Numerical and experimental investigations of flow condensation of R170 in a horizontal smooth tube

Q.L. Song[a,b], M.Q. Gong[a,*], G.F. Chen[a], Q.X. Tang[a,b], X.R. Zhuang[a,b], Z.Q. Yang[a,b], X. Li[a,b]

a. Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China
b. University of Chinese Academy of Sciences, Beijing 100049, China

Contribution：44

Technical Institute of Physics and Chemistry
CHINESE ACADEMY OF SCIENCES

1 Introduction

The traditional chlorinated refrigerants has been gradually replaced by the environmental refrigerants. Hydrocarbons are very appropriate refrigerant substitutes due to their environmental protection and excellent thermodynamic properties. As a kind of hydrocarbon, R170 can be used in a two-stage cascade refrigeration cycle as low-temperature stage refrigerant. Gong et al. proposed that R170 is an important middle-boiling component in mixed-gases Joule–Thomson refrigeration cycles. What's more, R170 is also the major component of natural gas. So the study of R170 is great interesting and valuable for both academic study and practice applications. Thorough condensation heat transfer and related flow characteristics study of R170 is very necessary.

Flow condensation heat transfer coefficient is closely related to the flow pattern. Therefore, a model to predict the condensation flow pattern and their corresponding heat transfer coefficient was developed, which was based on the previous experimental data and observations of the author's team. The simulation was conducted at various mass fluxes from 100 kg m-2 s−1 to 250 kg m-2 s−1 over a wide vapor quality range. The availability of this model was evaluated by comparing the numerical results to experimental data.

2 Simulation Method

To obtain the accurate two phase interface, transient VOF calculations was adopted to this simulation. The geometrical model of the present simulation condition is shown in Fig. 1, the circular tube with 4mm diameter, 390 mm length, was divided into 3 sections: the entrance section is 300mm, the condensation section is 20mm and the exit section is 70mm. The solution method and discretization scheme were shown in table 1. All the under-relaxation factors were set less than 0.5 to improve the calculation stability.

The evaporation-condensation model was used in the present simulation. Gravity force and surface tension were concerned.

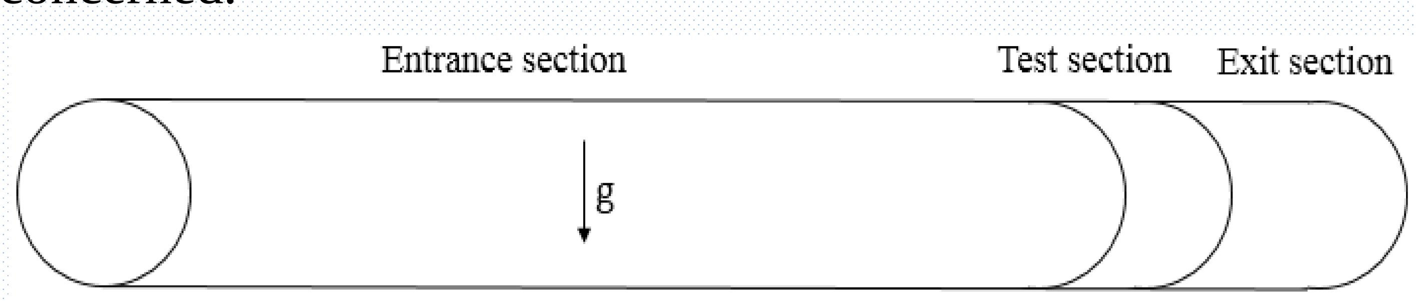

Fig. 1 Three-dimensional physical model

Table 1. Variable discretization scheme

Variable	Method
Pressure-Velocity Coupling	PISO
Gradient	Lest Squares Cell Based
Pressure	Body Force Weighted
Momentum	Second Order Upwind
Volume Fraction	Geo-Reconstruct
Turbulent Kinetic Energy	First Order Upwind
Turbulent Dissipation Rate	First Order Upwind
Energy	Second Order Upwind

3 Result and Discussion

3.1 Two-phase flow pattern

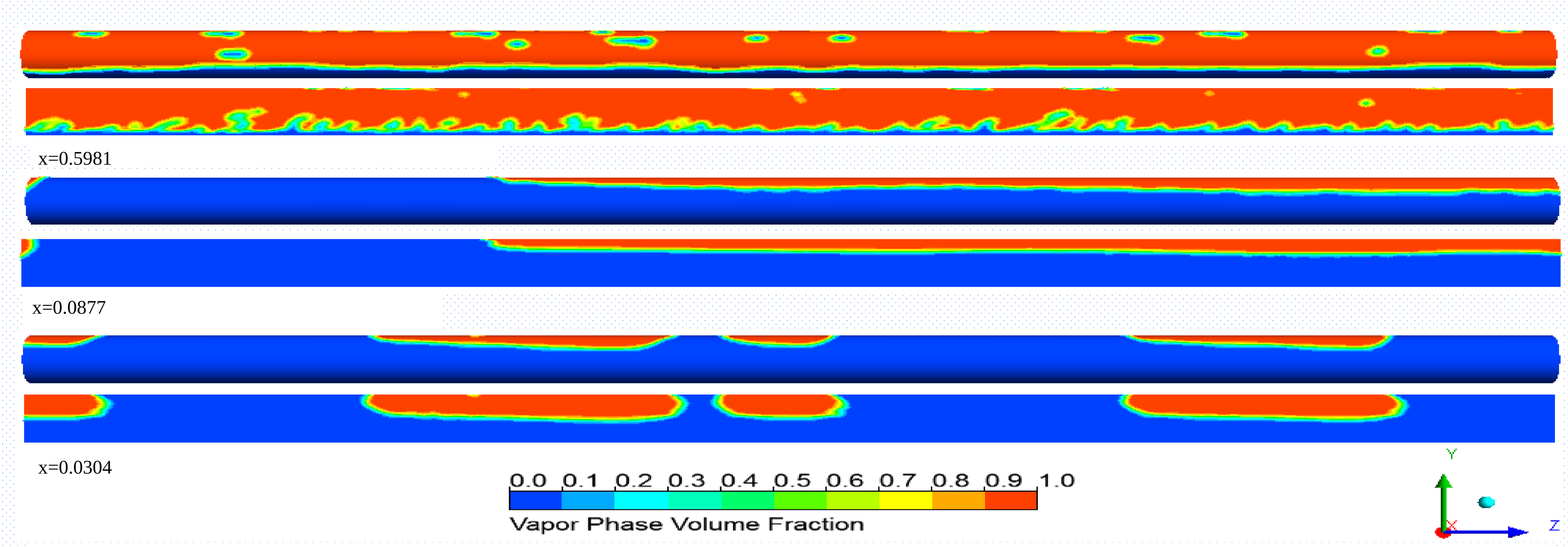

Fig. 2 Volume fraction fields of magnified test section and exit section at mass flux G=100 kg m^{-2} s^{-1} (upper: the wall of test section and exit section; nether: the symmetrical surface of test section and exit section)

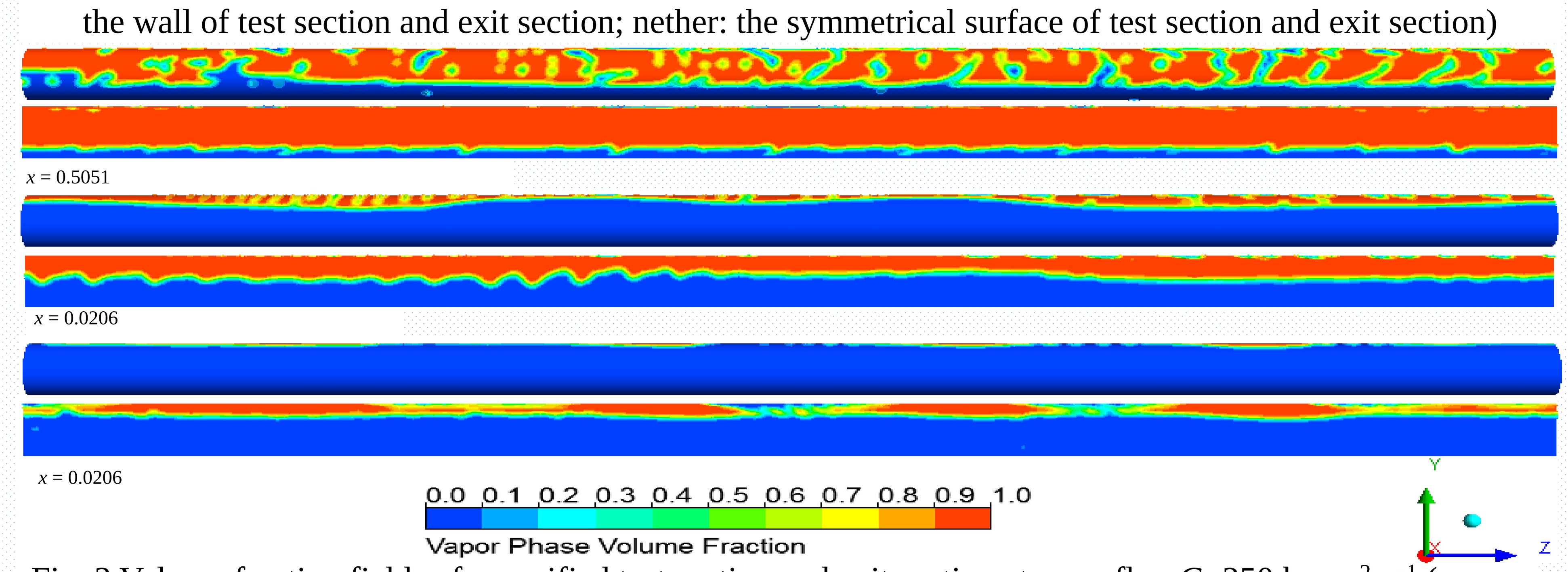

Fig. 3 Volume fraction fields of magnified test section and exit section at mass flux G=250 kg m^{-2} s^{-1} (upper: the wall of test section and exit section; nether: the symmetrical surface of test section and exit section)

Fig. 2 and Fig. 3 represent the volume fraction fields at various vapor qualities of R170 with mass flux G=100 kg m^{-2} s^{-1} and G=250 kg m^{-2} s^{-1}, respectively. A red color stands for the presence of only vapor phase (vapor volume fraction = 1), while a blue color implies the presence of only liquid phase (vapor volume fraction = 0).

- Annular flow, intermittent flow (slug flow and plug flow) and wave stratified flow were gained in the present simulation.
- With the increasing mass flux, intermittent flow is limited to very narrow vapor quality, and annular flow extends to a wider range of vapor quality.

3.2 Condensation heat transfer

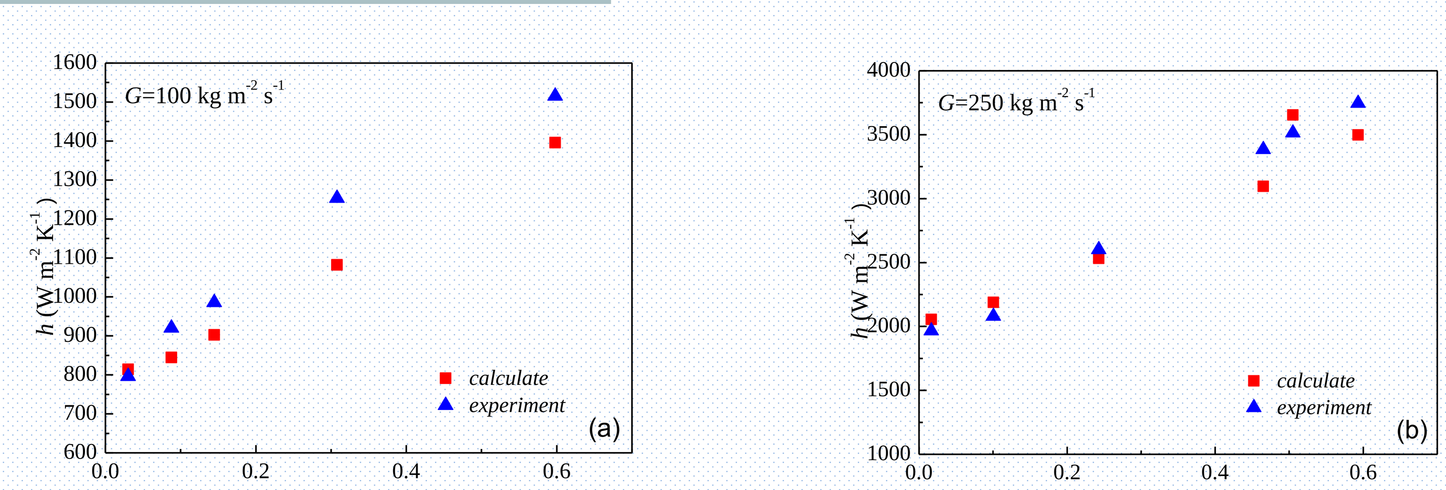

Fig. 4 Comparison of simulations with experimental data

Fig. 4(a) and (b) show the simulated and experimental results of the condensation heat transfer coefficients at the mass flux G=100 kg m^{-2} s^{-1} and G=250 kg m^{-2} s^{-1}, respectively.

- The condensation heat transfer increase with the increasing vapor quality and mass flux.
- The trend of the simulated values with vapor quality is similar to the experimental ones, and the maximum mean absolute relative deviation is 13.65%.

4 Conclusion

The two phase flow patterns and the condensation heat transfer were investigated experimentally at saturation pressure of 1–2.5 MPa with mass flux of 100–250 kg m^{-2} s^{-1} over a wide vapor quality range. In addition, the simulation results were also compared with the previous experimental results. The result shows that:

- Annular flow, intermittent flow (slug flow and plug flow) and wave stratified flow were gained in the present simulation, and the annular flow extends to a wider range of vapor qualities as the mass flux increases.
- Both gravity force and inertia force are essential roles in the present simulation and both of them shouldn't be ignored.
- The condensation heat transfer coefficient is larger in high mass fluxes and vapor qualities.
- The trend of the simulated values with vapor quality is similar to the experimental ones, and the maximum mean absolute relative deviation is 13.65%.