Flow Characteristics in Grooved Channel with Different Groove Lengths for Steady Flow

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Abstract

The steady flow in grooved channels is investigated experimentally. Parameters, including the flow rate, pressure drop and friction factor of grooved channels are examined systematically to characterize the flow. The behavior of pressure drop and friction factor is compared and discussed. The results show that the flow changes with the Reynolds number and the groove length of the channel influences the fluid flow. The local pressure is also measured and the local pressure drop is achieved by that. The inner flow of the grooved channel is then analyzed through the comparisons of the total and local pressure drop. The results show that the integral and local flow in grooved channel is in regularity.

Key words : Grooved channel, Steady flow, Pressure drop, Friction factor, Local pressure

1. Introduction

Nowadays, it is hot topic to develop clean and renewable energy for the problem of traditional energy. As a new way, ocean thermal energy[1-2] is promising to solve the problem. In the system of ocean thermal energy conversion (OTEC), the performance of fluid flow and heat transfer in heat exchanger is an important issue and many studies focus on this aspect.

Recently, Nishioka et al.[3] investigated the stability of Poiseuille flow in a plane channel. They clarified that the local velocity fluctuations display the sinusoidal wave forms when the Reynolds number increases near a critical value. As further increasing the Reynolds number, the wave form deviated gradually from this regular shape to irregular one. The above flow behavior has been proved by Nishimura et al.[4-6] and Greiner et al.[7] respectively in experimental and numerical way. They confirmed that the flow instability in the plane channels displays the form of Tollmien-Schlichting (T-S) wave. Wang & Wanka[8] numerically studied the convective heat transfer in the wavy channel. Their results showed that T-S wave exits in the wavy channel and the self-sustained wave could lead to the destabilization resulting in heat transfer enhancement. Sun et al.[9] made a further investigation of the grooved channel with a novel experimental mean. They obtained the first and second frequency of the T-S wave. Moreover, they found that increasing pressure will lead to higher amplitude of the T-S wave, which is significant for heat transfer in engineering.

In this study, the steady flow in grooved channels with different groove lengths will be detailedly detected in the experiment. The flow will be characterized by the total and local pressure drop, friction factor and local pressure. Moreover, the characteristics of the inner flow will be clarified.

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 consists of two grooved plates, as shown in Fig. 2. Eight sites can be used for measurement.

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Considering the effect of the entrance length, the third, fourth and seventh sites are placed with the pressure sensor. The distance between sites is d_1=210mm and d_2=420mm.

The configuration of the flow is shown in Fig. 3. In this study, there are total six kinds of grooved channels with the unit length *L*=20mm, *W*=200mm, *h*=2.5mm and the groove lengths *l*=4, 6, 8, 10, 12, 14mm.

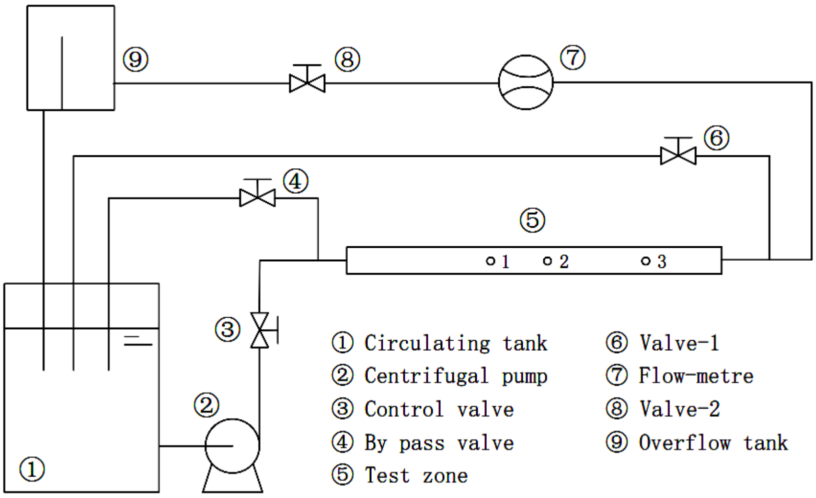


Fig. 1 Schematic diagram of the experimental system

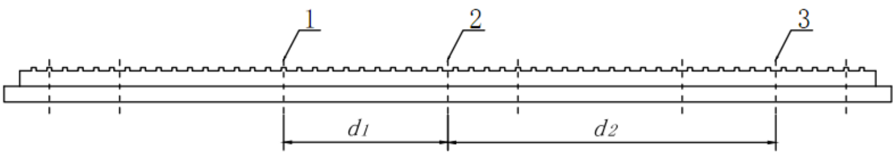
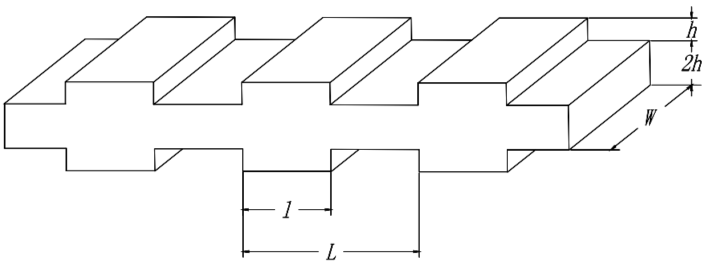


Fig. 2 Measuring sites positions on the grooved plate



L=20mm, *W*=200mm, *h*=2.5mm, *l*=4, 6, 8, 10, 12, 14mm

Fig. 3 Dimensions of the test section

3. Results and Discussion

3.1 Total pressure drop in grooved channel

In Fig. 4, the total pressure drop in different grooved channels gets similar variation tendency. It is seen that it increases slightly in the initial stage and the variation starts to increase rapidly when Reynolds number comes up to 500. It could be explained that the flow regime transforms from laminar into turbulent.

Comparing 6 different kinds of channels, it is detected that the total pressure drop keeps pace with the increment of groove length with the same Reynolds number. It means that the groove length makes a difference in the fluid flow. While, there is an exception that the total pressure drop of *l*=10 is more than that of *l*=12.

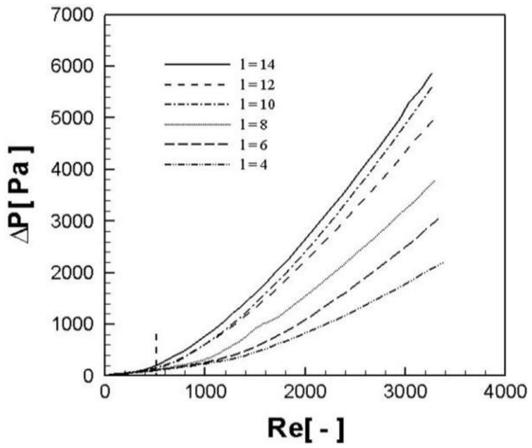


Fig. 4 Total pressure drop for the whole flow regime

3.2 Friction factor in grooved channel

The relationship between the friction factor and Reynolds number is shown in Fig. 5. It could be seen that three stages exist for the whole flow regime, which are sharp decrease, slight rise and new slight decline. The variation of friction factor is remarkable and rightly in coincidence with the flow regime transformation. Moreover, it is detected that there are a common laminar part Re (0~300) and a common turbulent part Re (above 2000) in channels.

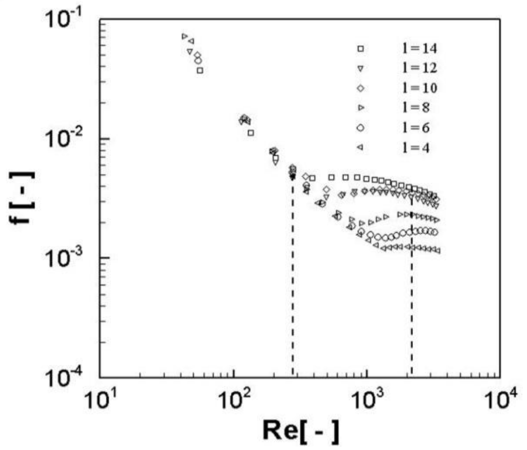
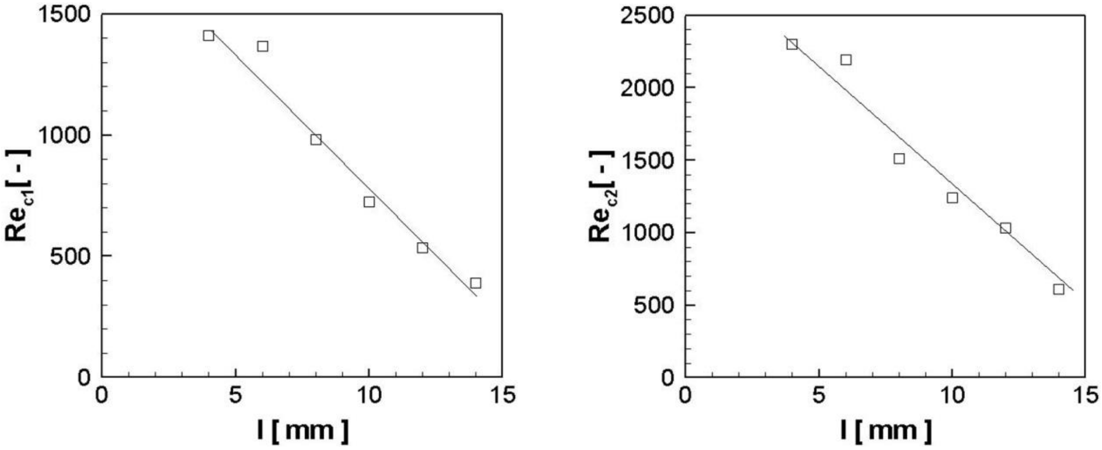


Fig. 5 Friction factor for the whole flow regime

The first and second critical Reynolds number are listed in Table 1 and the relationship between the critical Reynolds number and the groove length is shown in Fig. 6. It is detected that Reynolds number has a linearly decreasing trend with the increment of the groove length. It is perceived that the groove length is a factor influencing the time of flow regime transformation.

Table 1 First and second critical Reynolds number

l [mm]	Re_{c1}	Re_{c2}
14	390	612
12	537	1031
10	726	1242.8
8	982	1509
6	1367	2196
4	1409	2302

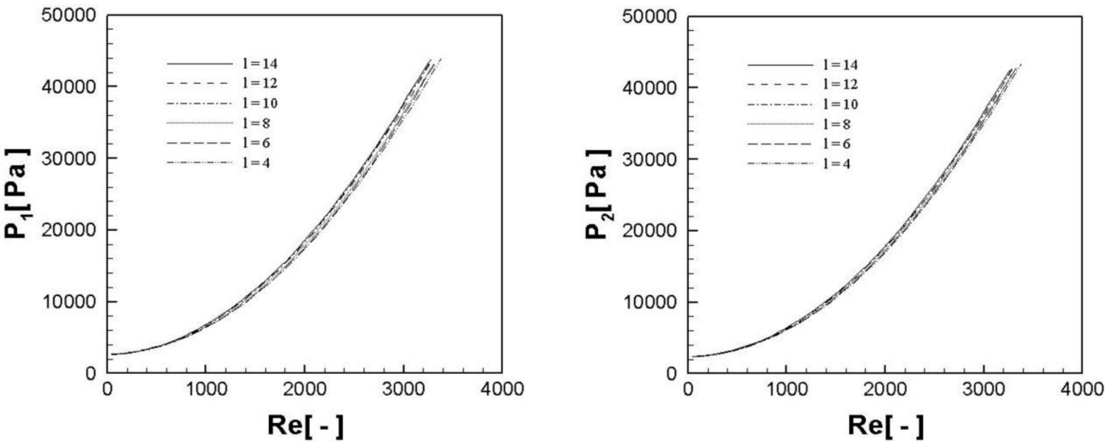


(a) The first critical Reynolds number (b) The second critical Reynolds number

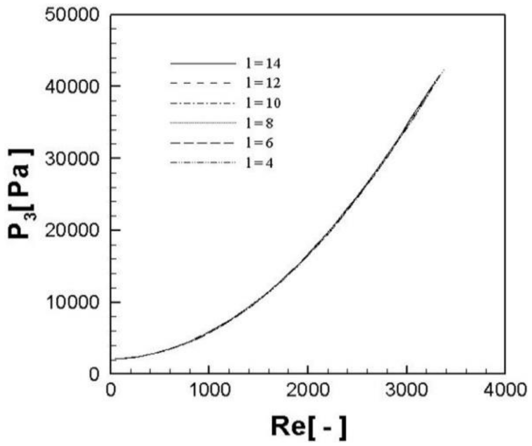
Fig. 6 Critical Reynolds number Re_{c1} and Re_{c2}

3.3 Local pressure in grooved channel

The local pressure of three measuring points in the channel is showed in Fig. 7. It is seen that the value of the local pressure is close with that in other channels for the same point. It could be considered that the local pressure in the channel is relatively stable and insensitive with the groove length.



(a) Measuring site 1 (b) Measuring site 2



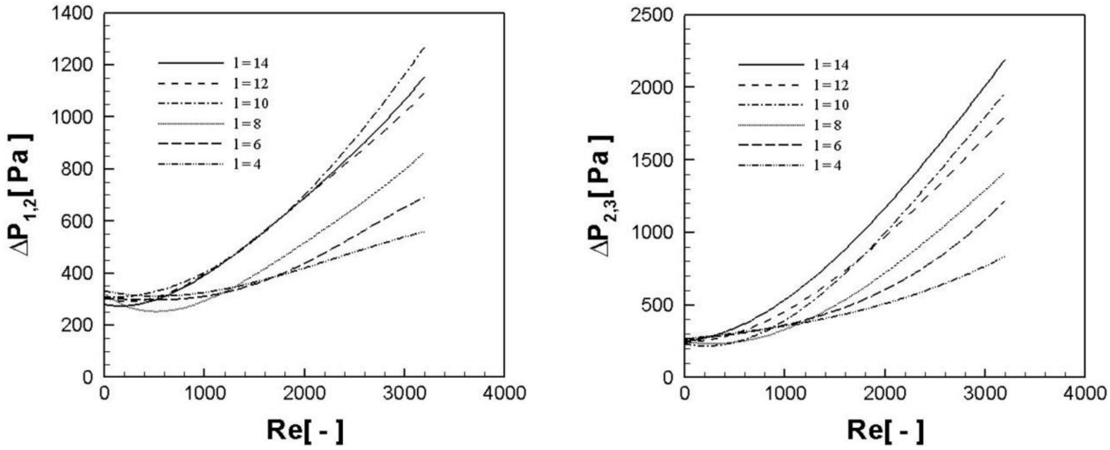
(c) Measuring site 3

Fig. 7 Local pressure for the whole flow regime

3.4 Local pressure drop between measuring sites

Based on the local pressure above, the local pressure drop is obtained in Fig. 8. It is seen that the value of the local pressure drops $\Delta P_{1,2}$ and $\Delta P_{2,3}$ appears a rising trend in coincidence with that of total pressure drop ΔP. It means the whole and partial flow is in regularity. Moreover, the local pressure drop with l=10 is quite unusual and even larger than that with l=14 as shown in Fig. 8(a).

Furthermore, the ratio of the local pressure drops $\Delta P_{2,3}$ and $\Delta P_{1,2}$ is compared in Fig. 9. The results show that with the increment of Reynolds number, the ratio increases close to 2, which is the length ratio d_2/d_1.



(a) Measuring site 2 to 1 (b) Measuring site 3 to 2

Fig. 8 Local pressure drop $\Delta P_{2,3}$ and $\Delta P_{1,2}$ for the whole flow regime

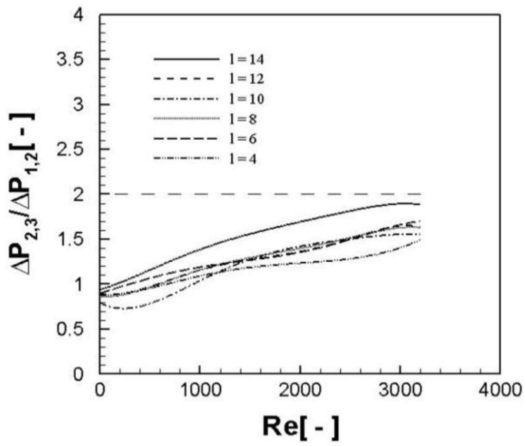


Fig. 9 Ratio of local pressure drop for the whole flow regime

4. Conclusions

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

(1) The flow in grooved channel keeps a variable trend in coincidence with the transformation of flow regime characterized by the pressure drop and friction factor.

(2) The grooved channels with different groove length show the distinction in fluid flow. With the same Reynolds number the pressure drop and friction factor keep pace with the growing of groove length. Specially, the value of l=10 is abnormally large, possibly due to the flow peculiarity.

(3) The flow of inner domain in grooved channel shows similar regularities as that of the whole domain. The local pressure drop is in coincidence with the total pressure drop. Moreover, the value of l=10 is even more than the others in the initial part of channel.

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References

[1] Cavrot DE, Economics of ocean thermal energy conversion (OTEC), Renewable Energy, Vol. 3, (1993), pp. 891-896.

[2] Lennard DE, The viability and best locations for ocean thermal energy conversion systems around the world, Renewable Energy, Vol. 6, (1995), pp. 359-365.

[3] Nishioka M, lida S, Ichikawa Y, An experimental investigation of the stability of plane Poiseuille flow, J. Fluid Mech, Vol. 72, (1975), pp. 731-751.

[4] Nishimura T, Heat and mass transport in channels with boundary irregularities for self-sustained oscillatory flow, Trends Heat Mass Momentum Transf, Vol. 3, (1997), pp. 65-83.

[5] Nishimura T, Kunitsugu K, Nakagiri H, Fluid mixing and local mass transfer characteristics in a grooved channel for self-sustained oscillatory flow, Heat Transfer Jpn Res, Vol. 27, (1998), pp. 522-534.

[6] Nishimura T, Kunitsugu K, Three-dimensionality of grooved channel flows at intermediate Reynolds numbers, Exp Fluids, Vol. 31, (2001), pp. 34-44.

[7] Greiner M, An experimental investigation of resonant heat transfer enhancement in grooved channels, Int. J. Heat Mass Transfer, Vol. 34, (1991), pp. 1383-1391.

[8] Wang G, Vanka SP, Convective heat transfer in periodic wavy passages. Int. J. Heat Mass Transfer, Vol. 38, (1995), pp. 3219-3230.

[9] Sun FM, Bian YN, Arima H, Ikegami Y and Xu XS, Strength characteristics of the self-sustained wave in grooved channel with different groove length, Heat Mass Transfer, Vol.46, (2010), pp. 1229-2337.