Experimental study of a double-diffusive system: application to solar ponds

C. F. Tavares[1], D. C. Alves[2], J.M.P Coelho[3], M. Abreu [4],
A. M. Joyce [5], Edgar C. Fernandes[6]

1: Dept. of Renewable Energies, INETI, Portugal, celia.tavares@ineti.pt
2: Dept. of Optics and Laser, INETI, Portugal, david.alves@ineti.pt
3: Dept. of Optics and Laser, INETI, Portugal, joao.coelho@ineti.pt
4: Dept. of Optics and Laser, INETI, Portugal, manuel.abreu@ineti.pt
5: Dept. of Renewable Energies, INETI, Portugal, antonio.joyce@ineti.pt
6: Dept. of Mechanical Engineering, IST, Portugal, ecfernandes@dem.ist.utl.pt

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A salt gradient solar pond is an artificial device used to collect and store solar thermal energy. A non-convective zone, in the middle of the solar pond, reduces thermal losses and allows a significant rise of temperature in the saltier lower zone where the solar thermal energy is stored. The non-convective zone, also named gradient zone, is characterized by a salinity gradient that increase the density with depth promoting the stability of this layer. The absorption of solar radiation in the pond creates a destabilizing temperature gradient in the non-convective zone that contradicts the density gradient. The different molecular diffusivities of heat and salt and the opposing effects on the vertical density distribution of the two gradients can lead to double-diffusive convection phenomena. In this context, a double-diffusive system has been studied experimentally in laboratory by heating a stratified salt layer from below. The instabilities caused by the destabilizing temperature gradients lead to the formation of convective zones separated from purely diffusive zone by thin interfaces. The main goals of this work are the study of the evolution of the double-diffusive layer and the analysis of the behaviour of the diffusive interface near conditions for which instabilities appear.

1. Experimental set-up

The experiments are performed in a box with the dimension of 100×100×100 *mm*. The lateral sidewalls made in transparent plexiglass are isolated by polystyrene. The isolation is removed temporary for flow visualization with PIV and Shadowgraph technique. PIV system allows the measurement of velocities in convective regions and the observation of the flow patterns. Since flow velocities are a less than a few tens millimetres per second a single cavity Nd:YAG laser (10 *Hz*, 532 *nm*) is used for PIV illumination. An optical set-up produces a laser sheet with user-defined 1 *mm* to 1.5 *mm* thickness. Images are acquired with a CCD camera, 640×480 pixels and 8.6×8.3 *μm* pixel pitch. A Shadowgraph technique is used to identify the positions of the interfaces zones. Vertical temperature and salinity profiles are measured during the experiments.

2. Methodology and Results

The box is initially filled with a vertical linear stratified salt solution (NaCl) with a salt concentration growing with depth, which produce a stable density gradient. Laboratory studies begin when the stable gradient layer is heated from bellow by raising the bottom temperature to a prescribed value above the ambient temperature.

As observed in many double-diffusive experiments, bottom heat flux lead to instabilities typified by a first bottom convective layer separated from the gradient zone by a thin interface. For large bottom heat flux, or small saline gradient, the development of secondary convective layers separated by thin density interfaces is observed. Figure 1 show experimental results 3783 *s* after heating from bellow an initial linear stable solute gradient.

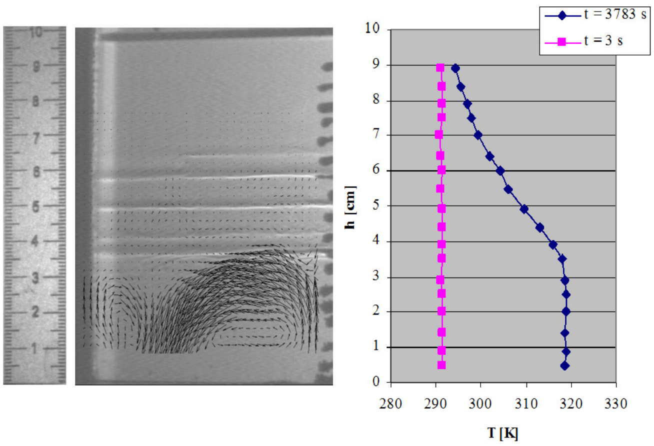

Fig. 1 – Convective zones separated by thin density interfaces and correspondent temperature profile. (Bottom temperature of 50 *ºC*; linear solute gradient of 0.55 *% cm*$^{-1}$)

3. Conclusions

The evolution of the system, namely the height of the bottom convective layer and the number of second convective layers separated by diffusive interfaces, depends on the initial solute gradient and on the value of temperature imposed at the bottom.

For high imposed temperature and weak linear solute gradient, vigorous convective layers separated by thin interface produces great instabilities and a (relatively) fast destruction of the diffusive zones. On the other hand, when the linear solute gradient is strong the system develops quasi-stationary states where the interfaces remain stable for a significant period of time.