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A Jet Induced Radial Flow on A Heated Circular Plate

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1. INTRODUCTION

A jet induced radial flow on a plate is common in nature and industry and has been extensively investigated [1]. In a gravity environment, when the jet of a liquid vertically flows from a nozzle onto a plate [2], the liquid may spread on the plate. A hydraulic jump occurs when a high velocity liquid flow enters a region of lower velocity during which the rapid liquid flow undergoes a deceleration and a noticeable rise in the liquid surface [3]. Conventional hydraulic jumps have been extensively studied [4].

On the other hand, the jet induced radial flow on the heated plate under thermocapillary effect may also show diverse phenomena. The diameter of the circular hydraulic jump is larger in microgravity than that in standard gravity. The hydraulic jump is dominated by surface tension and viscosity [5]. The literature review shows that there exists a noticeable absence in the study of the jet induced radial flow on the heated plate. In particular, the transition to chaos of the jet induced radial flow on the heated plate under thermocapillary effect remains unclear. This motivates the present study. Therefore, we conducted a series of experiments to investigate bifurcations in the transition to chaos. In this study, bifurcations are observed and the dependence of bifurcations on the Marangoni number and Reynolds number is characterized.

2. PROBLEM AND METHOD

We considered a jet induced radial flow on a heated circular copper plate of 150 mm diameter. The silicon oil was employed as the working fluid. Figure 1 shows a schematic of the experimental rig with measurement apparatus.

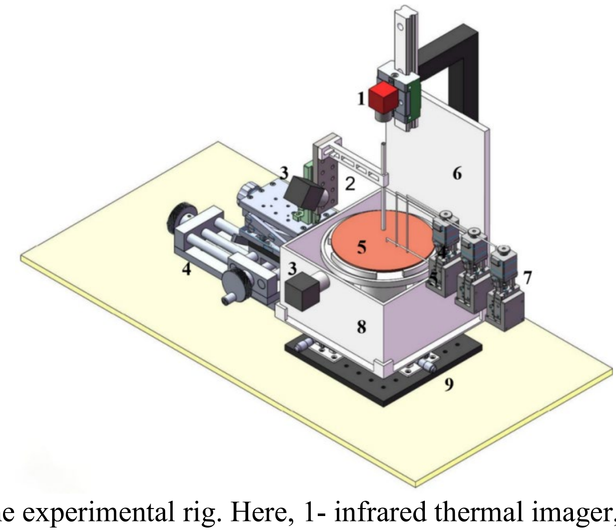


Figure 1. Schematic of the experimental rig. Here, 1- infrared thermal imager, 2- nozzle support, 3- CCD camera, 4- *x*-*y*-*z* displacement table, 5- 150mm circle copper plate, 6- light source, 7- K-type thermocouple bracket, 8- liquid storage tank, and 9- leveling support.

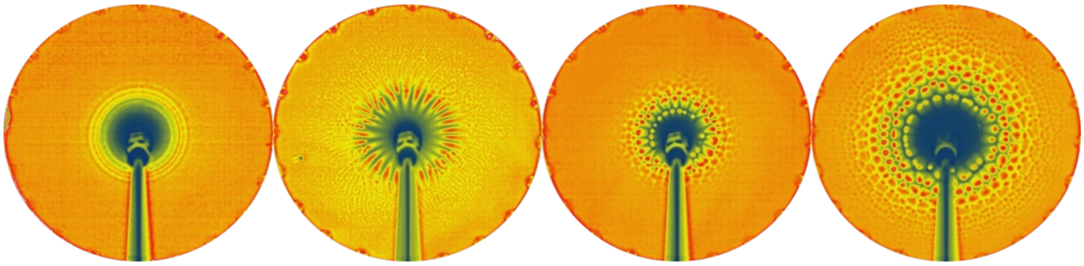
In the experiment, the rate of the jet flow and the temperature of the copper plate were varied and thus different Marangoni numbers ($1.05\times10^4 \leq Ma \leq 2.35\times10^5$) and Reynolds numbers ($10.62 \leq Re \leq 47.67$) were obtained. The temperature of the radial flow was measured using an infrared thermal imager and K-type thermocouples, respectively.

3. RESULTS

The experimental results show that there exists a radial temperature "jump" of the radial flow (the thickness is smaller than 1 mm). That is, the radial flow may be classified into three regions: a low temperature region under the cold jet dominance, a temperature jump region under the thermocapillary dominance, and a high temperature region under the Bénard-Marangoni convection dominance. In the low temperature region, the characteristic length dominated by the cold jet was measured based on the experimental results. The dependence on Re of the characteristic length is determined.

Based on infrared thermal images, the transition to chaos of the radial outflow is analyzed using power spectral density, phase space reconstruction and fractal dimension. Experimental results reveal concentric ring cells, ray cells, mixed cells and chaotic cells in the transition to chaos, as shown in Fig. 2. The fundamental frequency has been measured for various periodic modes of the radial flow. The fundamental frequency increases with increasing Re but decreases with increasing Ma, and the dependence of the frequency on Ma and Re is quantified. In the current parameter range, Ma and Re exhibit competing effects for which increasing Ma easily results in the periodic flow but increasing Re promotes the chaotic flow. Further, the distribution of flow modes in the Ma-Re parameter space are also mapped.

The average Nusselt number (Nu) was calculated over the entire copper plate. The results show that the average Nu increases with Ma and Re. The dependence of Nu on Ma and Re is also quantified.



Ring cell	Ray cell	Mixed cell	Chaotic cell
Re=10.6	Re=10.6	Re=10.6	Re=26.5
Ma=6.5×10^4	Ma=2.2×10^5	Ma=1.2×10^5	Ma=1.7×10^5
Pr=113.5	Pr=113.5	Pr=113.5	Pr=113.5

Figure 2. Radial flows under thermocapillary effect for different Marangoni numbers and Reynolds numbers.

4. CONCLUSIONS

An experimental study of a jet induced radial flow on a heated circular plate was conducted. The results reveal a noticeable temperature jump in the radial temperature distribution. Within the temperature jump region, various flow modes such as concentric ring cells, ray cells, mixed cells and chaotic cells are observed. The distribution of flow modes in the Ma-Re space is mapped and the dependence of the average Nusselt number on Ma and Re is quantified.

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