Difference between Experimental and Theoretical Pulsatile Flow in Grooved Channel

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Abstract

The differences between experimental and theoretical pulsatile flow in grooved channel are investigated experimentally. Time-varying flow rate of pulsatile flow at different Reynolds number is measured by electromagnetic flowmeter and verified by pulsatile flow visualization. The experimental results show that the experimental oscillatory fraction is different from the theoretical value under different Reynolds number and pulsatile frequency. In addition, the experimental pulsatile frequency shows a phenomenon of "step-down" when the stroke becomes larger. Finally, the experimental waveform of the pulsating flow has a phase shift with the theoretical one, and the phase shift increases as the period increasing. The above conclusions are of some significance to improve the efficiency of heat exchanger in practical engineering.

Key words: Grooved Channel, Pulsatile Flow, Oscillatory Fraction, Phase Shift

1. Introduction

Ocean thermal energy conversion (OTEC) technology has great prospects as a new type of clean energy. In order to improve the efficiency of power generation, as a fundamental element of the plate heat exchanger, the flow behavior in the two dimensional channel should be further studied.

At present, there are a lot of research results in two-dimensional channel. Sun&Bian[1] found that the amplitude of local pressure is mainly concentrated at both ends of the channel for steady flow, and increasing pressure makes the amplitude more obvious. Bian[2][3] obtained the optimal value of the pressure increment for the self-sustained oscillation at different Reynolds Numbers. For the pulsatile flow with sine function distribution, the waveforms of flow rate Q and pressure drop dP are the same, while the waveforms of Q and the local pressure P have a half cycle phase shift. Bian&Yu[4] found the optimal grooved length is l=10mm by experimental analysis. Mu, Zhang and Huang[5][6][7] respectively described the relationship between the operation conditions, including the oscillatory fraction P, Reynolds number Re, pulsatile frequency f, and the pressure drop dP, the amplitude of pressure drop as well as the local pressure P_i. It can be seen that although there are a lot of research achievements in the two-dimensional channels, the problem whether the theoretical conditions set in the pulsatile flow are consistent with the experimental values has not yet been noticed.

In this study, the difference between the experimental value and the theoretical setting value of the oscillatory fraction and the pulsatile frequency in the pulsatile flow will be explored, and the variational trend of the difference will be clarified. In addition, the pulsatile flow visualization, realized by the aluminum dust method under Re=500 and P=1, is also used to judge the flow characteristics.

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2. Experimental setup

The experimental system schematic diagram is shown in Fig. 1, and all the experimental apparatus are consistent with the previous ones. The Reynolds number Re, the maximum flow rate of pulsatile flow Q_0, the steady flow Q_s the oscillatory fraction P, and the flow rate in the grooved channels Q are calculated according to the following definitions:

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

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

$$P = \frac{Q_0 - Q_s}{Q_s}$$

$$Q = Q_S + Q_0 = Q_s(1 + \mathrm{P}\cdot\sin(2\pi f t))$$

Where ρ is the density of water, u=1.5u_m is the characteristic flow velocity, u_m is obtained through u_m=Q/(2Wh), and μ =$10^{-3}$$Pa{\cdot}s$ is the viscosity of water, f is the pulsatile frequency, s is the stroke of the piston pump, D=50mm is the diameter of the piston pump, W=200mm is the grooved width, and h=2.5mm is the grooved height.

The experimental conditions are as follows: grooved length l=10mm, the Reynolds number changes from 500 to 1500, theoretical oscillatory fraction P=1, all experiments are conducted at room temperature.

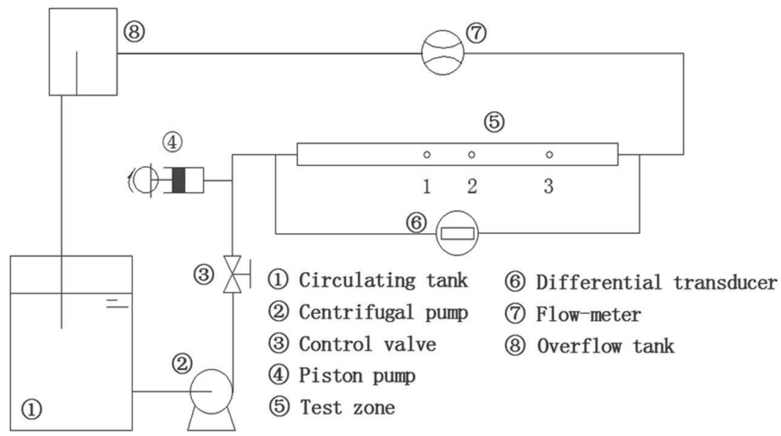
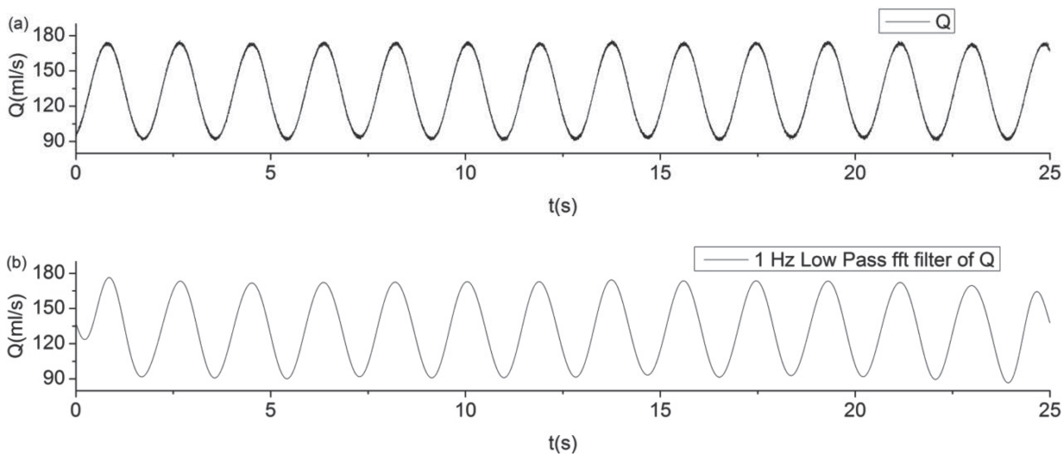


Fig. 1 Experimental system schematic diagram



(a) No filtering, (b) Filtering

Fig.2 Contrast with the data on no filtering and filtering

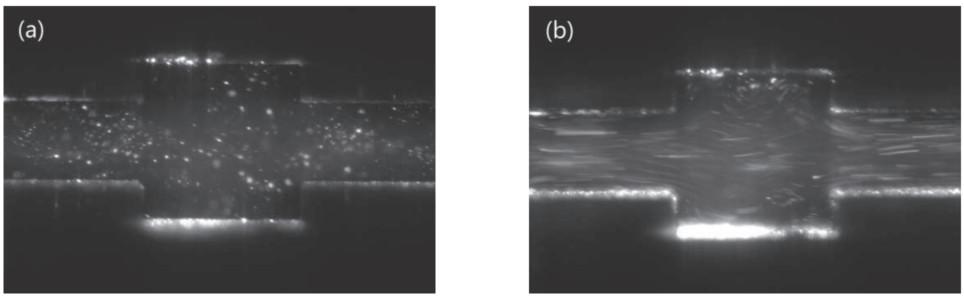
3. Results and discussion

3.1 Filter processing

Due to the interference of external factors such as noise, the original data of the experiment need to be filtered. All the experimental data are filtered by low pass. Because the cutoff frequency of each group of data are different, this section use *Re*=500, *P*=1, *s*=20 as an example, and the filtering effect is shown in Fig 2. The cutoff frequency of flow rate *Q* is 1*Hz*. It is found in the figure that the filtered data are inconsistent with the original data at the forepart and end, so all of the following conclusions are based on the middle section of the filtered data.

3.2 Difference between the experimental and the theoretical value of the oscillatory fraction

The theoretical oscillatory fraction *P* of this experiment *is*1. In other words, the time-varying pulsatile flow Q_i has a moment of Q_i =0. However in some experimental conditions, Q_i is constant greater than 0. This phenomenon can also be observed in the Fig. 3 of pulsatile flow visualization. Tracer particles appear spotted, which means that the speed at this time is almost equal to 0, as shown in Fig. 3(a). In contrast, the tracer particles in Fig. 3(b) have a linear shape, which



(a)Theoretical frequency *f*=0.0865 (b) Theoretical frequency *f*=0.5409

Fig.3 Visualization of pulsatile flow under *Re*=500, *P*=1, *t/T*=0.75 condition

Table 1 The maximum and minimum value of oscillatory fraction P^* under different Reynolds number

Re	500	600	700	900	1100	1300	1500
P^*_{max}	0.9599	0.9250	0.8735	0.8006	0.7297	0.6611	0.5870
P^*_{min}	0.3077	0.2379	0.1915	0.1267	0.0892	0.0610	0.0460

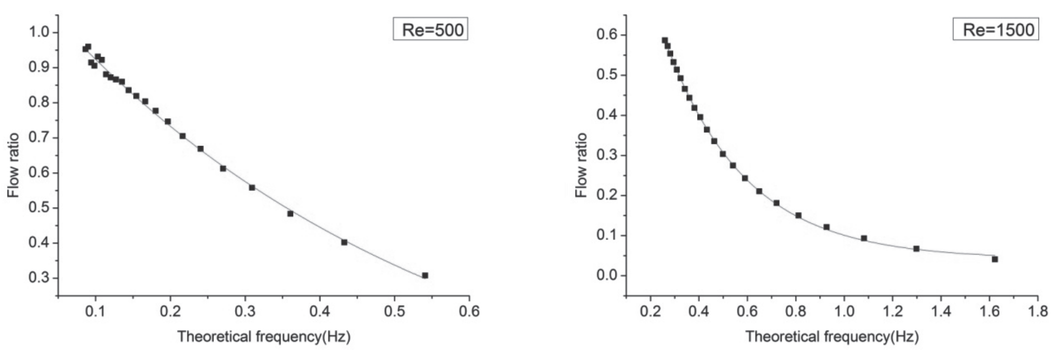


Fig.4 Difference between the experimental and the theoretical value of the oscillatory fraction

corresponds to a velocity greater than 0, that is, Q_i tends to 0 at low frequency, and $Q_i \neq 0$ at high frequency. This section focuses on the difference between the experimental and the theoretical value of oscillatory fraction.

Analyzing seven sets of data under different Reynolds numbers, it is found that the experimental oscillatory fraction P^* decreases with the frequency f increasing at the same Reynolds number. In addition, the experimental oscillatory fraction P^* are closed to 1 at low Reynolds number and low frequency. Conversely, the experimental oscillatory fraction P^* are less than 0.1 at high frequency and high Reynolds number. Table 1 shows the maximum and minimum values of P^* at different Reynolds Numbers. In addition, to the above rules observed in Fig. 4, the comparison of Re=500 and Re=1500 also intuitively shows that with the increment of the Reynolds number, the P^* changes from linear to nonlinear with the frequency f increasing.

The reason for the experimental oscillatory fraction P^* less than 1 is considered that the stroke of the piston pump is very short and the reciprocating velocity is very fast at higher pulsatile frequency. Due to the dominant viscosity of the fluid, which means the viscous force of the fluid is greater than the inertial force, the pulsatile flow has entered the deceleration phase before it reaches the maximum value. For the same reason, the flow rate has not reached 0 yet again entered the acceleration phase.

3.3 Difference between the experimental and theoretical value of the pulsatile frequency

The last section details the difference between the oscillation fraction P and P^*. In order to further clarify the difference between the experimental and theoretical pulsatile flow, this section will discuss the difference between the theoretical pulsatile frequency f and the experimental pulsatile frequency f^*.

First of all, in the seven experimental data, there is not much difference between the theoretical pulsatile frequency f and the experimental pulsatile frequency f^*. Secondly, as the Reynolds number increases, the difference between them gradually decreases, and the above conclusions can also be clearly observed in Fig. 5. Finally, a carefully look at Fig. 5, it is seen that with the increment of stroke s , the experimental pulsatile frequency f^* presents a "step-down" phenomenon;

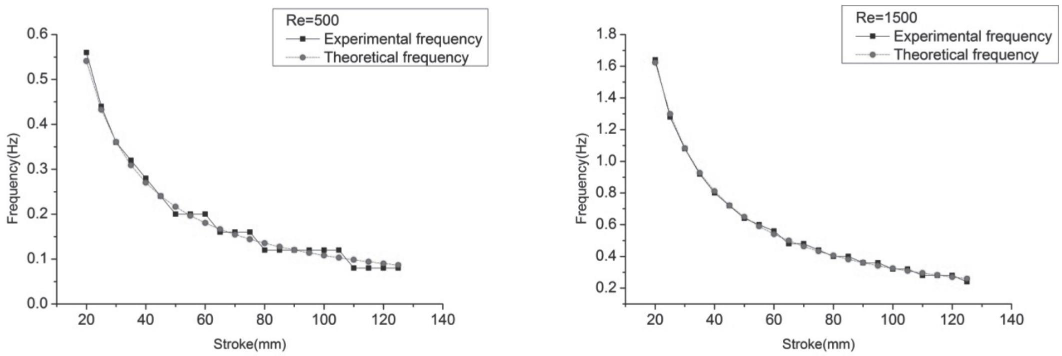


Fig.5 Experimental and theoretical value of the pulsatile frequency under different Reynolds number

Table 2 Parameter of "step-down"

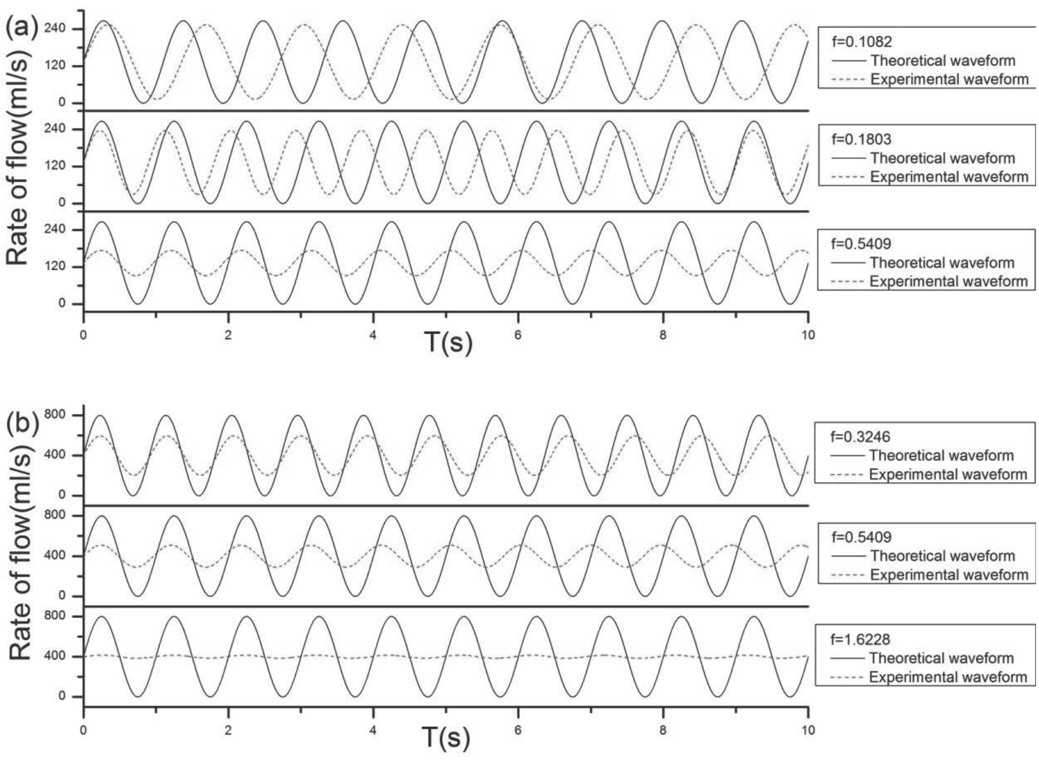
Re	500	600	700	900	1100	1300	1500
The first occurrence of "step-down" phenomenon of stroke value(*mm*)	50	50	45	65	70	75	65
The times of " step-down "	4	4	5	4	4	4	5
The maximum stroke interval of "step-down"(*mm*)	25	30	20	15	15	15	10

Take *Re*=500 as an example to illustrate this phenomenon. When the stroke *s* increases from 80*mm* to 105*mm*, the theoretical pulsatile frequency *f* gradually decreases, nevertheless the experimental pulsatile frequency *f** remains unchanged. This phenomenon exists in seven sets of experimental data and the first occurrence of a "step-down" phenomenon has a different stroke value, ranging from 45 to 50 for laminar flow and from 65 to 75 for turbulent flow. Furthermore, the "step-down" phenomenon of each group occurs four or five times. However, with the increment of *Re*, there is a gradual decrease in the maximum stroke interval for " step-down " . The detailed information is shown in Table 2. It is not clear why the phenomenon of " step-down " in the pulsation frequency has occurred, which may be the cause of the measurement error, or the cause of pulsatile flow, which still needs further study.

3.4 Difference between the experimental and the theoretical waveform of the pulsatile flow

Combined with the conclusions in Sections 3.2 and 3.3, this section uses the data from the previous two sections to plot the experimental and theoretical conditions of the pulsating flow waveform. From Fig. 6, it is further found that although the experimental frequency *f** of the pulsatile is not much different from theoretical frequency *f*, However, the phase shift between the waveform of the experimental pulsatile flow and its theoretical waveform gradually increases as the period increases. Moreover, the effect of pulsatile flow at high frequency and high Reynolds number is not ideal. which means, the experimental amplitude can only approach the theoretical amplitude at low Reynolds number and low pulsatile frequency.

Experiments show that there is almost no consistency between experimental and theoretical pulsatile flow. The oscillatory fractions are closed to the theoretical values at small Reynolds number and low pulsatile frequencies, but there are a phase shift between the experimental and the theoretical pulsatile flow waveform in this condition.



(a) *Re*=500, (b) *Re*=1500

Fig.6 Experimental and theoretical waveform

4. Conclusions

In this study, the pulsatile flow under the grooved channel is studied experimentally, and the following important conclusions are obtained:

(1) Under the same Reynolds number, the experimental oscillatory fraction of the pulsatile flow decreases with the increase of frequency. Only under the low Reynolds number and low frequency, experimental oscillatory fraction $P*$ is closed to the theoretical oscillatory fraction P.

(2) The experimental pulsatile frequency presents a phenomenon of "step-down". The differences between the experimental pulsatile frequency and its theoretical values decreases with increasing the Reynolds number.

(3) The experimental waveform of the pulsatile flow has a phase shift difference with the theoretical waveform, and the phase shift increases with increasing the period.

Acknowledgment

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