NUMERICAL STUDY ON FLOW AND HEAT TRANSFER CHARACTERISTICS OF PERISTALTIC PUMP

K. Tatsumi[1], Y. Miwa[1], Y. Matsunaga[2] and K. Nakabe[1]
[1] *Department of Mechanical Engineering and Science, Kyoto University, Kyoto, Japan*
[2] *Department of Mechanical Engineering, Osaka Prefecture University, Osaka, Japan*

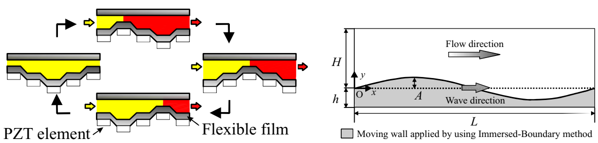
ABSTRACT

The present study focuses on a peristaltic micro pump [1]. Flow and heat transfer characteristics of a channel accompanying a wall with peristaltic motions are evaluated by numerical simulations, and the effects of the travelling wave amplitude, velocity, phase and shapes on the pump performance are discussed.

Keywords: Numerical simulation, Peristaltic pump, Pump performance, Heat transfer

1. INTRODUCTION

A proto-type device of peristaltic micro pump was manufactured and presented by Kanno et al.[1]. Its active part consisted of piezoelectric elements was attached to the channel from the outside of the channel wall as illustrated in Fig. 1(a). This contributes to a simplification of the device structure, and, moreover, makes it available in multi-test cases to replace only the test-section channel but not the pump, resulting in cost and time reductions. To design an effective peristaltic pump for practical use, however, detail information of the flow and heat transfer characteristics of such pumps is required. Therefore, in the present article, effects of the parameter of the periodically-moving wall on the flow characteristics and pump performance are evaluated together with the discussion of the thermal field of flow and heat transfer rate at walls.



(a) Schematic view of pump *(b) Computational domain*

Figure 1. Schematic view of peristaltic micro-pump.

2. NUMERICAL PROCEDURE AND CONDITIONS

Figure 1(b) shows the computational domain and coordinates. The channel height, H, and streamwise wavelength, L, were fixed at a constant value as H=100μm and L/H=10, respectively. Other geometric parameters are tabulated in Table 1 with their labels. In the sawtooth case, the wall is consisted of two sinusoidal functions so that steep and moderate slopes are respectively obtained in the leading and trailing part of the convex surface.

The present code was on the basis of Finite-Volume Method (FVM) and the governing equations solved were two-dimensional, time-dependent and incompressible continuity, Navier-Stokes and energy equations. To represent the peristaltic motion of the wall, Immersed Boundary Method [2] was adopted in the computation. No-slip and periodic conditions were applied to the walls and streamwise boundaries, respectively. To evaluate the heat transfer characteristics, the upper wall of the channel in the region of $3.75 \leq x/H \leq 6.75$ was heated under

Table 1. Computational conditions

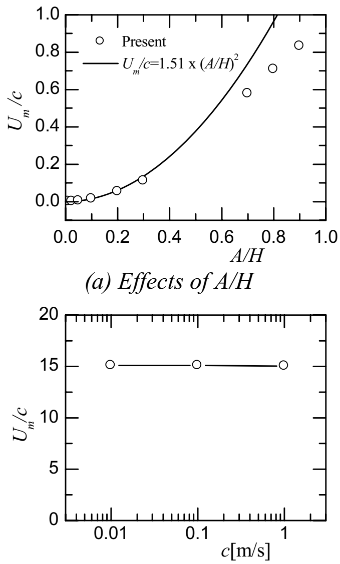
Label	A/H	c [m/s]
A1c01~A9c01	0.01~0.9	0.1
A1c001~A1c10	0.1	0.01~10
A1c01s (sawtooth)	0.1	0.1

978-0-9798064-0-7/µTAS2007/$20©2007CBMS

isothermal wall condition. The working fluid was water and the physical properties were kept constant.

3. RESULTS AND DISCUSSION

Figures 2(a) and (b) show how the wave amplitude, A, and wave travelling velocity, c, affect the mean streamwise flow velocity, U_m. As shown in Fig. 2(a), the relation between U_m and A matches well with the fitting function of a parabolic curve under small A/H conditions. This agrees well with the results predicted by Yun and Fung [3], indicating the validity of the present code. Under larger A/H conditions, U_m/c deviates from the parabolic profile and approaches to unity. On the other hand, in Fig. 2(b), U_m/c remains almost constant under the conditions of c=0.01~1.0m/s.

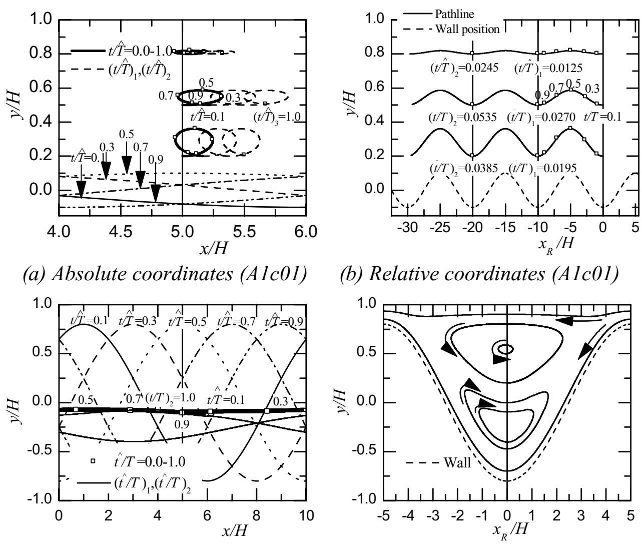


(a) Effects of A/H

(b) Effects of c

Figure 2. Relations between U_m/c, A/H and c.

Figure 3 shows the pathlines of the flow obtained in the cases, A1c01 and A8c01. Figures 3(a) and (c) are illustrated in absolute coordinates, and (b) and (d) in relative coordinates on the bases of the moving wall, respectively. In Fig. 3(a), the fluid flows in the streamwise direction moving back and forth in one period, while in (b), the flow moves in opposite direction drawing a sinusoidal pathlines in respect to the moving wall. In the case of larger A/H, as shown in Fig. 3 (c) and (d), a different flow characteristic is obtained. Namely, most of the fluids is apparently trapped between the concave walls and is convected at a velocity identical with that of the travelling wave. In Fig. 3(d), a pair of counter-rotating circulations appears in the center area, and reverse flows relative to the travelling wave are obtained near the top and bottom walls.



(a) Absolute coordinates (A1c01) *(b) Relative coordinates (A1c01)*

(c) Absolute coordinates (A8c01) *(d) Relative coordinates (A8c01)*

Figure 3. Pathlines in the cases, A1c01 and A8c01.

Figure 4 shows the relation between the U_m and mechanical work supplied from the wall to the fluid during one period. The values in the figure are normalized with that obtained in case A1c01. The work is defined by Eq. (1) using the pressure, y component of shear stress and velocity at the wall.

$$W = \frac{\int_0^L \int_0^{\Delta T} (p_w(x,t) + \tau_{w,y}) v_w(x,t) dt dx}{L \Delta T} \quad (1)$$

In comparison with the case A1c01, both U_m and W increase with respect to A (cases A1c01~A9c01) and c (cases A1c01~A1c10). However, the gradient of the latter case is larger than the former one indicating that a higher efficiency is obtained by increasing the peristaltic amplitude than the wave speed. In the case of sawtooth wave pattern, both U_m and W do not differ much with those of case A1c01 (3% increase with W in case A1c01S). This indicates that pumping efficiency depends more significantly on the wave amplitude and speed than on the wall shape pattern.

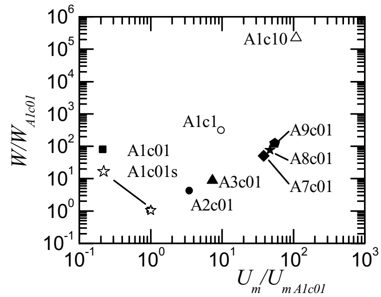


Figure 4. Mechanical work, W vs U_m.

Figure 5 shows the time history of the Nusselt number spatially averaged along the heated area at the channel top wall. Nu_m is defined as $Nu_m = q_w H/\lambda(T_w\text{-}T_0)$, where q_w, T_w, T_0 and λ are the wall heat flux, wall temperature, flow inlet bulk mean temperature and fluid thermal conductivity. By the influence of the flow motion, Nu_m fluctuates periodically and possesses maximum and minimum values at $t/T\cong 0.5$ and 1.0, respectively. On the contrary, the maximum streamwise velocity is obtained at $t/T\cong 0.3$. Therefore, a phase difference appears between the velocity of the mean flow and heat transfer profiles.

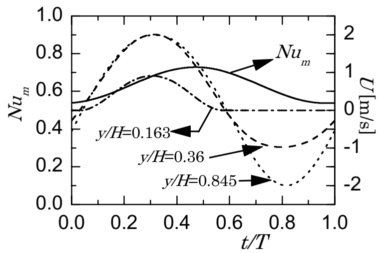


Figure 5. Nusselt number at heated wall surface and streamwise velocity at x/H=0.5.

4. CONCLUSIONS

Two-dimensional unsteady computation was conducted for a peristaltic pump. The mean flow velocity increased in a quadratic form against the peristaltic wave amplitude, and linearly to the travelling wave speed, respectively. Under large amplitude conditions, the velocity profile deviates from the quadratic form, and a pair of counter-rotating circulation was observed in the concave part of the moving wall. A phase shift between the profiles of the mean velocity and Nusselt number was obtained at the heated wall.

ACKNOWLEDGEMENTS

This study was carried out as a part of Advancing Technology Excellence "Nano-Medicine" project, which is under Kyoto City Collaboration of Regional Entities assigned by JST.

REFERENCES

[1] I. Kanno, T. Suzuki, H. Hata, H. Shintaku, S. Kawano and H. Kotera, *Development and Characterization of a Travelling Wave Micropump Driven by Piezoelectric Actuators*, 2nd Int. Symp. Micro & Nano Tech. (ISMNT-2), 226 (2006).

[2] C. S. Peskin, *Numerical Analysis of Blood Flow in the Heart*, J. Comp. Physics, **25**, 220 (1977).

[3] F.C.P. Yin and Y.C. Fung, J., *Comparison of Theory and Experiment in Peristaltic Transpor*", J. Fluid Mech, **47**, 93, (1971).