ASCHT2019-179

Thermal and Flow Characteristics of Marangoni Convection Near a Micro Bubble Attached to the Channel Wall

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Abstract

In this study, the Marangoni convection generated by locally heating the wall near a micro-bubble which is attached to the channel wall is investigated using numerical solution. When the position of the hot spot deviated from the center of the bubble, a pair of vortices closely located to the bubble was formed. The position of the hot spot affected the flow structure significantly: namely the height position of the high temperature area at the bubble surface changes, and the distance to the top and bottom walls of the hot spot defines the vortex size and direction.

Keywords : Micro-Bubble, Marangoni Convection, Numerical Analysis, Hot Spot, Vortices

1. Introduction

Marangoni flow around a bubble provides various types of aspects in relation to the properties of the bubble and temperature distribution. One interesting phenomenon is the Marangoni convection around the bubble attached to the wall of a microchannel, the wall of which is locally heated near the bubble. In this case, a pair of strong vortices with the vorticity direction perpendicular to the wall is generated (see Fig.1) [1]. These flows can be applied to microfluidic devices for fluid mixing, driving flow, concentrating and dispersing particles. However, the three-dimensional flow structure, the cause of the flow, and the effects of the hot spot conditions are not understood yet. In this study, we will numerical investigate the heat and flow characteristics of this Marangoni flow, and evaluate the effects of the hot spot location and the size on the flow structure.

2. Numerical method

The governing equations solved in the present computation are the continuity, Navier -Stokes, and energy conservation equations. The equations are discretized using Finite Volume method. Immersed boundary (IB) method was used to model the interface between the fluid and bubble. Marangoni effect was considered by inserting the modified velocity derived from Eq. (1) to the grid to which the IB method was applied.

$$\frac{\partial u_s}{\partial n} = -\frac{1}{\mu}\frac{\partial \sigma}{\partial T}\frac{\partial T}{\partial s} \tag{1}$$

μ is viscosity, σ is surface tension. s and n are the tangential and the normal directions to the interface, respectively. The fluid properties of water at 20°C was used in the computation as the effects of property variation as the temperature effect was not large. Figure 2 shows the computational domain of the sphere bubble attached to the bottom wall. The radius of the bubble is R = 25μm, and the distance between the bubble center and channel wall is 24.5μm. A hot spot of circular shape of radius 5μm is applied to the bottom wall at location of (0,l,0). The temperature of the hot spot is uniform, and is 80°C, while other boundaries were set as 20°C. No-slip condition is applied to the top and bottom boundaries of the domain, and symmetric condition is applied to the side boundaries for temperature and velocity fields.

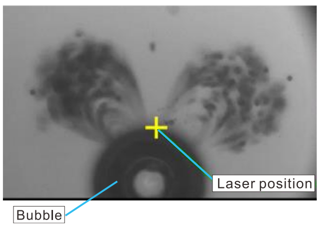
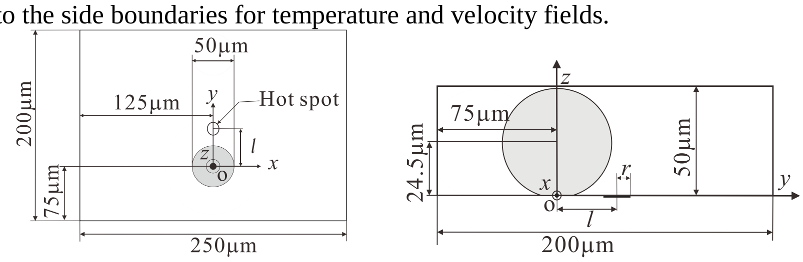


Figure 1: Top view of a pair of vortices generated around the micro bubble [1].



(a) top view (b) side view

Figure 2: Computational domain of the sphere (bubble) attached to the bottom wall of parallel plate channel.

3. Results and Discussion

Figure 3 shows the streamlines and temperature of the bubble surface, T_{surf}, for the case of the hot spot located at the bubble center (l=0). T_{surf} shows an axisymmetric distribution about the z – axis, and a vortex ring is generated around the bubble due to the Marangoni effect.

Figure 4 shows the case of the hot spot location deviated from the bubble center (l/R=2.0). In this case, high T_{surf} area at the bubble surface is located at the side of the bubble surface. The fluid flows from this area to the low temperature area along the surface due to the Marangoni effect. The flow, then, reaches the top and bottom walls and flow in the x directions along the wall. The flow partially separates from the bubble and wall, and a portion of the fluid flow back and generate vortices as shown in Fig. 4(a) as fluid should be supplied to the high T_{surf} area.

Figure 5 shows the result of the case when the hot spot is located closer to the bubble center within R as l/R=0.4. T_f shown in the figure is the temperature of the fluid at y - z section (x=0). Area of high T_f and T_{surf} is formed in adjacent to the bottom wall. Due to the tangential direction of the high T_{surf} area, Marangoni convection in x and y positive directions is generated significantly. To conserve the mass, part of the flow forms vortices near the wall and returns to the high T_{surf} area. On the other hand, Marangoni convection and vortices decreases near the top wall. The effect of the area size of the hot spot is also discussed in our presentation.

4. Conclusions

We investigated the mechanism of the Marangoni flow and a pair of vortices generated around the micro-bubble attached on the channel wall. As the hot spot is located far from the bubble, high temperature area is formed at the side of the bubble and a large scale vortices is generated in the height direction of channel. When hot spot is located very close to the bubble, strong vortices is generated locally which was attributed to the direction of the Marangoni flow and flow separation. Thus we can control the vortex structure by changing the position (and size) of the heating area.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 17H01050.

References

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[2] Y. Zheng et al., Lab. Chip, 11, 3816 (2011).

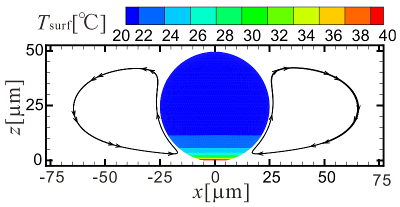
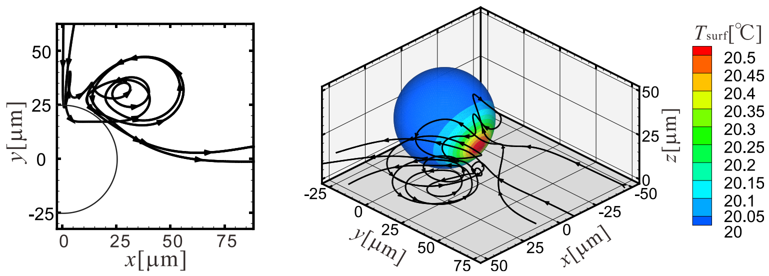
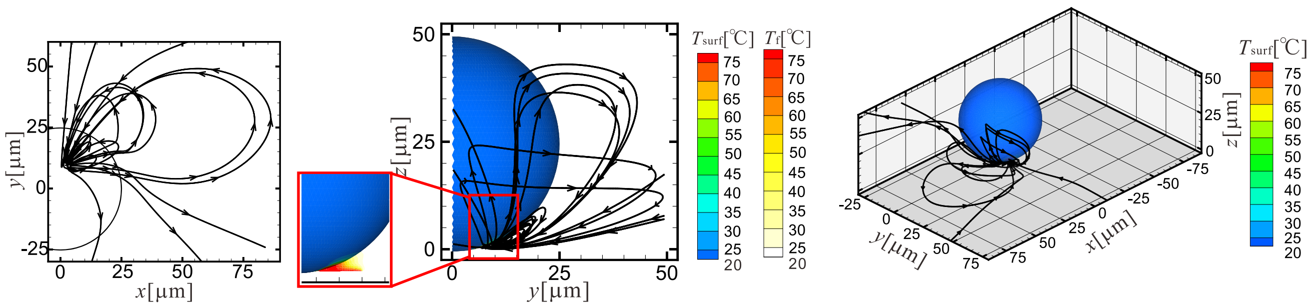


Figure 3: Streamlines and surface temperature distribution for the case of heating the bubble's center.



(a) top view (b) bird-eye view

Figure 4: Streamlines and temperature distribution of bubble surface and fluid for the case of l=50μm.



(a) top view (b) side view (c)bird-eye view

Figure 5: Streamlines and temperature distributions of bubble surface and fluid for the case of l=10μm.