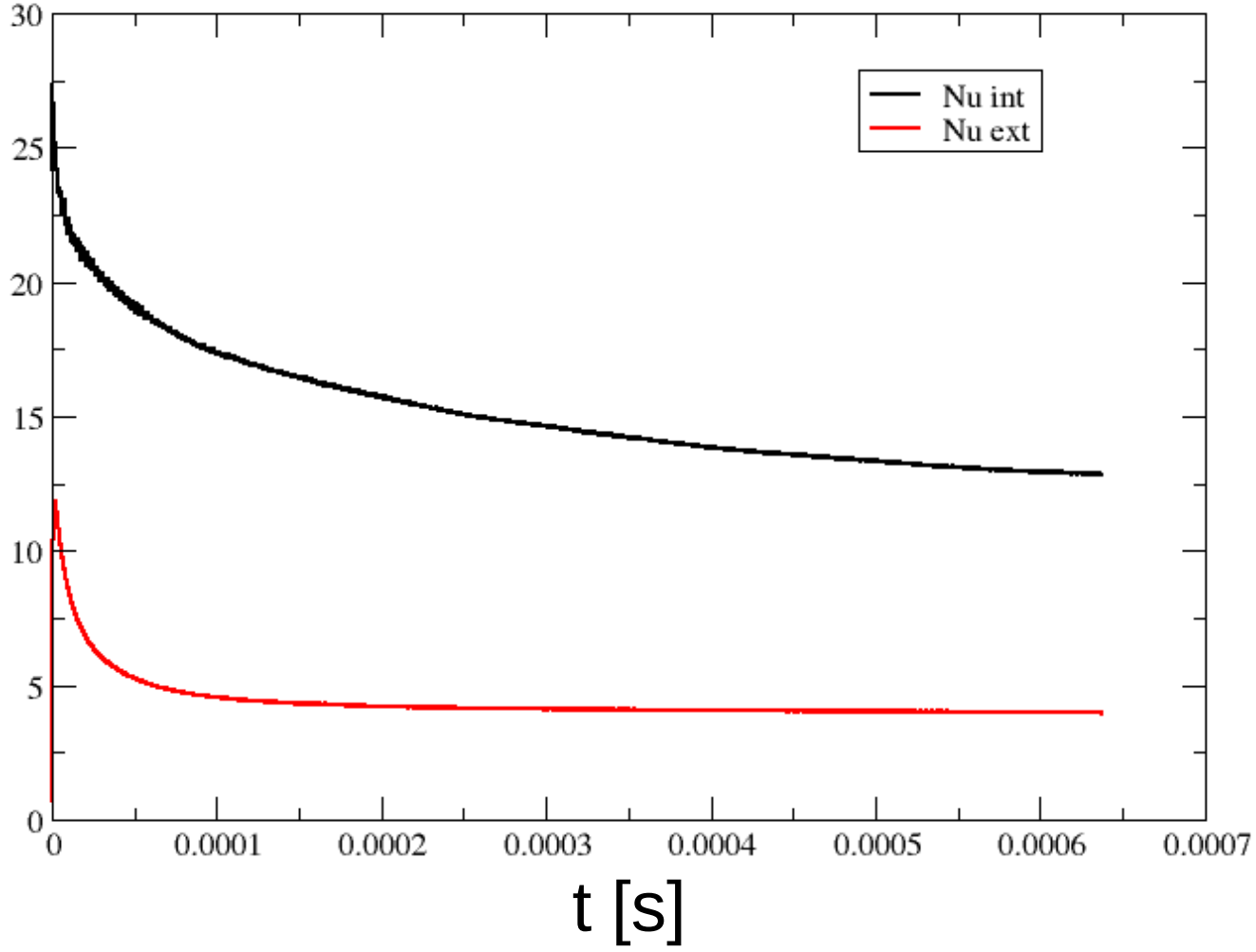


T_s – model k_{liq}
T_s – model k_{eff}
T_s - DNS

Large differences are observed at low and high Peclet number

Nusselt number

More detailed investigation on the 1 m/s case

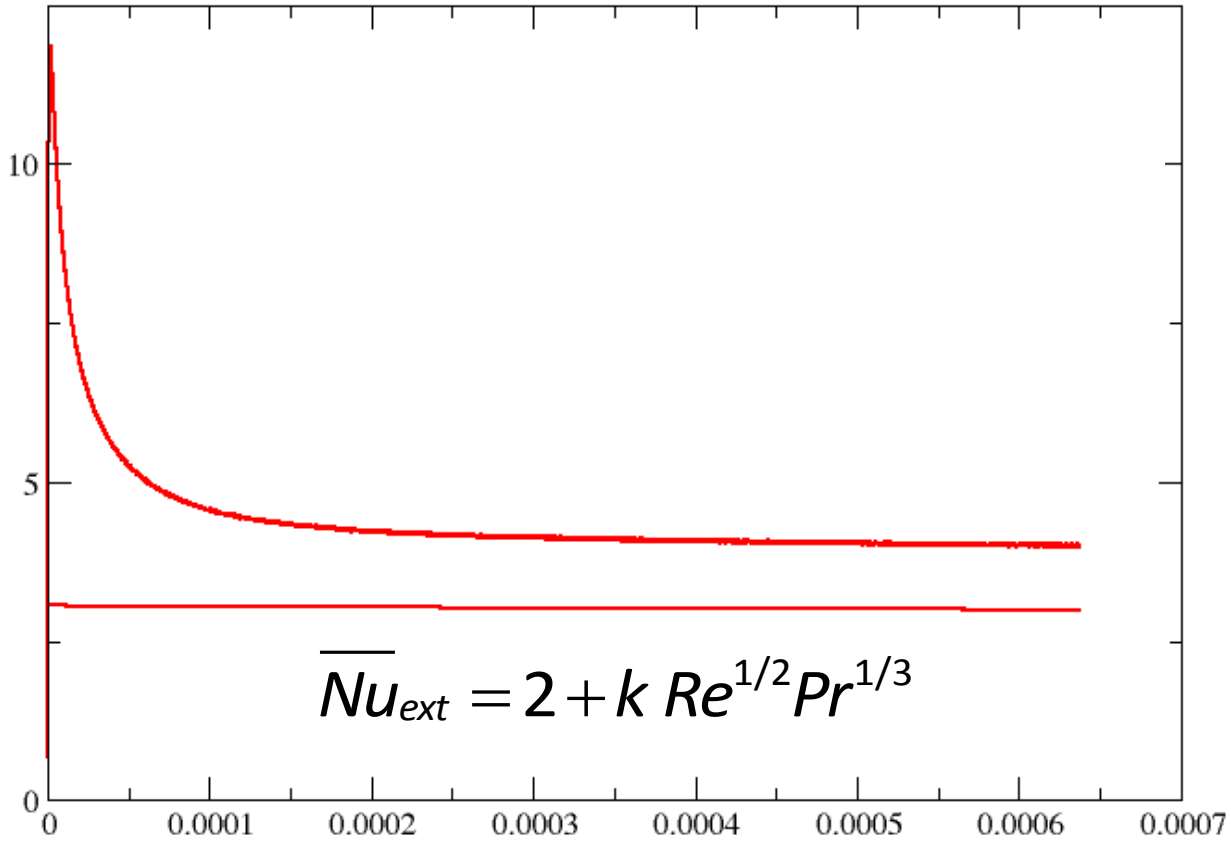


$$\overline{Nu_{int}} = \frac{D\,\frac{dT}{dn}}{T_s - \bar{T}_L}$$

$$\overline{Nu_{ext}} = \frac{D\,\frac{dT}{dn}}{T_\infty - T_s}$$

Comparison with R-M

$\overline{Nu_{ext}}$

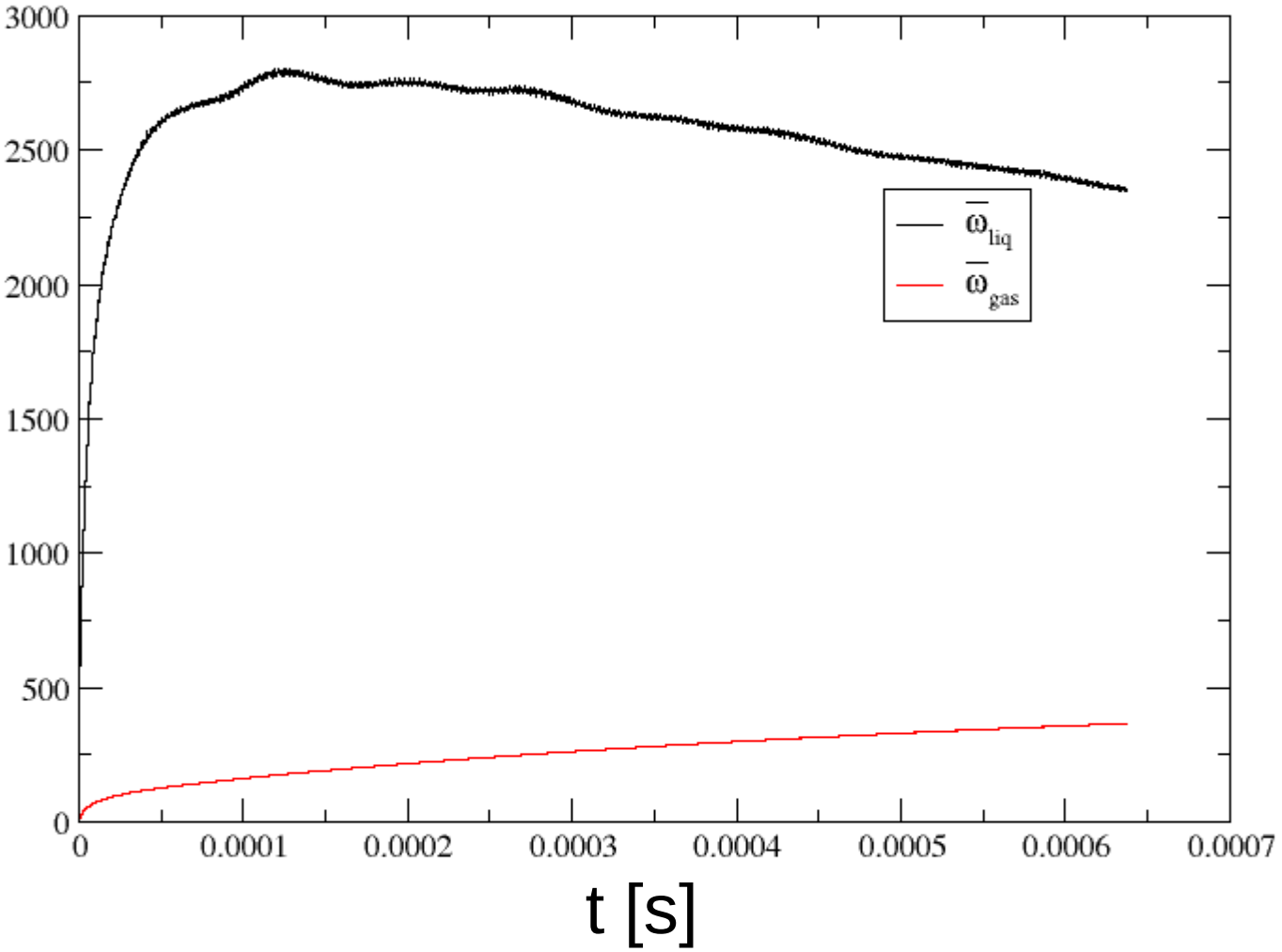


t [s]

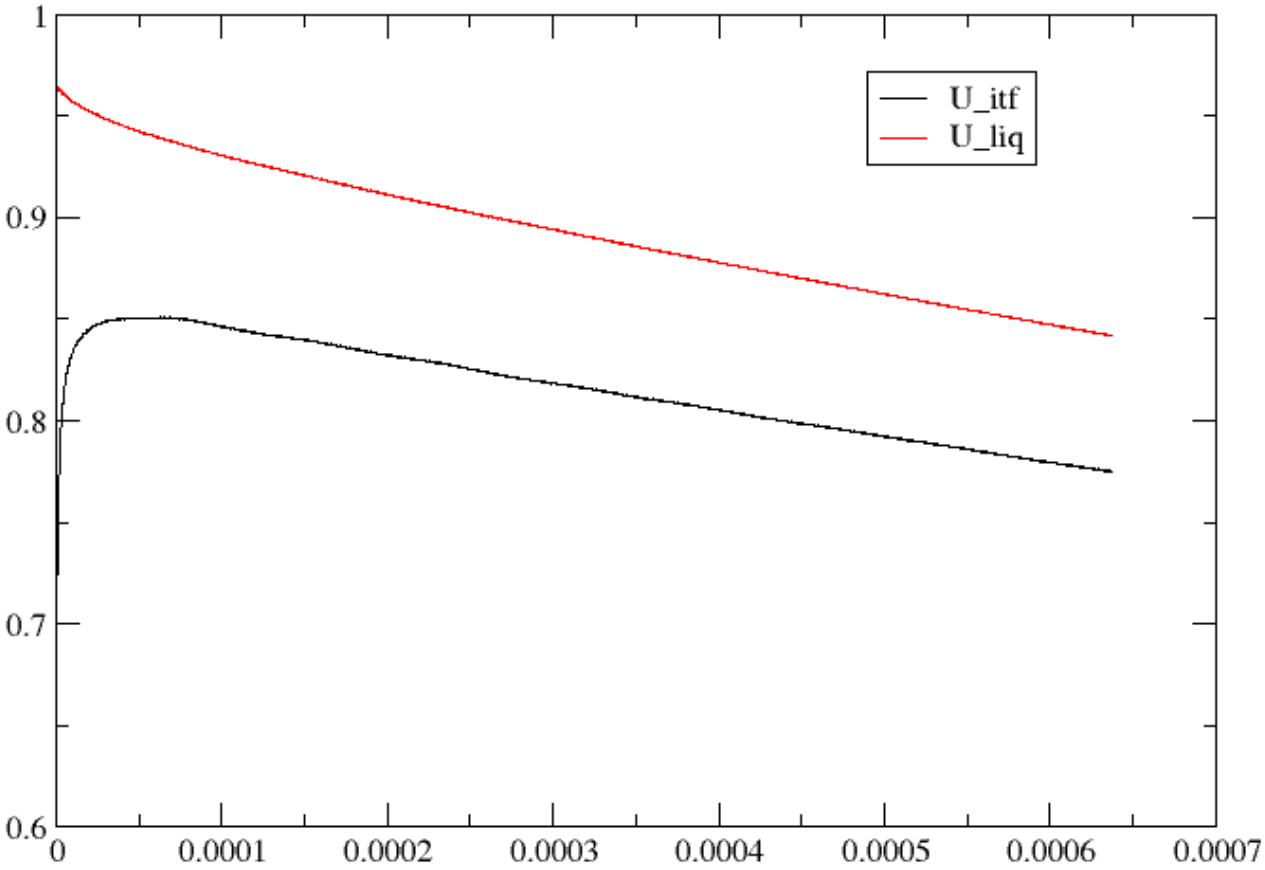
Deviation from the Ranz Marshall correlation…

Mesh resolution too coarse to capture the boundary layer

Vorticity



Mean vorticity can be linked to the Hill vortex model



The sliding velocity is very different than the one used in the model (0.8 versus 0.03)

Conclusion

- A DNS database has been used to investigate droplet heating
- Potential of two phase flow DNS to improve modelling has been illustrated
- Quantitative results on droplet transient heating + vortex formation has been shown

Acknowledgments

The author is grateful to BP and EPSRC (grant EP/K020528/1) for the financial support.

Thank you for your attention