Flow Characteristics in the Grooved Channel for Pulsatile Flow

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Experimental system of two-dimensions grooved channel for pulsatile flow had been calibrated. On this basis, the available pulsatile operating range was decided. Furthermore, the overall pressure drop and the local pressure for the grooved channel had been measured and their characteristics of pulsatile behaviors were described. It is showed that the maximum oscillatory fraction and the maximum oscillatory period are P=0.28 and T=2.4s, respectively. Moreover, it is found that the overall pressure drop changes with the pulsatile flow rate in the same phase shift, while the local pressure changes in an opposite trend with a little phase shift.

Key Words : Grooved channel, Pulsatile flow, Operating range, Oscillatory fraction, Oscillatory period

1. Introduction

It is well known that the plate type heat exchanger has been widely applied to the practical engineering since its higher heat transfer efficiency, especially in the ocean thermal energy conversion system(OTEC). Even so, it still could not meet the requirement for the much higher efficiency depending only on the complex channel shape. The novel technique used to enhance the heat or mass transfer rate has attracted the attention of many researchers.

The earlier study was conducted by Bellhouse *et al*.[1], they pioneered the study of how large fluid oscillations can improve fluid mixing and mass transfer in a 2-D furrowed channel and found that the combination of a large laminar oscillation with a much smaller mean flow through a wavy-walled channel could achieve a higher mass transfer rates. Nishimura *et al*.[2] systematically studied the flow and mass transfer characteristics in wavy-walled channels for pulsatile flow. They pointed out that the mass transfer enhancement depends on three parameters: net flow Reynolds number, oscillatory fraction of the flow rate, and Strouhal number. The enhancement factor increases with the increment of these three parameters in their experimental range. Ghaddar *et al*.[3] numerically investigated the relationship between the flow instability and the heat transfer enhancement in grooved channels. They indicated that the occurrence of T-S wave is a common feature for the 2-D channels, and they further pointed out that the oscillatory flow imposed at the T-S frequency will lead to a resonant excitation and associated transport enhancement. Based on the above results, Sun *et al*.[4] completed the experimental study in the grooved channels with different groove length for steady flow. They obtained the first and second frequency of the T-S wave. Moreover, they found that increasing pressure will result in a higher amplitude of the T-S wave, this behavior is significant for the efficient heat transfer in practical engineering. For the pulsatile flow, Arima *et al*.[5] numerically and experimentally examined the imposed oscillatory flow on the fluid flow at lower net Reynolds number in a grooved channel, and described the effects of operating conditions on the vortex strength and the heat transfer Nusselt number. There also have many experimental and numerical studies on 3-D channels for the pulsatile flow[6~9], they mainly focused on the effects of the pulsatile operating conditions on the heat or mass transfer for laminar and turbulent pulsatile flow.

To lay a foundation for the in-depth study, in the present work, the pulsatile operating conditions for the grooved channel experimental system will be calibrated, and then, the operating range of the pulsatile parameter

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will be confirmed. Finally, some pulsatile flow behaviors will be described.

2. Experimental apparatus and parameters

The experimental system is shown in Fig. 1, which is almost the same as that used in reference [4], only adding a solenoid valve and a time controller before the flow enters the grooved channel. The time controller is used to change the time of the solenoid valve in *On* or *Off* so as to obtain the different pulsatile period. The definitions of the oscillatory fraction *P* and the oscillatory period *T* used in this study are identical with the reference [5]. The test section is shown in Fig. 2, and its dimension is *L*=20mm, *W*=200mm, *h*=2.5mm and *l*=12mm.

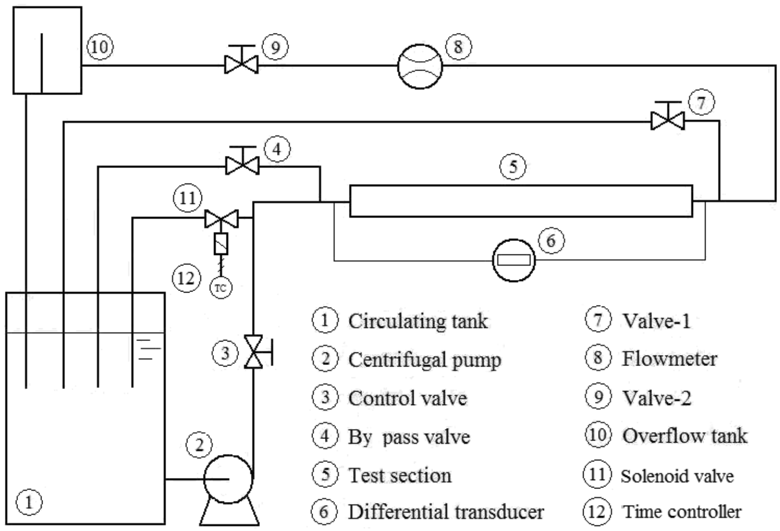
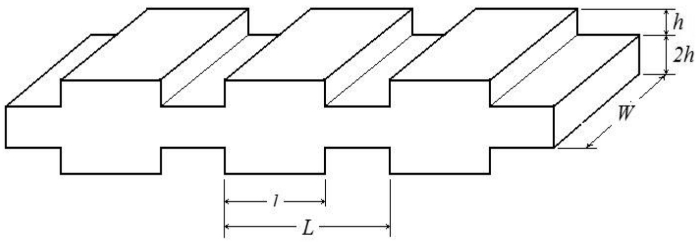


Fig. 1 Sketch of experimental system



L=20mm, *W*=200mm, *h*=2.5mm and *l*=12mm

Fig. 2 Dimension of grooved channel

3. Results and discussion

3.1 Representative form of pulsatile flow

The pulsatile flow generated by the self-circulating experimental system is shown in Fig. 3, which is obtained at the net flow rate *Q*=200ml/s(±4ml/s) with *On*=*Off*=0.7s. To express the time-history of the pulsatile flow rate clearly, all the experimental data have been treated with Matlab software. The straight line above is the fitting steady flow (i.e. the net flow) and the smooth curve below is the fitting pulsatile flow. Obviously, the pulsatile flow rate changes approximately in the form of sinusoidal wave. But because of the special setting location of the solenoid valve, the flow rate of the pulsatile flow is much smaller than that of the steady flow. Therefore, the amplitude of pulsatile flow generated from this experimental system is very low. For this figure, the oscillatory

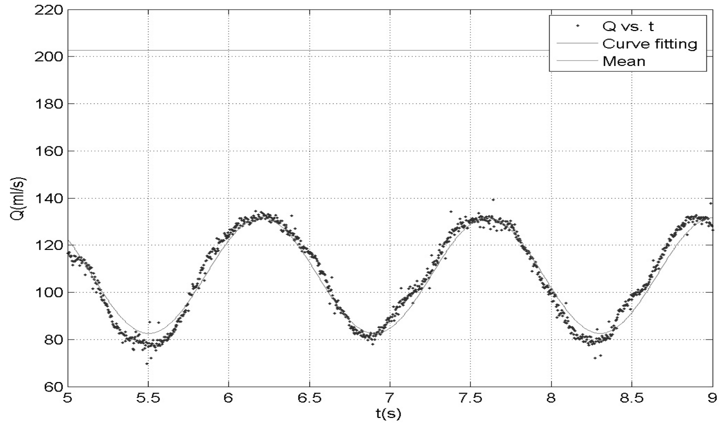


Fig. 3 Variation of pulsatile flow rate

fraction is *P*=0.121.

3.2 Available experimental range

To confirm the available experimental operating range, the experiments at different net flow rate with the various *On* and *Off* time combinations are carried out. When *Q*=100~900ml/s, *On*=0.2~1.2s and *Off*=0.1~1.2s, the distribution of the available experimental operating range is shown in Fig. 4, the area surround by the dotted lines determined the minimum and the maximum *T* and *P*, respectively, that is *T*=0.5~2.4s, *P*=0.001~0.28. Obviously, the maximum *P* is smaller, therefore, it is necessary to design a new oscillatory flow generating device to gain the more effective pulsatile flow.

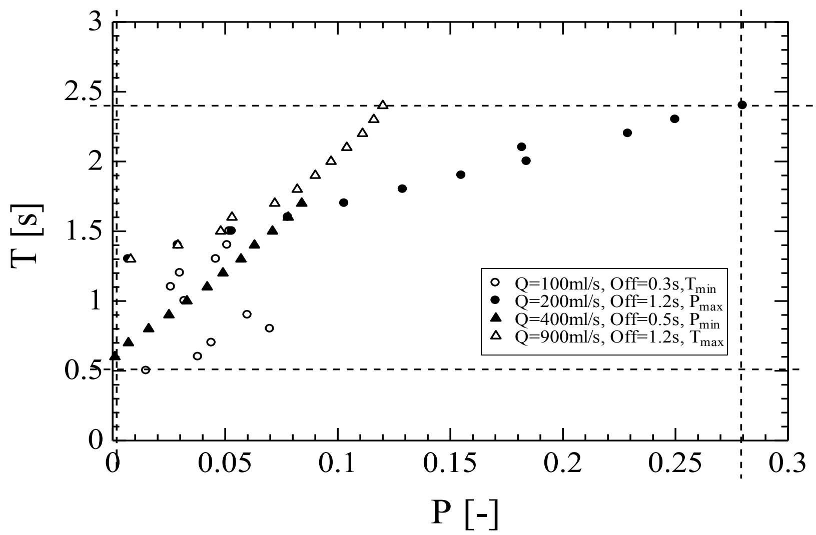


Fig. 4 Available experimental operating range

3.3 Effects of the oscillatory period and the net flow rate on the oscillatory fraction

According to the experimental data, the better pulsatile flow with a obvious amplitude is obtained when the *On* and *Off* time is equivalent. Fig. 5 shows the relationship between the oscillatory fraction *P* and the oscillatory period *T*. It is seen that the *P* increases with the *T* increasing, and except the net flow rate *Q*=100ml/s, the *P*

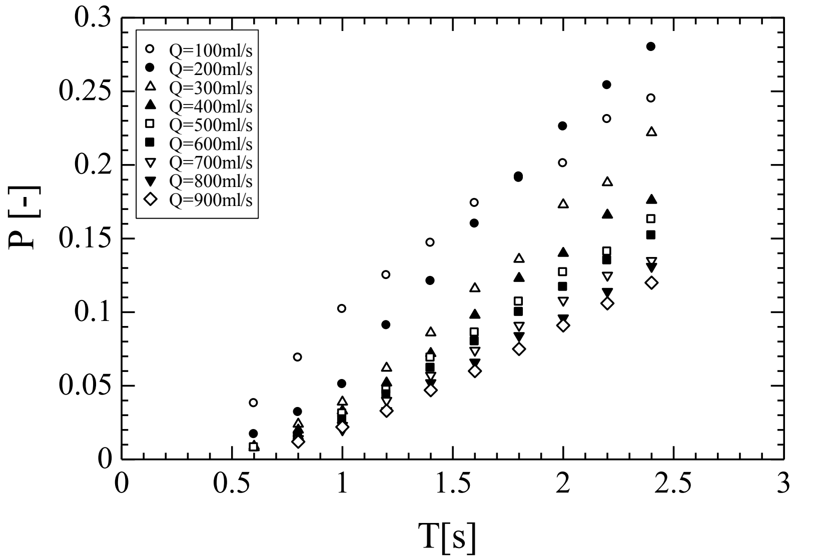


Fig. 5 Effect of the oscillatory period on the oscillatory fraction

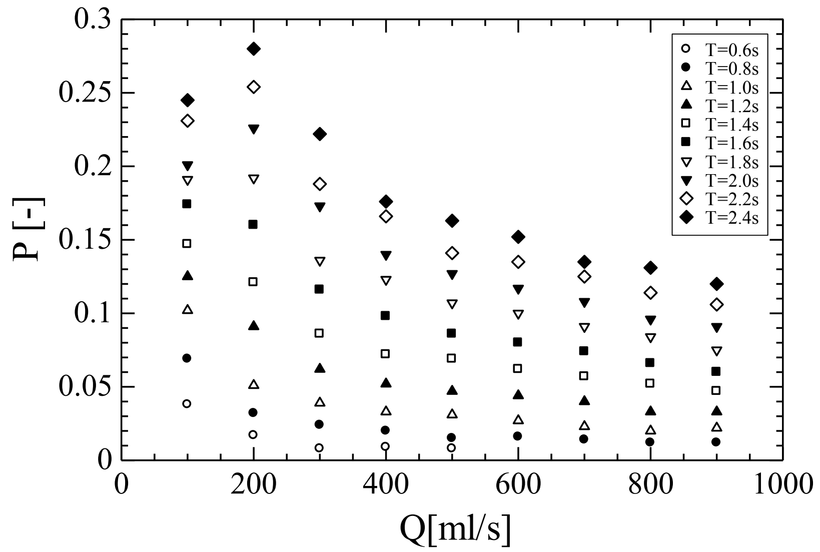


Fig. 6 Effect of the net flow rate on the oscillatory fraction

decreased with the increment of *Q* from 200ml/s to 900ml/s. Fig. 6 could illustrates this phenomenon more clearly. These two figures mean that the maximum *P*=0.28 could be obtained at *Q*=200ml/s, *T*=2.4s (i.e. *On*=*Off*=1.2s).

3.4 Characteristics of overall pressure drop and local pressure

After the available experimental range is decided, the characteristics of pulsatile flow about the overall pressure drop *dP* and the local pressure *P*7 were explored. At *On*=*Off*=0.6s, *Q*=400ml/s, the time histories of the *dP* and the *P*7 were recorded as shown in Fig. 7. For the convenient compare, the pulsatile flow rate was also displayed here. For this case, the oscillatory fraction is very small, only is *P*=0.052. The results showed that when the flow starts to oscillate, the *dP* will be triggered the same behavior with the zero phase shift. Meanwhile, the *P*7 displayed a different behavior, that is, *P*7 changes in an opposite trend with a little phase shift during the periods of the pulsatile flow rate increasing and decreasing. Generally, the pulsatile flow will promote the motion of the

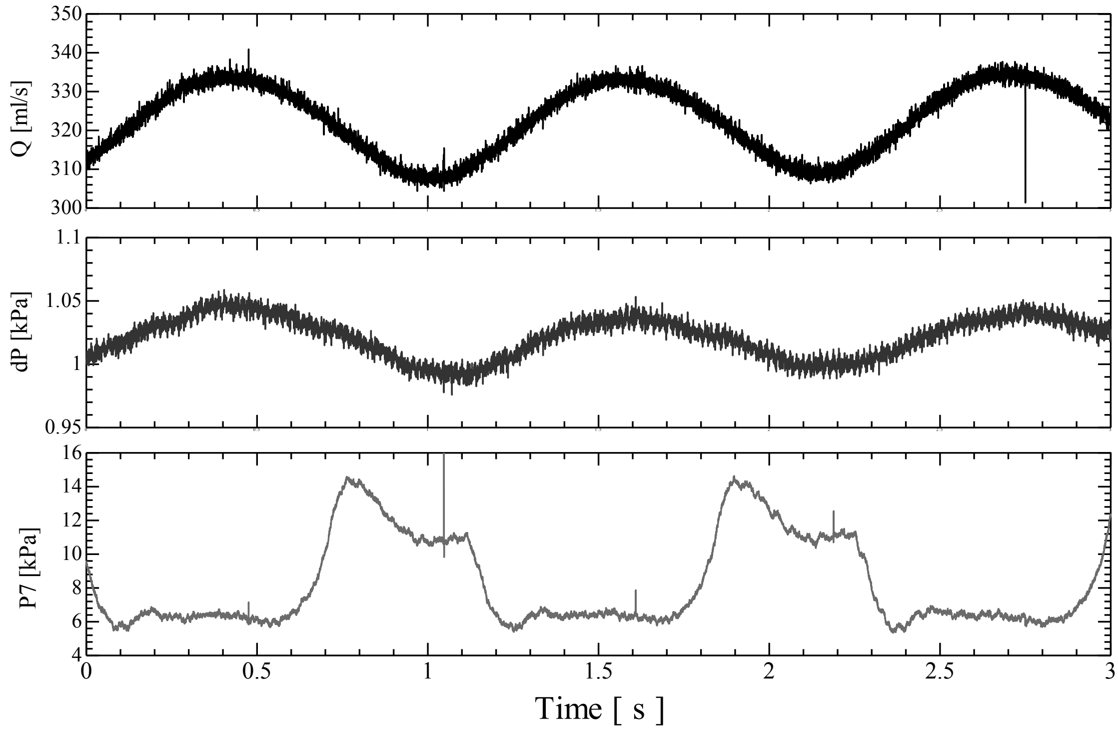


Fig. 7 Characteristics of overall pressure drop and local pressure varies with time for pulsatile flow

flow vortex and thus enhance the heat and mass transfer in the flow channel. But it could not measure the above performance with the present experimental apparatus. To have a good insight to the pulsatile flow, it should consider to improve the flow channel and the measurement system.

4. Conclusions

The performance of the used grooved channel experimental system for pulsatile was calibrated, and then, the time-histories of the overall pressure drop and the local pressure had been recorded. Based on the above experiments, the conclusive remarks could be drawn as follows:

(1) With the present experimental system, the pulsatile flow in the form of sinusoidal wave could be generated by the solenoid valve. The available pulsatile operating range are decided, that is, the pulsatile period T=0.5~2.4s, the oscillatory fraction P=0.001~0.28. The maximum P=0.28 could be obtained only at Q=200ml/s with *On*=*Off*=1.2s, i.e. T=2.4s.

(2) For the pulsatile flow, the overall pressure drop *dP* will change with the pulsatile flow rate in the same phase shift, but the local pressure *P*7 will change in an opposite trend with a little phase shift. These flow behaviors will be relative to the enhancement of heat and mass transfer in the grooved channel. It is necessary to carry out some studies to prove it.

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References

[1] Bellhouse, B.J., Bellhouse, F.H., Curl, C.M., MacMillan, T.I., Gunning, A.J., Spratt, E.H., MacMurray, S.B. and Nelems,

J.M. , A high efficiency membrane oxygenator and pulsatile pumping system and its application to animal trials. *Trans. Amer. Soc. Artif. Int. Organs.*, Vol. 19, (1973), pp. 72-79.

[2] Nishimura, T. and Kojima, N. , Mass transfer enhancement in a sysmmetric sinusoidal wavy-walled channel for pulsatile flow, *Int. J. Heat Mass Transfer*, Vol. 38, (1995), pp. 1719-1731.

[3] Ghaddar, N.K., Magen, M., Mikic, B.B. and Patera, A.T., Numerical investigation of incompressible flow in grooved channels. Part 2. Resonance and oscillatory heat-transfer enhancement, *J. Fluid Mech.*, Vol. 168, (1986), pp. 541-567.

[4] Sun, F.M., Bian, Y.N., Arima, H., Ikegami, Y. and Xu, X.S., Strength characteristics of the self-sustained wave in grooved channels with different groove length, *Heat and Mass Transfer*, Vol. 46, (2010), pp. 1229-1237.

[5] Arima, H., Mori, Y. and Ikegami, Y., Effect on forced oscillation flow in periodically grooved channel under low Re number flow in the parallel plate, *Trans. of JSME*, Vol. 72, No. 717, B (2006), pp. 1327-1334.

[6] He, S. and Jackson, J.D., An experimental study of pulsating turbulent flow in a pipe, European *J. Mech. B/Fluids*, Vol. 28, (2009), pp. 309-320.

[7] Jin, D.X., Lee, Y.P. and Lee, D.Y. , Effects of the pulsatile flow agitation on the heat transfer in a triangular grooved channel, *Int. J. Heat and Mass Transfer*, Vol. 50, (2007), pp. 3062-3071.

[8] Gao, P.Z., Liu, T.H., Yang, T. and Tan, S.C., Pressure drop fluctuations in periodically fluctuating pipe flow, *J. Marine Sci. Appl.*, Vol. 9, (2010), pp. 317-322.

[9] Yan, B.H., Yu, L. and Yang, H., Forced convection with laminar pulsating flow in a tube, *Heat and Mass Transfer*, Vol. 47, (2011), pp. 197-202.