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Experimental and numerical investigations of film flow behaviors in resonance section over corrugated plates

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Background

- The structured packing column is widely used in chemical processing, but the entire tower flow modeling involves significant computational work.
- Over the decade, packed columns have become popular due to the possible efficiency and capacity increase compared to tray columns
- Most of the studies on film flow resonance have emphasized the occurrence conditions, such as the shapes and steepness of corrugations. Investigations of resonance have been performed primarily on sinusoidal and triangular corrugations. However, the mechanism and how the resonance phenomenon affects the flow have not been formulated into a systematic study.

Bottom eddies and resonance section

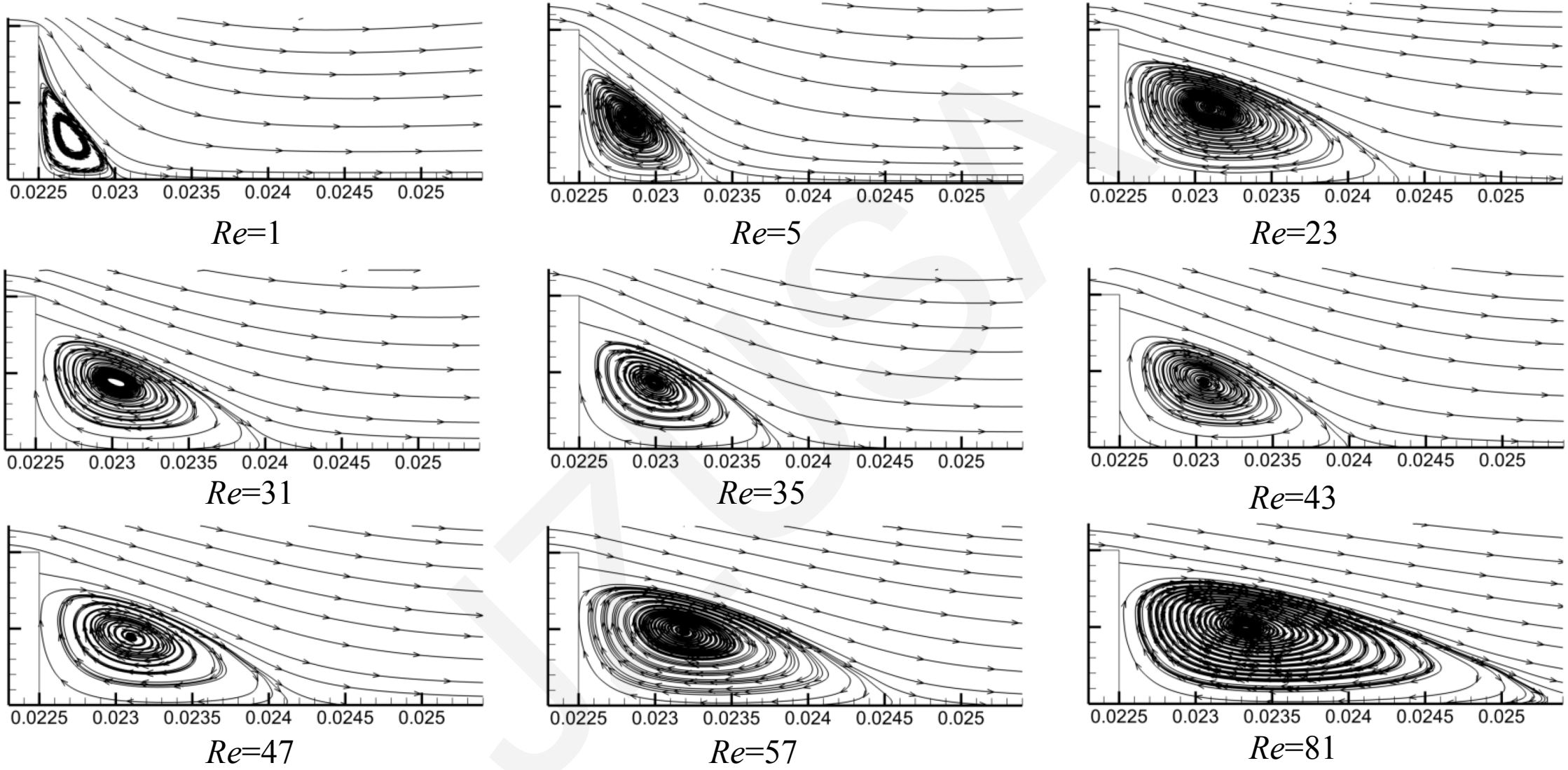


Fig. 3.2 Eddy areas in different Reynolds numbers (simulation resluts)

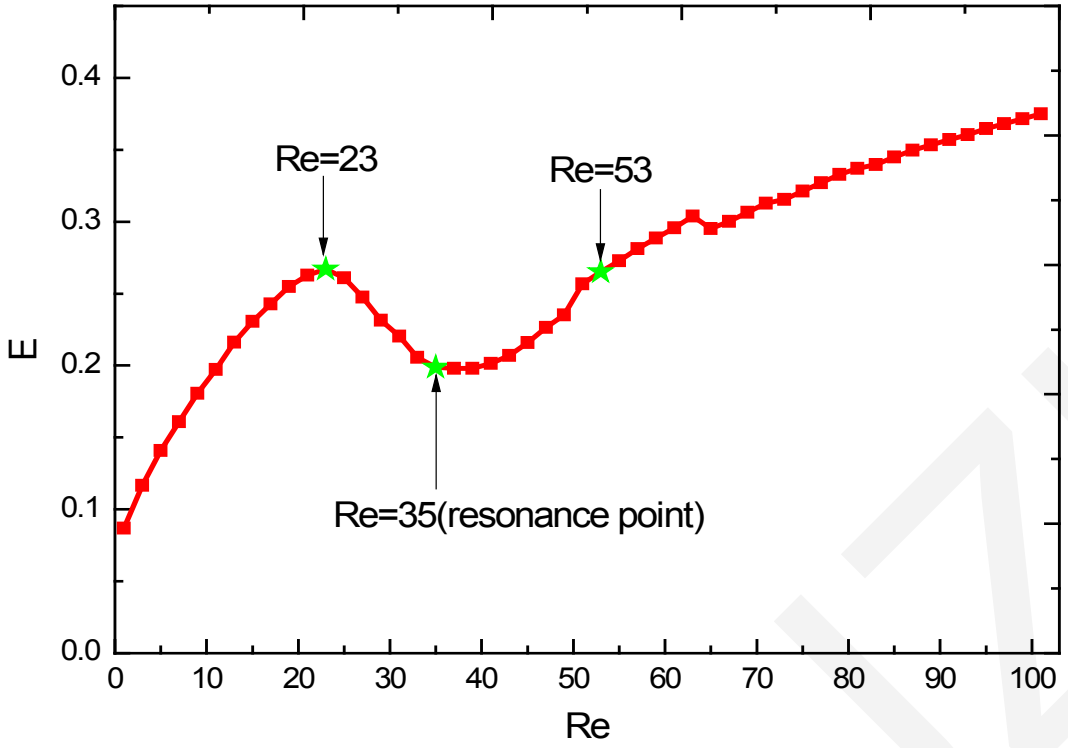
resonance section

Fig. 3.2 Eddy areas in different Reynolds numbers (simulation resluts)

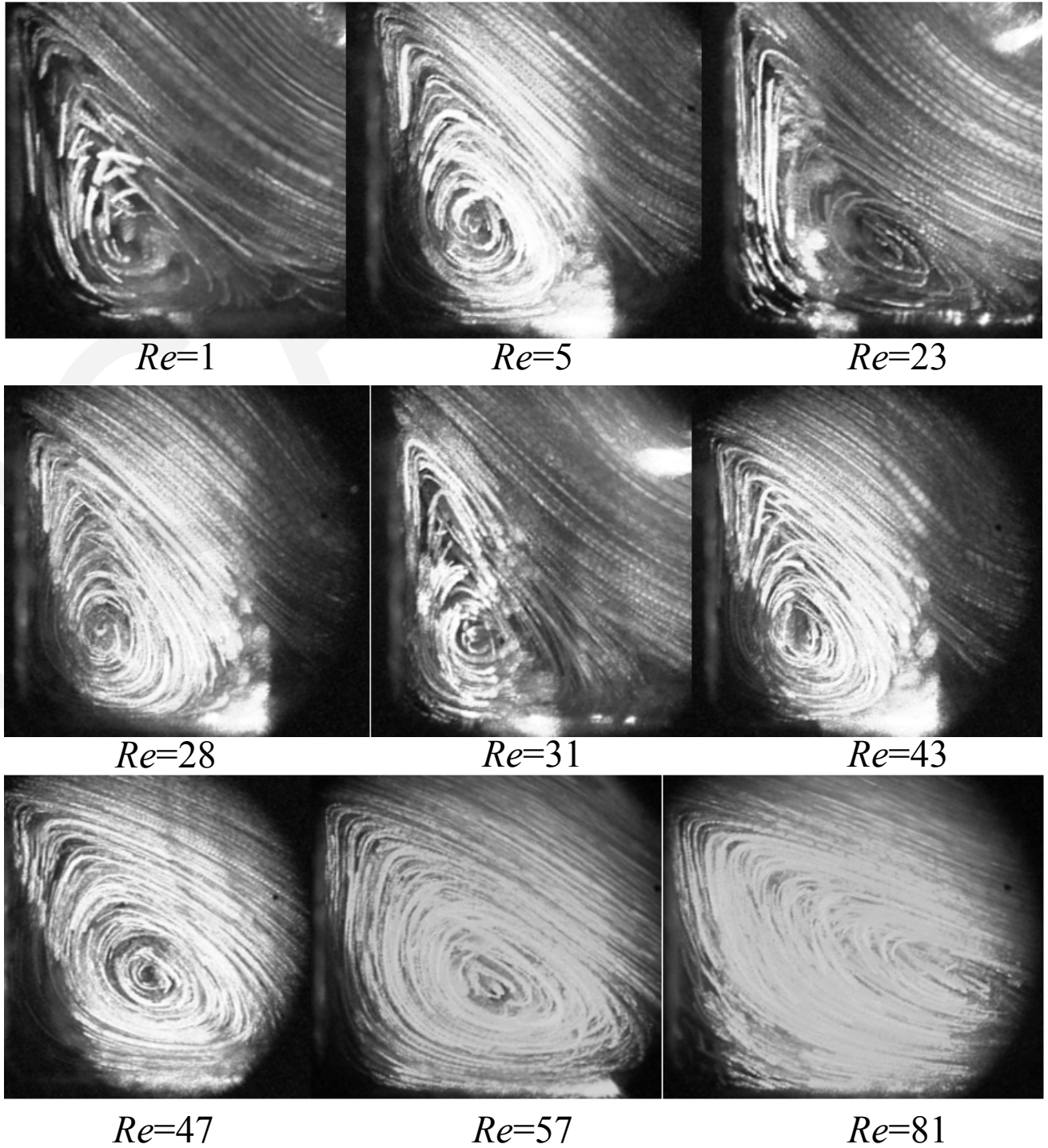
$$E = \frac{B_a}{L_0}$$

B_a is the eddy length in horizontal direction

L_0 is the length of the rectangular corrugation bottom.



Eddy suppression occurs in a certain Re region(23-53), and the inhibition effect is enhanced at the resonance point. We suppose that a ***resonance section*** exists in which the oscillation of the film surface is enhanced, and the bottom eddies are suppressed.



Free surface amplitude

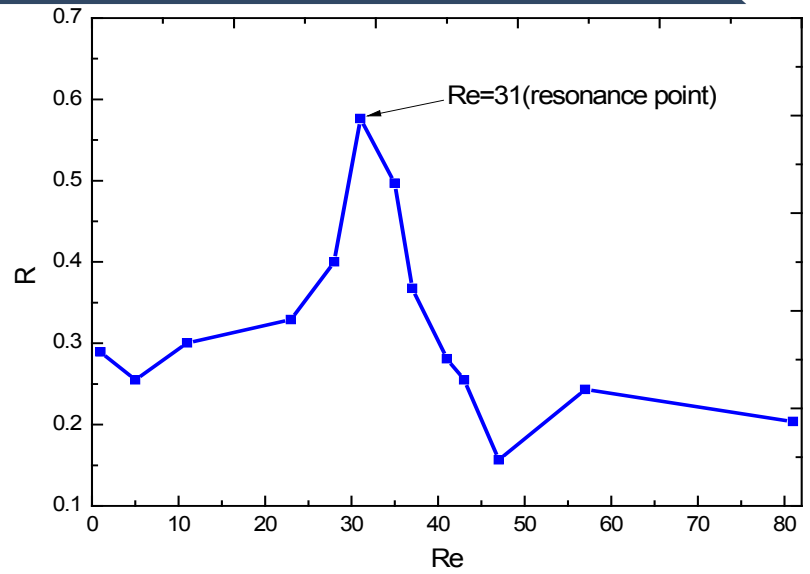


Fig. 3.5 (a) Experiment data

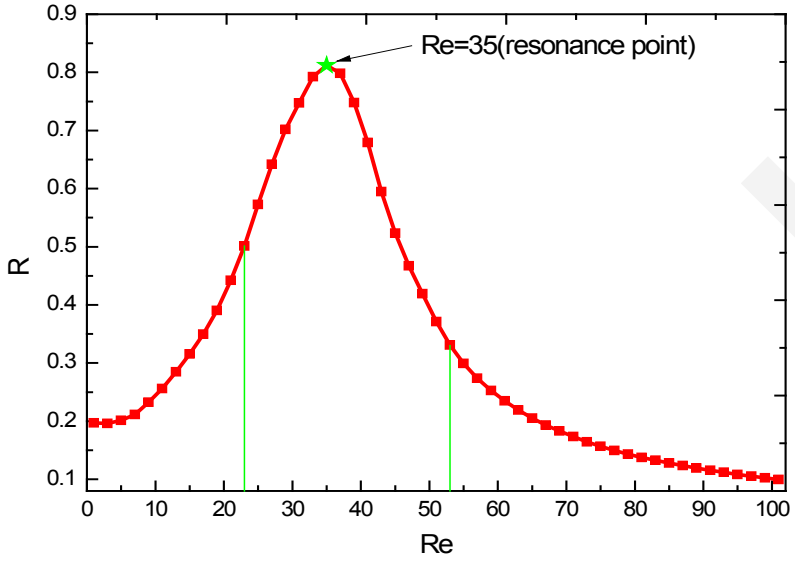


Fig. 3.5 (b) Simulation data

$$R = \frac{H}{A} .$$

H is the free surface amplitude. *A* is the height of the corrugation.

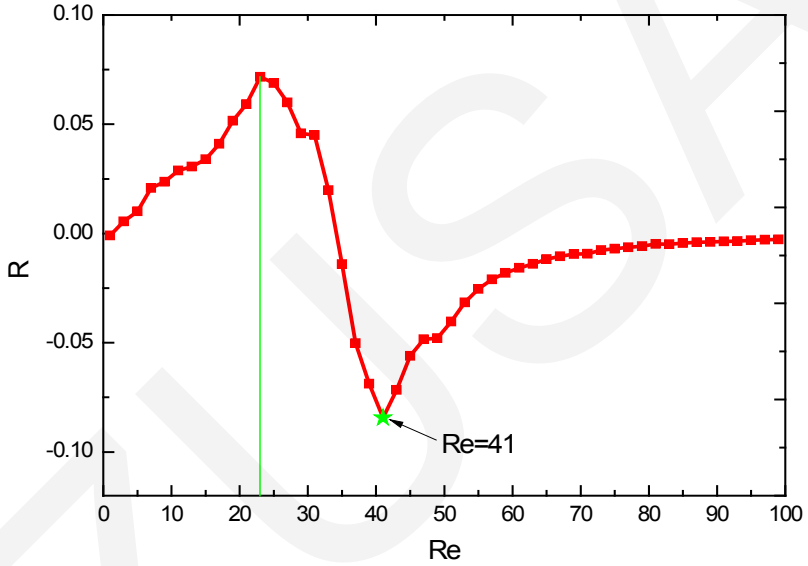


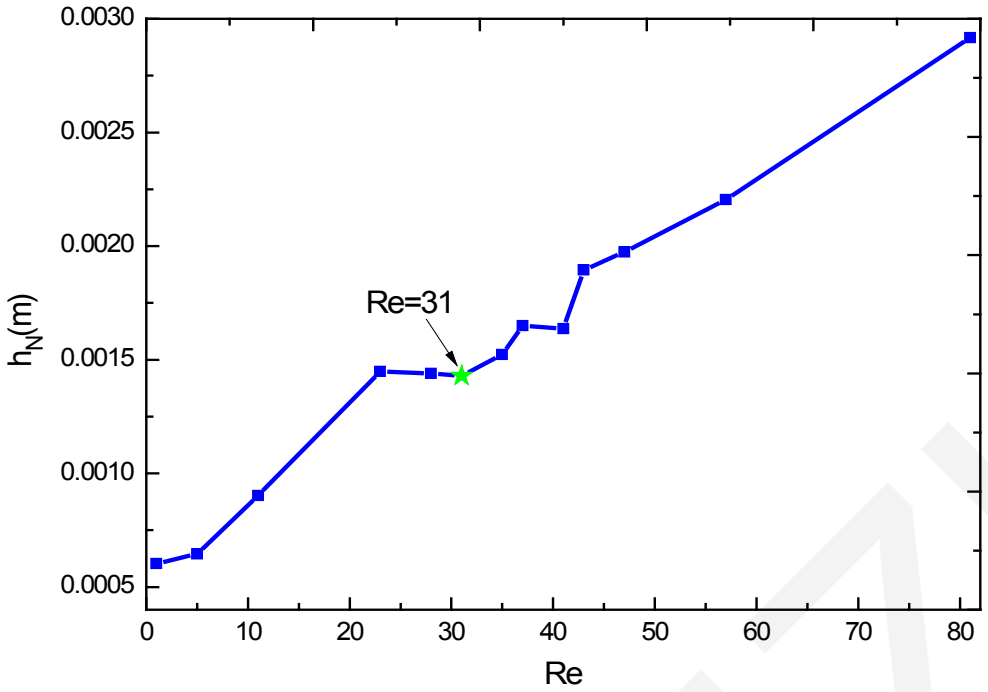
Fig. 3.5 (c) The increment of the simulation data

The first inflection point (Re = 23) corresponds to the lower bound of the resonance section. The second inflection point (Re = 41) is lower than the upper bound of the resonance section.

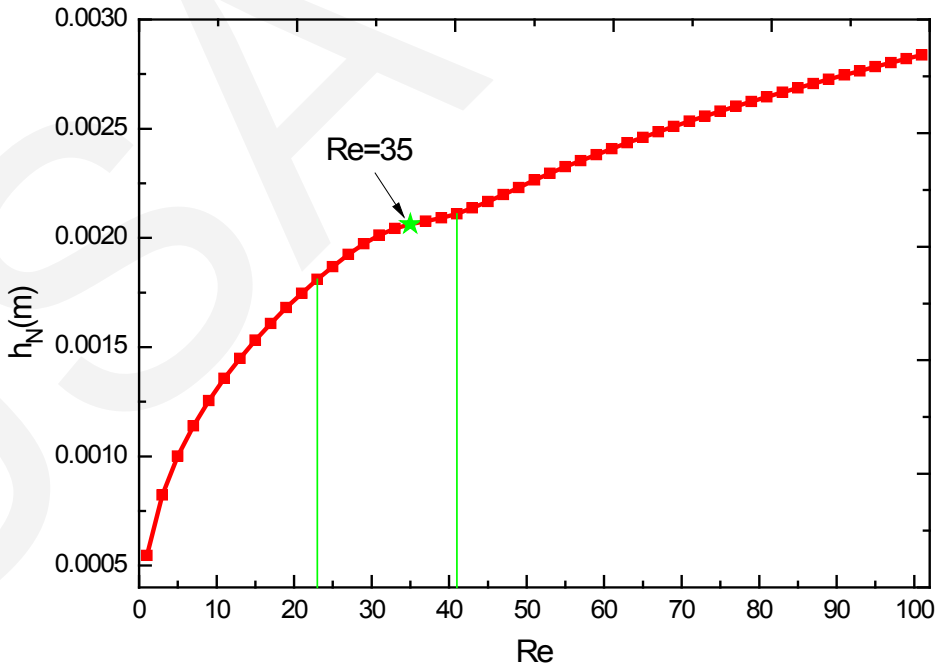
According to the definition, the resonance section enhances the oscillation of the film surface. It is more reasonable to reset the upper bound of the resonance section as Re = 41. Therefore, Re from 23 to 41 should represent the resonance section.

Average thickness of the liquid film

$$h_N = \frac{1}{m}\sum_{i=1}^{m}\left|y_{P_i} - y_{W_i}\right|$$



(a) Experiment results

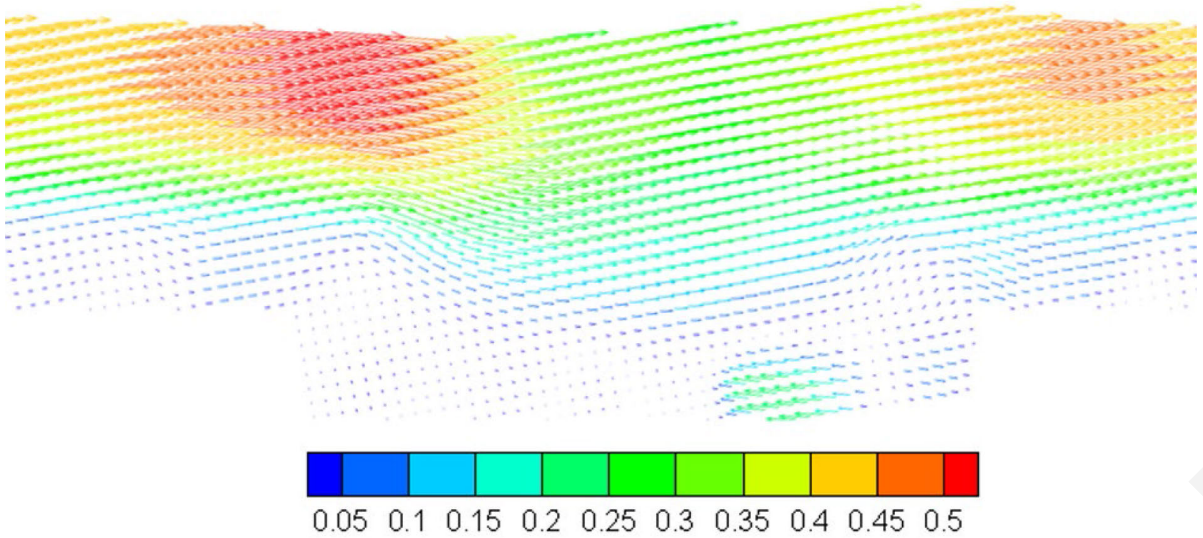


(b) Simulation results

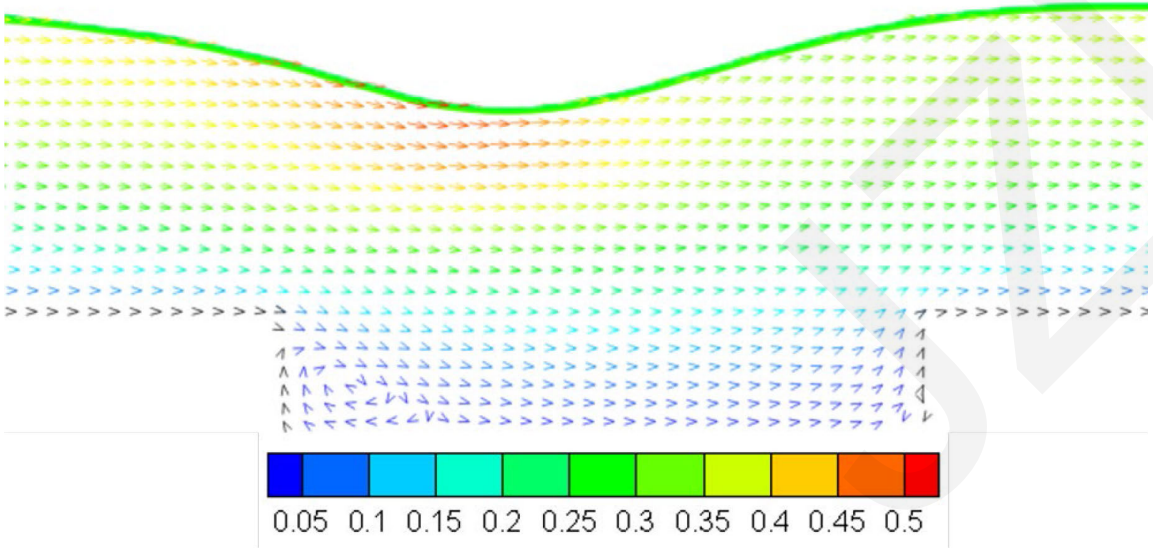
Fig. 3.6 Transformation law of average thickness of liquid film with different Reynolds numbers

Conclusion: The data of Figure 3.6 show that the curve becomes gentler in the resonance section. Beyond the range of the resonance section, h_{N} increases with a fixed slope. The results indicate that the resonance section has a suppression effect on the variations in the average liquid film thickness.

Velocity vectors at the resonance point



(a) Experiment results



(b)Simulation results

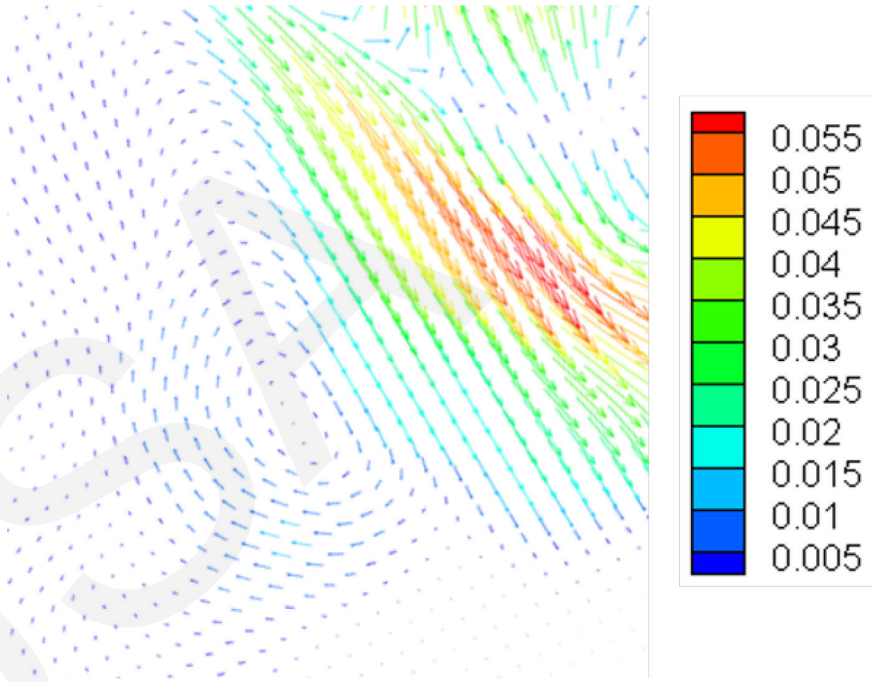


Fig. 3.8 Velocity vector of bottom eddy(experiment results)

In the left corner of the corrugation bottom, the vectors are in a continuous line. A reflux recirculate region occurs in this area. A clear velocity distribution of the bottom eddy cannot be processed from the experimental result of the whole flow field. We perform the PIV treatment on the images captured by the microlens.

Velocity distribution of Free surface

U_x is significantly affected by Re. As the surface oscillation of the film flow intensifies, the differences in U_x between the points on the free surface follow suit.

In the resonance section, U_y is enhanced.

It can be concluded that the resonance section enhances the normal velocity intensity of the free surface.

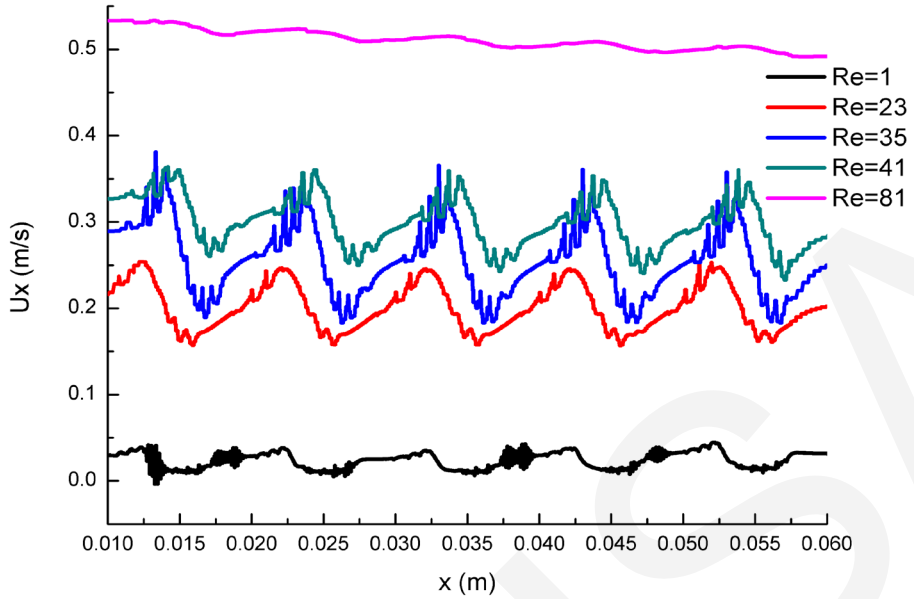


Fig. 3.9 X-Direction

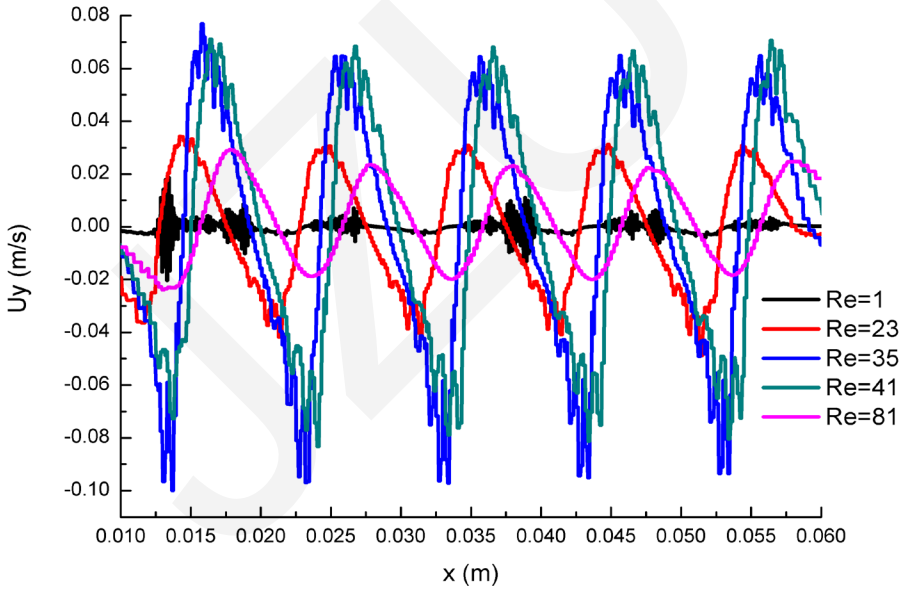
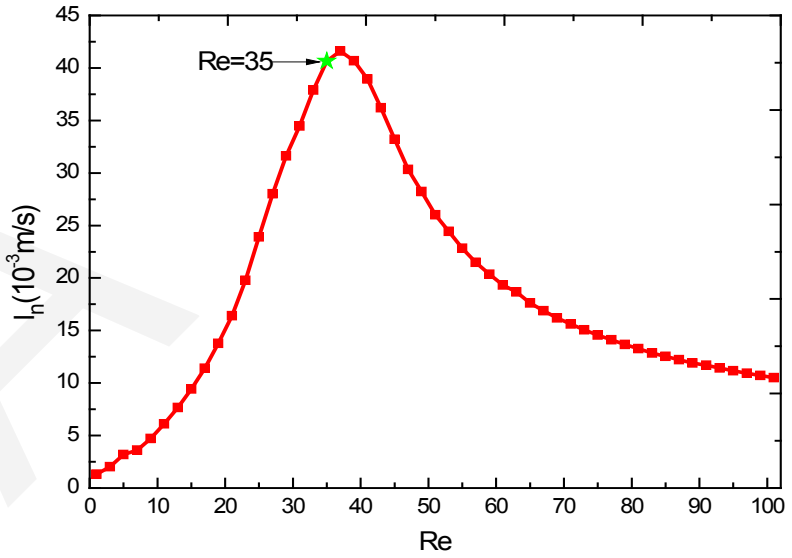
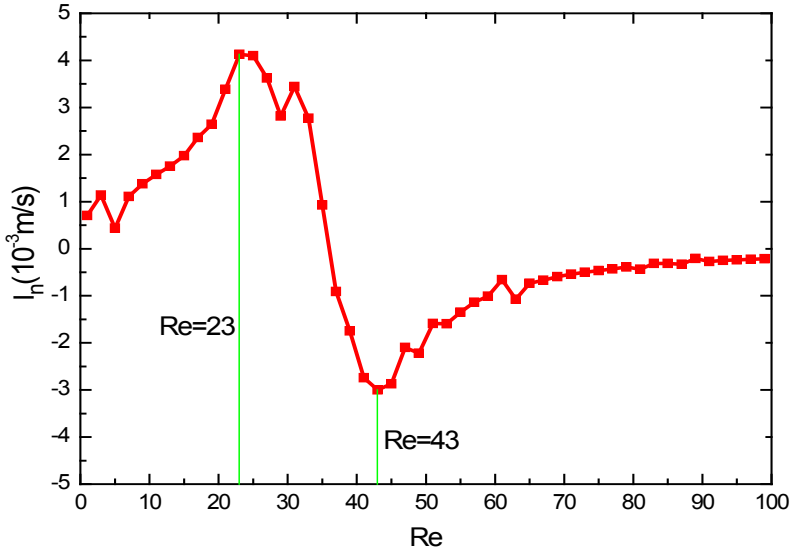


Fig. 3.10 Y-Direction



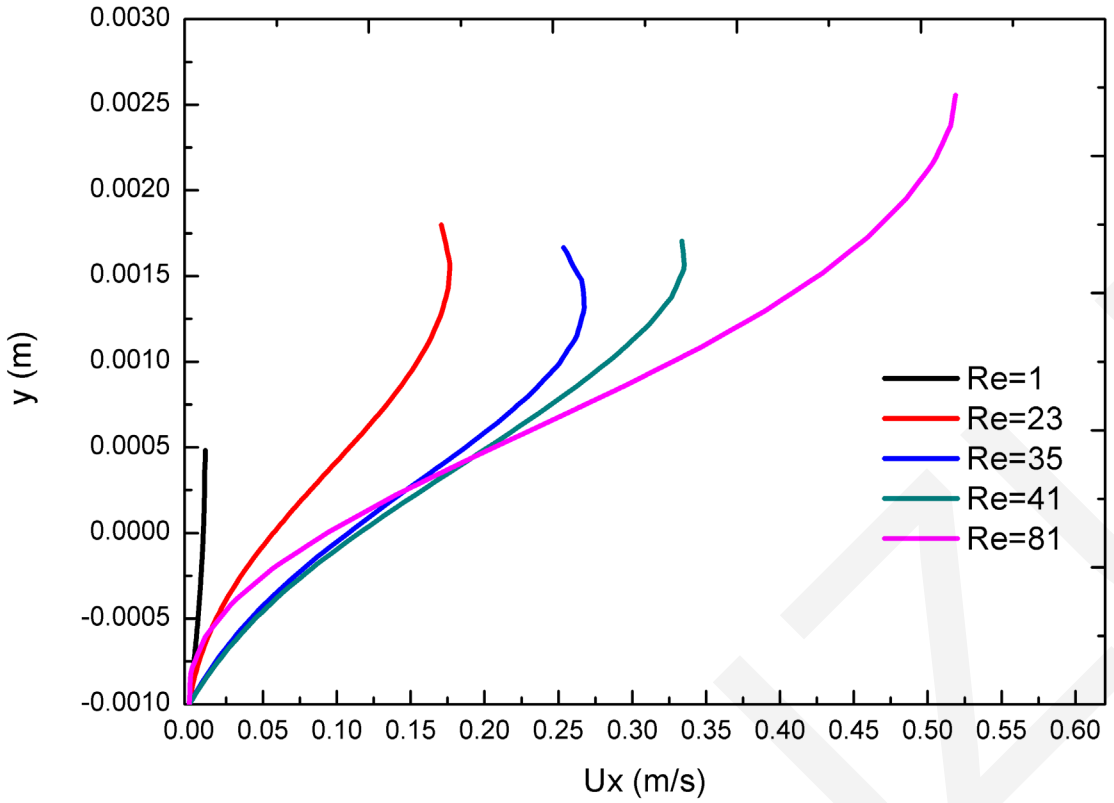
(a)The normal velocity intensity



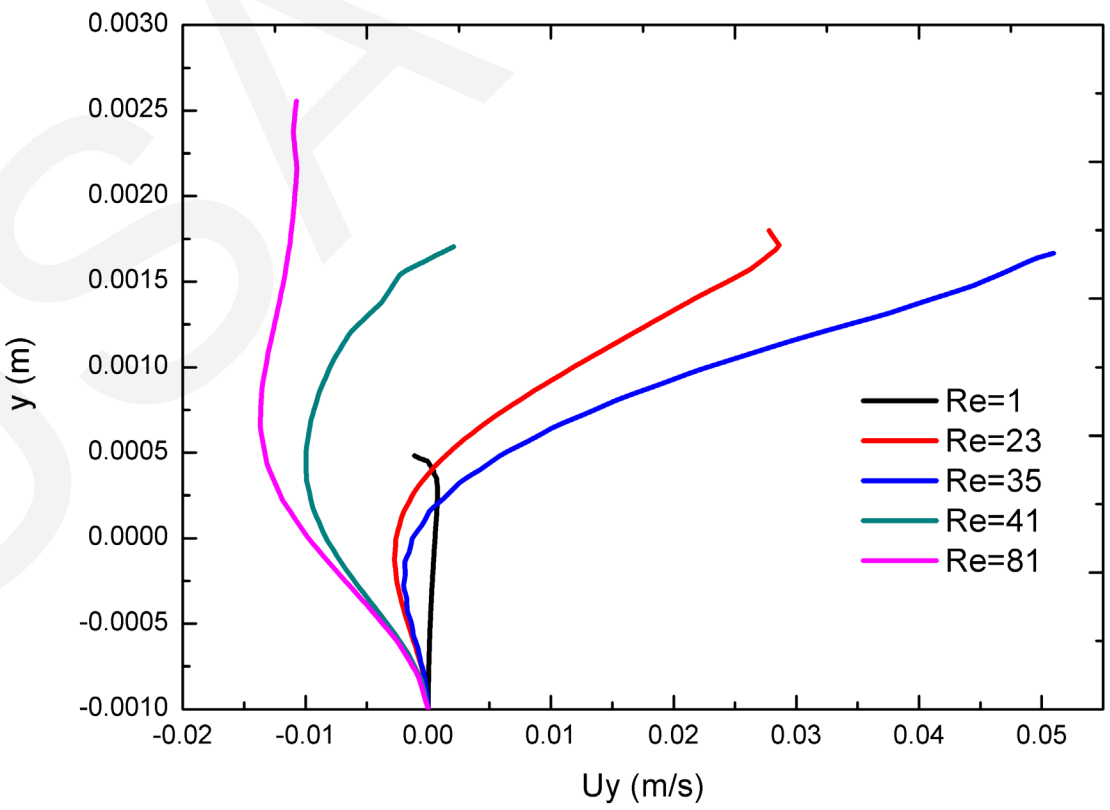
(b)The increment in normal velocity intensity

Fig 3.11

厚度方向速度分布



(a) x方向速度$\boldsymbol{U_x}$



(b) y方向速度$\boldsymbol{U_y}$

不同雷诺数液相厚度方向的速度分布（x=0.025m）

Conclusion

Film flow resonance could maximize the oscillations of a free surface. The resonance phenomenon was related with a range of Re rather than a specific Re. We proposed the resonance section, in which the oscillation of the film surface was enhanced and the bottom eddies were suppressed. Simulations and experiments were performed to study the film flow resonance. The results demonstrated that

(1) The suppression of eddies occurred in a certain Re region, and it was the most obvious at the resonance point. The upper and lower bounds of the resonance section corresponded to the two inflection points of the free surface amplitude.

(2) The resonance phenomenon exhibited a suppression effect on the increase in the average liquid film thickness. In the resonance section, the average thickness of the liquid film increased more slowly than the other sections and even decreased.

(3) The velocities of the reflux recirculate region were much slower than those of other regions. In regions close to the free surface, the normal velocities were larger. As the surface oscillation of the film flow intensifies, the velocity difference in the X-direction (flow direction) between the points on the free surface followed suit. The normal velocity intensity of the free surface was enhanced in the resonance section. In the corrugation bottom region, the velocities in the X-direction were increased by resonance.