# Numerical Simulation of Natural Convection in a Vertically Installed Wet Thermal Insulator

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## 1. Introduction

Natural convection in an enclosure with disconnected vertical partitions inside is thought of as major concerns in the design of thermal insulators. For example, in a system-integrated modular advanced reactor (SMART), vertical partitions are disposed inside the so-called wet thermal insulator [1] with gaps at the top and bottom ends to compensate for thermal expansion (Fig. 1). In such a case, buoyancy driven flow circulates throughout the enclosure, i.e., fluid rises up in the hot-side layers, passing through the gap at the top, moving downward in the vertical channels near the cold side, and returning to the hot-side layers via the gap at the bottom. Compared with the case of connected partitions, this often causes an undesirable increase in the circulation flow rate and heat transfer within the enclosure, thus deteriorating the thermal insulation performance. In this study, laminar natural convection in a tall rectangular enclosure with disconnected vertical partitions inside is investigated numerically. The effects of main governing parameters such as the modified Rayleigh number, enclosure height to width ratio, and number of fluid layers are scrutinized along with a discussion of the heat transfer regimes.

## 2. Methods and Results

### *2.1 Computational Setup*

Figure 1 illustrates a schematic of the tall rectangular enclosure considered, which is subjected to a horizontal temperature difference imposed over two side walls, with equally spaced vertical interior partitions separated from insulated top and bottom walls by a distance $\delta$. Assuming that a steady incompressible laminar flow exists throughout the enclosure and fluid properties are constant except for density varying with temperature (Boussinesq approximation), a series of simulations are carried out with the aid of a commercial computational fluid dynamics code, Fluent 12.0 [2], for channel width to height ratio $\delta/H$ of $4\times10^{-4}$−$1.4\times10^{-3}$, number of fluid layers $N$ of 4−20, and Rayleigh number defined by $Ra=\beta(T_h\text{-}T_c)gW^3/\alpha\nu$ of up to $3.4\times10^7$. The simulations are conducted on the grid system consisting of 40×2280 cells in each fluid layer with a minimum grid spacing of $0.01\delta$, while adopting a second-order upwind method for discretization and SIMPLE algorithm for pressure-velocity coupling.

### *2.2 Temperature Distribution*

Figure 2 shows isotherms in the partially partitioned enclosure at various modified Rayleigh numbers. At $Ra^*=(W/H)Ra=6.3\times10^3$, isotherms are arranged parallel to the side walls of the enclosure and are uniformly spaced in the horizontal direction except the region near the top and bottom walls, i.e., temperature varies almost linearly in the horizontal direction and the conduction dominates the overall heat transfer. When $Ra^*$ increases, the isotherms tend to flatten (perpendicular to the side walls) in the central part of the enclosure, while closely spaced isotherms owing to a steep temperature gradient are presented near the side walls. These results indicate that the temperature variation within the fluid layer diminishes inward from the sides into the center of the enclosure, and the heat transfer regime changes from conduction to the circulation dominant regime with an increase in the modified Rayleigh number.

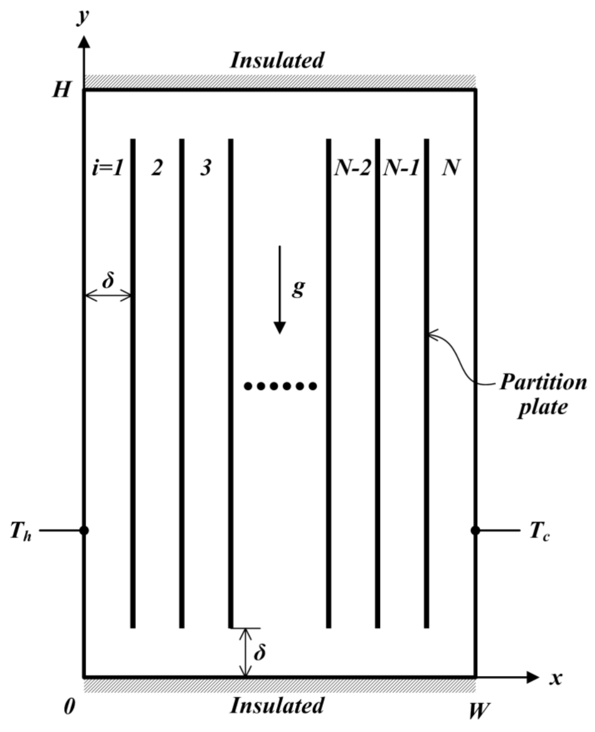


Fig. 1. Schematic of a rectangular enclosure with disconnected interior partitions

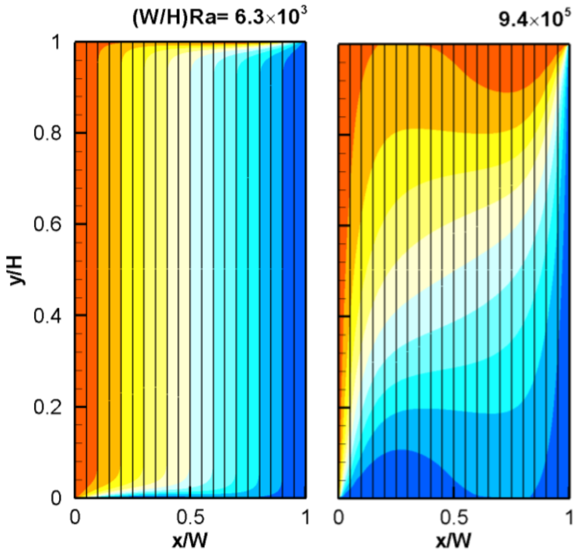


Fig. 2. Influence of modified Rayleigh number on temperature distribution for *N*=20

### *2.3 Mean Velocity Distribution*

The influence of the modified Rayleigh number on the formation of natural circulation inside the enclosure is shown in Fig. 3, where the mean velocity of the buoyancy driven flow in each fluid layer relative to that in the first layer is plotted for *N*=20. At $Ra^*=6.3\times10^3$, it is observed that similar to the temperature distribution, the mean velocity varies almost linearly with the layer index. On the other hand, at a higher $Ra^*$, the velocity magnitude is found to decrease non-linearly toward the center of the enclosure, and its reduction rate increases with an increase in $Ra^*$. Together with the numerical results depicted in Fig. 2, this suggests again that natural convection becomes increasingly significant with a rise of the modified Rayleigh number.

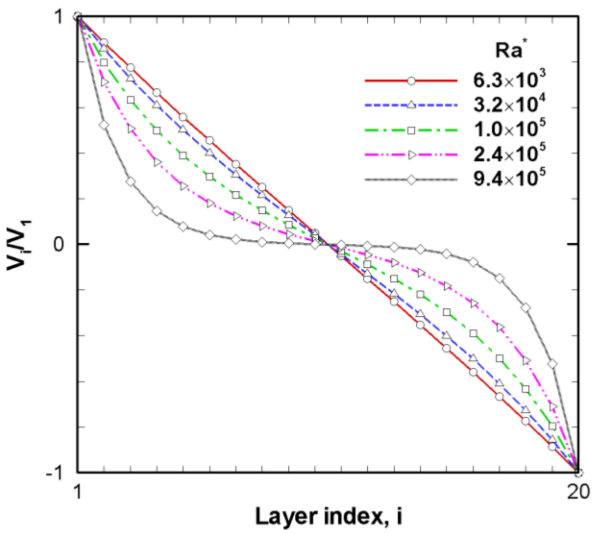


Fig. 3. Effect of modified Rayleigh number on mean velocity distribution for *N*=20

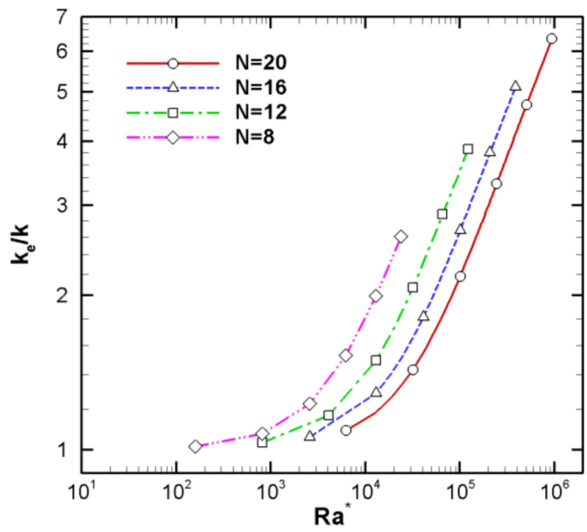


Fig. 4. Influence of modified Rayleigh number on effective conductivity of the enclosure for various *N*

### *2.4 Effective Conductivity*

Figure 4 shows the relationship between the effective conductivity of the enclosure $k_e$ (normalized by fluid conductivity $k$) and the modified Rayleigh number for varying the number of fluid layers. As expected, it is shown that the effective conductivity increases with the modified Rayleigh number, i.e., convective heat transfer arising from natural circulation becomes pronounced as $Ra^*$ increases. It also appears that for a given $Ra^*$, the effective conductivity decreases with an increase in the number of fluid layers, the influence of which becomes significant at a higher $Ra^*$.

## 3. Conclusions

This study investigates the laminar natural convection in a tall rectangular enclosure having isothermal side walls of different temperatures and insulated top and bottom walls with disconnected vertical partitions inside. The obtained results show that the effective conductivity increases with increasing the modified Rayleigh number, but decreases with an increase in the number of vertical partitions.

## Acknowledgement

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## REFERENCES

[1] S. H. Kim, Y. I. Kim, C. T. Park, S. Choi, J. Yoon, Effect of Gaps on the Performance of the Vertically Installed Wet Thermal Insulator, Proceedings of the 2012 International Congress on Advances in Nuclear Power Plants (ICAPP '12), Jun. 24-28, 2012, Chicago, USA.
[2] ANSYS Inc. Fluent 12.0 Theory Guide, 2009.