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# Study on the thermal and fluid behaviors in a conventional wavy channel and a curve-wave channel

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## ABSTRACT

The development of the electronic devices with the growing heat generation raises the high requirement for heat dissipation devices. Extensive research has been carried out for enhancing convective heat transfer rate in various heatsinks. The curve-wave channel proposed in the authors' previous work exhibits the superior thermal performance with a slight increase in pressure drop compared with a smooth-curve channel. In the present study, the thermal behaviors, the overall performance and the secondary flow characteristics in a curve-wave channel and a conventional wavy channel are numerically investigated and compared.

The results show that the thermal performance of the conventional wavy channel is improved and the maximum temperature on the heated wall can be lowered 1.2-3.6 K after introducing the overall curvature. However, it is also noted that the overall performance factor decreases while Reynolds number grows, in other words, the superiority of the curve-wave channel is more obvious at small Reynolds number. The analysis of the secondary flow characteristics shows that the stronger secondary flow is generated in the curve-wave channel regardless of Reynolds number, which indicates the overall curvature has an important effect on the flow in the wavy channel.

**Keywords:** heat dissipation, curve-wave channel, thermal behaviors, overall performance, secondary flow

## NOMENCLATURE

| | |
|---|---|
| *Abbreviations* | |
| *f* | Fanning friction factors |
| Nu | Nusselt number |
| *q* | surface heat flux (W/m$^2$) |
| Re | Reynolds number |
| *Symbols* | |
| 0 | conventional wavy channel |

## 1. INTRODUCTION

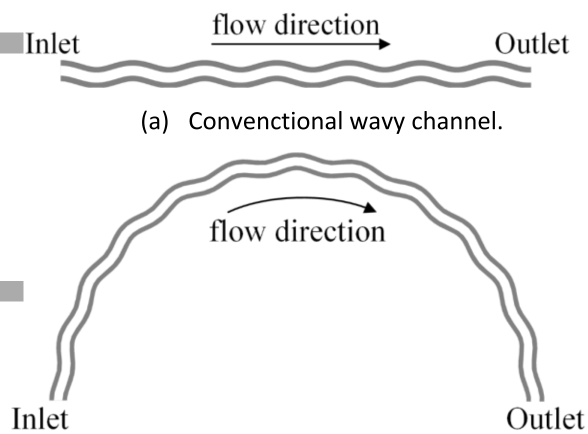
Heat dissipation has been one of the essential issues in the development of the electronic devices with the high heat generation since the proper working temperatures have to be maintained for ensuring the performance and lifespan of the electronic devices [1]. Various techniques have been proposed for high-efficiency heat transfer based on the basic heat transfer enhancement principles such as increasing heat transfer area, introducing flow disturbance and modifying fluid properties.

Wavy channels have received great attention due to their superior thermal performance and relatively simple structure compared with other channel configurations. Extensive works have been carried out for exploring the flow and heat transfer characteristics in wavy channels and the effects of geometrical parameters have been investigated [2-4]. The thermal performance of the wavy channel can be further improved through increasing wave amplitude or decreasing wavelength [5, 6]. However, it is also reported that the wave amplitude significantly affects the maximum number of channels configured on a heatsink with a given area [7]. As is well-known, curved channel possesses a more compact structure against a straight one. Similarly, a curve-wave channel is more compact compared with a conventional wavy channel, which may deal with the issue that the thermal performance of a wavy channel is limited by the limited growing of wave amplitude in a heatsink. In our previous study, a curve-wave channel was proposed for enhancing the heat transfer rates in a smooth curved channel, which exhibited the superior thermal performance with the penalty of slight pressure drop increase [8, 9].

In the present study, the thermal behaviors, the overall performance and the secondary flow characteristics in a conventional wavy channel and a curve-wave channel are numerically investigated and compared, which is expected to provide some guidance for the design of a heatsink with wavy channel structure.

## 2. CHANNEL CONFIGURATIONS

As shown in **Fig. 1**, the channel sidewalls wave along a straight line in a conventional wavy channel, in other words, the overall curvature of a conventional wavy channel can be considered as zero. By contrast, the sidewalls wave along a curve in a curve-wave channel and the overall shape of the channel is closer to a curved channel. In this way, a straight channel and a curved channel can be views as the special case of a conventional wavy channel and a curve-wave channel with the wave amplitude of zero, respectively.




(a) Convenctional wavy channel.

(b) Curve-wave channel.

**Figure 1.** Schematic diagram of two wavy channels.

For a fair comparison, the wave amplitude, the wavelength and the total length are taken as the same for two wavy channels, which are 0.6 mm, 20.9 mm and 388.9 mm respectively. The overall curvature radius of the curve-wave channel is 80 mm. The cross-section is identical for two channels, which is rectangular with the width of 3 mm and the height of 6 mm. The thickness of the wavy sidewalls is 1.5 mm while the thickness of the flat cover and base plates is 6 mm.

## 3. NUMERICAL INVESTIGATIONS

### *3.1 Modeling of conventional wavy flow and curve-wave flow*

The flow in both wavy channels was assumed to be steady, incompressible and laminar. The effects of gravity and radiative heat transfer were assumed to be negligible. Water and aluminum were chosen to be the working fluid and the channel material respectively, and their thermal properties were thought as independent with temperature.

### *3.2 Boundary conditions*

The uniform velocity determined by various Reynolds number was applied at the inlet boundary condition, where a uniform temperature of 300 K was set for the working fluid. The atmosphere pressure boundary condition was applied at the outlet. Only the bottom wall was heated with a heat flux of 50000 W/m$^2$.

### *3.3 Numerical schemes*

The calculation domains were discretized with structured grids, in particular, the fluid zones near the convective surfaces were refined. Pressure-velocity coupling items were solved using SIMPLE algorithm and Pressure items were discretized with Standard algorithm. The second-order upwind scheme was employed to solve the momentum and energy equations.

## 4. RESULTS AND DISCUSSIONS

### *4.1 Thermal behaviors*

First, the convective heat transfer rates in two wavy channels are compared in **Fig. 2**. For a given Reynolds number, the overall Nusselt number is higher in the curve-wave channel, indicating that the overall curved structure enhances the heat transfer in the conventional wavy channel. Besides, it is shown that the heat transfer enhancement is more significant at small Reynolds numbers.

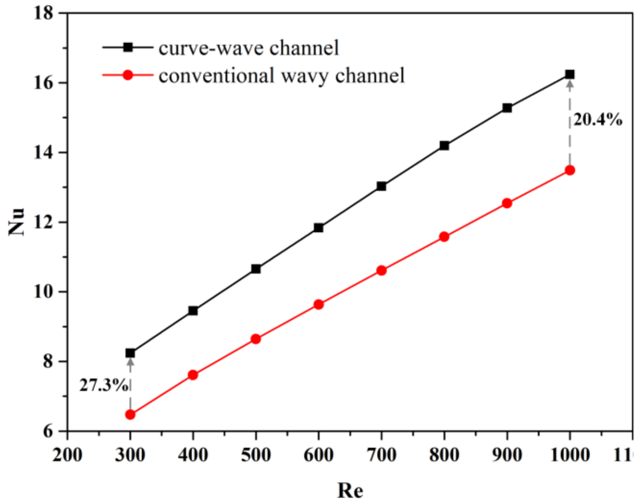



**Figure 2.** Comparison of Nusselt numbers in the two wavy channels.

Due to the overall curvature, the maximum temperatures are decreased by 3.6 K at Re = 300 and 1.2 K at Re=1000 as shown in **Fig. 3**, which further demonstrates the superior thermal performance of the curve-wave channel.

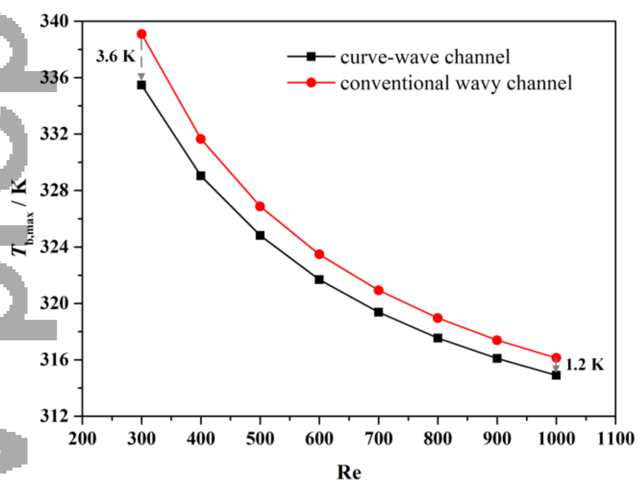



**Figure 3.** The maximum temperature on the heated surface of the two wavy channels.

## *4.2 Overall performance*

As expected, the friction factor in the curve-wave channel is higher than that in the conventional wavy channel for a given Reynolds number, as shown in **Fig. 4**. The heat transfer enhancement obtained from the overall curvature is at the cost of the increasing pressure loss. Therefore, the performance factor composed of the ratio of Nusselt numbers and the ratio of friction factors in the two wavy channels is applied to evaluate the overall performance of the curve-wave channel.

It is found in **Fig. 5** that the performance factors are larger than 1.00 within the whole range of Reynolds numbers. It can be concluded that the enhancement in heat transfer is predominant compared with the increase of pressure loss. However, it is noted that the performance factor falls with the growing of Reynolds number, which suggests the increasing rates of friction factor is higher than that of Nusselt number. The result indicates that the superiority of the curve-wave channel is more noticeable at small Reynolds numbers.

The thermal resistances under the various pumping powers for two wavy channels are compared in **Fig. 6**. For a given pumping power, the curve-wave channel always provides a lower thermal resistance, which confirms that the curve-wave channel possesses better thermal performance. It is also found that the reduction of the thermal resistance gets flat with an increase in pumping power. One may infer that the increase in flow rate may be not an efficient and economical way to improve the thermal performance of two wavy channels when the flow rate is above a certain value.

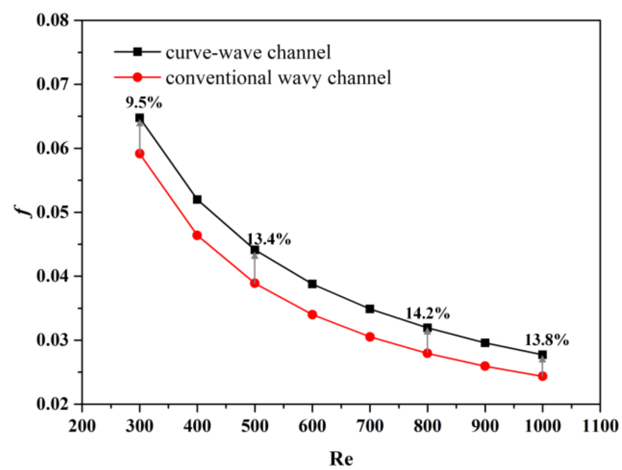



**Figure 4.** Comparison of fanning friction factors in two wavy channels.

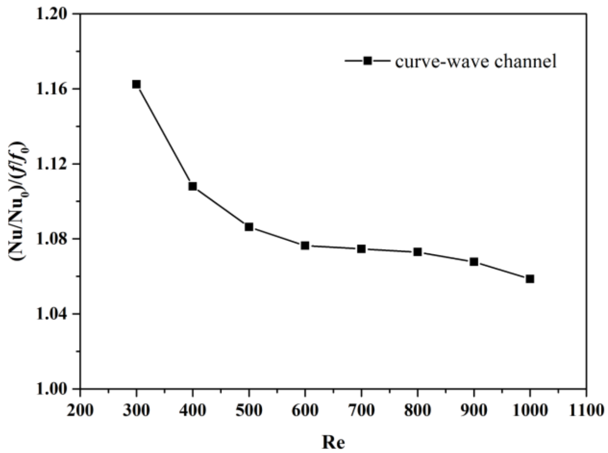



**Figure 5.** Performance factors of the curve-wave channel.

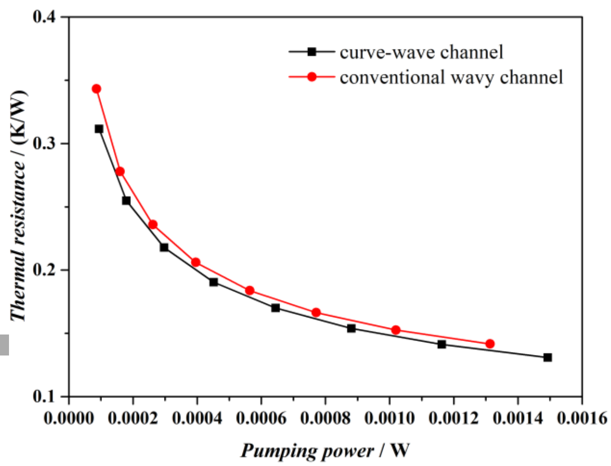



**Figure 6.** Thermal resistance and the required pumping power for the two wavy channels.

To further explore the thermal behaviors in the two wavy channels, the heat flux removed by the different convective surfaces is analyzed. As shown in **Fig. 7**, more heat flux is removed by the bottom and top convective surfaces with the growing of Reynolds number in the conventional wavy channel. The difference in heat flux removed by the inner surface and the outer surface can be neglected, which can be attributed to the overall curvature of zero.

As shown in **Fig. 8**, the variations of the surface heat flux are slight in the curve-wave channel when Reynolds number increases, which is different from those in the conventional wavy channel. Due to the overall curvature, the heat flux removed through the outer surface is higher than that through the inner surface. However, it is noted that the difference of removed heat flux at the bottom and the other convective surfaces is relatively small compared with that in the conventional curve-wave channel. Therefore, the maximum temperature on the bottom heated wall is significantly lowered after introducing the overall curvature, as shown in **Fig. 3**.

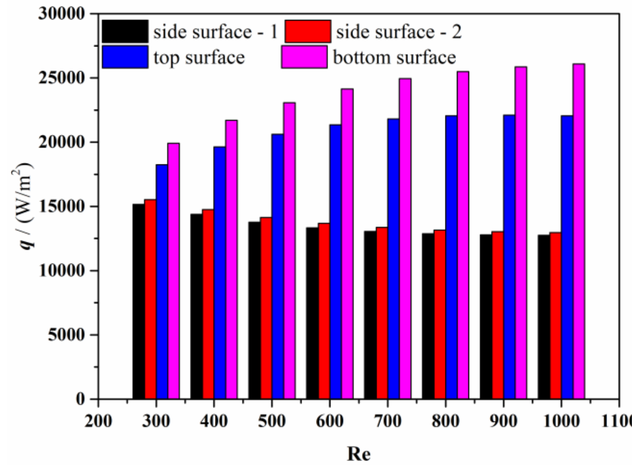



**Figure 7.** Average heat flux on the convective surfaces in the conventional wavy channel.

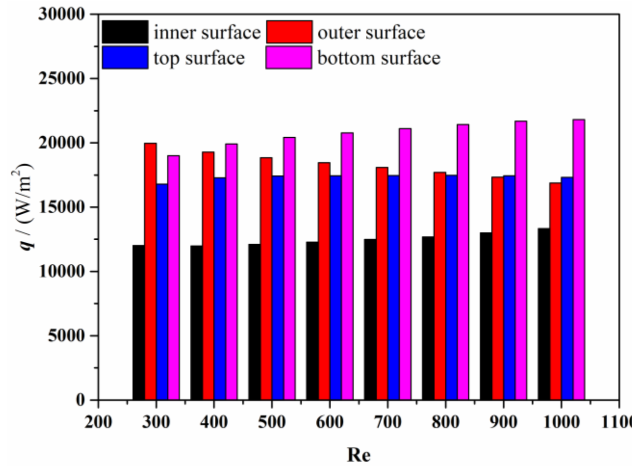



**Figure 8.** Average heat flux on the convective surfaces in the curve-wave channel.

*4.3 Secondary flow*

It is well known that the superior thermal performance of a curved channel compared with a straight channel can be attributed to the secondary flow. Therefore, the secondary flow characteristics in the conventional wavy channel and the curve-wave channel are examined in the following section.

**Figures 9 and 10** compare the secondary flow at the half length in the two channels at the Reynolds numbers of 300 and 1000, respectively. Since the flow is symmetrical about the half-height plane, therefore, only the upper cross-section is present for conciseness. It is noted that the secondary flow is stronger in the curve-wave channel at two Reynolds numbers, indicating the important effects of the overall curvature. The form of the secondary flow in two wavy channels is similar when Re = 300, where a vortex generates with the same rotating direction. However, the structure of the secondary flow is a little complicated in the conventional wavy channel when Re = 1000. It may be inferred that the mechanism of the secondary flow is different in the two wavy channels.

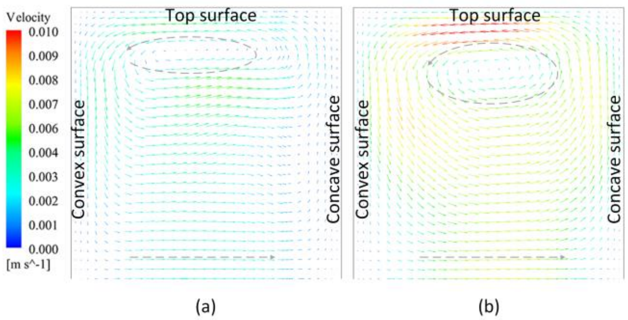



**Figure 9.** The secondary flow distributions at the half-length in (a) the conventional wavy channel and (b) the curve-wave channel for Re = 300.

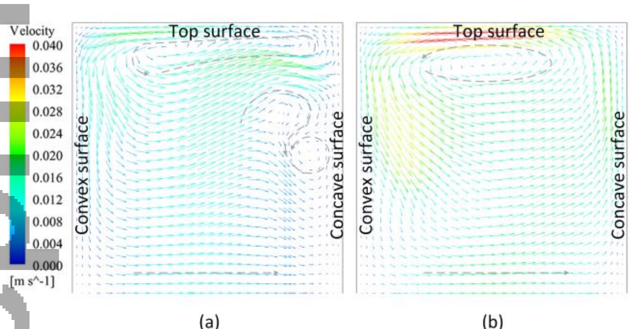



**Figure 10.** The secondary flow distributions at the half-length in (a) the conventional wavy channel and (b) the curve-wave channel for Re = 1000.

## 5. CONCLUSIONS

The thermal behaviors, the overall performance and the secondary flow characteristics in a conventional wavy channel and a curve-wave channel are numerically investigated and compared. The heat transfer performance of the curve-wave channel is better than that of the conventional wavy channel, with the penalty of increasing pressure loss. The overall performance factors indicate the superiority of the curve-wave channel is more obvious at small Reynolds number. The secondary flow is found stronger in the curve-wave channel, indicating the great effects of the overall curvature on the flow in the wavy channel.


## ACKNOWLEDGEMENT

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