Computational fluid dynamic simulation of a solar enclosure with radiative flux and different metallic nano-particles
Kuharat, S, Beg, OA, Kadir, A and Babaie, M

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ANSYS FLUENT CFD METHOD

Simulations are executed in ANSYS software with the SIMPLE algorithm available with the pressure-based solver appropriate for incompressible flows. Quadrilateral "quad" elements have been used in the meshing process, and the square enclosure case is AR = 1 in Fig. 1. Quad elements are commonly used in a simple geometry to reduce simulation times. Fig. 2 illustrates the grid sensitivity analysis which shows that the simulations attain mesh-independent convergence with 10,000 elements.

VALIDATION

To validate the results obtained from the ANSYS Model for natural convection inside a 2-D enclosure filled with copper-water nanofluid, with a Rayleigh number of $10^5$, a comparison is conducted with the earlier study of Abo-Hana and Otten (2008) for an aspect ratio of 1 (narrow enclosure) as shown in Fig. 3 A-B. The CD simulation, using ANSYS FLUENT, achieves close correspondence with the results in [3] as testified by the very close similarity in stream line and isotherm pattern contours. Other test cases were also conducted to further confirm confidence in the ANSYS FLUENT model. Once confidence was established in the simulations it is possible to progress with complexity in the geometry, buoyancy nanofluid type and radiative effects.

CONCLUSIONS

- Results of selected simulations have been presented in Figs. 3-8
- Simulations show that the Rossladean model predicts a temperature field (Fig. 4) very different from that obtained without radiation. For low optical thickness in the problem, the temperature field predicted by the Rossladean model is not physically realistic. The P1-differential radiative model produces a more homogeneous thermal effect adjacent to the hot wall and enables radiation to penetrate more evenly through the nanofluid enclosure, whereas the Rossladean model predicts a biased temperature enhancement only on the top left corner
- The P1-differential model produces the correct profile since the radiation source in the energy equation, which is proportional to the absorption coefficient, is small. The Rossladean model uses an effective conductivity to account for radiation, and yields the wrong temperature field, which in turn results in an erroneous velocity field
- Deviations in the velocity profiles are of the order of 0.1 for the three cases of the Rossladean model, P1 model and no radiation model. The P1-differential model accurately simulates the presence of a momentum boundary layer along the hot and cold walls. These concerns with other studies in the literature [3],
- Higher Rayleigh numbers (Fig. 8) are achieved for the Titanium water nanofluid compared with Silver water profiles are much closer to those obtained from nanofluids which is attributable to the higher thermal conductivity of the former.
- With decreasing aspect ratio (AR = ratio of height of enclosure to width of enclosure) there is significant expansion in the thermal dual zone at the upper and lower zone of the enclosure. For AR < 0.5 the thermal expansion is stronger than the other aspect ratios. However, at higher aspect ratios, the streamline distributions are more symmetrical than at the lower AR value where the symmetry is observed and a stagnation emerges in the circulation which is biased towards the left hot wall of the enclosure. Vortex structure is therefore clearly influenced by aspect ratio
- Overall the isocontours are compressed towards the hot wall and the cold ceiling and most of the enclosure is occupied by warmer fluid at higher AR value. Due to this effect, the single cell is expanded in both vertical and horizontal directions at higher aspect ratio with lesser distortion in the flow. This expansion results in boundary layer formation
- Nusselt number at the left hot wall is maintained at low aspect ratios (AR =0.5) and increased at high aspect ratio (AR=1) indicating that shorter and boundary layer enclosures achieve significantly better heat transfer rates than taller and narrower enclosures.
- The present simulations provide a good benchmark for experimental studies and may also be generated for other metal nano-particles (gold, zinc etc.) and extended to the unsteady case. These aspects are currently under consideration [7, 8]