Code_Saturne
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Buoyancy effects on turbulence in AGR channels.

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Introduction

Operating reactors in the UK are predominantly of gas-cooled designs (the one exception being the Sizewell B PWR). The main criteria to select a particular coolant gas are: safety, chemical inertness and high thermal efficiency. For example, in currently-operating Magnox and Advanced Gas-Cooled Reactor (AGR) stations (Figure 1), the coolant is carbon dioxide principally flowing upward . On the other hand, in "Generation IV" Very High Temperature Reactors (VHTR) the coolant proposed is helium which flows downward.

In general, convective heat transfer is divided into two main regimes: forced convection, in which the motion of the flow is driven by an applied pressure gradient, and natural convention, in which the motion is caused by body forces generated by density variations (buoyancy effects). Under "post-trip" condition, where the heat loading is relatively high relative the flow rate, there is a superpositioning of forced and natural convection, creating a heat transfer regime termed "mixed convection".

When an ascending turbulent flow is strongly heated it may undergo relaminarization. Under such conditions, there may be an impairment of heat transfer. For downward turbulent flow an opposite effect is observed: heat transfer levels are enhanced. It is possible to characterize the heat transfer regimes by dimensionless parameters such as Gr/Re^2 or the Buoyancy Number ($Bo=8exp(4)\cdot 16Gr_q/((2\cdot Re)^{3.425}Pr^{0.8})$. At lower values of these parameters, the flow regime is dominated by forced convention, while an increase causes a shift of the flow regime towards one where buoyancy forces are important.

Thus, to be able to carry out a reliable numerical studies for future nuclear power plant designs, there is a need to assess the actual RANS turbulence models in the computation of flows in vertical pipes under the conditions described above.

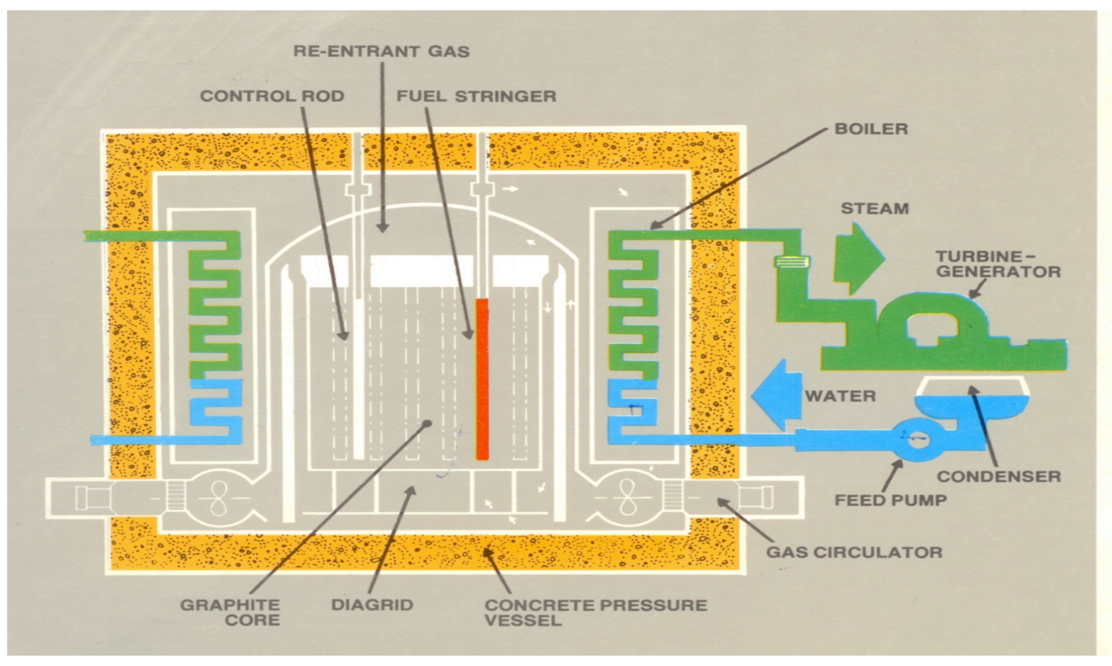

Figure 1: AGR plant design.

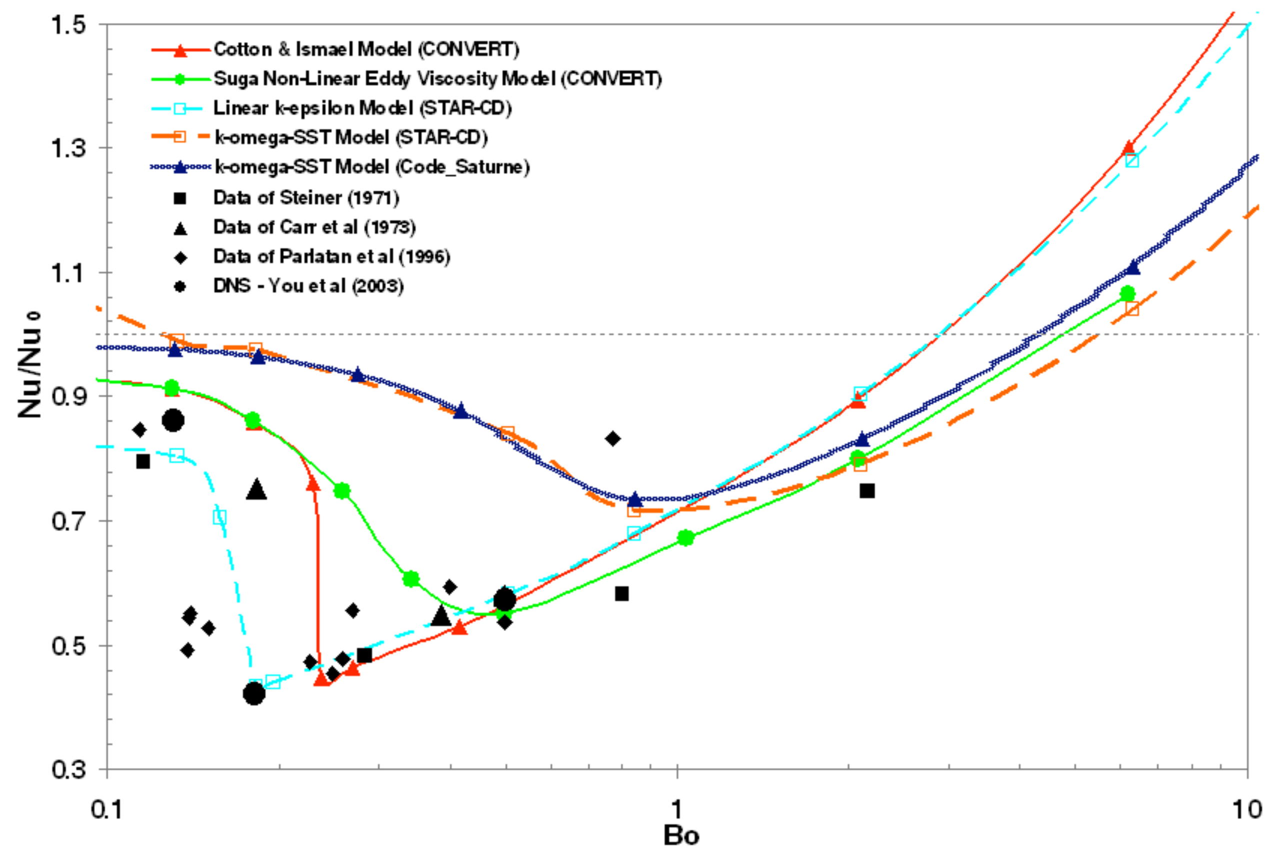

Figure 4: Nusselt number as a function of Bo. (2)

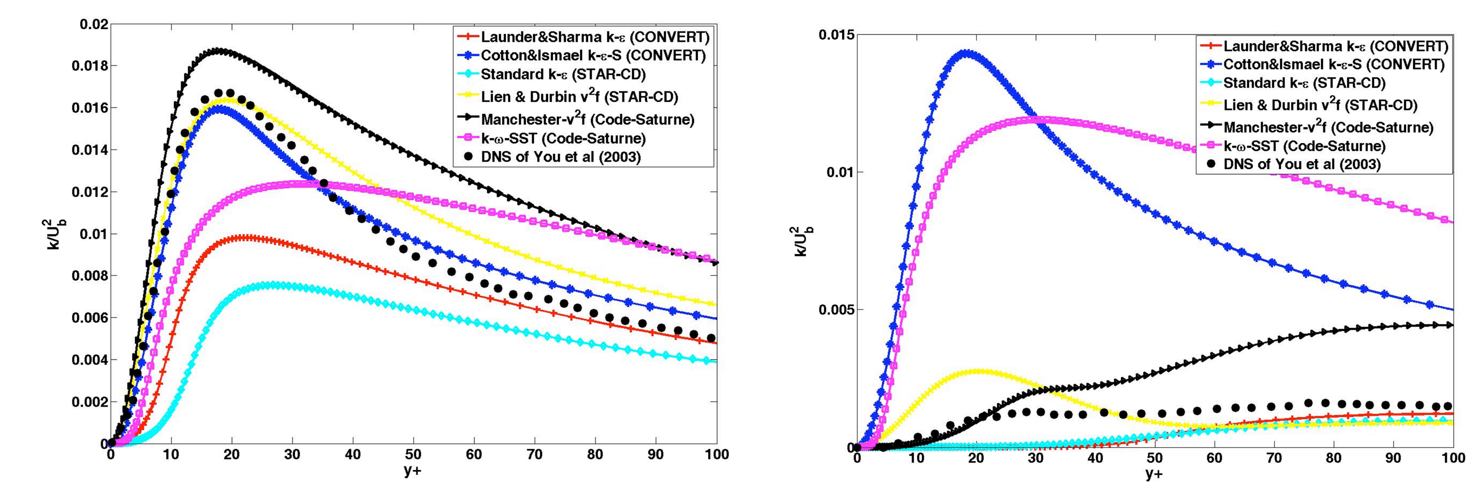

Figure 5: Turbulent kinetic energy profiles at Gr/Re2=0.06 and Gr/Re2=0.087

Problem Definition

The geometry under investigation is presented in Figure 2, with following parameters:

- Radius =0.1m
- Ascending flow
- Constant heat flux at the wall
- Working Fluid: air
- Boussinesq Approximation. i.e. variation of fluid properties other than the density are ignored. In addition, density variations are only taken in account in the gravitational force term in the Navier-Stokes equations.
- Re_D=2650 (based on the bulk velocity and radius diameter) corresponding to a Re_τ=180 (based on friction velocity and the pipe diameter)

Different hear transfer regimes have been analysed, from Gr/Re2=0.000 (Forced Convection), then Forced Convection / Mixed convection, Relaminarization (Gr/Re2=0.087), Recovery and Natural Convection

CFD Codes used in this work

- CONVERT (In-house code)
- Star-CD (Commercial code)
- *Code_Saturne* (Industrial code)

Turbulence model tested:

- Launder-Sharma k-ε model [1]
- Cotton-Ismael k-ε-S model [2]
- Chen k-ε model [3]
- Suga NLEVM [4]
- k-ω SST model [5]
- Lien and Durbin (LDM) v^2-f model [6]
- Manchester v^2-f model [9]
- L.E.S

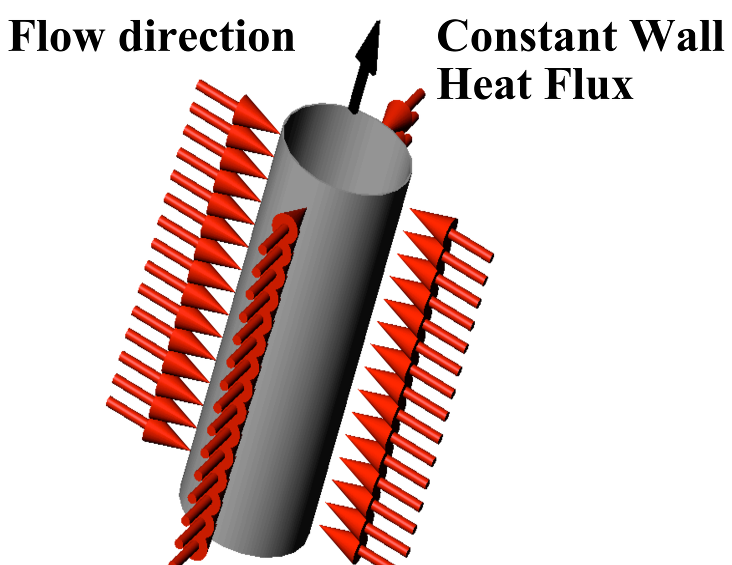

Figure 2: Geometry

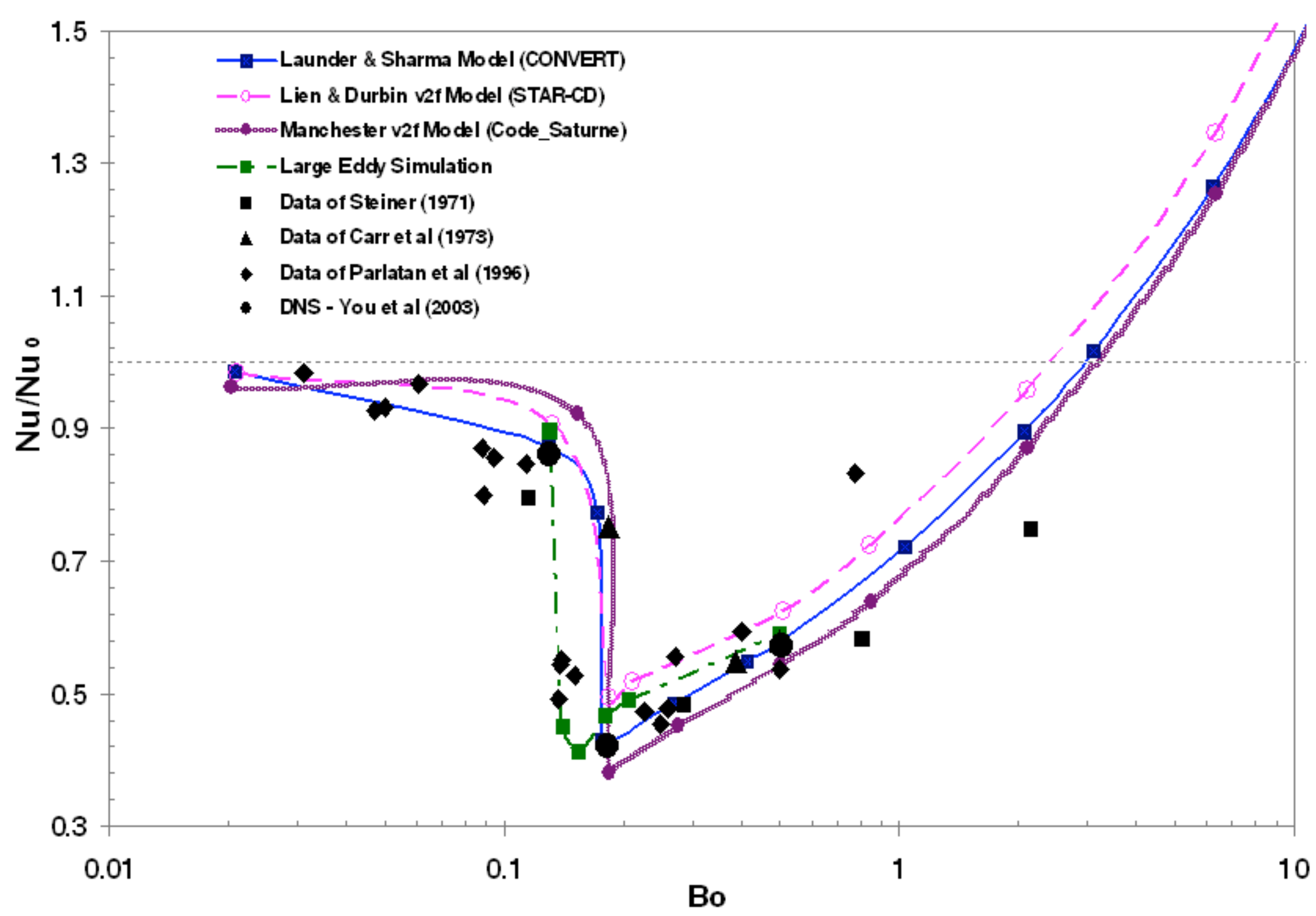

Figure 3: Nusselt number as a function of Bo. (1)

Conclusions and Future Work

- Different turbulence models have been tested, and the present findings can be summarized as:
  - Interestingly, the less sophisticated linear k-ε turbulence models (LS CONVERT and also Linear Star-CD) predict Nusselt numbers the most accurately. The v2f-based models also captures laminarization quite accurately.
  - The relatively more advanced turbulence non-linear k-ε model of Suga et al. [4] is observed to suffer from convergence problems at high Gr/Re^2. Thus, further investigations are needed to track the parameters causing these stability problems.
  - Although the k-ω SST model predictions are less satisfactory in comparison with the other models discussed above, a clear agreement is observed between the results obtained using Star-CD and those generated using *Code_Saturne* .
  - It should be noted, however, that mixed convection flows have a number of complicating features. Work is now in progress to assess more thoroughly the detailed performance of the various turbulence models.
  - The recent LES results, carried out by Y. Addad [8], are observed to predict a somewhat early impairment point in better agreement with the experimental data of Parlatan et al. These recent LES runs, in progress, would help in providing more points for future validation of the RANS models discussed above.

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