UNIVERSITY OF BIRMINGHAM

COMSOL CONFERENCE 2014 CAMBRIDGE

Study of Supercritical Coal Fired Power Plant Dynamic Responses for Grid Code Compliance

A. Gil-García, I. Kings, B. Al-Duri
University of Birmingham, School of Chemical Engineering, Edgbaston, Birmingham B15 2TT, UK

Introduction

Supercritical coal fired power plant (SC-CFPP) is a clean coal technology with improved thermal efficiency up to 46%, around 10% above current coal fired power plants. Before it can be adopted in the UK, its response to changes in energy demand must be pre-studied from different approaches.

The supercritical water (SCW) heat transfer coefficient (HTC) is being investigated in the boiler cycle, exactly at the water wall stage by using the *Conjugate Heat Transfer* interface offered by Comsol Multiphysics® 4.4.

This study is focused on a 2D test element (water pipe) wherein a compressed water flow (300 bar) is heated up by a constant heat flux or a constant temperature applied on the pipe walls, in order to make the fluid reach the supercritical state and surpass the pseudocritical (PSC) line *(at 401.9° C approx.).*

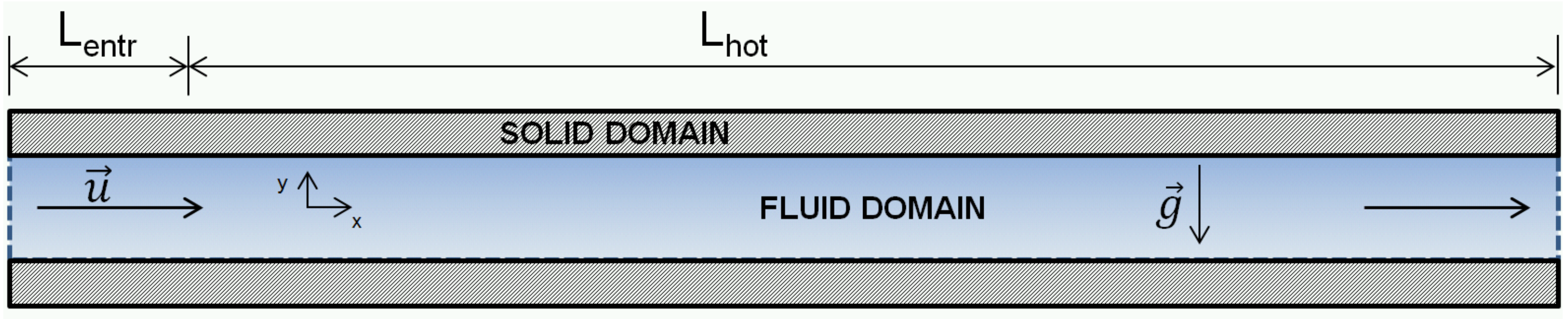

Figure 1. Computational domain for the 2D test element

Computational methods

The *Conjugate Heat Transfer* interface supports flows at Mach number 0.3 or lower, and although SCW is a compressible fluid, it was firstly verified its Mach number range was kept below this limit. The pipe material (Inconel 625) and SCW had to be created as new materials, including in the latter the appropriate thermodynamic data from the NIST database. The equations of momentum and energy are as follow:

$$\frac{\partial\tilde{\nu}}{\partial t}+\mathbf{u}\cdot\nabla\tilde{\nu} = c_{\mathrm{b1}}\tilde{S}\tilde{\nu}-c_{\mathrm{w1}}f_{\mathrm{w}}\left(\frac{\tilde{\nu}}{l_{\mathrm{w}}}\right)^2+\frac{1}{\sigma}\nabla\cdot((\nu+\tilde{\nu})\nabla\tilde{\nu})+\frac{c_{\mathrm{b2}}}{\sigma}\nabla\tilde{\nu}\cdot\nabla\tilde{\nu}$$

$$\rho C_p\left(\frac{\partial T}{\partial t}+(\mathbf{u}\cdot\nabla)T\right) = -(\nabla\cdot\mathbf{q})+\tau{:}\mathbf{S}-\frac{T}{\rho}\frac{\partial\rho}{\partial T}\bigg|_p\left(\frac{\partial p}{\partial t}+(\mathbf{u}\cdot\nabla)p\right)+Q$$

Within this interface, the *Turbulent Flow* was chosen as any flow inside a boiler pipe is meant to reach this regime quickly. Among the different turbulence models, the *Spalart-Allmaras* is being utilised at the moment due to two reasons. First, because it is a no-slip model (low Reynolds) that considers the flow near the wall (important in terms of heat transfer) and second because it is a one-equation turbulence model (more robust).

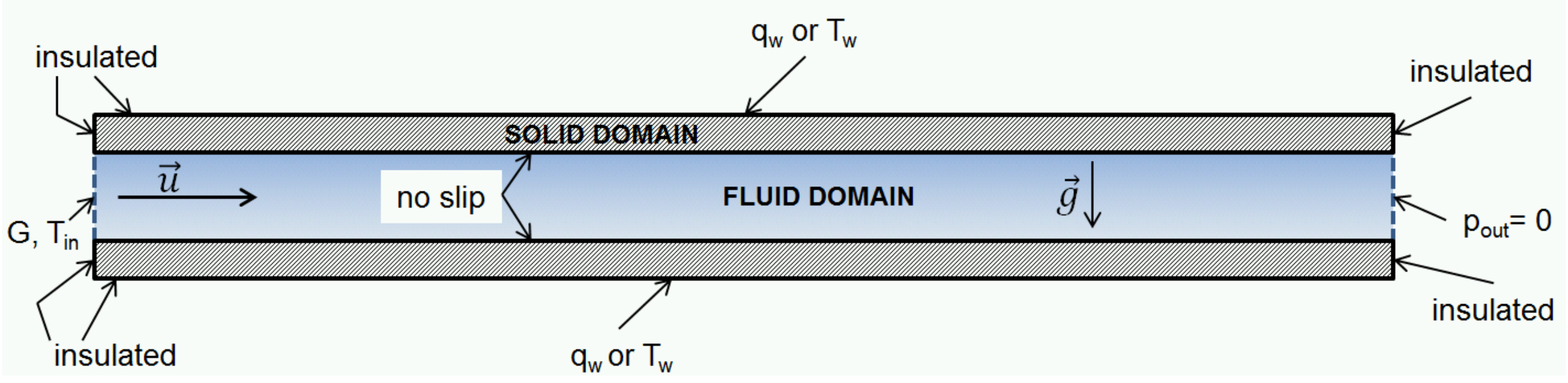

Figure 2. Boundary conditions for the 2D test element

A mapped mesh was chosen given the nature of the flow, with an arithmetic sequence distribution in order to refine the wall-fluid interfaces, where the heat transfer between the solid and the flow takes place. Also, a series of boundary layers was added on the fluid domain, with a smaller stretching factor than usual in order to stabilize the convergence in this sensitive zone.

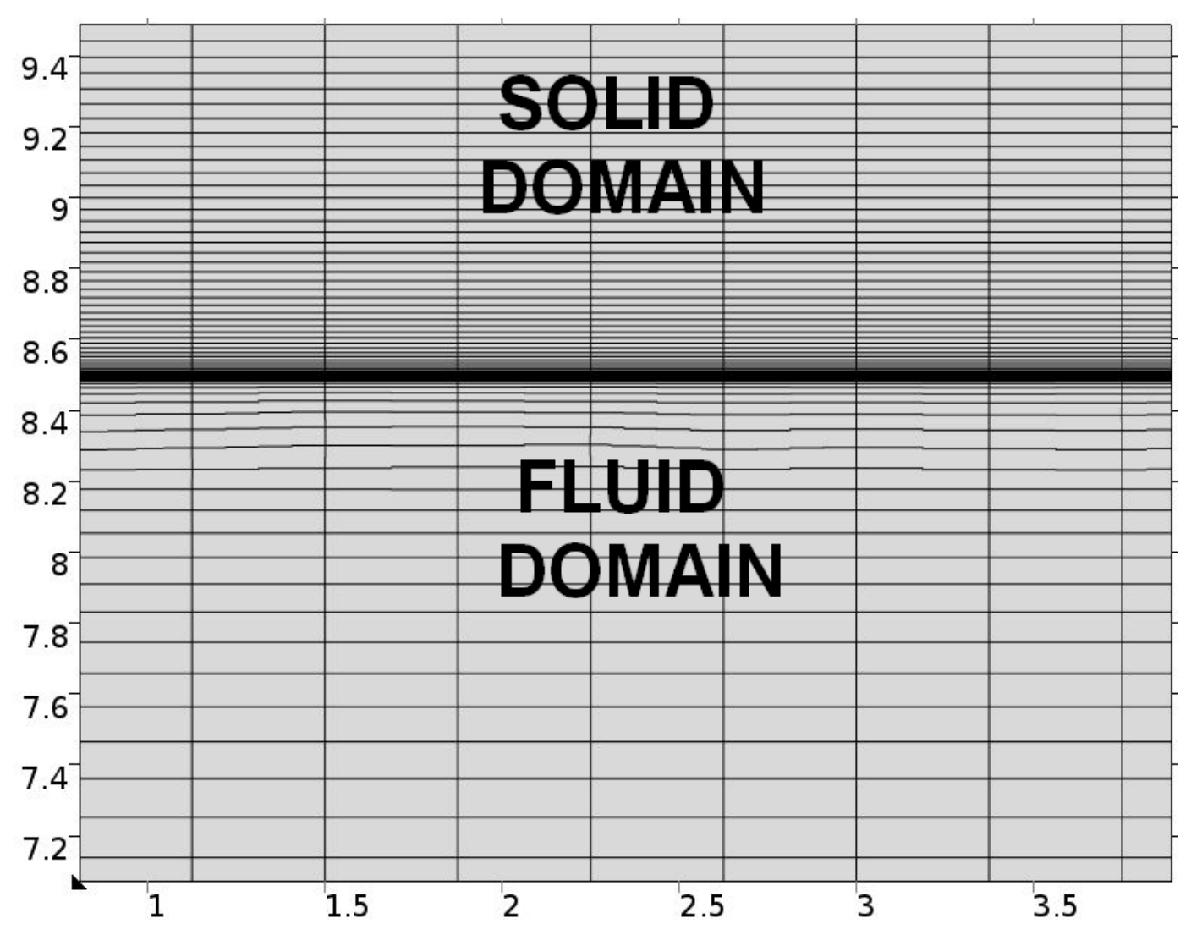

Figure 3. Upper half of the test element showing the wall-fluid interface (axes numbers in mm.)

Results

The results obtained are related to the following conditions:

- Pipe inner diameter: 1.6 mm
- Pipe outer diameter: 3.6 mm
- Pipe length: 1000 mm
- Heated length: 976 mm
- Applied heat flux: 350 kW/m^2
- Water inlet temperature: 350° C
- Water mass flux: 600 kg/m^{2}s

The heat flux was applied on both upper and lower walls in order to observe the effect of gravity on the HTC.

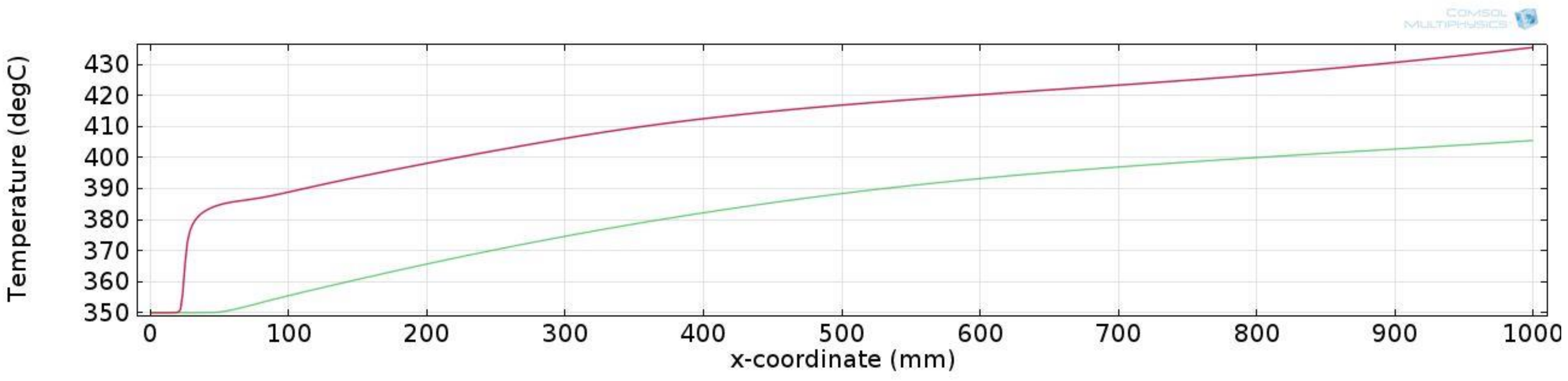

Figure 4. Wall temperature profiles (in red) and bulk temperature profile (in green) along the pipe.

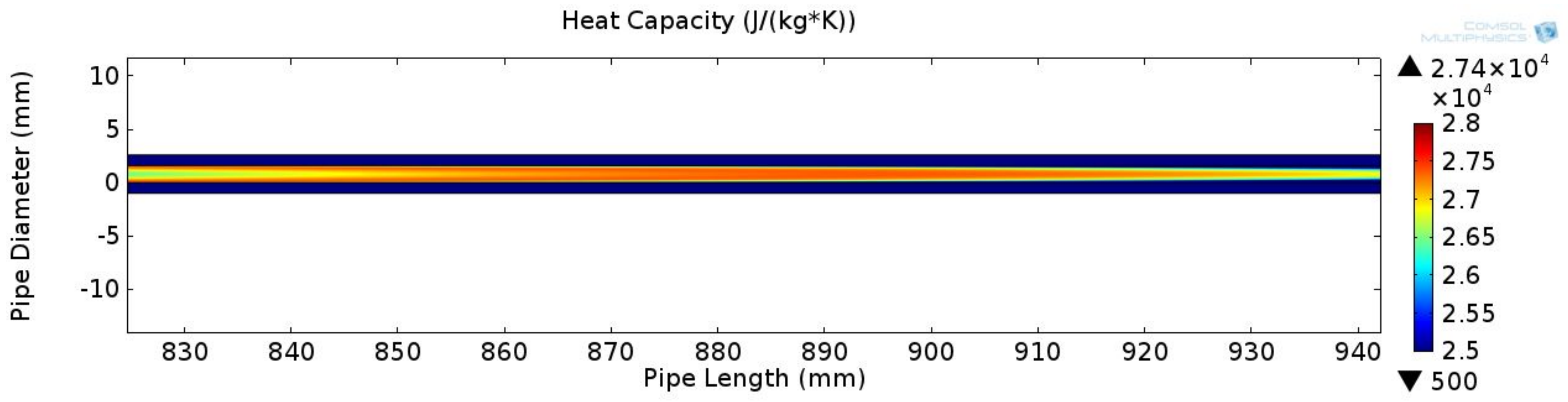

Figure 5. Heat capacity sensitive behavior when surpassing the PSC point.

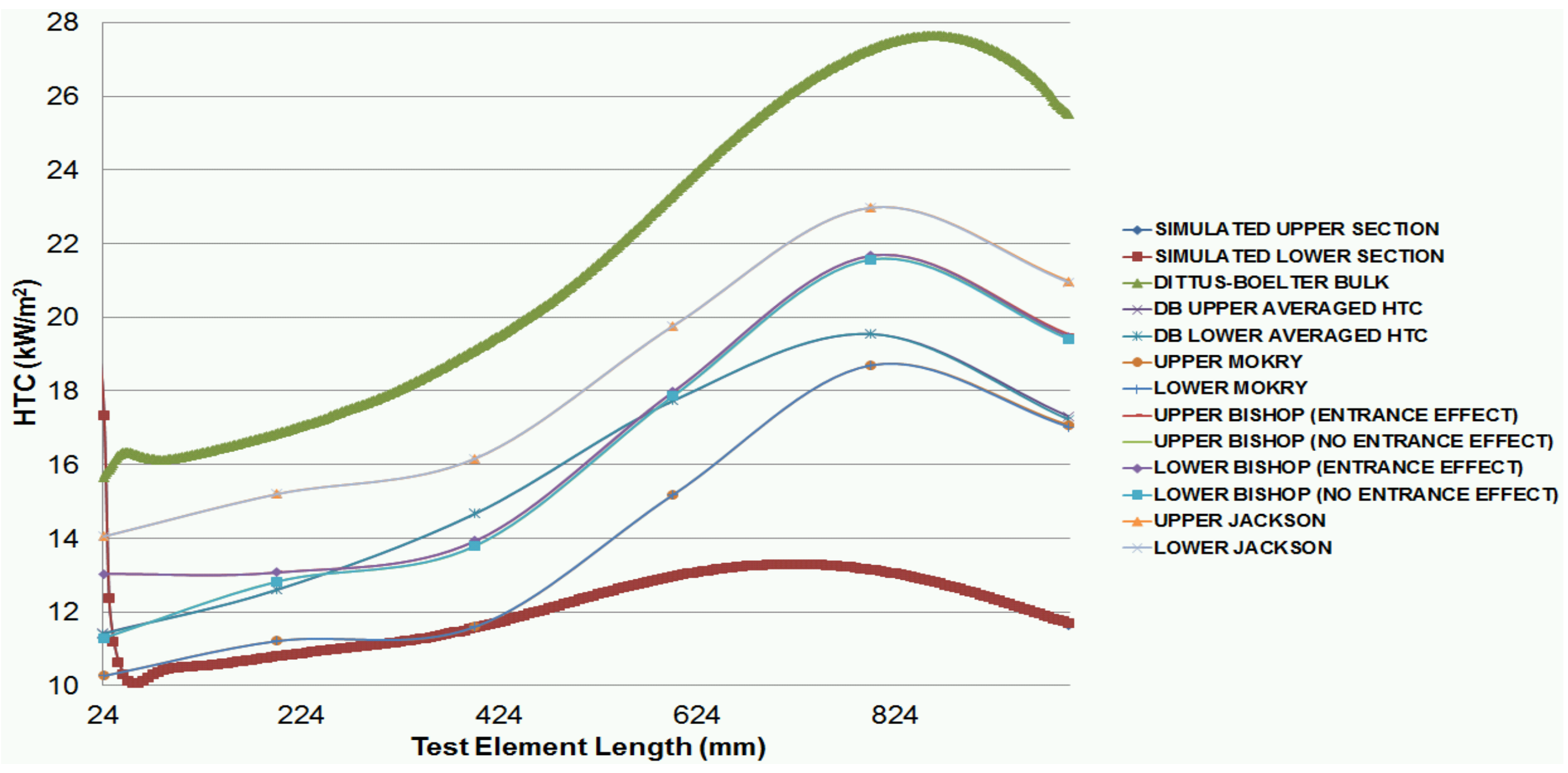

Figure 6. Comparison of the obtained HTCs (in red) with other correlations found in the literature.

Conclusions

- The HTC line obtained is smaller in general than most predictions from correlations. The correlation from *Mokry et al.* fits quite well before reaching near its maximum value.
- The maximum HTC obtained takes place when the PSC state is mid-way between the wall and the bulk of the flow, whereas the correlations show the maximum HTC when the PSC is located approximately in the bulk.
- The gravity effect can be considered negligible when using small inner diameters. Testing higher diameter involves a more power-demanding mesh
- Different working conditions must be tested in order to see the HTC behaviour, coupled with other configurations (i.e. inclined, vertical).
- The interface will be applied on 3D geometries in order to compare with the 2D results, and also this will enable new inner geometries (i.e. riffled tubes).

References

- Sarah Mokry *et al.* Development of supercritical water heat-transfer correlation for vertical bare tubes. Nuclear Engineering and Design 241 (2011) 1126–1136
- Jan A.M. Withag *et al*. Heat transfer characteristics of supercritical water in a tube: Application for 2D and an experimental validation. J. of Supercritical Fluids 70 (2012) 156– 170
- Jackson, J.D., 2002. Consideration of the heat transfer properties of supercritical pressure water in connection with the cooling of advanced nuclear reactors. Proceedings of the 13th Pacific Basin Nuclear Conference, Shenzhen City, China, October 21–25.

EPSRC Engineering and Physical Sciences Research Council
THE UNIVERSITY OF WARWICK
Tsinghua University
NORTH CHINA ELECTRIC POWER UNIVERSITY
e.on
EMERSON
SCOTTISHPOWER

Excerpt from the Proceedings of the 2014 COMSOL Conference in Cambridge