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CHT-17: Numerical investigations of turbulent natural convection in open ended channels

Victoria Timchenko
School of Mechanical & Manufacturing Engineering, UNSW, Sydney, Australia
Email: v.timchenko@unsw.edu.au

Computational investigations of turbulent natural convection in the channels with open boundaries are presented. Open-ended channels occur in the double-skin, building-integrated photovoltaics (BIPV) systems in which an air gap is formed between the envelope of a building and a secondary PV façade. Since the efficiency of the arrays is reduced as their temperature increases when PV arrays are heated by solar radiation, there is a need in the passive cooling of the BIPV systems which can be achieved by means of natural convection of air in the channel. Complex physical phenomena which occur in such channels, in particular turbulence mean that heat transfer within the channel is greatly affected by the fluid motion in the duct. Large Eddy Simulations have been used to study the development in model channels of the 3-D flow, its effect on heat transfer and transition to turbulence. Uniformly and non-uniformly heated configurations in which heat sources alternated with unheated zones on both walls were studied to simulate opaque PV arrays and glazed panes/windows of the building. A separation of the thermal plumes from the heated walls of the channel has been observed. It was shown that in the case of the non-uniformly heated channel on both sides these plumes move across the channel and turn into travelling waves leading to significant mixing thereby allowing larger heat transfer rates comparing with one side uniformly heated channel.

The numerical model results were validated by comparison with experimental data obtained at CETHIL in Lyon and UNSW in Sydney. Validating computational models of turbulent natural convection by comparison with experimental data presents a challenging problem as the difference between experimental and numerical results could be the effect of an inadequate model or the use of inappropriate boundary conditions. A better agreement with the experiment might be obtained by "improving" the model, or by obtaining "better" boundary conditions or a combination of the two. The issue of "improving" the model has been explored by accessing the performance of four different large-eddy simulation subgrid-scale models for natural convection in an asymmetrically-heated vertical parallel-plate channel with a high aspect ratio. The compressible three-dimensional Favre-filtered mass, momentum and energy conservation equations have been closed using the Smagorinsky, dynamic, approximate localised dynamic and Vreman models. Based on the comparison with experimental data, it has been shown that the Smagorinsky model predicts inaccurate near-wall flow dynamics and delayed transitional behaviour while both dynamic procedures to compute the Smagorinsky model coefficient result in over prediction of wall temperatures, suggesting an under estimation of subgrid-scale dissipation. At the same time, time-averaged wall temperature and velocity field profiles have been well captured by the Vreman model, demonstrating its superiority when compared to the rest of the models.

However, there was still a problematic aspect of the numerical work and to match the experimental data, random fluctuations in the inlet velocity needed to be introduced. Since the fluctuations needed to be "tuned", this was interpreted as being the result of an interaction between the fluid flows generated in the laboratory as the result of the discharge of the heated air from the apparatus and other equipment. As a result a 2-D numerical model of the apparatus and the laboratory were developed. The problem related to validation of numerical models by comparison with experimental results is clearly illustrated by the 2-D simulations.

More recently including radiation and the effects of humidity of air have been studied by including a participating medium in the model. The effects of wall and gas radiation on turbulent natural convection in the open ended channel were explored using LES coupled with Discrete Ordinates Method (Carlson and Lathrop [1965]). To model radiation properties of water vapour, the SLW/WSGG algorithm as proposed by Solovjov and Webb [2000] for calculating the absorption coefficients in the medium, was utilized. Three-dimensional simulations have been undertaken in the channel with one wall uniformly heated and side walls assumed to be adiabatic for different values of emissivity of the active walls.

It has been shown that introducing the effect of wall to wall radiation with high value of walls emissivity result in significant changes in the heat transfer and flow in the channel with both mixing and cooling rates increased. Including gas radiation for humid air with the water molar fraction of 0.02 corresponding to saturated conditions at inlet temperature of 25◦C, had very low effect comparing with wall radiation.

It follows that in future studies of BIPV channels the effects of humidity do not need to be included into modelling thereby significantly reducing the computational effort.

References

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