Three-Mode Heat Transfer Simulations in Parallelogrammic Air Enclosures

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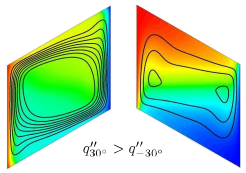
Context

- In closed fluid cavities, the natural convection driven by the temperature difference between vertical hot and cold walls has been investigated in numerous occasions.
- The heat transfer is much more important when the vertical hot wall is located below the cold one (left cavity in the figure), compared to a case for which the vertical hot wall is located above the cold one (right cavity in the figure).
  - This phenomenon is refered to as the **thermal diode potential**.
- The objective of this study is to investigate the thermal diode potential of air-filled enclosures when the three modes of heat transfer are considered.



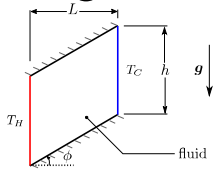
Temperature fields (colored background) and evenly distributed stream functions (black lines).

Methodology

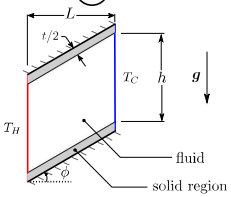
- Finite-volume CFD simulations;
- 2D, laminar and steady;
- Mesh ranging from 22 500 to 40 500 elements;
- 2nd order schemes;
- Single adiabatic enclosures with or without solid regions.

Calculation domains:

- Domain (D1):



- Domain (D2):



Analysis parameters:

- Nusselt number:

$$\overline{Nu} = \frac{q''}{q''_{ref}} = \frac{q''}{k_f(T_H - T_C)/L},$$

- Thermal diode parameter:

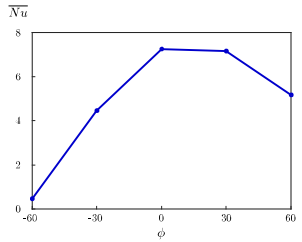
$$\xi = \frac{\overline{Nu}|_{\phi=60°}}{\overline{Nu}|_{\phi=-60°}}.$$

Governing dimensionless parameters tested:

• h/L	1	Aspect ratio of the cavity
• Ra	$5 \cdot 10^5$	Rayleigh number
• Pr	0.71	Prandtl number
• ϕ	-60°, -30°, 0°, 30°, 60°	Inclination angle
• t/L	0.01, 0.1	Thickness ratio of the solid regions
• k_{solid}/k_{fluid}	1, 10	Thermal conductivity ratio
• ϵ	0.1, 0.9	Uniform internal surface emissivity
• $\frac{T_H + T_C}{2(T_H - T_C)}$	9.75	Radiation mean temperature

Pure-Convection Cavity

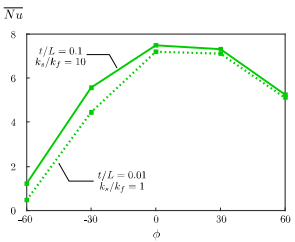
D1

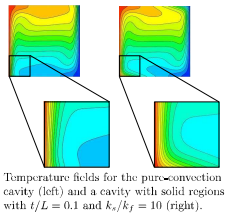


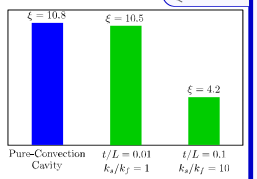
High asymmetry around $\phi = 0°$:
⇩
High thermal diode potential ($\xi = 10.8$).

Convection-Conduction Cavity

D2




Temperature fields for the pure-convection cavity (left) and a cavity with solid regions with $t/L = 0.1$ and $k_s/k_f = 10$ (right).



Convection-conduction **vs.** **Pure convection**

⇩

Slight increase of the Nusselt numbers.

⇨ Decrease of the temperature gradients in the fluid near the vertical walls;

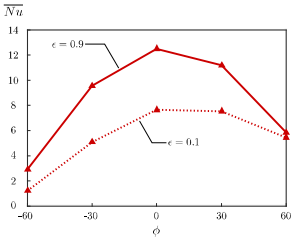
⇩

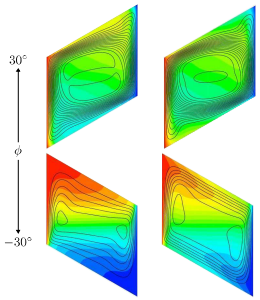
Decrease of the convection heat transfer.

Moderate decrease of the thermal diode potential.

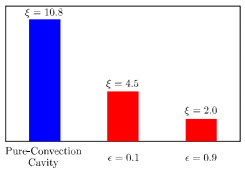
Convection-Radiation Cavity

D1





Temperature fields (colored background) and evenly distributed stream functions (black lines).



Convection-radiation **vs.** **Pure convection**

⇨ Important increase of the Nusselt numbers.

⇨ If ϵ increases:

- For $\phi > 0°$:

  Large decrease of the convection heat transfer.

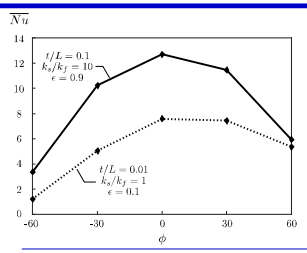
- For $\phi < 0°$:

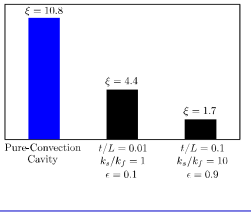
  Small increase of the convection heat transfer.

Drastic decrease of the thermal diode potential.

Three-Mode Heat Transfer Cavity

D2





Three-mode heat transfer **vs.** **Pure convection**

⇨ Important increase of the Nusselt numbers.

Further decrease of the thermal diode potential.

Conclusion

- Due to the overall increase of the heat transfer and to the important interaction between the three modes of heat transfer, the thermal diode potential of parallelogrammic air-filled enclosures is significantly reduced when the three heat transfer modes are considered.
- For more details, see *The thermal diode and insulating potentials of a vertical stack of parallelogrammic air-filled enclosures*, to appear in the International Journal of Heat and Mass Transfer.

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