EXPERIMENTAL AND NUMERICAL STUDY OF MARANGONI-NATURAL CONVECTION

L. H. Tan*, E. Leonardi*, T. J. Barber*, S. S. Leong*, T. A. Kowalewski**
*School of Mechanical and Manufacturing Engineering,
University of New South Wales, Sydney 2052, AUSTRALIA
** IPPT PAN, Department of Mechanics & Physics of Fluids, PL 00-049 Warszawa, POLAND

ABSTRACT

An experimental and numerical study of thermal Marangoni - natural convection was carried out to examine the flow behaviour under various conditions of liquid layer depth and heating conditions. Particle Image Velocimetry (PIV) and numerical results using FLUENT V6 are in good agreement. The liquid free surface profile due to the presence of the menisci is shown to be important for validation.

INTRODUCTION

Figure 1 shows the experimental setup of the PIV system. A cylindrical glass container of diameter 56.1 mm is filled with 10 cSt silicone oil to a layer depth of a few millimetres. The shallow depth reduces the strength of natural convection and allows Marangoni convection to dominate [1]. For visualization purposes, the oil is seeded with PSP polyamide particles and a laser diode illuminates the vertical centre plane of the oil. Under steady axisymmetric conditions, the complete flow behavior can be observed on this plane [2]. A CCD camera connected to an image acquisition board records the images for post-processing with PIV software. The container is placed in a water bath to maintain the side and bottom walls at a cooler temperature. A cylindrical copper piece (tip diameter 5 mm) connected with a soldering iron heats up the oil layer at the centre of its free surface. Owing to changes in local surface tension due to the imposed temperature gradient, oil at/near the surface flows out to the cold sidewalls followed by a return bulk flow (Figure 2 and 3).

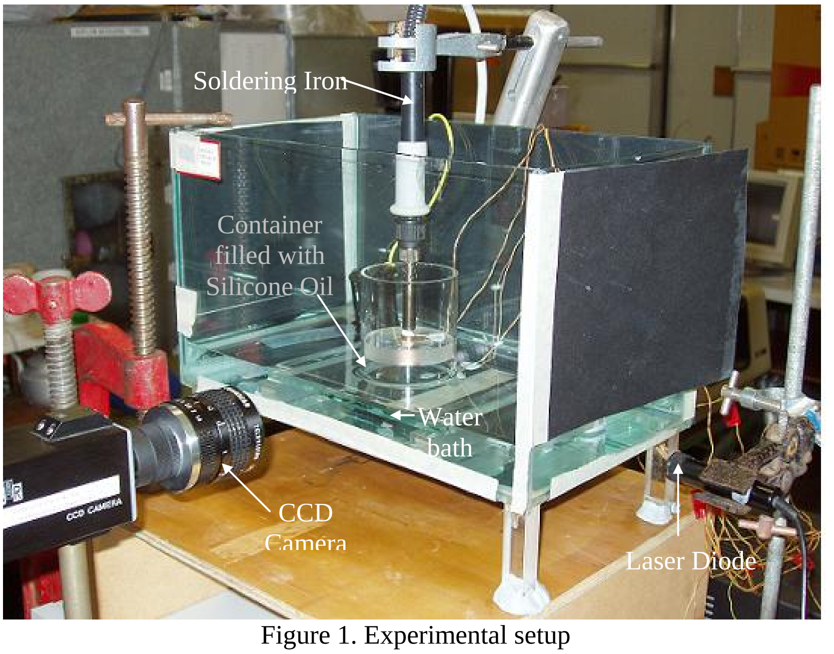

Figure 1. Experimental setup

RESULTS AND CONCLUSIONS

Figure 2 shows the experimental flow patterns at the centre below the hot tip, with a depth of 4 mm and temperature difference of 11.8 K. This corresponds to a Marangoni number, Ma = 3624. Figure 3 shows the flow patterns right of centre. A numerical model within FLUENT was constructed for comparison, using the Boussinesq approximation and assuming laminar, axisymmetric flow. Figure 4 shows the streamlines from the numerical predictions, providing comparison with Figure 3. The qualitative agreement is evident between the two.

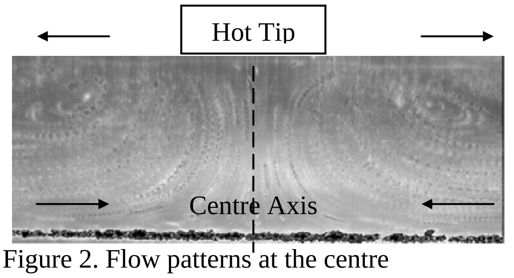

Figure 2. Flow patterns at the centre

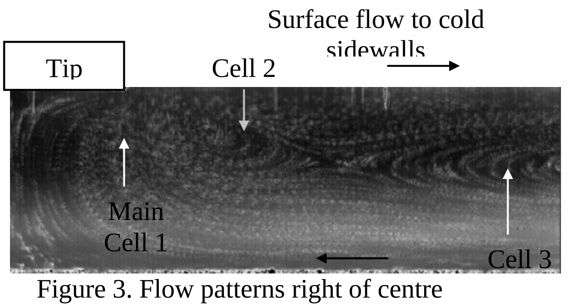

Figure 3. Flow patterns right of centre

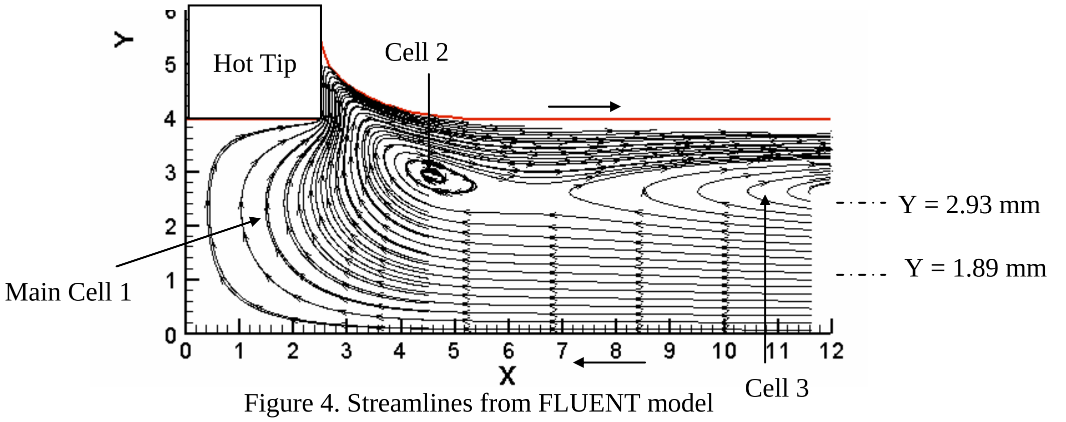

Figure 4. Streamlines from FLUENT model

The presence of two cells (Cell 2 and Cell 3) embedded within the main Cell 1 and rotating in the same direction can be seen in both experimental and numerical results. The meniscus present at the tip is modelled in FLUENT based on captured images to give more accurate quantitative comparisons. Figures 5 and 6 display the experimental and numerical velocity magnitudes across the layer at heights of y = 1.89 mm and y = 2.93 mm, showing good agreement between the two.

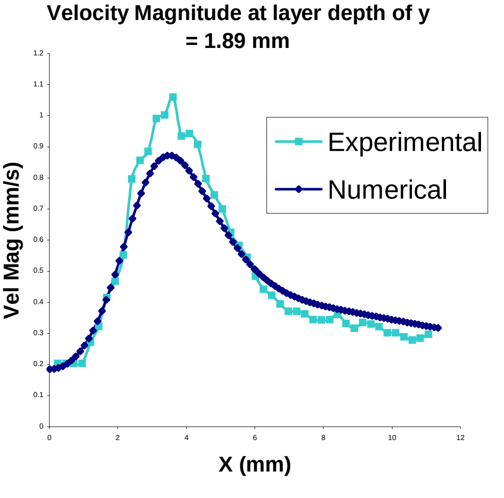

Figure 5. Velocity at y = 1.89 mm

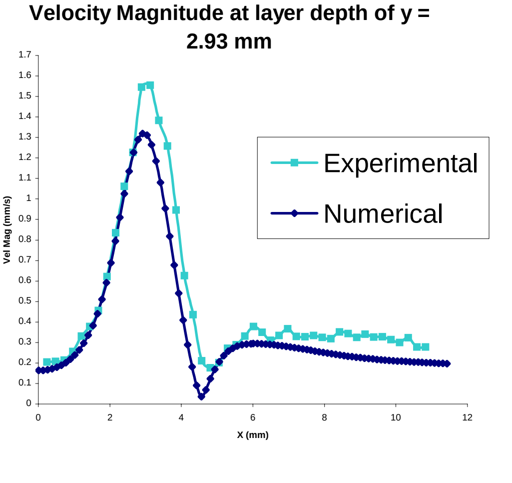

Figure 6. Velocity at y = 2.93 mm

In the paper, experimental and numerical results will be presented with a variation in parameters such as liquid layer depth and temperature differences. The effects of these parameters on the flow patterns and velocities will be presented.

REFERENCES

[1] D. Schwabe, U. Moller, J. Schneider, A. Scharmann, *Instabilities of shallow dynamic thermocapillary liquid layers*, Phys. Fluids A, 4 (11), (1992), 2368-2381.

[2] J. A. Szymczyk, *Interaction between thermocapillary and buoyancy driven convection*, Experiments in Fluids 12, 151-156 (1992)