# Prediction of onset of density wave oscillation in single-heated and dual-heated systems using the MARS code

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## 1. Introduction

Some previous studies reported the effect of the node size on the onset of density wave oscillation(DWO) [1],[2]. This study considered the effects of the node size and time step on the onset of density wave oscillation(DWO) in single- or dual-heated-channel systems. The MARS code was used in this study. In addition, three different boundary-condition approaches were compared in terms of their adequacy in predicting DWO.

## 2. DWO determination method

We tested three different boundary-condition approaches to investigate the onset of DWO:

• The heat power is fixed. Water is injected from the bottom using a velocity inlet. Gradually reduce the flow rate and observe if the flow oscillates.

• The heat power is fixed. A pressure boundary is imposed on the inlet and outlet. Gradually reduce the pressure difference between the inlet and outlet and observe if the flow oscillates.

• Pressure boundaries are applied to the inlet and outlet, and the pressure drop is fixed. Gradually increase the heat power and observe if the flow oscillates.

We adopted the DWO determination method proposed by [3]. A flow example under DWO in the single-heated-channel system is shown in Fig. 1. First, the mass flow rate is normalized as follows:

$$\dot{m}' = \frac{\dot{m} - \bar{\dot{m}}}{\bar{\dot{m}}} \quad (1)$$

Then, the normalized mass flow rate is analyzed by the fast Fourier transform. If the frequency of the first peak is less than 1 Hz and the amplitude of the first peak is greater than 0.3, the flow is considered to be under density wave oscillation.

To represent DWO, we use the concepts of inlet subcooling number( $N_{sub}$ ) and phase change number($N_{pch}$).

$$N_{sub} = \frac{h_f - h_{in}}{h_{fg}} \times \frac{\rho_f - \rho_g}{\rho_g} \quad (2)$$

$$N_{pch} = N_{Zu} = \frac{h_{out} - h_{in}}{h_{fg}} \times \frac{\rho_f - \rho_g}{\rho_g} \quad (3)$$

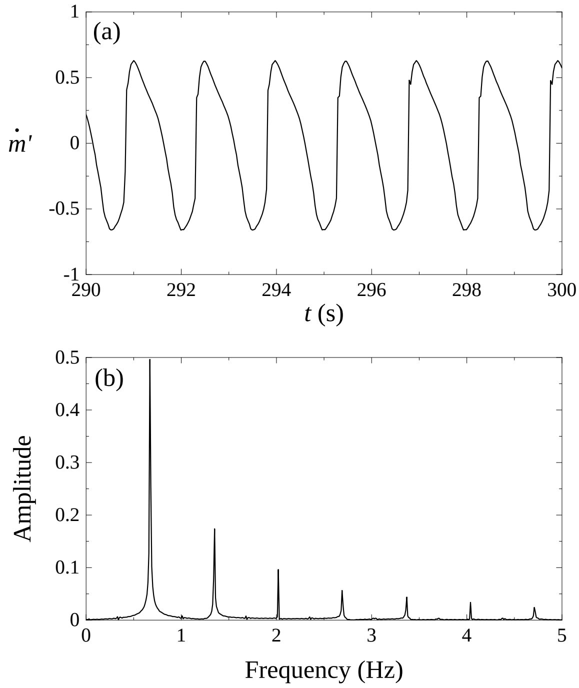


Fig. 1. Flow example under DWO: (a) Normalized mass flow rate and (b) FFT result

## 3. Result: Single-heated-channel system

Figure 2 shows the schematic of the MARS modeling for the single-heated-channel system [4]. Figure 3 shows the simulation result using the first approach. Though the flow is predicted to be oscillatory, the oscillation is not physical based on the FFT result. The first or dominant peaks are unclear, and their amplitude is small. Thus, the first approach was unsuitable for determining DWO in the single-heated-channel system. Although not presented in this manuscript, the second approach had a risk of causing a flow excursion in case the pressure drop was too small. The third approach successfully determined DWO in the single-heated-channel system, as shown in Fig. 1.

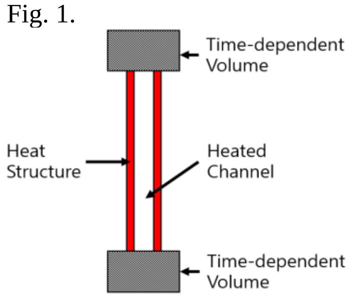


Fig. 2. MARS modeling for single-heated-channel system [4]

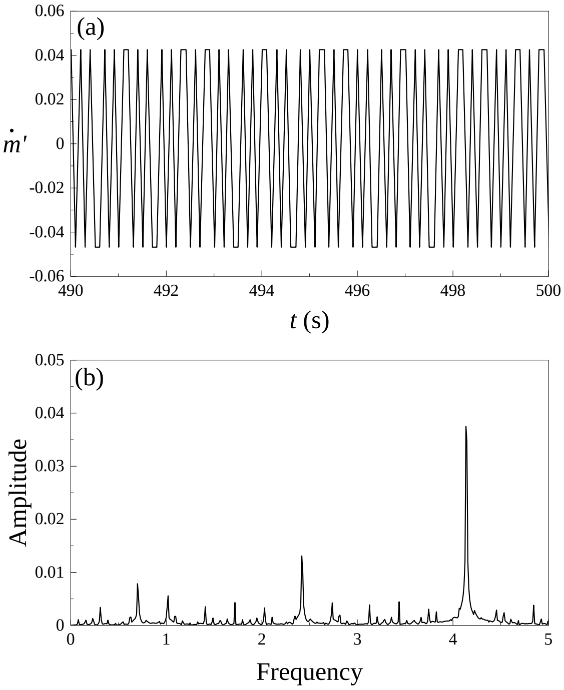


Fig. 3. Simulation result ($T_i$ = 475.2 K and $\dot{m}$ = 0.007 kg/s) when the first approach was used.

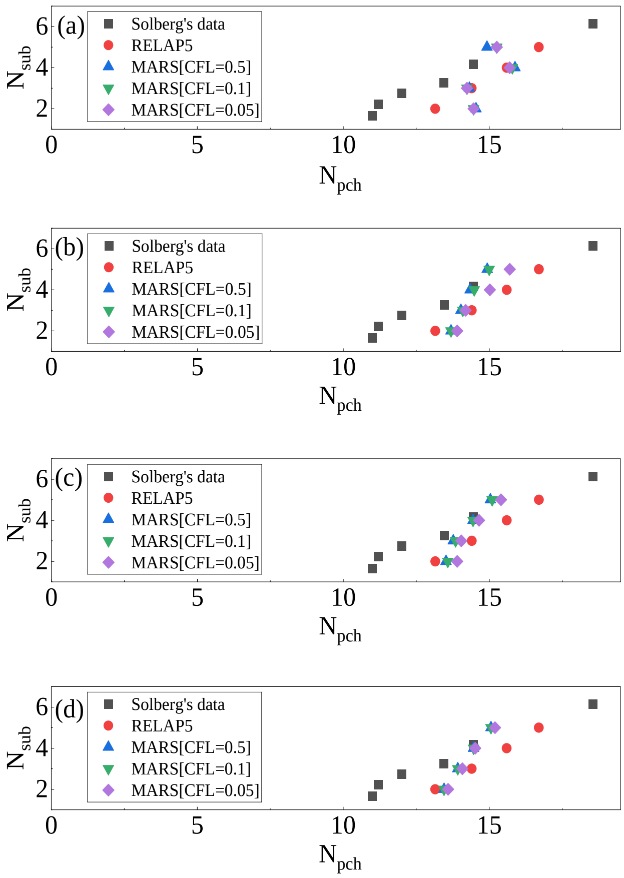


Fig. 4. Comparison of the conditions for the onset of DWO when the number of nodes is (a) 12, (b) 24, (c) 48, and (d) 96.

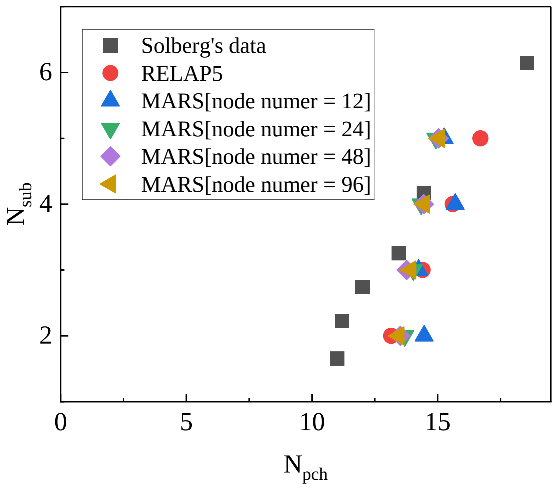


Fig. 5. Comparison of the conditions for the onset of DWO when the CFL is 0.5.

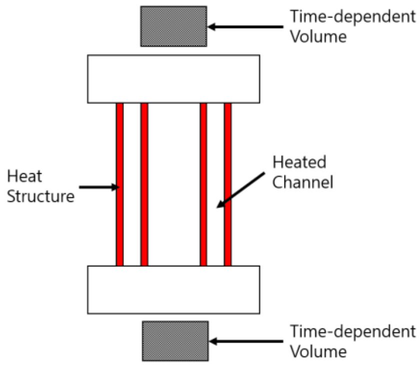


Fig. 6. MARS modeling for the EREC experiment

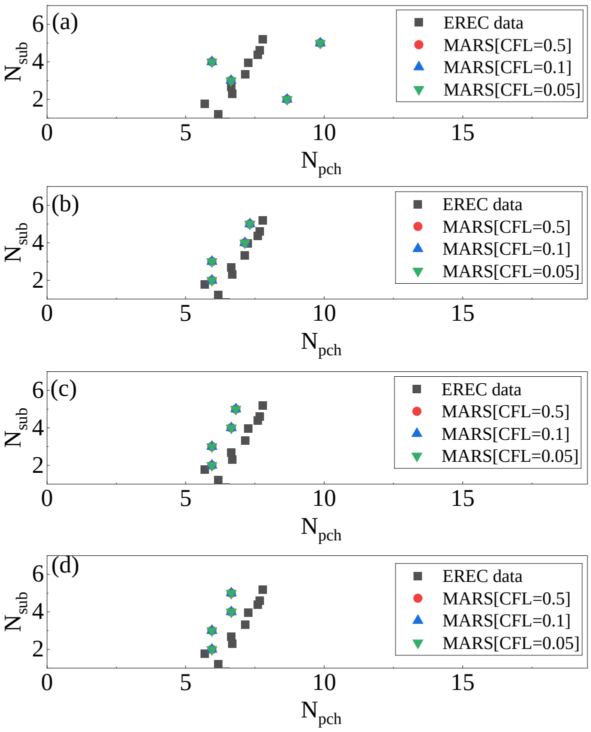


Fig. 7. Comparison of the conditions for the onset of DWO when the number of nodes is (a) 5, (b) 20, (c) 40, and(d) 80.

Figures 4 and 5 compare the predicted conditions for the onset of DWO. The effects of node size and time step appear insignificant unless the number of nodes is as small as 12.

## 4. Dual-heated-channel system

Figure 6 shows the schematic of the MARS modeling for the EREC experiment [3].

In contrast to the single-channel system, the first approach was suitable for determining DWO in the dual-channel system. The second approach had a risk of causing a flow excursion if the pressure drop was too small. The third approach had a difficulty to match the simulation and experimental conditions.

Figure 7 compares the conditions for the onset of DWO. The effects of node size and time step appear insignificant unless the number of nodes is as small as 5.

## 5. Conclusions

The third modeling approach was suitable for determining DWO in the single-heated-channel system, whereas the first modeling approach was suitable for the dual-heated-channel system. The effects of node size and time step appeared insignificant unless the number of nodes was small.

## Acknowledgments

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