Proceedings of the 18th UK Heat Transfer Conference

9-11 September 2024, Birmingham

UKHTC2024-001

THE EFFECT OF THE TEMPERATURE GRADIENT ON THE THERMOCAPILLARY DROPLET FLOW IN A VIBRATING FLUID INSIDE A ROTATING CYLINDER

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1. ABSTRACT

The volume-fluid (VOF) method was used to numerically analyze the thermocapillary isolated droplet rising in a vibrating liquid in a rotating 3D cylinder in a zerogravity environment. The Marangoni effect caused by the temperature differential drives the droplet from the cold region to the hot region. Complex droplet behaviors in zero gravity have been observed, attributed to certain forces that are ignored in the presence of gravity. Temperature gradient (∇T) increment accelerates the droplet's migration speed toward the hotter side of the vibrating fluid and a rotating cylinder with varying Marangoni numbers (Ma_T). A flow pattern figure that illustrates the actual flow behind each modification is included with every result.

2. INTRODUCTION

The fluid's bubble or droplet moves in the direction of the temperature gradient due to a process known as Marangoni flow, which occurs when fluid moves from lower to higher surface tension regions. Because of its significance in the design of space shuttle experiments, droplet motion inside a cavity has drawn the interest of researchers [1]. It is possible to gain a better understanding of the physical phenomena that occur in space and then manage them in the most effective way by using the CFD approach to simulate complex behaviors like Marangoni flows under low rotation and light vibration conditions.

3. METHDOLOGY

Using a linear model, Young et al. (1959) examined the thermocapillary flow of droplets and bubbles for the first time. The Reynolds and Marangoni numbers are the two most significant factors influencing thermocapillary motion [2]:

$$Re_T = \frac{r_d V_T}{\nu} \quad (1)$$

$$Ma_T = \frac{r_d V_T}{\alpha} = Re_T . Pr \quad (2)$$

$$Pr = \frac{\nu}{\alpha}, where\ \nu = \frac{\mu}{\rho} \quad (3)$$

The variables r_d, ν, and α represent the droplet radius, dynamic viscosity, thermal diffusion.

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As shown in Figure 1b, the computational domain was defined as a cavity with a non-slip adiabatic wall and no velocity at the inlet or outlet. All calculations began at time t = 0. In order to achieve the steady state against temperature gradient, the matrix liquid has been heated before patching the droplet using Ansys [3] Fluent's "region" function. Due to their temperature dependence, the density, viscosity, and surface tension coefficient for silicon oil and droplet were calculated using UDF. The present simulation utilized the density and viscosity thermophysical properties of the host liquid and Fluorinert (FC-75) droplet, which were taken from Table (1) of [4]. The density change as the host liquid and droplet's temperature changes is derived from:

$$\boldsymbol{\rho = A + BT} \qquad (4)$$

and the data regarding the viscosity variation between the two liquids' temperatures is derived from:

$$\boldsymbol{\mu = exp(C + D/T)} \qquad (5)$$

The surface tension coefficient is 3.6×10^{-5} N/m.K. between the oil (DC-200) and the fluorinert (FC-75) droplet. After thorough examination and validation, the VOF model by [3] was used with the user defined function (UDF) for the density and viscosity of the droplet and host liquid. Findings in figures 1(a,b) demonstrate that the surface tension, viscosity, and density user-defined functions (UDFs) were correctly coded, suggesting that it is a good option for resolving thermocapillary issues. The thermocapillary flow is characterized as laminar flow. The continuum surface force (CSF) model, which was put forth by [5], is used to compute the surface tension force for the cells with the droplet-host liquid interface. σ is a symbol for the surface tension.

$$\sigma = \sigma_0 + \sigma_T(T_0 - T) \qquad (6)$$

where σ_o denotes the surface tension coefficient at a reference temperature T_o, and σ_T is the rate of change of surface tension with temperature. The host liquid consists of incompressible Newtonian fluids.

4. RESULTS

The research findings are derived from simulating an isolated droplet with a diameter of 10 mm, positioned at the center of the cylinder and twice its diameter from the cold bottom wall. Prior to the droplet being released into an unstable vibratory motion, steady-state rotation and temperature distribution have been established. Every simulation was performed at time t = 0 with a stationary droplet and host liquid at initialization, no velocity at the inlet or outlet, and atmospheric pressure as the pressure. Figure 1(a,b) shows a flow pattern for a temperature gradient (∇T) of 0.5 K/mm, which corresponds to thermal Reynolds (Re_T) and Marangoni (Ma_T) numbers of 6.97 and 713, respectively. This indicates the droplet sequence migration towards the warmer region due to temperature-dependent surface tension, a phenomenon known as the Marangoni phenomenon. Figures 2 and 3 illustrate a series of droplet rotations about the y-axis in a vibrating fluid with an internal vibration frequency of $f = 0.1\ s^{-1}$ and a frequency amplitude of A = 0.005 m/s^2, as well as in a rotating cylinder with an angular velocity of (ω) = 0.5 rad/s. The distance traveled over time for various temperature gradients, consistently pointing in the direction of the hotter side, shows how variations in temperature gradient (Marangoni number).

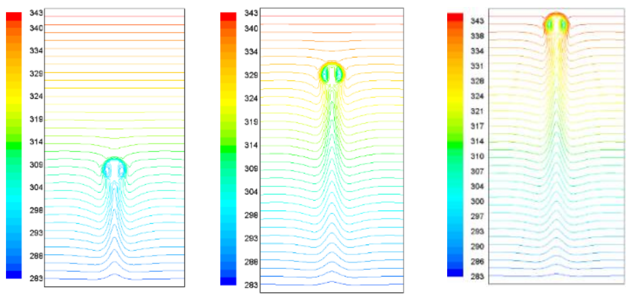


Fig. 1a Droplet trajectory toward the hotter side at t= 30s, 50s, 58s respectively, for 2d axisymmetry.

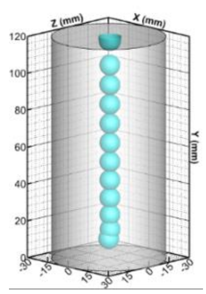
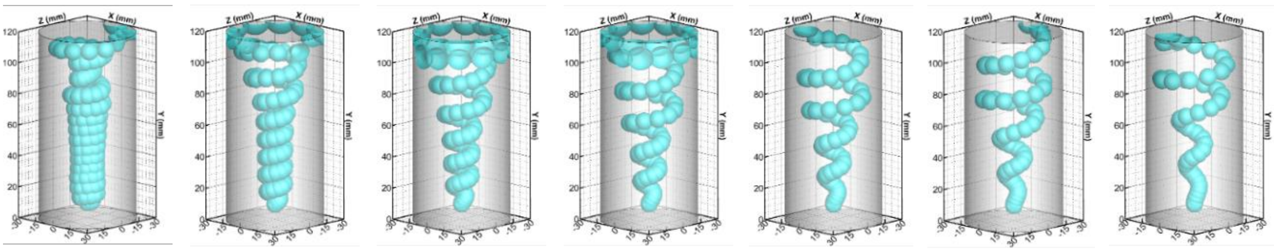


Fig. 1b Droplet trajectory toward the hotter side 3d.

The flow pattern in Figure 2 illustrates how droplet behavior in a zerogravity environment is affected by small and negligible vibrations in a normal gravity environment, where they do exist and must be taken into account. It also clearly shows that the temperature differential is the primary cause of the droplet behavior as it approaches the hotter surface. likewise taking note of the curves in Figure 3a. This implies that the variations affect droplet behavior at smaller temperature variations, i.e., below 350 K or below $Ma_T < 830$. However, the effect decreases significantly at large differences in temperature between hot and cold surfaces ($Ma_T > 1206$; $T_{Top} > 370$ K and higher). When T_{top} increases, the droplet velocity increases threefold, resulting in a shorter time to reach the upper surface, roughly 40 seconds when $T_{top} = 443$ K compared to 145 seconds when $T_{top} = 313$ K, when the droplet distance traveled as a function of time is plotted in Figure 3b. The rotational movement of the cylinder walls and the vibration of the host fluid are the main reasons why the droplet takes longer to reach the hot surface. As opposed to the droplet's migration in fixed cylinders, which happens in 108 s.



T_{top}=313K, Ma=289 T_{top}=333K, Ma=556 T_{top}=350K, Ma=830 T_{top}=370K, Ma=1206 T_{top}=390K, Ma=1641 T_{top}=410K, Ma=2131 T_{top}=443K, Ma=3056

Fig. 2 droplet migration and behavior sequence under the effect of the three forces (fluid vibration, cylinder rotation, and ΔT).

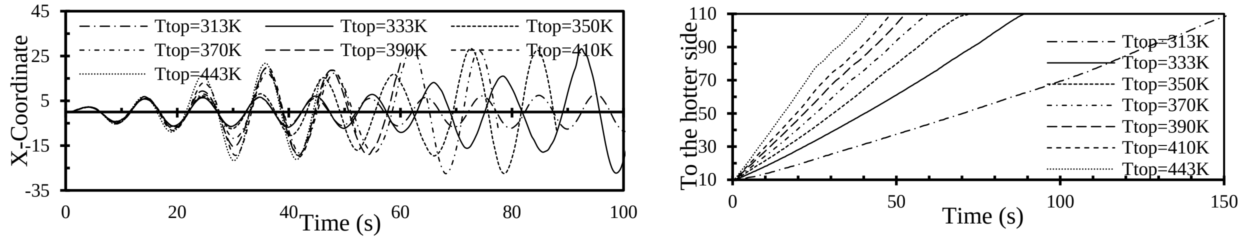


Fig. 3(a, b) shows the rotation of the droplet around the y-axis and the distance towards the hotter side for different temperature gradients.

5. CONCLUSIONS

Both the Marangoni droplet flow phenomenon in a gravity-free medium and the impact of temperature gradients on the migration behavior of droplets in a vibrating liquid within a rotating cylinder were illustrated. The findings demonstrate the significance of certain forces, like temperature variations, cylinder rotation and fluid vibration that are irrelevant in the presence of gravity. The surface tension coefficient and the VOF model with UDF are both well encoded, according to the results. This method, which is based on the Geo-Reconstruct algorithm, may be able to resolve Marangoni flow in zero gravity.

Acknowledgement

We wish to acknowledge the support of Kuwait Foundation for the Advancement of Sciences (KFAS).

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