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Short Paper

Numerical Observations of a Bifurcating Plane Impinging Jet in a Confined Channel

Cho, J. R.*

* School of Mechanical and Automotive Engineering, Inje University, Kimhae 621-749, Korea.
E-mail: mechjrc@inje.ac.kr

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1. Introduction

There has been a growing engineering interest in the bifurcation of fluid flow occurring at a low Reynolds number due to the importance of designing MEMS-based fluidic devices. Lee et al. (2002) actively used the bifurcation of an impinging jet on a V-shaped plate to build a MEMS flow sensor. An experimental and computational study was reported by Uzol and Camci (2002) that made use of a slightly different geometry with a much larger scale. Gregory et al. (2005) showed that a fluidic oscillator comprised of two jets in a mixing chamber increases mixing. In this study we numerically investigated an impinging plane jet in a confined channel. Even though this flow configuration is often encountered in heat sinks and flow distributors, to the best knowledge of the author, no such work has been reported in technical periodicals.

2. Flow Modeling

The present flow configuration is shown in Fig. 1. The channel length was $L = 140$, and the channel width was $H = 10$. The flow inside the channel was assumed laminar because the typical Reynolds numbers in micro-fluidic devices range from 0.01 to 100 (Liu et al., 2000). We focused our attention on the particular case in which equal amounts of fluid were pumped out through the top and bottom exits. A convection boundary condition was applied at the outlets to minimize any effects due to the finite channel length. We employed 60 x 210 grids; few changes were observed when the grid number was doubled at $Re = 150$. The flow features were visualized by injecting a passive scalar through the slot inlet and by solving the scalar conservation equation with a Schmidt number of 1 inside the channel.

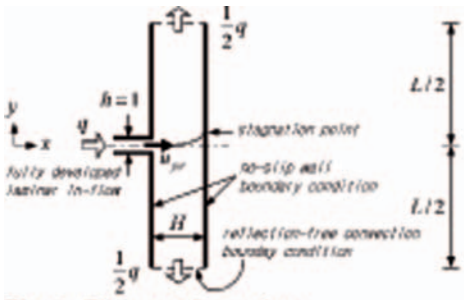

Fig. 1. Flow configuration.

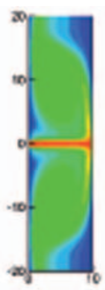

Fig. 2. Symmetric, steady flow at Re = 120.

3. Results and Discussion

The flow field was observed while the Reynolds number changed from 120 to 160. Figure 2 shows a snapshot of the scalar field at $Re = 120$. At this low Reynolds number the viscous friction limited the nonlinear inertial motion of the fluid. Thus the fluid flow became *steady and symmetric* with respect to the jet axis. However, the flow bifurcated into an *impulsive intermittent state* when the Re was increased to between 130 and 150. The intermittent flapping motion of the jet column at $Re = 150$ is shown in Fig. 3. The flapping period was $T = 21.1$ nondimensional time units. The flapping motion was quasi-sinusoidal and lasted approximately 19 periods (see Figs. 3(a)-(d)). After that, the flapping motion suddenly disappeared and the flow remained at a symmetric steady state for approximately

2,000 time units until the next oscillation started (see Fig. 3(e)). The duration of this quiescent state was reduced with the increase of Reynolds number. Hsu et al. (2001) visualized the continuous flapping motion of the jet in a laterally unbounded condition. However, in present wall-bounded configuration, the two large re-circulating flow structures formed within the top and bottom part of the channel interact with the jet. This interaction was supposed to be responsible for the intermittent behavior. If the Reynolds number was increased slightly to 160, the jet suddenly bifurcated to *a continuous sinusoidal flapping state*. The sinusoidal flapping oscillations continued with a period of $T = 19.1$ (see Fig. 4). The impingement point movement was also sinusoidal. However, the upper and lower flow fields were not symmetric in a time-averaged sense. Therefore, the mean location of the impingement point was slightly off the geometric center. The asymmetric flow pattern under symmetric boundary conditions is not surprising: Experimental and numerical observations of this so-called symmetry breaking *pitchfork* bifurcation in the sudden expansion channel were reported by Durst et al. (1993).

4. Conclusions

The flow pattern of an impinging jet in a confined channel was altered drastically with a moderate change in Reynolds number. These bifurcations are expected to alter the mass and heat transfer characteristics as well. Therefore, special attention is necessary when designing micro-fluidic devices.

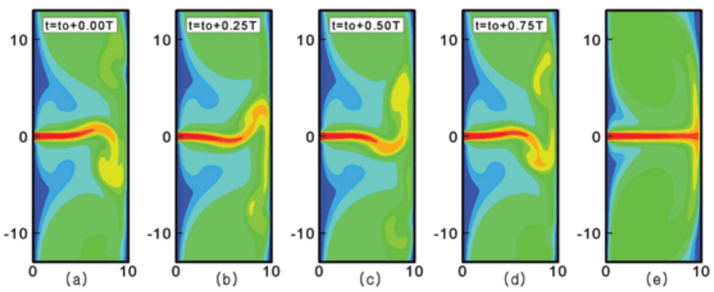

Fig. 3. Snapshots of the scalar field at *Re* = 150.

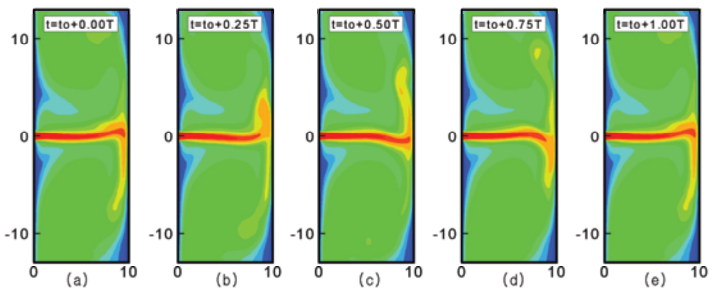

Fig. 4. Snapshots of the scalar field at *Re* = 160.

Acknowledgments

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