Proceedings of the 9th International Conference on Fluid Flow, Heat and Mass Transfer (FFHMT'22)
Niagara Falls, Canada – June 08-10, 2022
Paper No. 127
DOI: 10.11159/ffhmt22.127

Natural Convection in Phase Change Material: Experimental Study

Justine NOEL[1], Christel METIVIER[1], Nicolo SGREVA[1], Sébastien LECLERC[1]
[1]Université de Lorraine, LEMTA, CNRS
NANCY, 54000, FRANCE
justine.noel@univ-lorraine.fr ; christel.metivier@univ-lorraine.fr;
nicolo.sgreva@univ-lorraine.fr; sebastien.leclerc@univ-lorraine.fr;

Extended Abstract

Phase change materials (PCM) are extensively studied nowadays in the context of energy storage. These materials can release a significant amount of energy with latent heat. However, the thermal conductivity of PCM is usually low, leading to a slow phase transition. Several methods exist to improve this process. One of these consists in increasing heat transfer via convection. Natural convection in PCM is widely studied by theoretical and numerical means [1,2,3]. The review proposed by Dhaidan & Khodadadi [1] highlights the effect of convection of PCM on the melting and heat transfer considering different geometries and thermal boundary conditions. Madruga & Curbelo [2] and Favier *et al.* [3] have focused on the dynamics of thermo-convective instability determining the threshold, the convective structures and their evolution with increasing Ra. However, few experimental investigations exist. This is due to the fact that PCM are opaque in solid phase and cannot therefore be easily studied by classical optical methods such as PIV or LIF. To tackle this issue, we propose to use Magnetic Resonance Imaging (MRI) which allows to image through opaque materials and to measure velocity fields inside the liquid part. We use these techniques to investigate the influence of Rayleigh-Bénard Convection (RBC) on solid-liquid interface. A PCM, hexadecane with melting point of $T_m = 17.9°C$, is placed in a cylindrical cavity. Initially the sample is maintained at a homogeneous cold temperature T_c such as $T_c < T_m$, in order to have the PCM in solid state. Then, we apply a vertical temperature gradient by imposing several increasing temperature steps at the lower wall. In the conductive regime, the liquid-solid interface is flat and horizontal. The continuous melting of the solid leads to an increase of the fluid depth. Within our experimental conditions, the convection occurs above $Ra \approx 1430$. The thermo-convective flow affects the melting interface leading to a wavy interface, with higher liquid height in uprising flow and lower liquid height in downward flow regions. Our experiments show that the transient evolution of the mean liquid height $\bar{h}$ is enhanced with convection since $\bar{h} \propto t^{0.8}$, i.e. $\bar{h} \propto t^{\frac{1}{2-3\beta}}$ with $\beta = \frac{1}{4}$, while $\bar{h} \propto t^{0.5}$ in the conductive regime similarly to the Stefan's problem. The steady averaged liquid height $\bar{h}$ increases 4 times larger in the convective regime than in the conductive regime. In our experiments the range of A, ratio between the solid and liquid heights, is such as $A > 1.5$. Within this range of values, we obtain convective pattern under the form of hexagons / polygons, in agreement with Davis et al. [4]. As the melting boundary grows, we observe a decrease in the polygon number. The polygonal pattern is characterized by a constant dimensionless wavelength, i.e. $\lambda/\bar{h} \approx 2$, and thus a constant wavenumber around 3.1 similarly to the primary bifurcation in the classical Rayleigh-Bénard Convection. Heat transfer is evaluated via the Nusselt number Nu. Close to the onset of convection and above, our results highlight a scaling law $Nu \propto Ra^{\beta}$ with $\beta = \frac{1}{4}$ similarly to the classical RBC. The kinetic energy E_c is also evaluated via velocity measurements leading to $E_c/E_0 \propto Nu^4$. They reflect clearly an increase in the convective intensity from both thermal and dynamical points of view.

References

[1] N. S. Dhaidan and J.M. Khodadadi, "Melting and convection of phase change materials in different shape containers: A review", *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 449–477, 2015.
[2] S. Madruga, N. Haruki and A. Horibe, "Experimental and numerical study of melting of the phase change material tetracosane", *International Communications in Heat and Mass Transfer*, vol. 98, pp. 163-170, 2018.
[3] B. Favier, J. Purseed and L. Duchemin, "Rayleigh-Bénard convection with a melting boundary", *Journal of Fluid Mechanics*, vol. 858, pp. 437 – 473, 2019.
[4] S. H. Davis, U. Müller and C. Dietsche. "Pattern selection in single component systems coupling Bénard convection and solidification.", *Journal of Fluid Mechanics*, vol. 144, pp. 133-151, 1984.