Pressure Drop Characteristics of Laminar Pulsatile Flow in Grooved Channel with Different Groove Lengths

Han Huang[*1], Hirofumi ARIMA[*2], Yongning BIAN[*1] and Yasuyuki IKEGAMI[*2]

[*1]State Key Laboratory of Structural Analysis for Industrial Equipment
Dalian University of Technology, 116024, China
[*2]Institute of Ocean Energy, Saga University, 840-8502, Japan

Abstract

Pressure drop characteristics of laminar pulsatile flow in grooved channel with different grooved lengths are investigated experimentally. The experiment are carried out with five kinds of grooved channel, and the Reynolds numbers of the mainstream flow considered in this work ranges from 300 to 525. The sampling data of pressure drop is analysis by amplitude, mean value and phase shift. The result shown that the relation between amplitude and frequency of pulsatile is the same to different grooved channel. It is found that the amplitude trend to constant when f is beyond f_c in laminar pulsatile flow. The mean pressure drop increases with the Reynold number, and it also increases with the grooved length increasing. However the mean pressure drop has opposite relationship with frequency in one grooved channel. Furthermore the phase shift between pressure drop and velocity performs more obvious with the frequency increases, while the oscillatory fraction decrease. It also performs obvious in long grooved length of channel.

Keywords : Grooved channel, Pulsatile flow, Pressure drop, Frequency, Oscillatory fraction

1. Introduction

Lately, both energy crisis and environmental problems get more and more attention with the rapid growth of economic development. Ocean thermal energy conversion (OTEC) is considered as a new generation of safe and clean renewable energy. Because it can be used all year round, and stable in the ocean renewable energy. It is one of the important breakthrough technology that to improve the utilization efficiency of heat exchanger and reduce pumping power loss. To heat transfer enhancement, especially in the OTEC system which heat exchanger is better to compact and economic, it could be realized by means of changing the wall shape of the employed channels. Meanwhile, The pulsatile flow, which is formed by imposed an oscillatory frequency to a steady flow is proved to be another effective method to enhance the fluid mixing and heat transfer. Therefore, it is necessary to expand the knowledge of heat transfer enhancement in OTEC by combining these two methods.

Ghani& Sidik[1] gives a comprehensive reviews on the hydrothermal performance of microchannel heat sink. It overviews several leading literatures concerning the effects of channel geometrical parameters on enhancing heat transfer which is including grooved channel.Greiner[2] experimentally investigated resonant heat transfer enhancement in grooved channels, and confirms that hydrodynamic resonant benefit to enhance heat transfer. The result shown that 20% flow rate oscillation at optimal frequency has more than doubles the convective heat transfer coefficient.Sun& Bian[3] found that increasing pressure in the grooved channel will lead to higher amplitude of the T-S wave, which is significant for heat transfer in engineering.Bian & Jia[4] investigated the effect of pulsatile flow on enhancing mass transfer in a wavy-walled tube.Nishimura& Oka[5] make an experiment about the influence of pulsatile flow on enhancing mass transfer in grooved channel. In fact, pulsating flow has same effect on heat transfer and mass

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E-mail of corresponding author: ybian@jdlut.edu.cn

transfer by increasing the flow instability. Hence pulsatile flow can enhance heat transfer in the grooved channel.

In OTEC plant, it is also necessary to reduce pumping power while enhancing heat transfer.Adachi& Tashiro[6] have carried out experiment to study pressure drop characteristics in the grooved channel. They clarify the effect of grooves on the pressure drops for the low–middle Reynold number regime (100<Re<1000).

In this study, the pressure drop characteristics of laminar pulsatile flow have been investigated further. The experiment setup is five kinds of grooved channel as Adachi& Tashiro[6], Nishimura& Oka[5], Sun& Bian[3], Adachi & Hasegawa[7]. The critical Reynold number is 532 which is conclude by Sun& Bian[3]. We further study the effect of frequency of pulsatile flow and oscillatory fraction on pressure drop in the different groove length.

2. Experimental Setup

The apparatus of the experiment is shown in Fig. 1. The flow is provided by a centrifugal pump. The city water is used as the working fluid. The flow rate is controlled by a control valve and measured by an electro-magnetic flow-meter. The test section is made up with two grooved plates, as shown in Fig. 2. Eight points can be used for measurement. The configuration of the flow period is shown in Fig. 3. In this study, total five kinds of grooved channels with the unit length L=20mm, W=200mm, h=2.5mm and the groove lengths l=4, 6, 8, 10, 12mm are used.

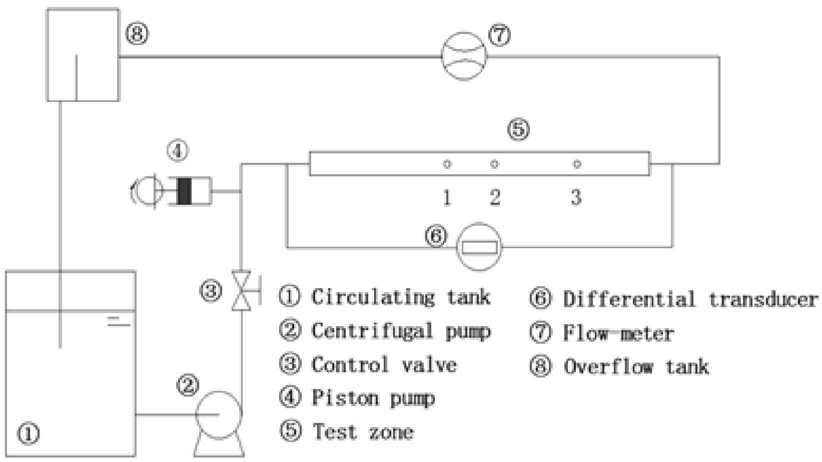


Fig. 1 Schematic diagram of the experimental system

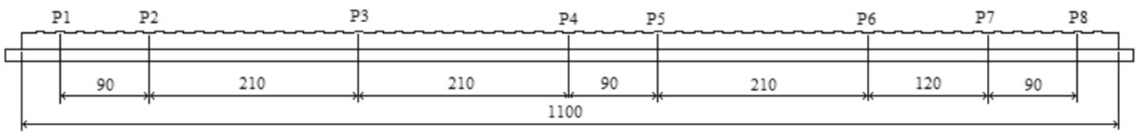
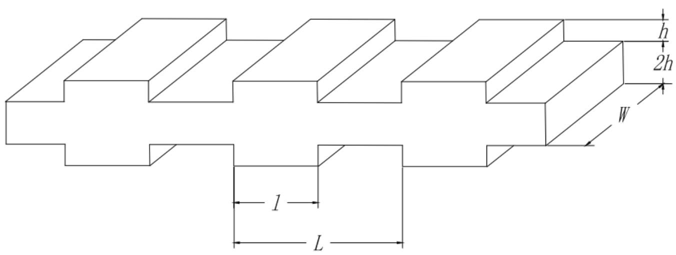


Fig. 2 The measuring point positions on the grooved plate



L=20mm, W=200mm, h=2.5mm, l=4, 6, 8, 10, 12mm

Fig. 3 Dimensions of the test section

The Reynolds number Re , the amplitude of the pulsatile flow Q_o, the steady flow Q_s, the oscillatory fraction *P*, and the flow in the grooved channels *Q* are calculated according to the following definitions:

$$\mathrm{Re} = \frac{\rho u h}{\mu}$$

$$Q_0 = 0.5\pi^2 D^2 \cdot f \cdot s$$

$$p = \frac{Q_0}{Q_s}$$

$$Q = Q_s + Q_0 = Q_s(1 + p \cdot \sin(2\pi f t))$$

P is the density of water, $u = 1.5u_m$ is the characteristic flow velocity and $u_m = Q_s/(2Wh)$, while μ is the viscosity of water which is $0.001 Pa \cdot s$ in the experiment and *f* is the frequency of the pulsatile flow. *s* is stroke of the piston pump. *D*=50*mm*, is the diameter of the piston pump in the piston pump. All the experiments are conducted under the room temperature. In the experiment, four kind of steady flow Q_s experiments in total are carried out which is 80ml/s, 100ml/s, 120ml/s and 140ml/s. Meanwhile, the oscillatory fraction *P* is 0.6, 0.8 and 1 in five kinds of grooved channels.

3. Results and Discussion

3.1 Filter processing

In order to investigate the pressure drop characteristics of laminar pulsatile flow in different grooved channel, the pressure drop signal is measured at both ends of the plate for five kinds of channel, and all experimental data are processed with a low-pass filter. In this study, sampling data of *Q* are processed by 3Hz low pass fit filter and data of pressure drop are processed by 1Hz low pass fit filter. In Fig4, a set of data filtering shows that the proposed digital filter processing realized accurate measurement.

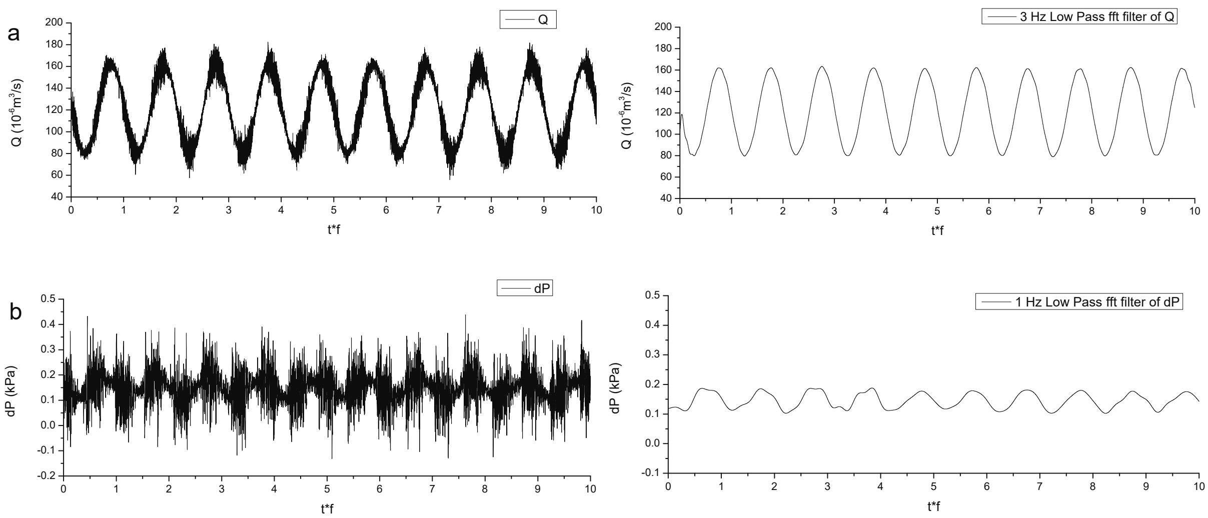


Fig. 4 Sampling data filter for *Q* and pressure drop

3.2 Mean pressure drop in different grooved channel

In Fig. 5, the mean pressure drop in different grooved channels gets similar tendency while the Reynolds number increases. It is seen that it increases linearly in the grooved channels of l=4mm and l=6mm when the Reynold number is ranging up to 525. For other grooved channels, the total pressure drop has a tendency to increase faster with the Reynold number. Sun& Bian[3] also confirmed similar result that the critical Reynold number of l=12mm is 532 in laminar flow regime, while Re_c of others grooved channels increase with the decreasing of the grooved length. When the Reynold number exceeds the critical value Re_c, the pulsatile flow in grooved channels changes to transitional flow, and the total pressure drop cannot increase linearly.

Comparing with different channels, the total pressure drop increase with the increasing of the grooved length. Therefore, the pressure drop has been directly affected by the grooved under laminar pulsatile flow. It is necessary to expand the knowledge of the effect of pulsatile flow and the grooved length on pressure drop characteristics.

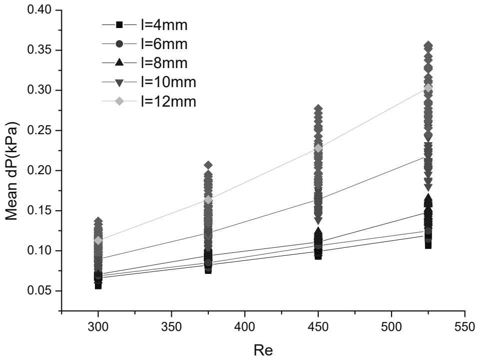
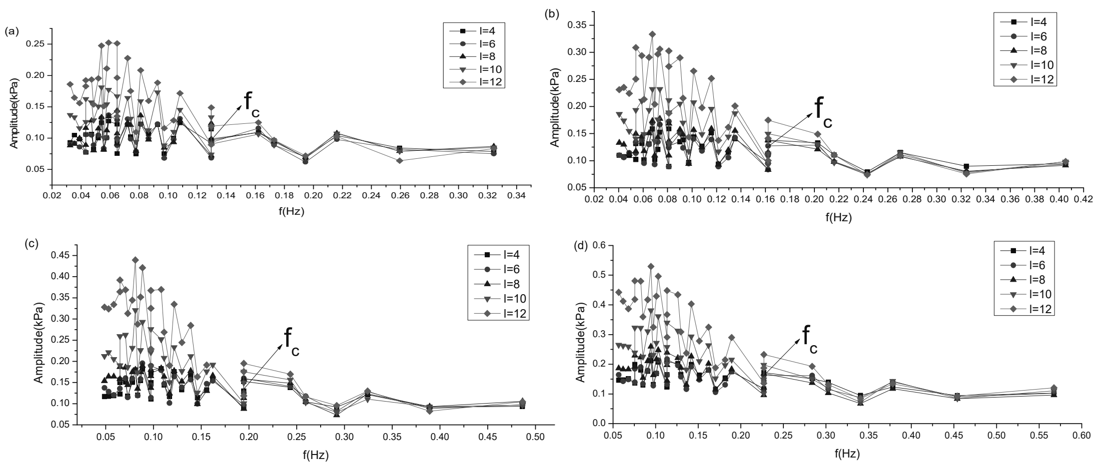


Fig. 5 Mean pressure drop for the whole flow regime

3.3 Effect of frequency to the amplitude of pressure drop

The relationship between the amplitude of pressure drop and the frequency of pulsatile flow is shown in Fig. 6. It could be seen that the amplitude of pressure drop varies greatly at a constant flux Q_o, and amplitude of pressure drop in the grooved length of 12mm is larger than other grooved. For the grooved length of 4mm, 6mm, and 8mm, the amplitude of pressure drop almost the same as the frequency increases.



(a) Q_s=80ml/s, Re=300; (b) Q_s=100ml/s, Re=375; (c) Q_s=120ml/s, Re=450; (d) Q_s=140ml/s, Re=525

Fig. 6 Amplitude of pressure drop in different frequency of pulsatile flow

In Fig. 6(a)-(d), the amplitude of pressure drop in different grooved channels trend to a constant while the frequency increases to a certain value. Meanwhile, the groove channel in different grooved length have same critical frequency is shown in Fig. 6.

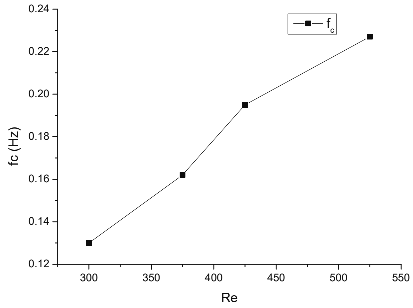
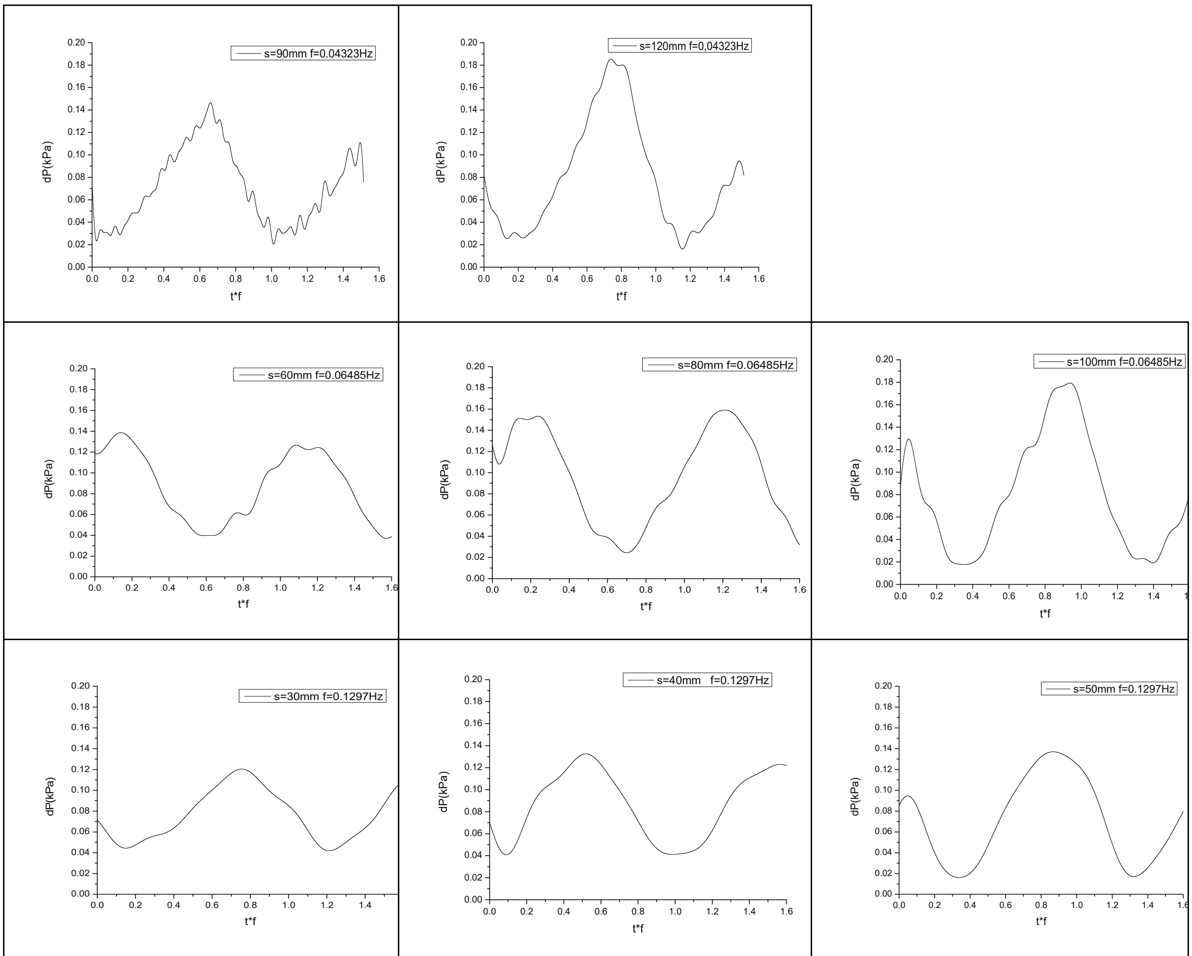


Fig. 7 Critical frequency of pulsatile flow in different Reynold number

The critical valve of frequency is shown in Fig7. The relationship between the critical value and Reynold number is obvious shown. It is detected that the critical frequency has a linearly increasing trend with the increment of Reynold number. It is perceived that the groove length has no significant effect on amplitude of pressure drop when the frequency is beyond the critical value.

3.4 Effect of frequency (*f*) and the oscillatory fraction (*P*)to the pressure drop



(a) P=0.6	(b) P=0.8	(c) P=1

(a) P=0.6; (b) P=0.8; (c) P=1; (top) f =0.04323Hz; (middle) f =0.06485Hz; (bottom) f =0.1297Hz

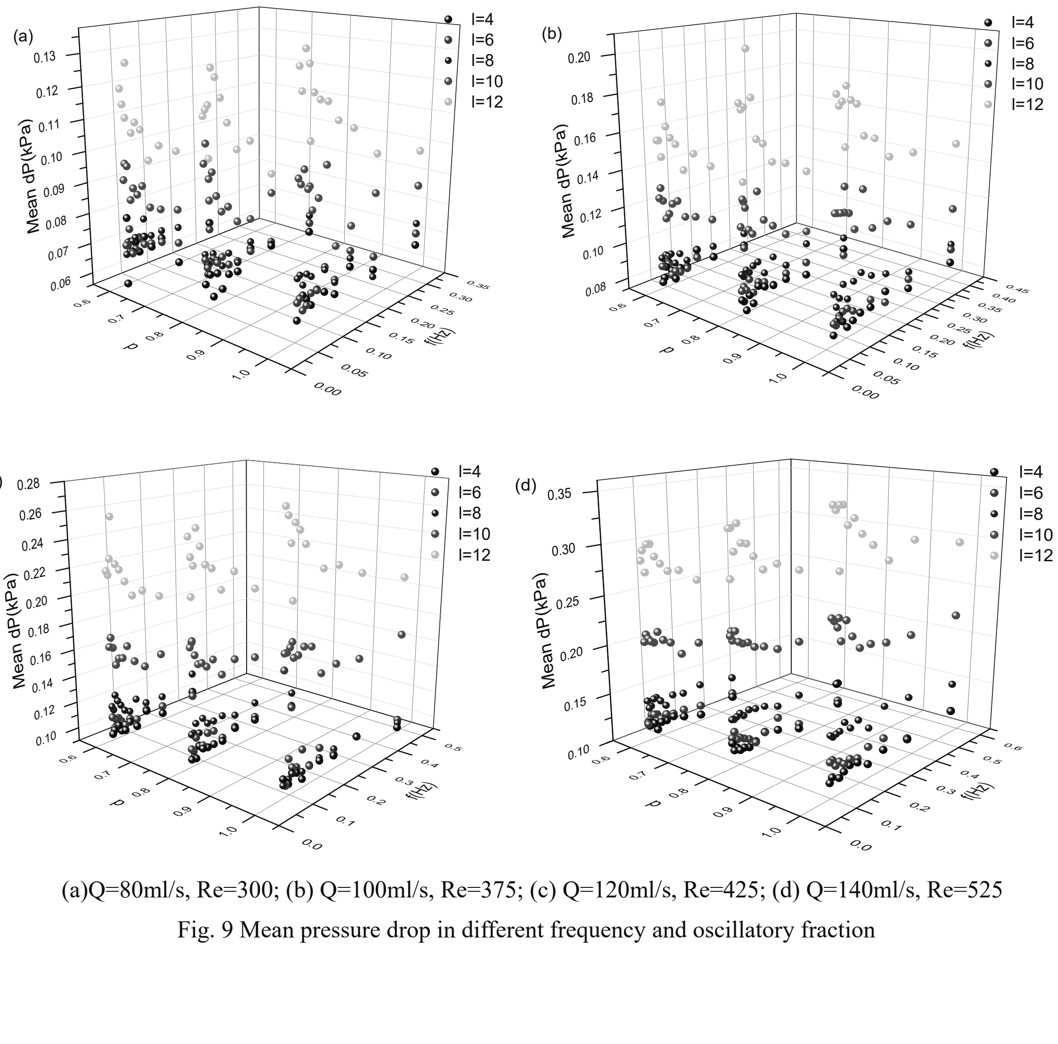
Fig. 8 Pressure drop in different frequency and oscillatory fraction on Re=300

In order to investigate the influence of the frequency (*f*) and the oscillatory fraction (*P*) on pressure drop, some experimental data are compared which are same frequency or same oscillatory fraction. It is shown in Fig.8 that the pressure drop in the grooved length of *l*=4mm and the Reynold number Re=300. In the each oscillatory fraction (*P*), the amplitude of pressure drop decreases with the frequency increasing. Meanwhile the amplitude of pressure drop increases with *P* increasing at same frequency.

Fig. 8(a)-(c) shows the influence of oscillatory fraction on the pressure drop. When the oscillatory fraction *P* increases, the amplitude of pressure drop increases at the same frequency. Fig.8 (top)-(bottom) shows when the frequency of pulsatile flow increases, the amplitude of pressure drop decreases at the same oscillatory fraction. Therefore, the frequency of pulsatile flow have opposite influence on the amplitude of pressure drop comparing with the oscillatory fraction.

3.5 Effect of multiple factors to the value of pressure drop in different grooved channel

The mean pressure drop of three kinds of oscillatory fraction in the channel is obtained in Fig. 9. It is seen that the mean pressure drop is maximum in grooved length l=12mm. For the grooved length l=12mm, the effect of frequency on the mean pressure drop is more obvious, and it increase with the value of pressure drop decreasing. The value of grooved length l=10mm is less than the value of l=12mm. However, the mean pressure drop fluctuates in a small range with frequency and fraction increasing in the grooved length l=4mm,6mm and 8mm. So it can be concluded that the pressure drop is relatively stable in the channel of l=4~8 in the laminar pulsatile flow.



(a)Q=80ml/s, Re=300; (b) Q=100ml/s, Re=375; (c) Q=120ml/s, Re=425; (d) Q=140ml/s, Re=525

Fig. 9 Mean pressure drop in different frequency and oscillatory fraction

3.6 Phase shift between pressure drop and velocity in different channel

In Fig 10, for the same plate, phase shift between pressure drop and velocity increases with the frequency of pulsatile flow, while decreases the oscillatory fraction. The influence of frequency change is more obvious in laminar flow. Comparing different grooved length, it is revealed that the phase shift is more likely and obviously to occur in long plates.

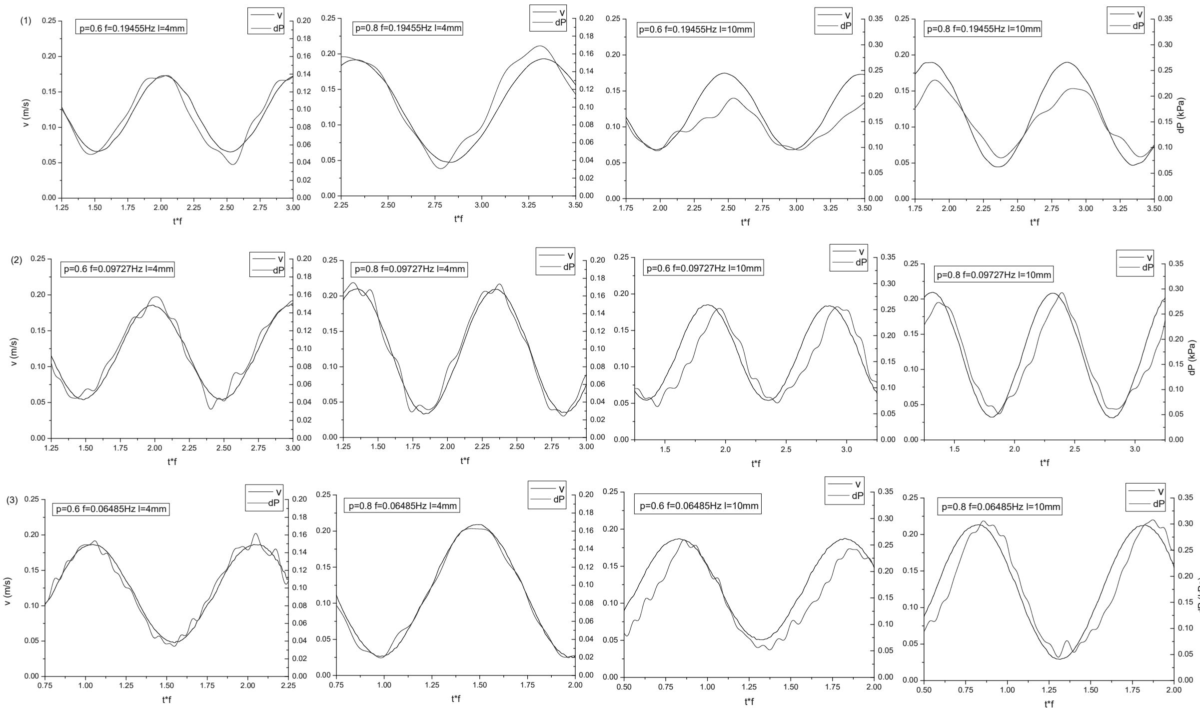


Fig. 10 the time history of voracity and pressure drop

4. Conclusions

In the present study, the pulsatile flow in grooved channels is explored experimentally. The most important results are concluded as follows:

(1)The mean pressure drop of all kind of grooved channel in laminar flow is almost linear relationship with the Reynold number ,and it keep pace with the growing of grooved length in the same Re.

(2)The frequency of pulsatile flow makes directly influence to pressure drop on the aspect of amplitude, mean value and phase shift. There is critical frequency to all grooved channels. When f is beyond f_c, the amplitude of pressure drop trend to a constant value in all grooved channel. The critical frequency has a linearly increasing trend with the increment of Reynold number. It is found that the mean pressure decreases with the frequency increasing which occurs prominent in the grooved length l=12mm.

(3)The amplitude of pressure drop for each channel increases monotonously with the oscillatory fraction at each Reynolds number.

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