Theoretical and Experimental Research on CO_2 Electrical Heating Pool Boiling Heat Transfer Outside a Horizontal Tube

Shengchun Liu

Liushch@tjcu.edu.cn

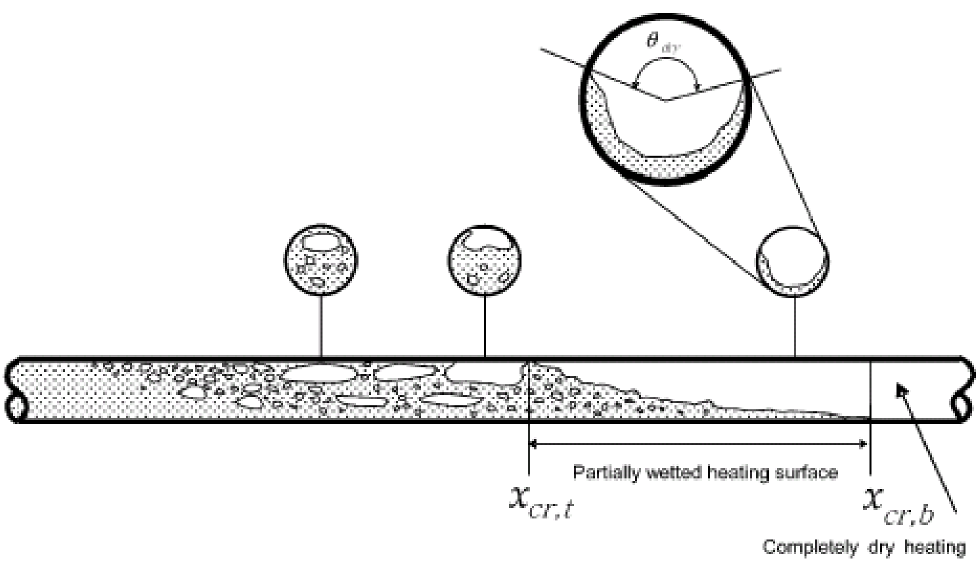
Tianjin University of Commerce, China

Outline

天津商業大學
TIANJIN UNIVERSITY OF COMMERCE

1 Introduction

1)With the relatively excellent physical properties, CO_2 is widely applied in heat exchangers with small diameter pipes. However, when boiling in evaporators, drying up happens easily that it leads to the deterioration of heat transfer. (Hihara E. and Tanaka S., 2000).



1 Introduction

Meanwhile, a small amount of lubricating oil in the refrigeration cycle would have negative impact on heat transfer (Yun R., 2002). Katsuta M. (2004) and Ding (2009) came to the same conclusion through their researches in recent years. Ribatski S. and Jabardo (2009) observed these phenomena would not occur in flooded evaporators, because the heat transfer surfaces are soaked in refrigerant. Moreover, CO_2 is prone to boil at the same evaporation temperature for weak tension on surface. Ye (2007) and Liu *et al*. (2005) proposed that CO_2 boiling heat transfer coefficient is higher.

1 Introduction

2)The electrical heating pool boiling technology studied in this paper obtains a wide application in heat transfer devices in power, energy *etc*, because of its obvious advantages of compact structure and superiority on heat transfer performance.In this paper, numerical simulation on electrical heating pool boiling heat transfer with CO_2 as refrigerant outside a horizontal tube is carried based on a software FLUENT.

2 PHYSICAL MODELS

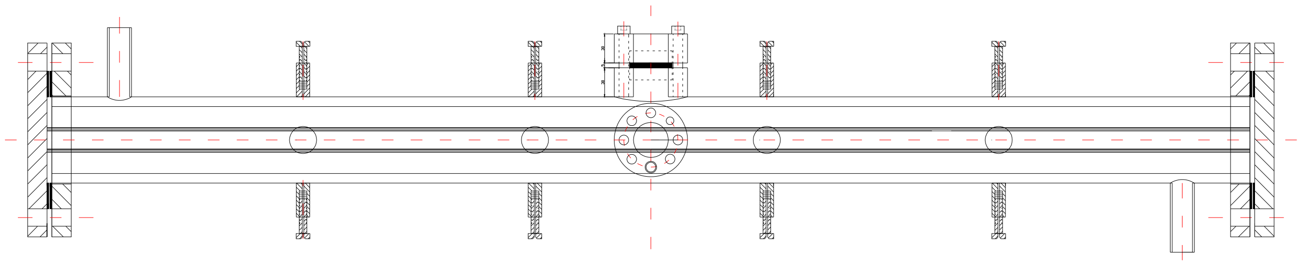


Figure 1: Structure of test section

Figure 2: Horizontal model of test section

2 PHYSICAL MODELS

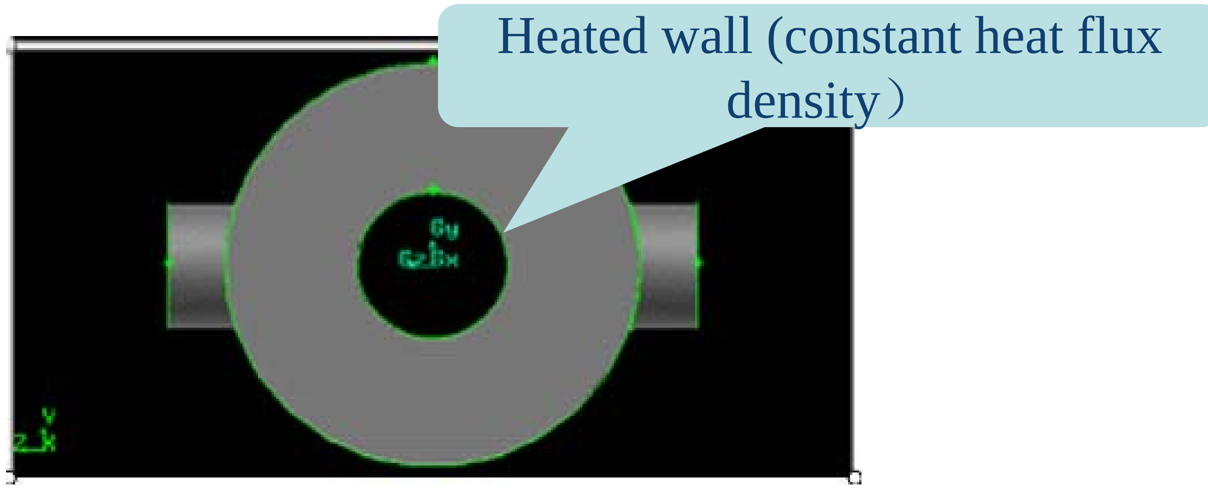


Figure 3: Vertical model of test section

An electricity-controlled heating method is adopted. Changing the heat power of the electrical heating tube is realized by changing the voltage of tube ends, thereby changing the heat flux density. Thermocouple is installed to measure the temperature of tube’s wall and saturated CO_2.

3 MATHEMATICAL MODELS

Some hypothesis on fluid flow through the tube are carried as follow:

(1) The flow inside the tube is steady and incompressible;

(2) Phase transition is conducted when fluid's temperature reaches certain value;

(3) The wall is at non-slip boundary condition;

(4) Take the influence of gravity into account;

(5) Ignore the heating effect produced by viscous dissipation when fluid flows.

The Mixture model in FLUENT is used in this paper. Mixture model is a simplified model of multiphase-flow. It solves the continuity, momentum and energy equation, the volume fraction equation of the second phase, and simulation of the volume fraction of two-phase flow.

3 MATHEMATICAL MODELS

Continuity equation in Mixture model :

$$\frac{\partial}{\partial \mathrm{t}}(\rho m)+\nabla\cdot(\rho_m\overline{v}_m)=\dot{m}$$

Momentum equation in Mixture model:

$$\frac{\partial}{\partial \mathrm{t}}(\rho_m\overline{v}_m)+\nabla\cdot(\rho_m\overline{v}_m\overline{v}_m)=-\nabla p+\nabla\cdot[\mu_m(\nabla\overline{v}_m+\nabla\overline{v}_m{}^T)]+\rho_m\overline{g}+\overline{F}+\nabla\cdot(\sum_{k-1}^{n}\alpha_k\rho_k\overline{v}_{dr,k}\overline{v}_{dr,k})$$

Energy equation in Mixture model:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k\rho_k E_k)+\nabla\cdot\sum_{k=1}^{n}(\alpha_k\overline{v}_k(v_k E_k+p))=\nabla\cdot(k_{eff}\nabla T)+S_E$$

4、 RESULTS AND ANALYSIS

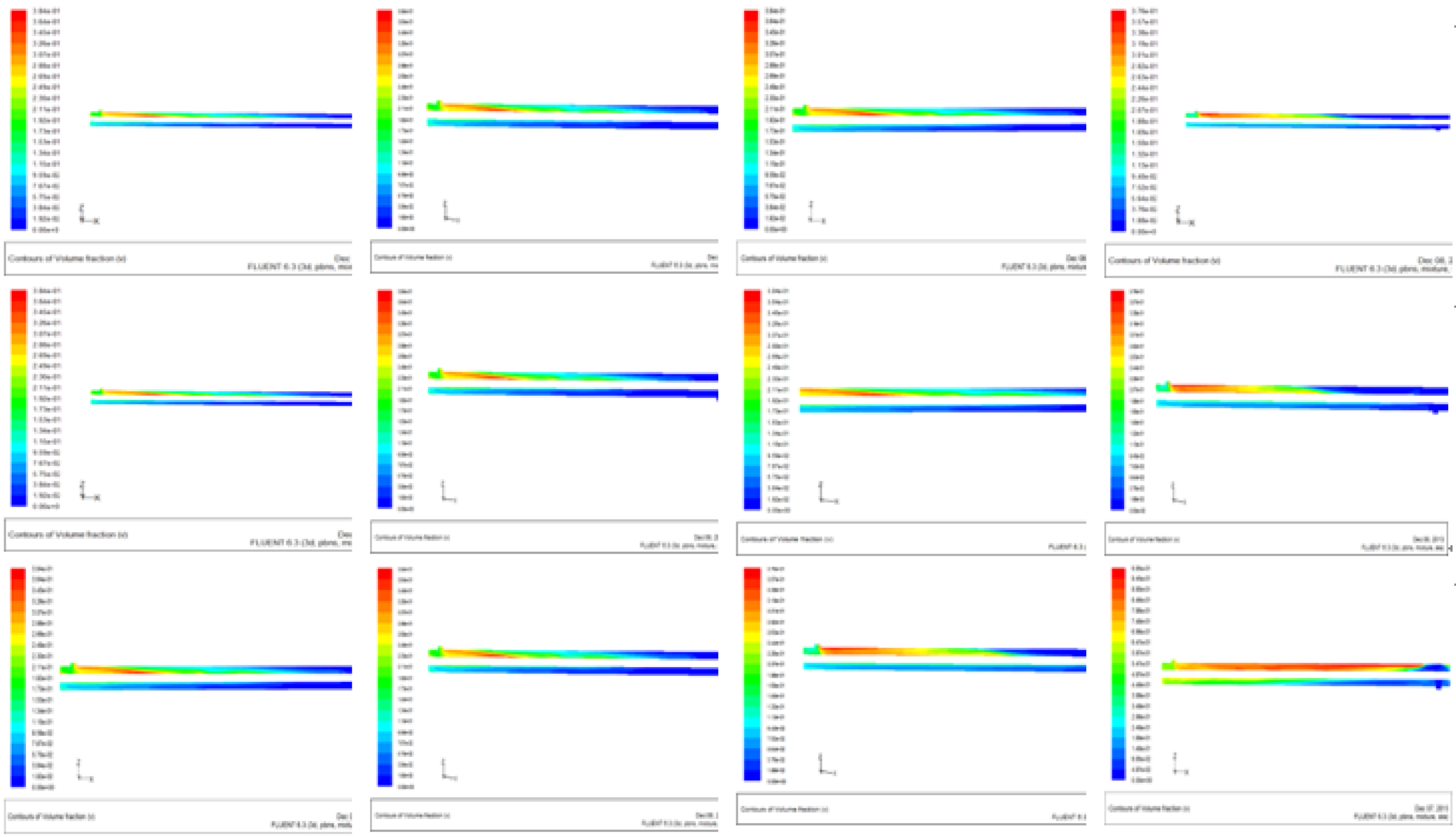
Numerical Method

(1)The entrance condition is velocity inlet boundary conditions.
(2)The exit condition is pressure outlet boundary, the backflow of upper export gas is zero.
(3)The wall boundary is constant heat flux density.
(4)According to the evaporation pressure, corresponding phase-transition temperature in UDF is set.

Simulation Results Analysis

Flow boundary conditions: inlet velocity v=5m/s, evaporation pressure P set as 2.6, 3.2, and 3.6MPa.The inner wall heat flux density is 10548, 20675, 34177,51054 kW/m^2, the out wall is considered adiabatic. Thermal properties of CO_2 reference to Xue *et al*. (2004).

4 RESULTS AND ANALYSIS



P=2.6 MPa

P=3.2 MPa

P=3.6 MPa

q=10548W/m^2 q=20675W/m^2 q=34177W/m^2 q=51054W/m^2

Figure 4: Contours of volume fraction under different pressure and heat flux

4 RESULTS AND ANALYSIS

天津商業大學 TIANJIN UNIVERSITY OF COMMERCE

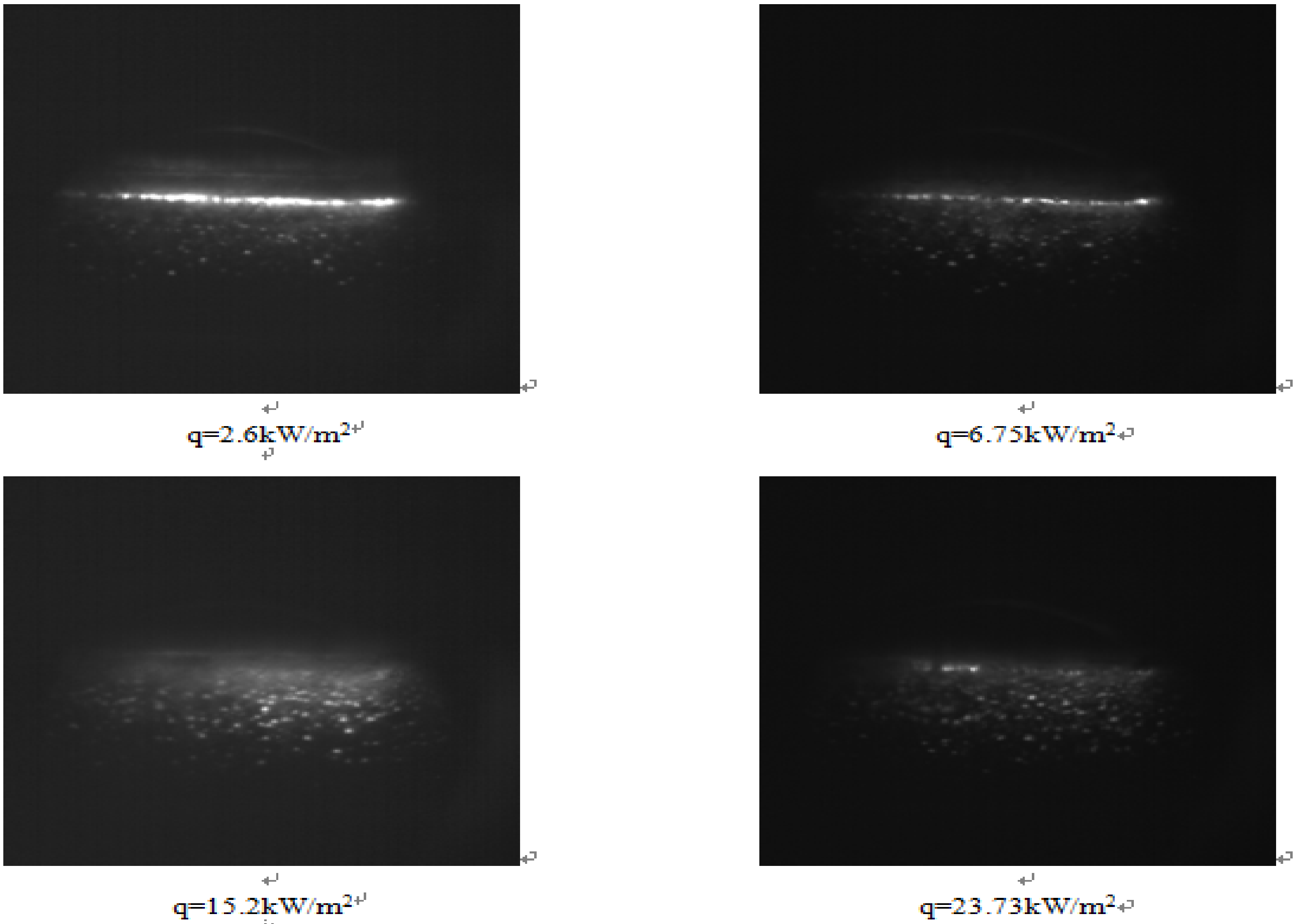


Fig. 5 : CO_2 pool boiling images at 3.6 MPa under different heat flux density

4 RESULTS AND ANALYSIS

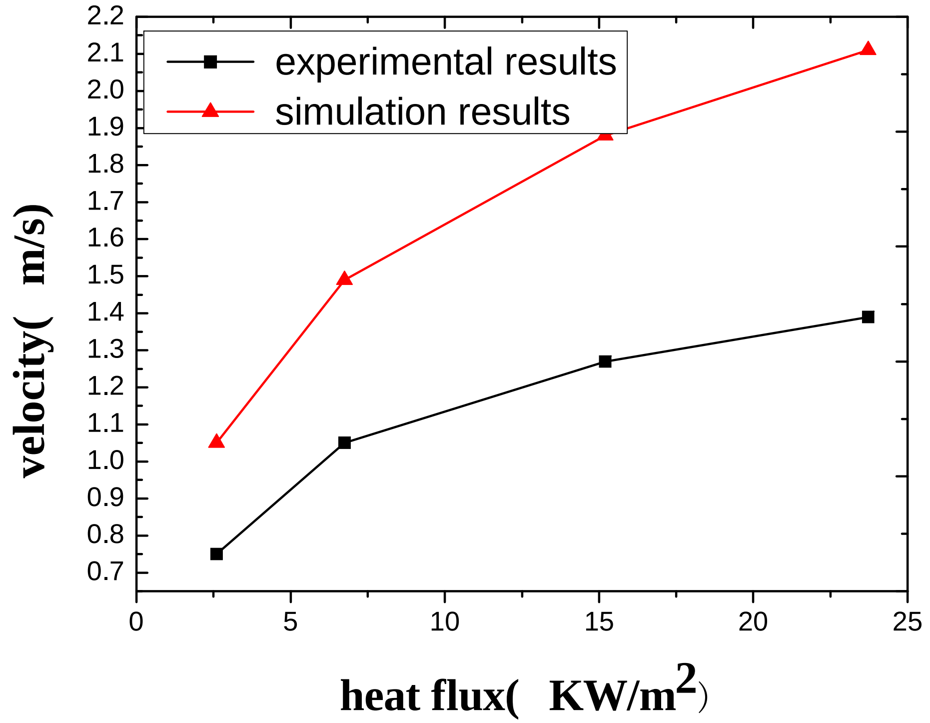


Fig. 6: Comparison between simulation results and experimental results

The simulation values are relatively higher and the data locate in the range of 1.40~1.52 times higher than experimental data.

5 CONCLUSIONS

天津商業大學 TIANJIN UNIVERSITY OF COMMERCE

It is concluded by comprehensive analysing the simulation results and experimental results as follow:

- During the boiling process of refrigerant CO_2 outside the horizontal tube, the quantity of bubbles increases along the flow direction. Bubbles appear on the wall and slowly flee until they devote into the main flow. Most of the bubbles gather in the upper space of the annular space due to gravity effect;

- Under the same condition of heat flux density, the gas volume rate outside the horizontal tube increases with the evaporation pressure. When pressure is fixed, it increases with heat flux density;

5 CONCLUSIONS

- The comparison of velocity on center location of pool boiling experimental tube between simulation results and experimental results under different heat flux density is analyzed. Integrally, simulation results of pool boiling heat transfer match the experimental results perfectly, which verified the reliability of this paper's model.

6 ACKNOWNLEDGEMENT

TIANJIN UNIVERSITY OF COMMERCE

◆ The work presented in this paper is supported by the National Natural Science Foundation of China (No.51006073).

天津商業大學
TIANJIN UNIVERSITY OF COMMERCE

Thank You for your attention!