

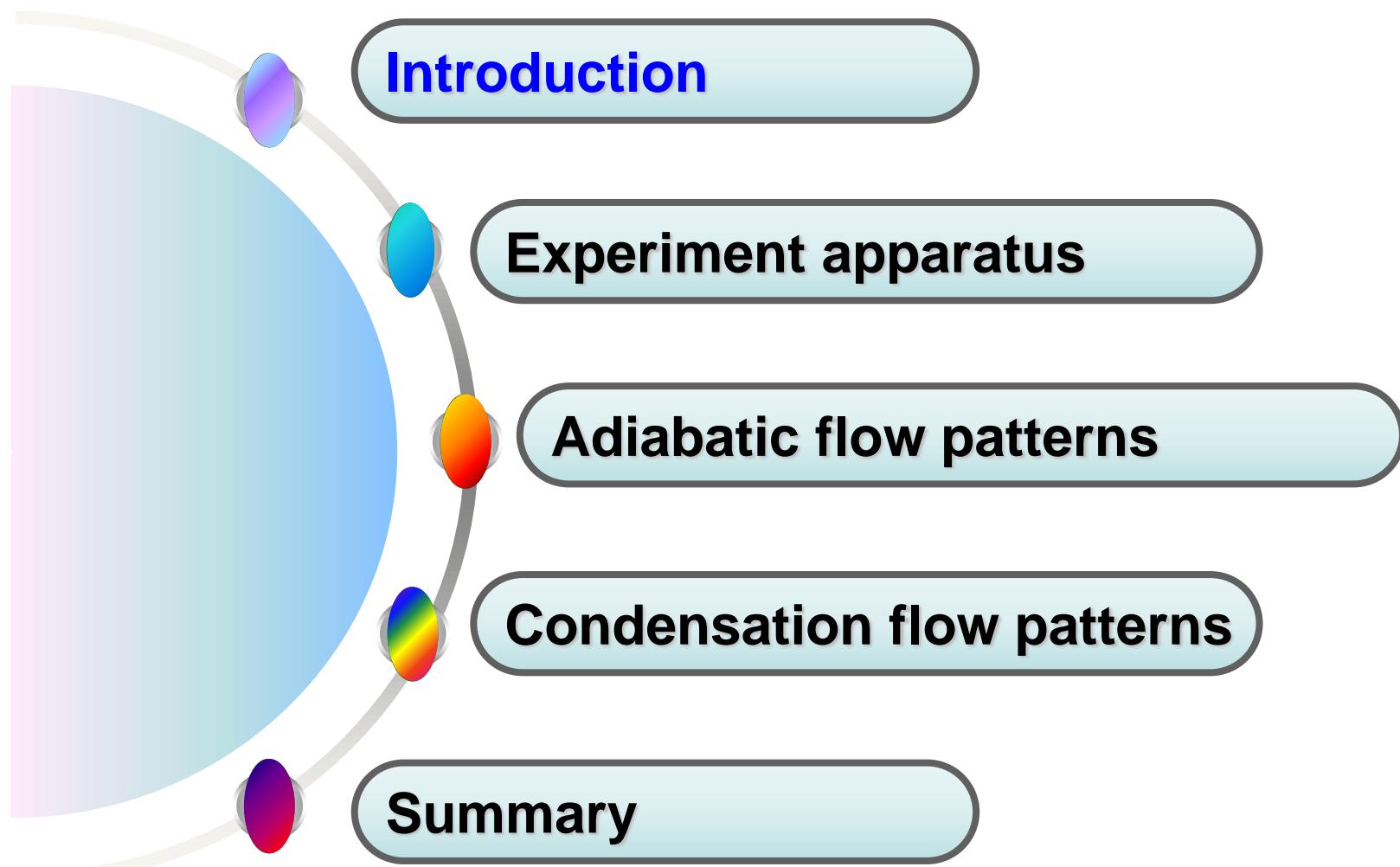


Two-phase Flow Patterns for Zeotropic Mixtures of Tetrafluoromethane/ethane in a Horizontal Smooth Tube

Song Q.L., Gong M.Q., Wang H.C., etc.

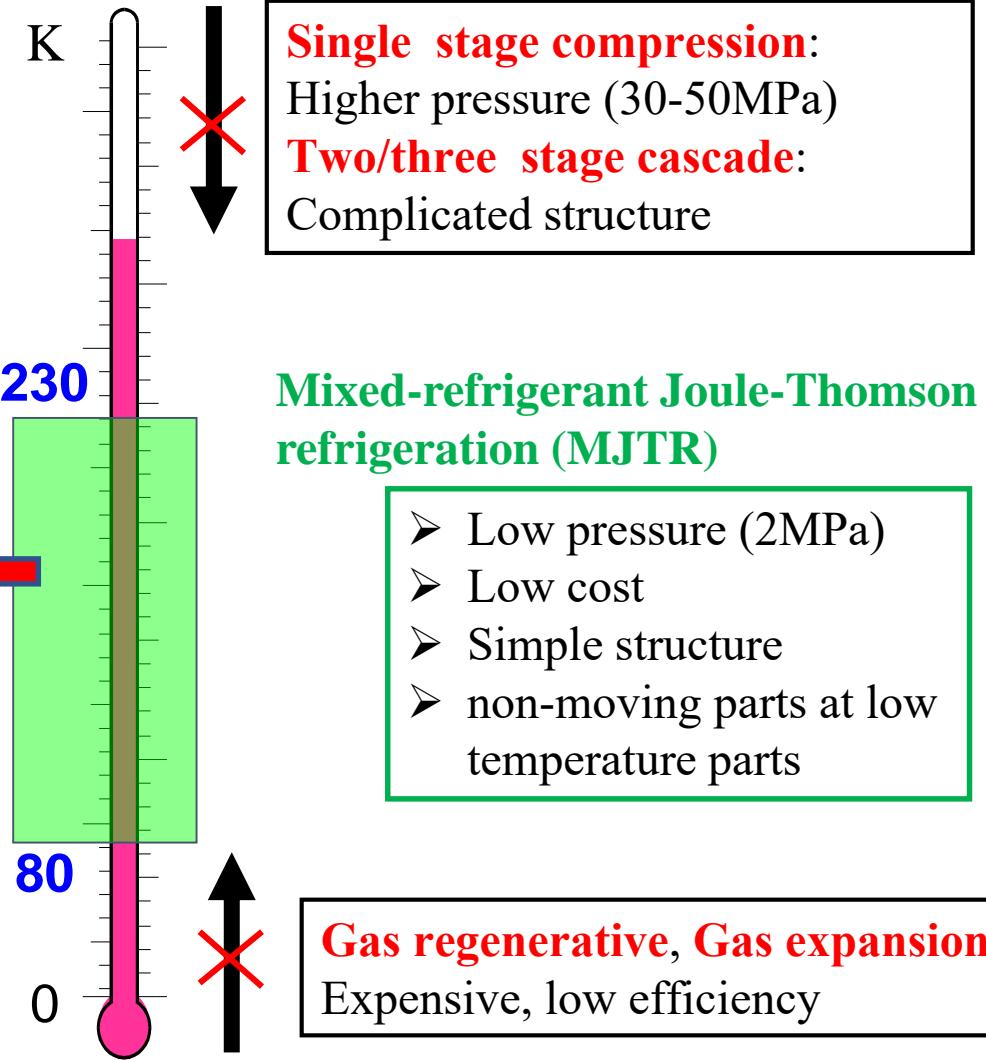
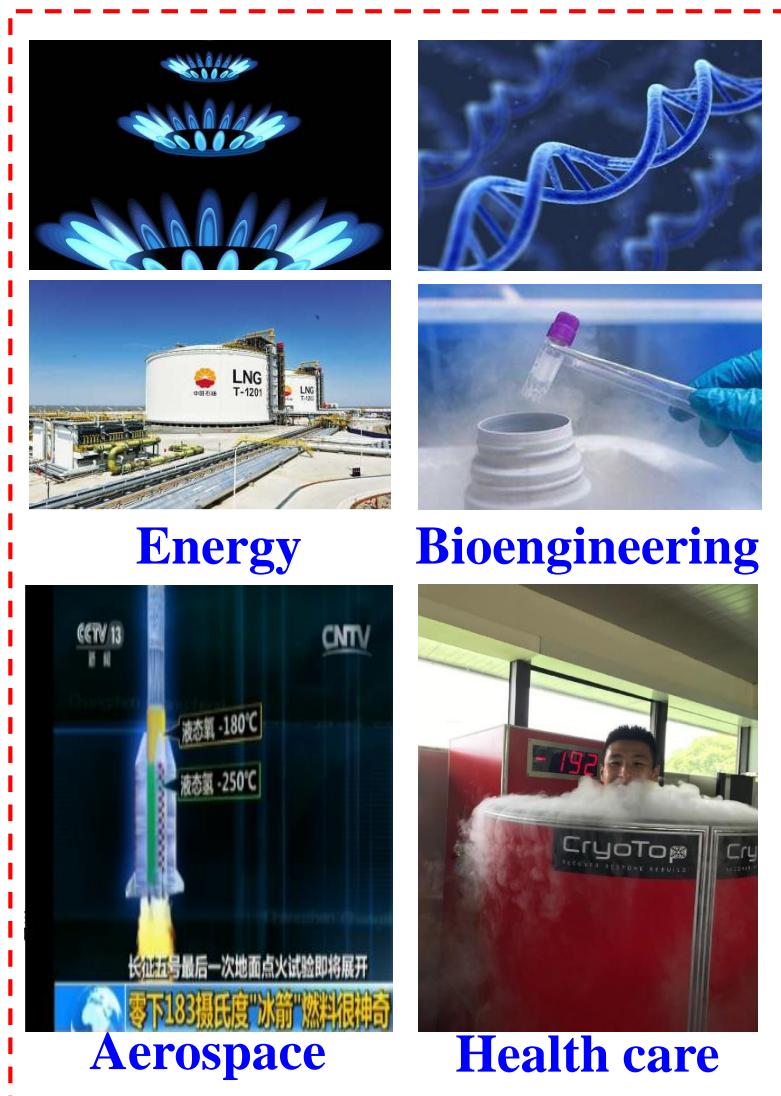
**Key Laboratory of Cryogenics,
Technical Institute of Physics and Chemistry ([TIPC](#)),
Chinese Academy of Sciences, Beijing, China**

Main Content

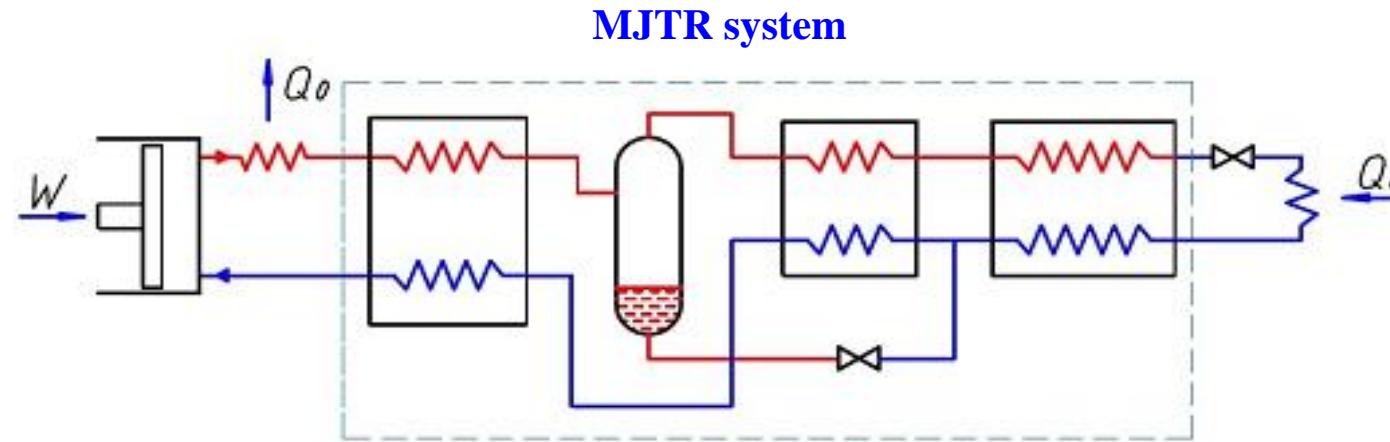


Introduction

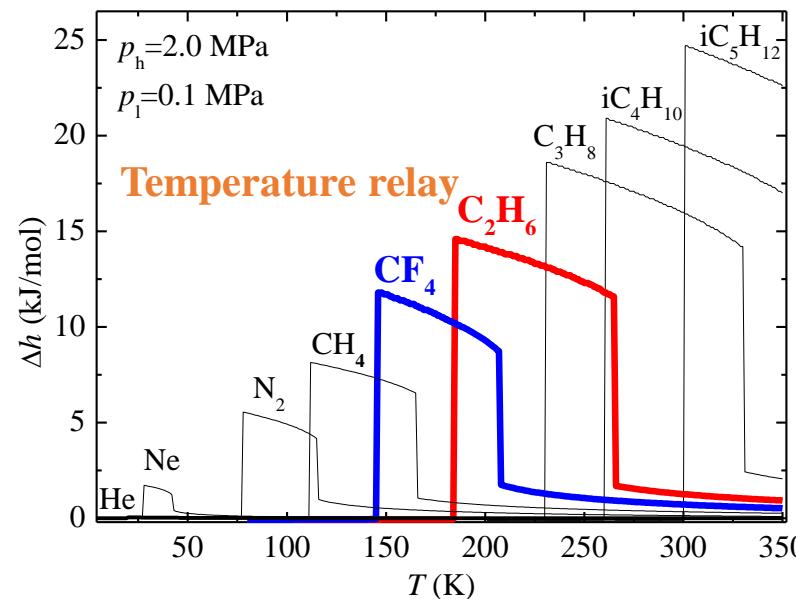
A wide range of demand



Introduction



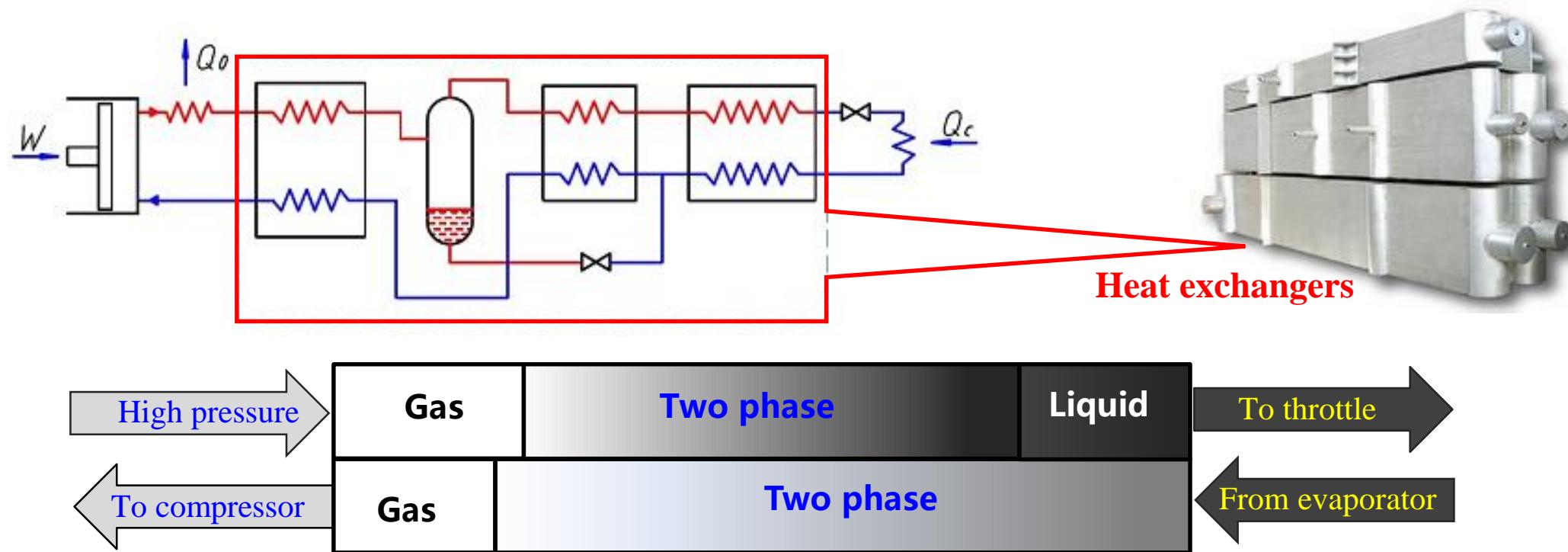
Mixed-refrigerants



- Pure fluids with **different boiling points**
- **Zeotropic mixture**
- **Temperature relay**

Tetrafluoromethane (R14) and ethane (R170) are the essential components in the mixed-refrigerants.

Introduction



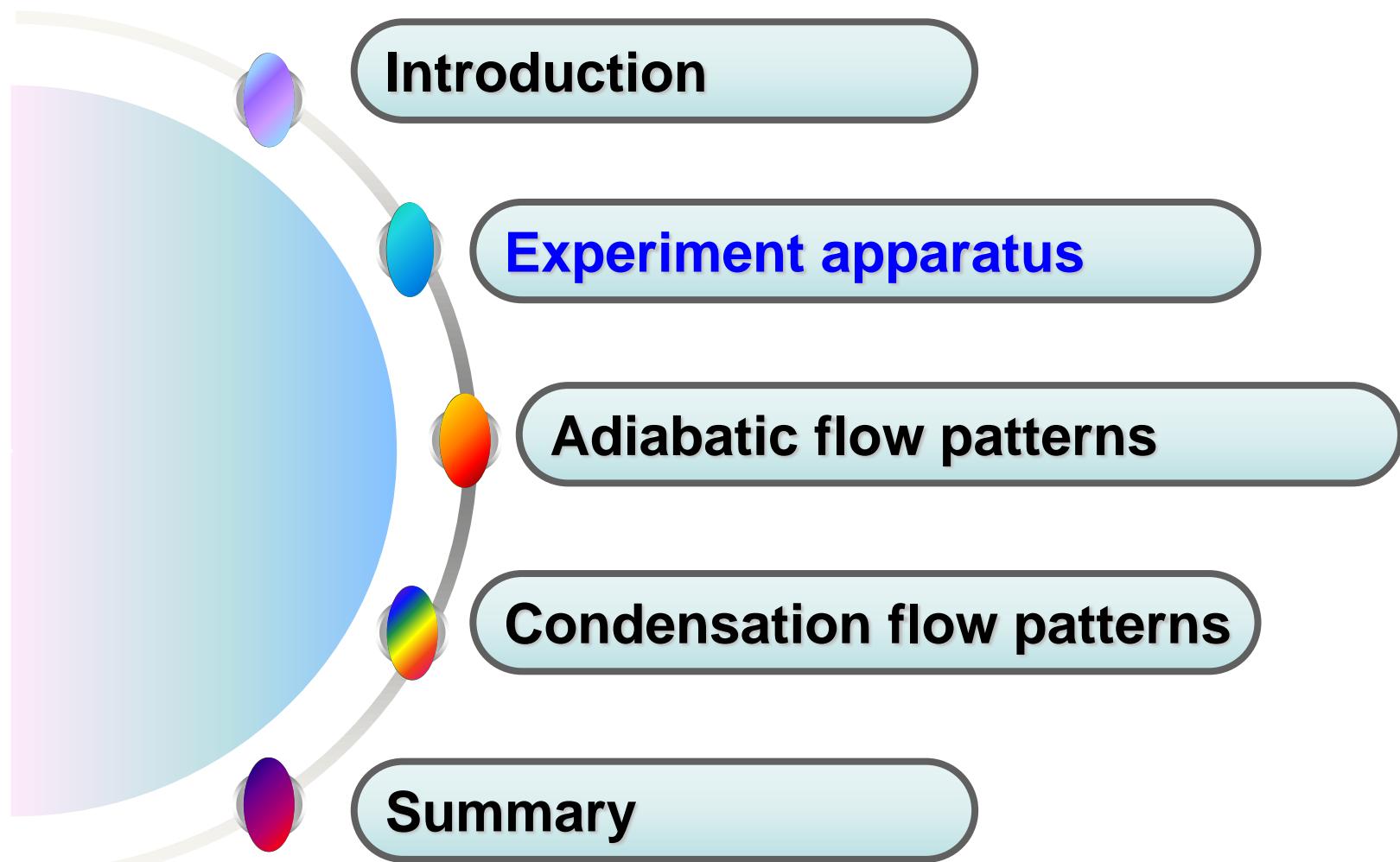
- Physical mechanism of two-phase **heat transfer** and **pressure drop** is closely related to **flow patterns**.

◆ Aim of this work

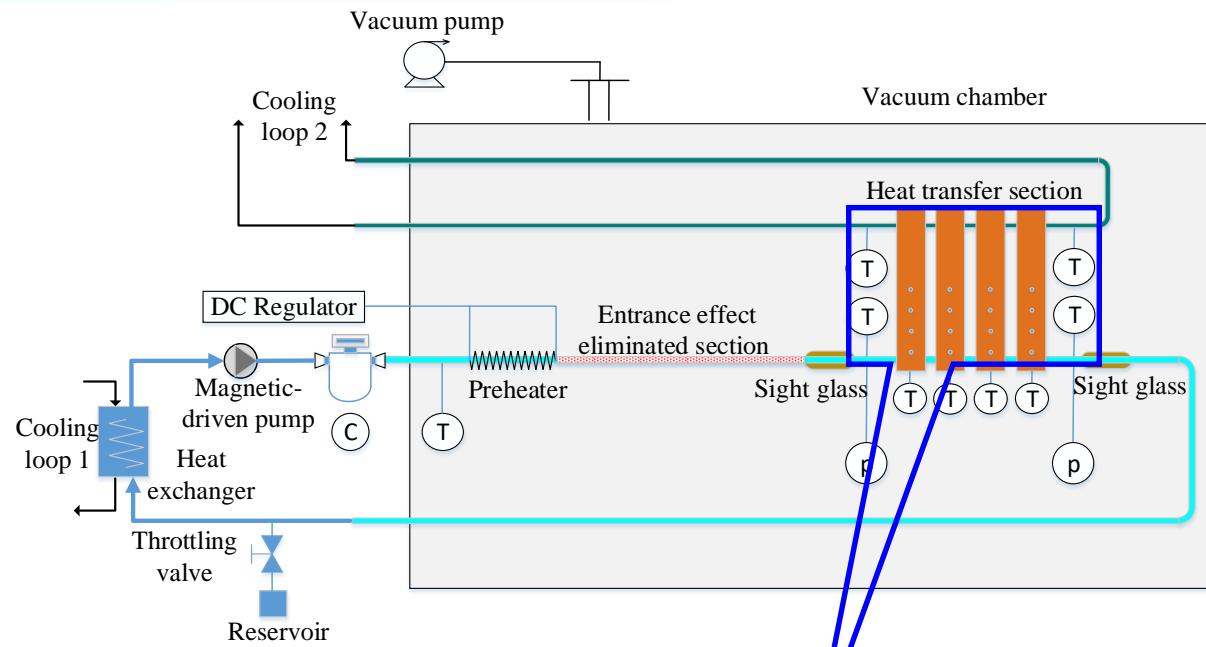
A comprehensive presentation of the experimental studies on

- **Adiabatic and condensation flow patterns for R14/R170 mixtures**

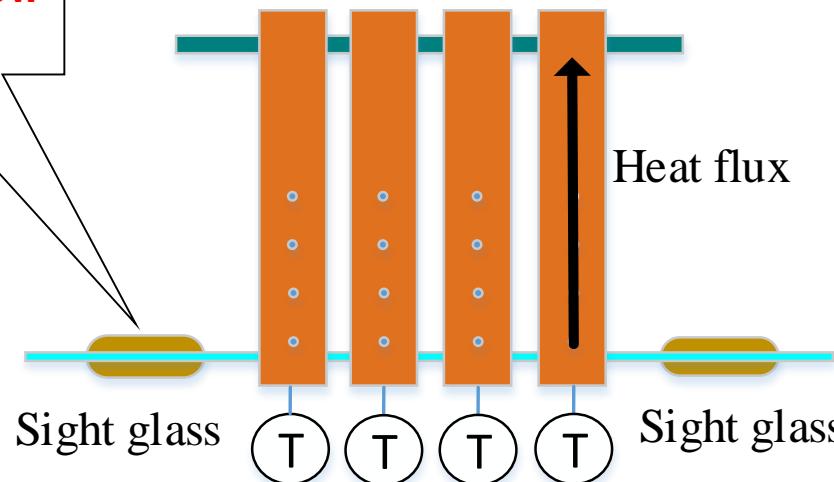
Main Content



Experiment Apparatus



View glass - flow pattern



Temperature distribution one-dimension Fourier Law

$$q_{copper} = \frac{\sum_{i=1}^3 \left(\lambda_i \frac{T_i - T_{i+1}}{d_{i+1} - d_i} \right)}{3}$$

$$q = q_{copper} \frac{S_1}{S_2}$$

Experiment Apparatus

◆ Experiment conditions and uncertainties

Experimental conditions							
Fluids	Composition	p (MPa)	ΔT_{bd} (K)	q (kW m $^{-2}$)	G (kg m $^{-2}$ s $^{-1}$)	x	D (mm)
R14/R170	0.19/0.81,						
	0.44/0.56,						
	0.63/0.37	1.5-2.5	3.6-30.7	8.4-42.2	100-350	0-1	4
	0.8/0.2						

Experimental uncertainties			
Parameters	Instruments	Range	Uncertainties
T	Pt100	80-300 K	0.1 K
p	Pressure sensor	0-4 MPa	0.02%
G	Mass flow meter	0-108 kg h $^{-1}$	0.1%

Experiment Apparatus



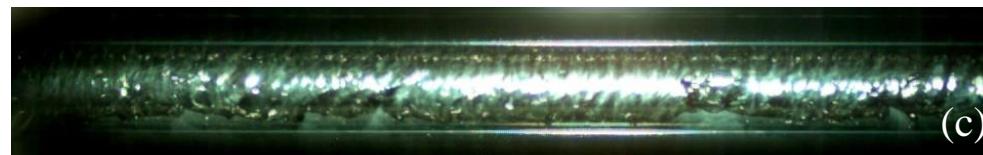
(a)

Intermittent flow



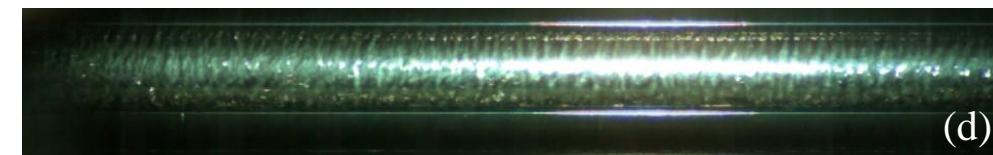
(b)

Transition flow



(c)

Wavy-annular flow



(d)

Smooth-annular flow



(e)

Wavy-stratified flow

Intermittent: intermittent vapor slug with **liquid bridge**;

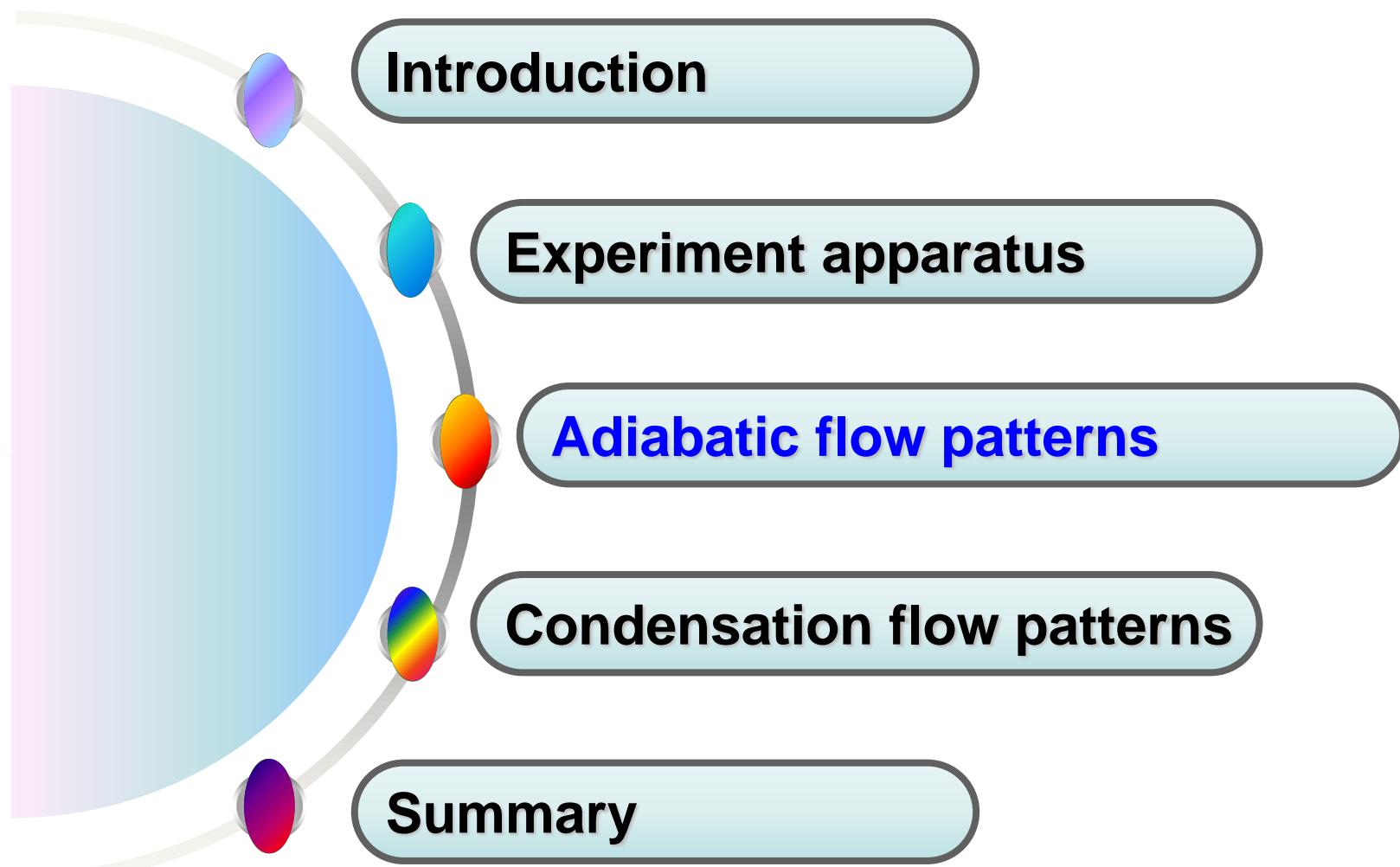
Transition: thick liquid layer in bottom with liquid waves **can flap the tube top**;

Wavy-annular: liquid film has discernible **interfacial waves**, **can't flap the tube top**;

Smooth-annular: **thin and fairly smooth liquid film** along the entire tube perimeter;

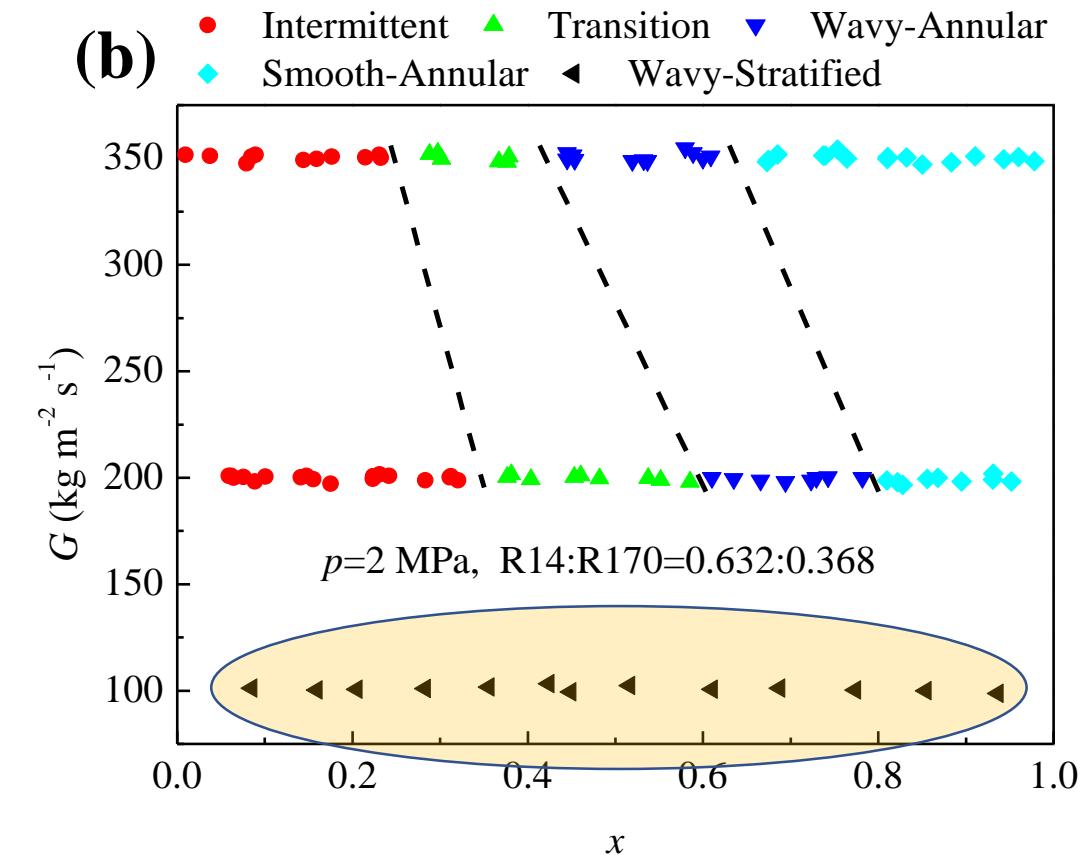
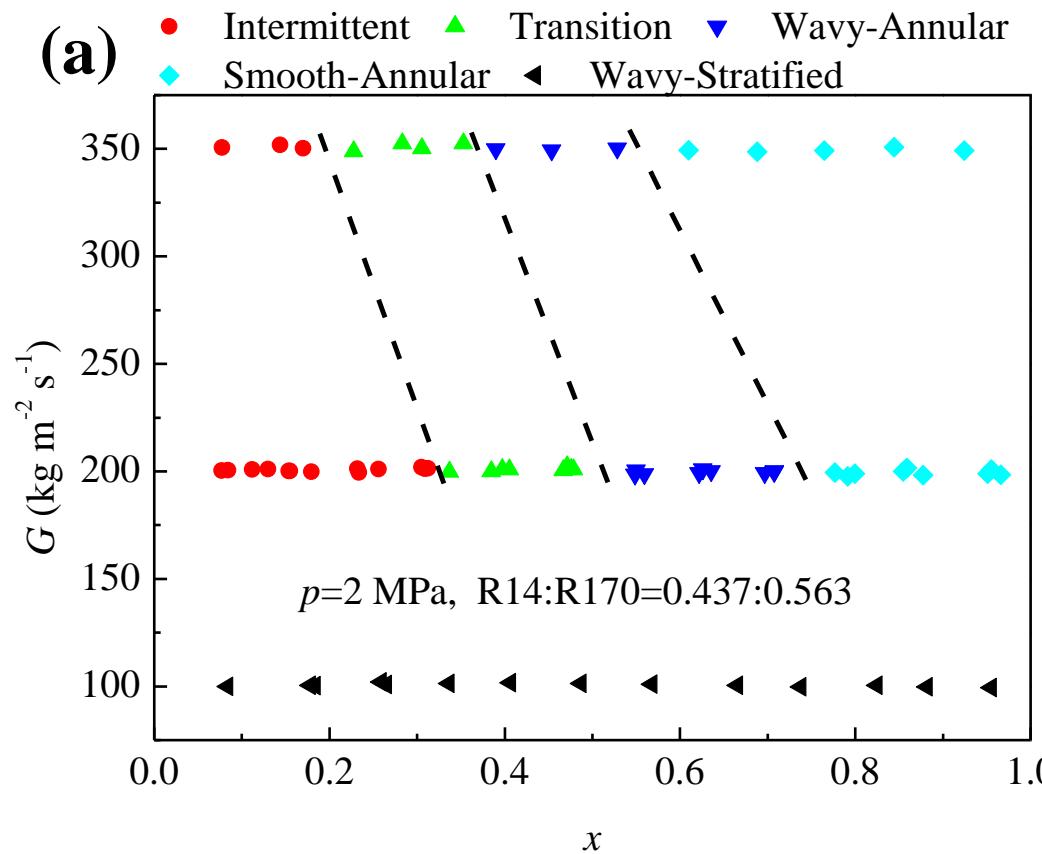
Wavy-stratified: separate liquid and vapor layers with **soft liquid waves**.

Main Content



Adiabatic flow patterns

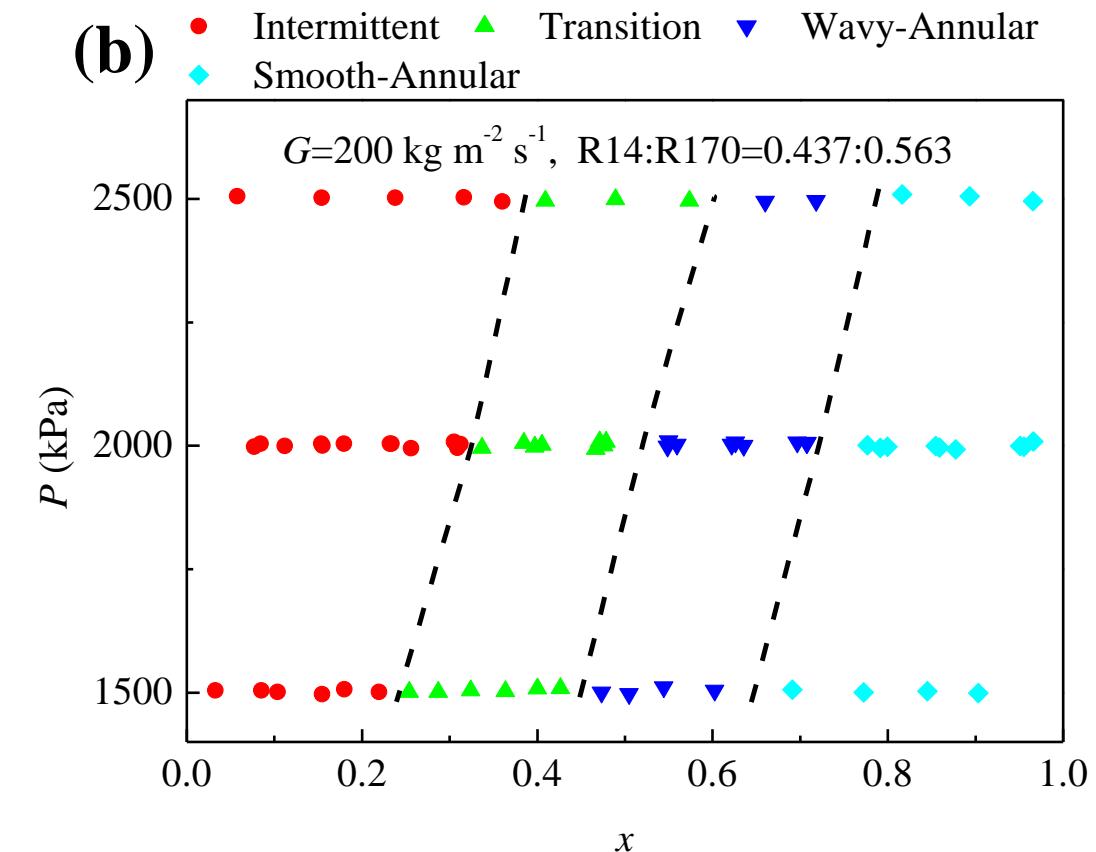
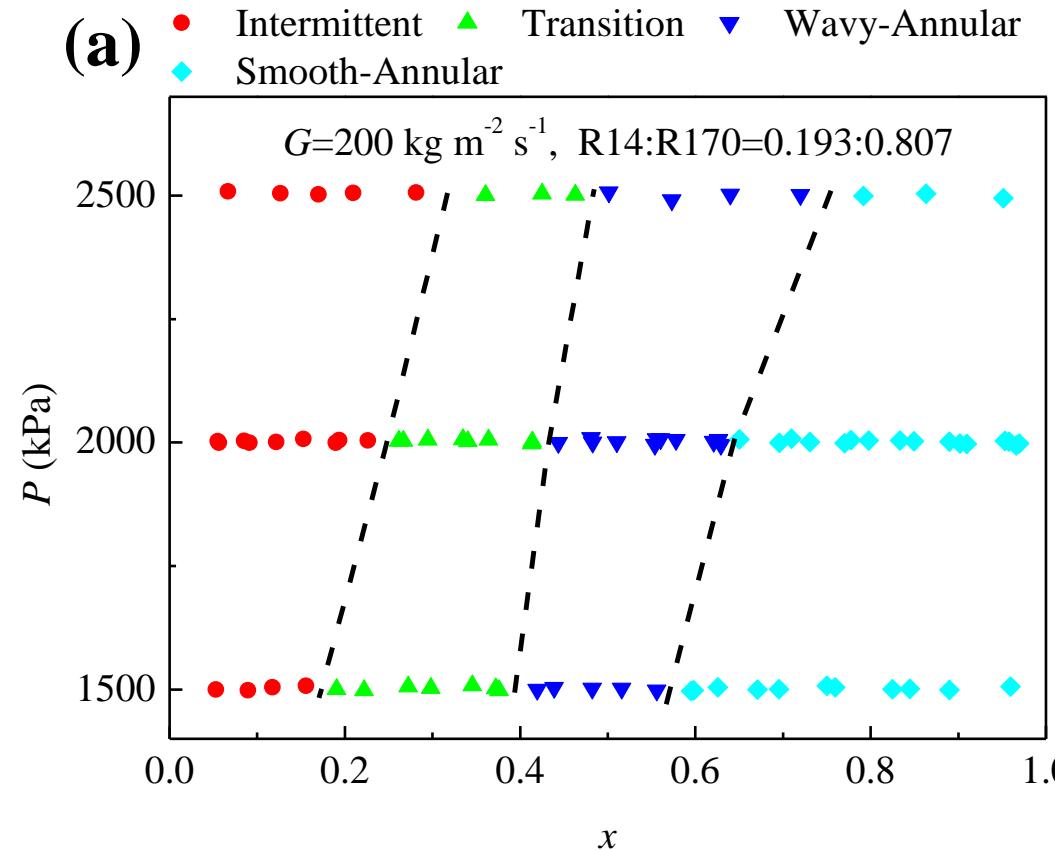
◆ Effect of mass flux



- Transition vapor qualities **decrease with mass flux**
- Wavy-stratified flow occur at **lower mass flux**

Adiabatic flow patterns

◆ Effect of saturation pressure



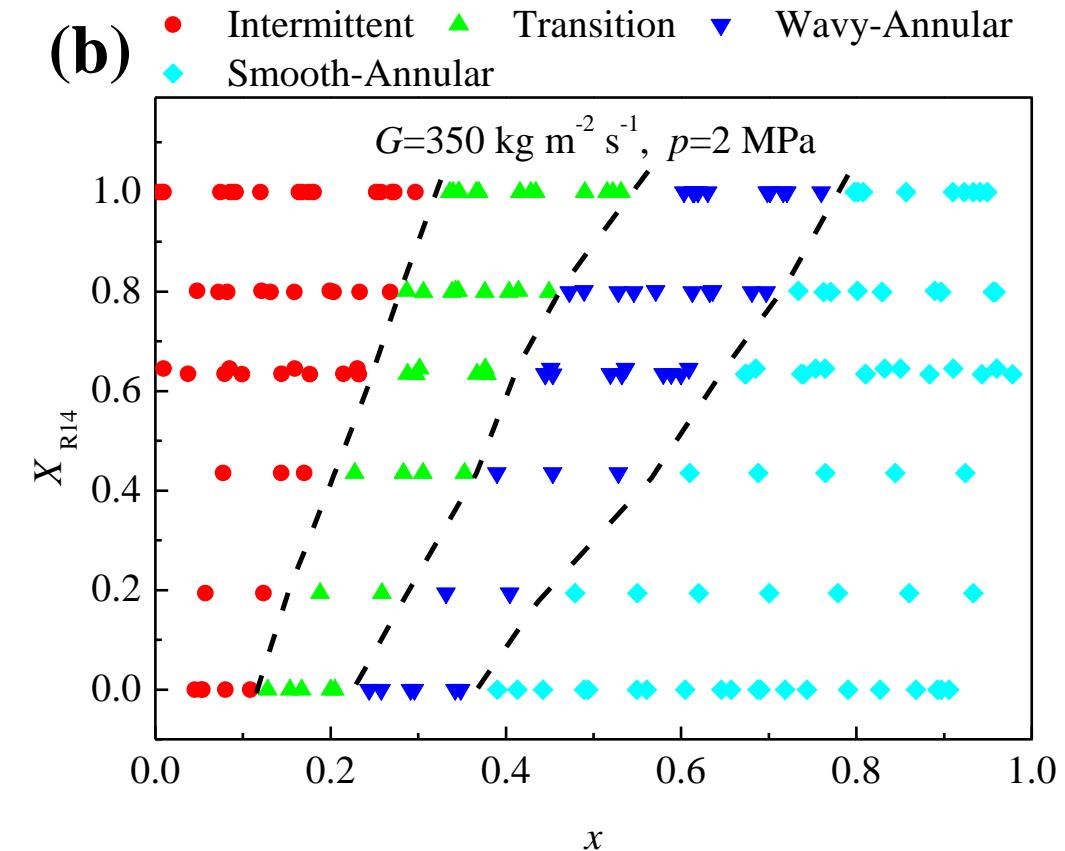
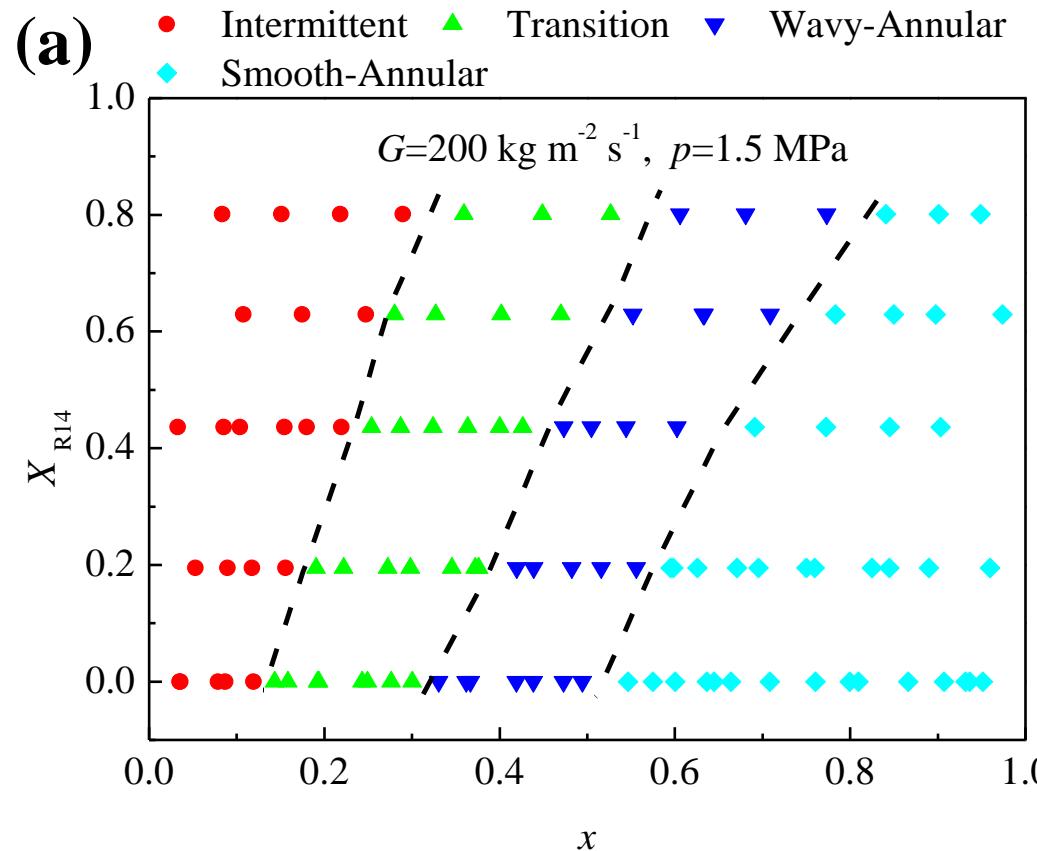
➤ Transition vapor qualities increase with saturation pressure

p → Thermodynamic properties

$$\left\{ \begin{array}{ll} \rho_v & \mu_v \\ \rho_l & \mu_l \end{array} \right.$$

Adiabatic flow patterns

◆ Effect of concentration

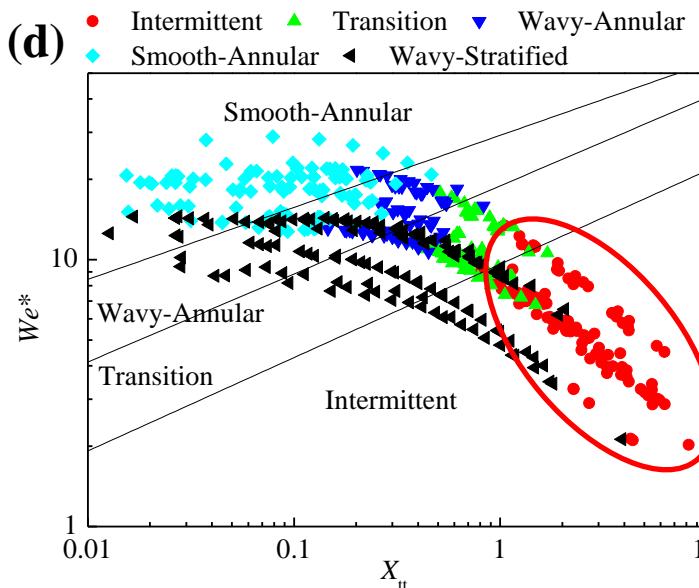
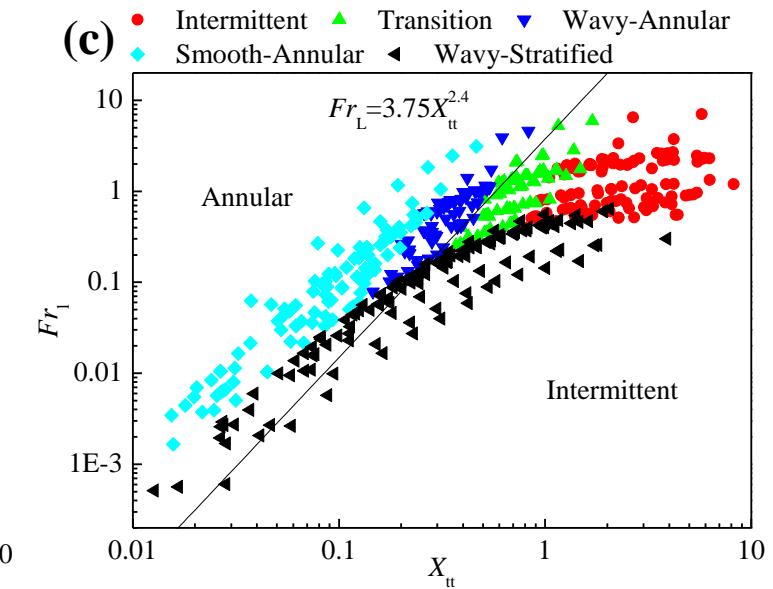
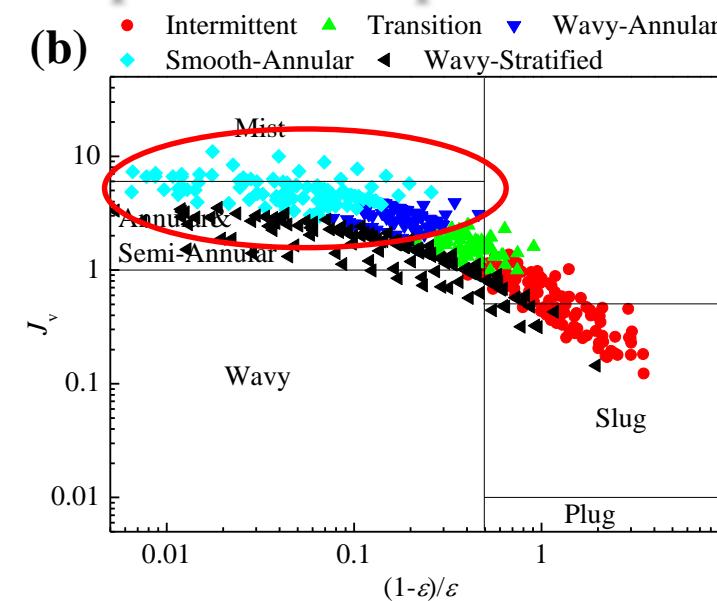
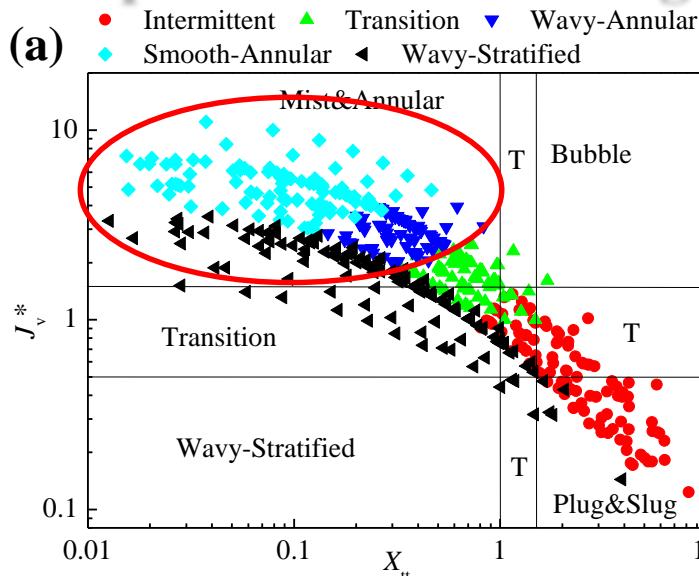


➤ Transition vapor qualities increase with the concentration of R14

Concentration → Thermodynamic properties

Adiabatic flow patterns

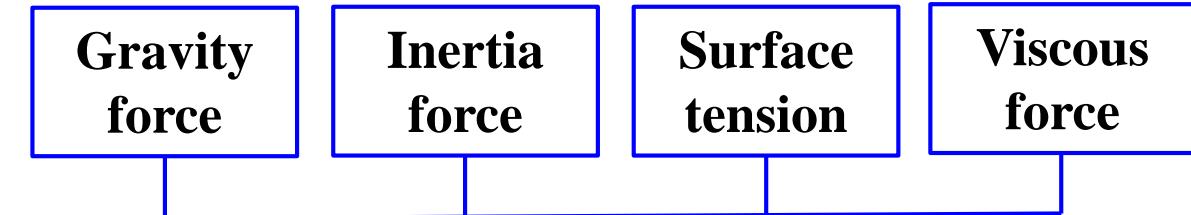
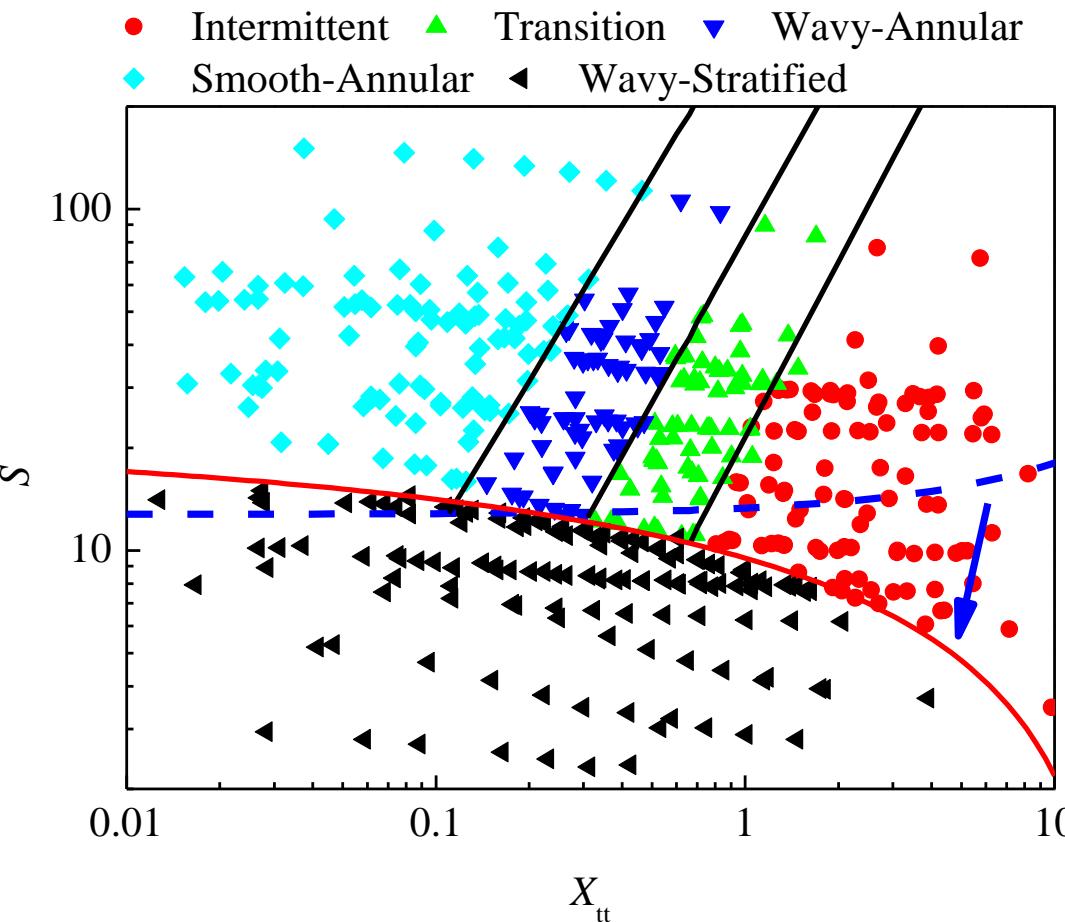
◆ Comparison with existing flow pattern maps



- Breber et al. and Tandon et al.: well predict the majority of annular flow.
- Barbieri et al.: accurately predict the transition tendency from intermittent flow to annular flow.
- Zhuang et al.: accurately predict the intermittent flow.

Adiabatic flow patterns

◆ New flow pattern map



$$S = Fr_v \cdot Bd^{-0.15} \cdot Ca_1^{-0.1}$$

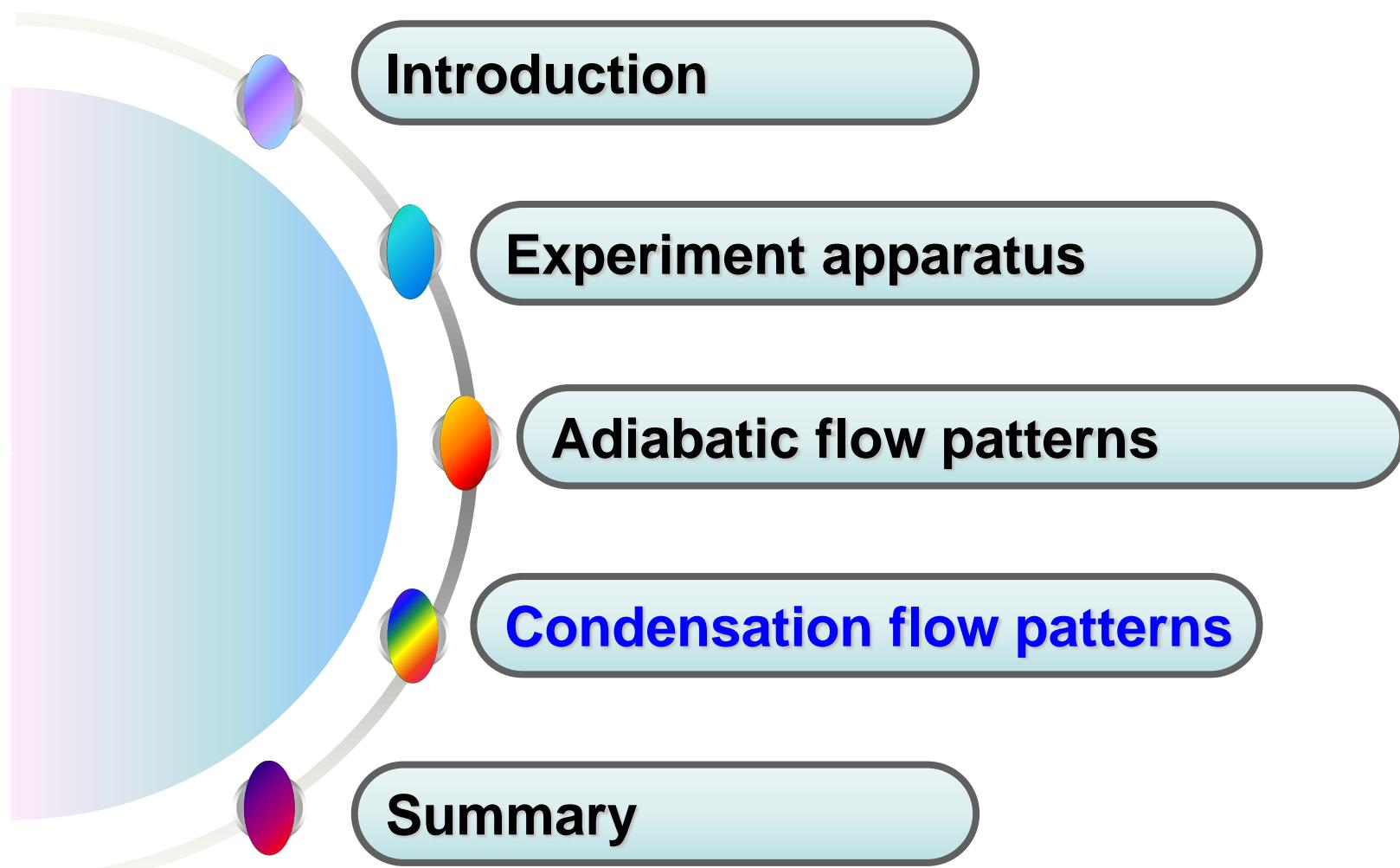
WS: $S < 22 - 12.5X_{tt}^{0.2}$

I to T: $S = 21.45X_{tt}^{1.71}$

T to WA: $S = 83.4X_{tt}^{1.62}$

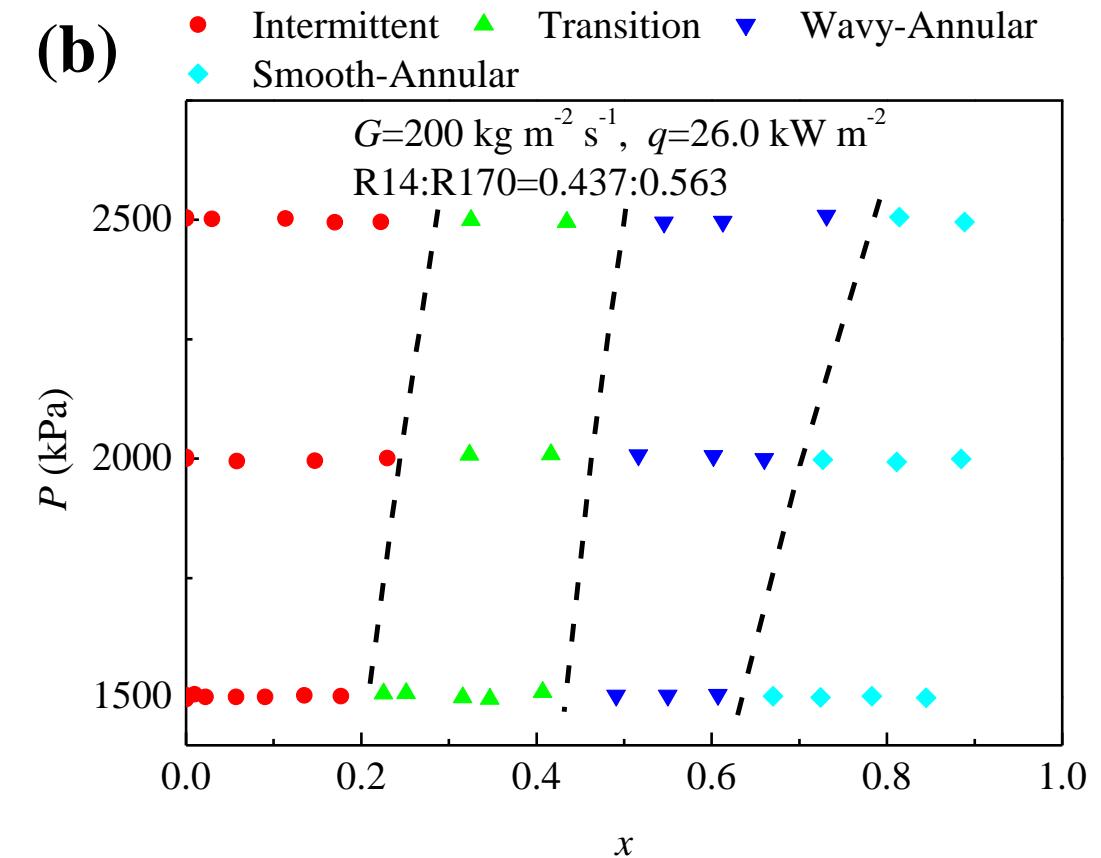
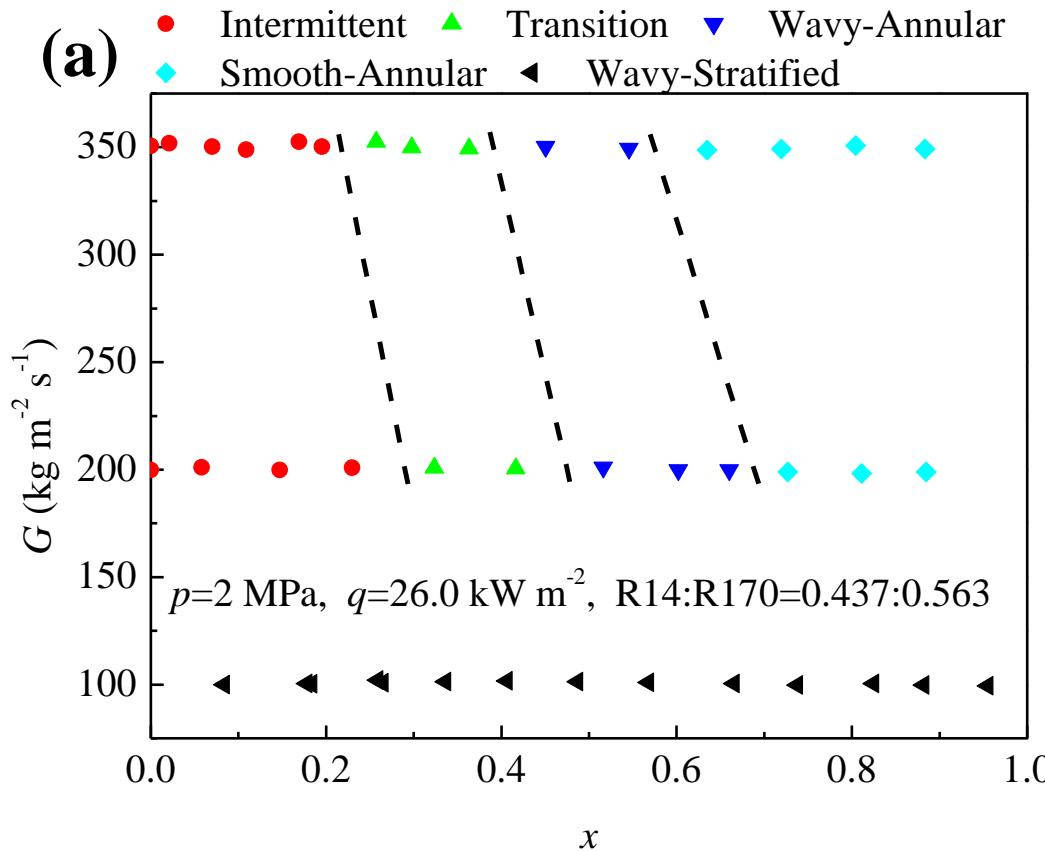
WA to SA: $S = 360.6X_{tt}^{1.52}$

Main Content



Condensation flow patterns

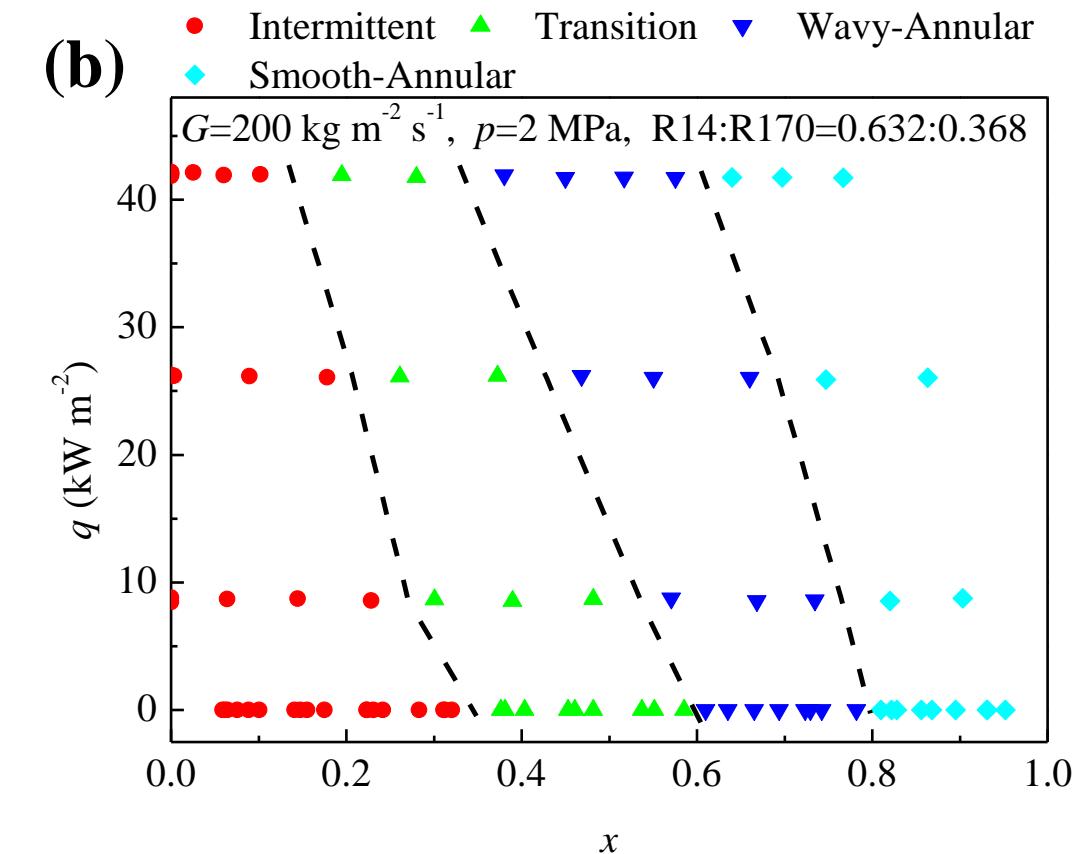
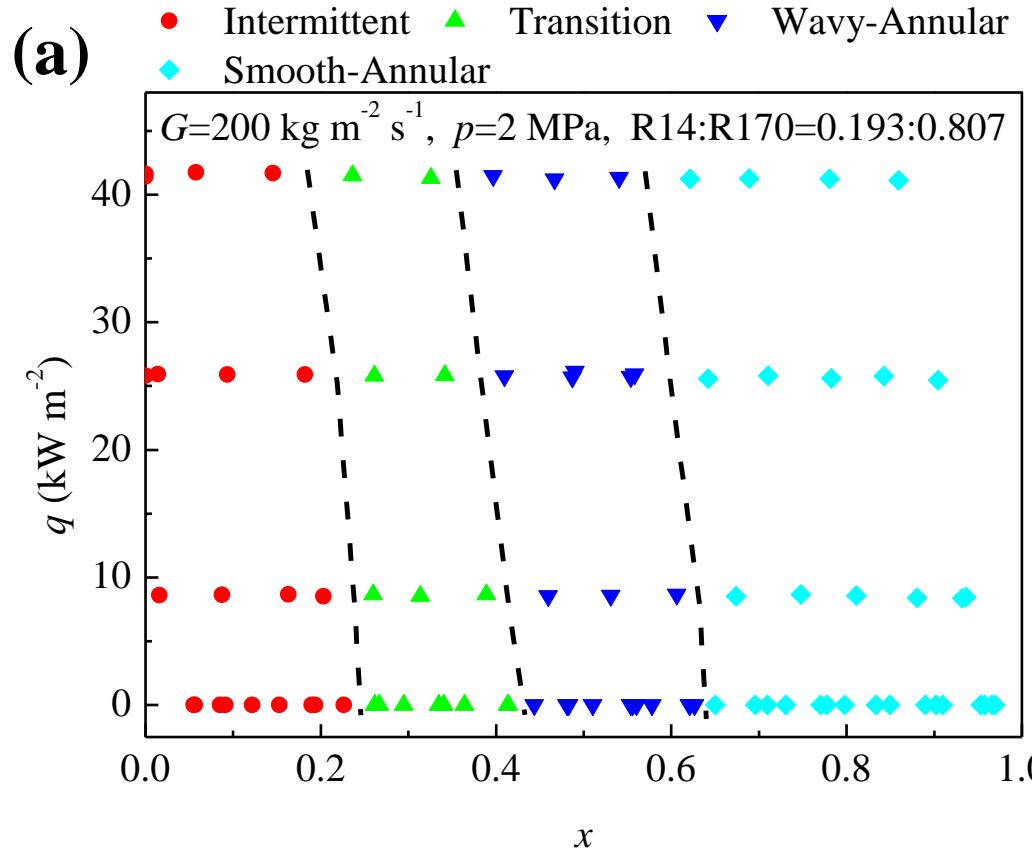
◆ Effect of mass flux and saturation pressure



- Transition vapor qualities decrease with mass flux
- Transition vapor qualities increase with saturation pressure

Condensation flow patterns

◆ Effect of heat flux

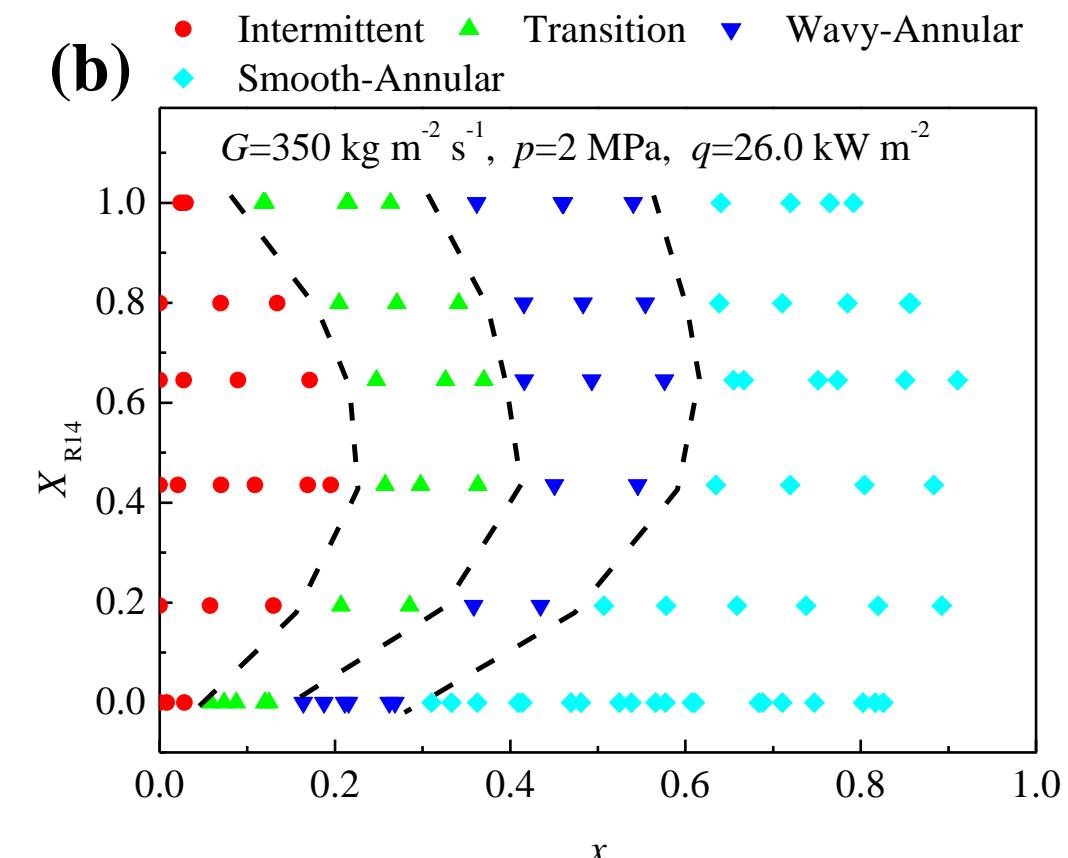
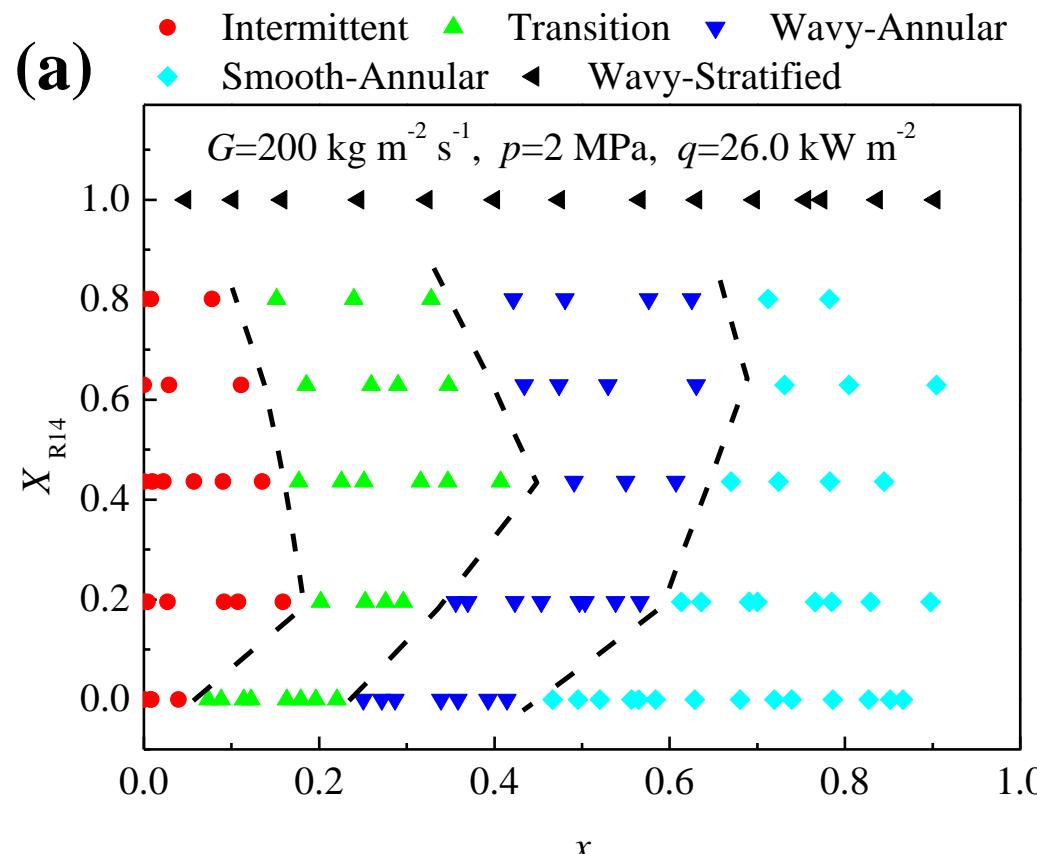


- Transition vapor qualities decrease with heat flux
- The effect of heat flux is more pronounced at higher R14 concentration (Fig. (b))

$$H_{\text{lv,R170}} > H_{\text{lv,R14}}$$

Condensation flow patterns

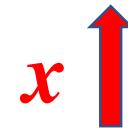
◆ Effect of concentration



➤ Transition vapor qualities increase first and then decrease

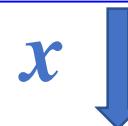
□ Dynamic influence

$$\rho_{l,R14} > \rho_{l,R170}, \quad \rho_{v,R14} > \rho_{v,R170}$$

x 

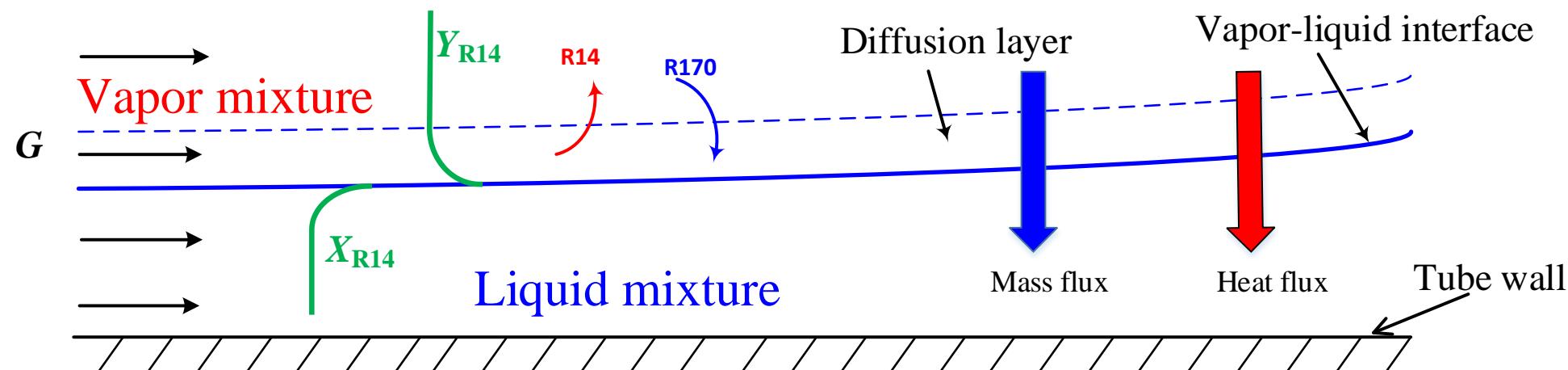
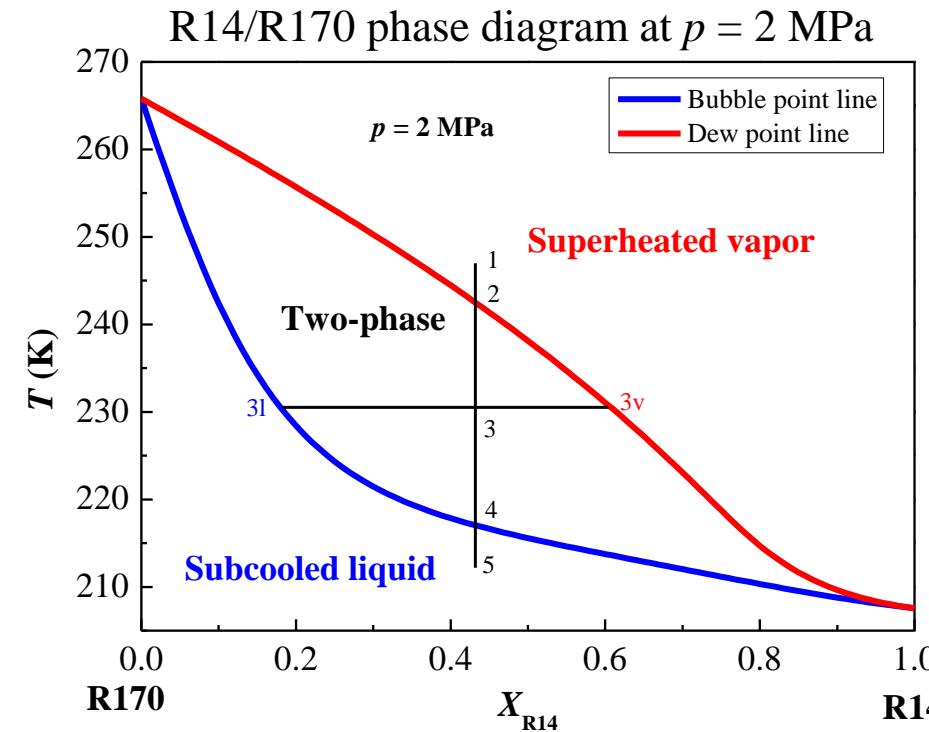
□ Thermodynamic influence

$$H_{lv,R170} > H_{lv,R14}$$

x 

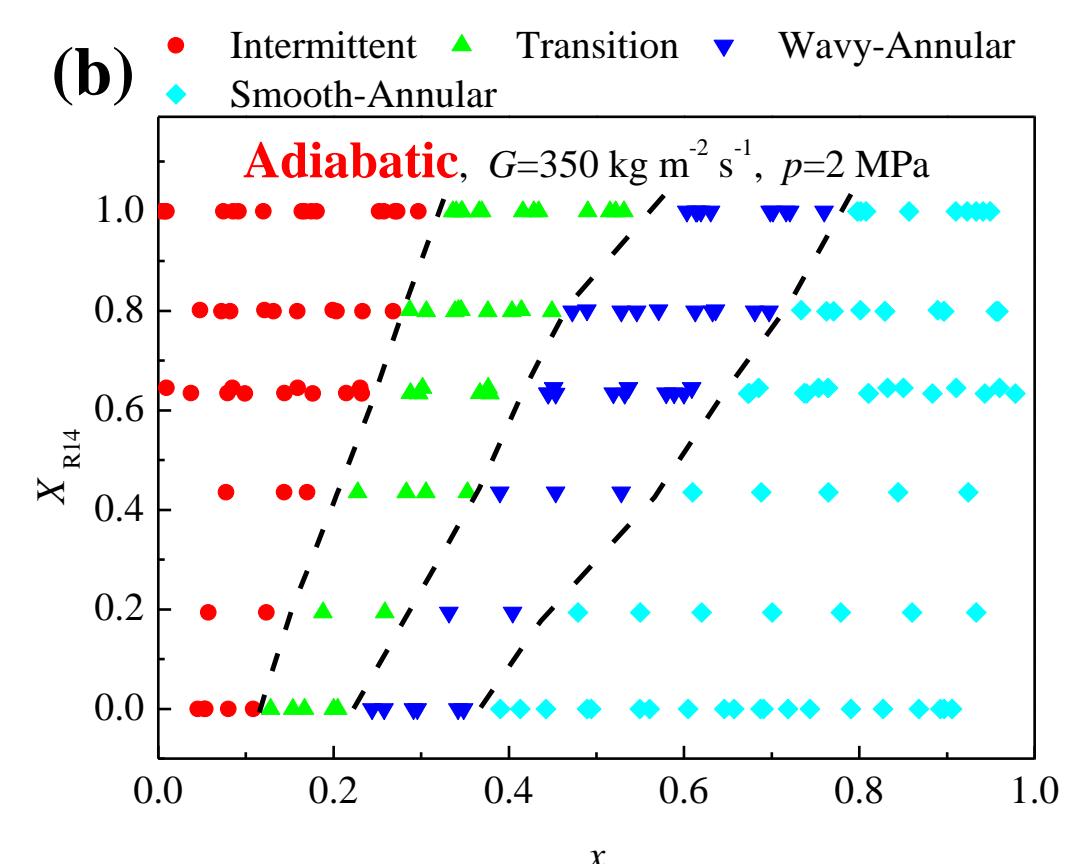
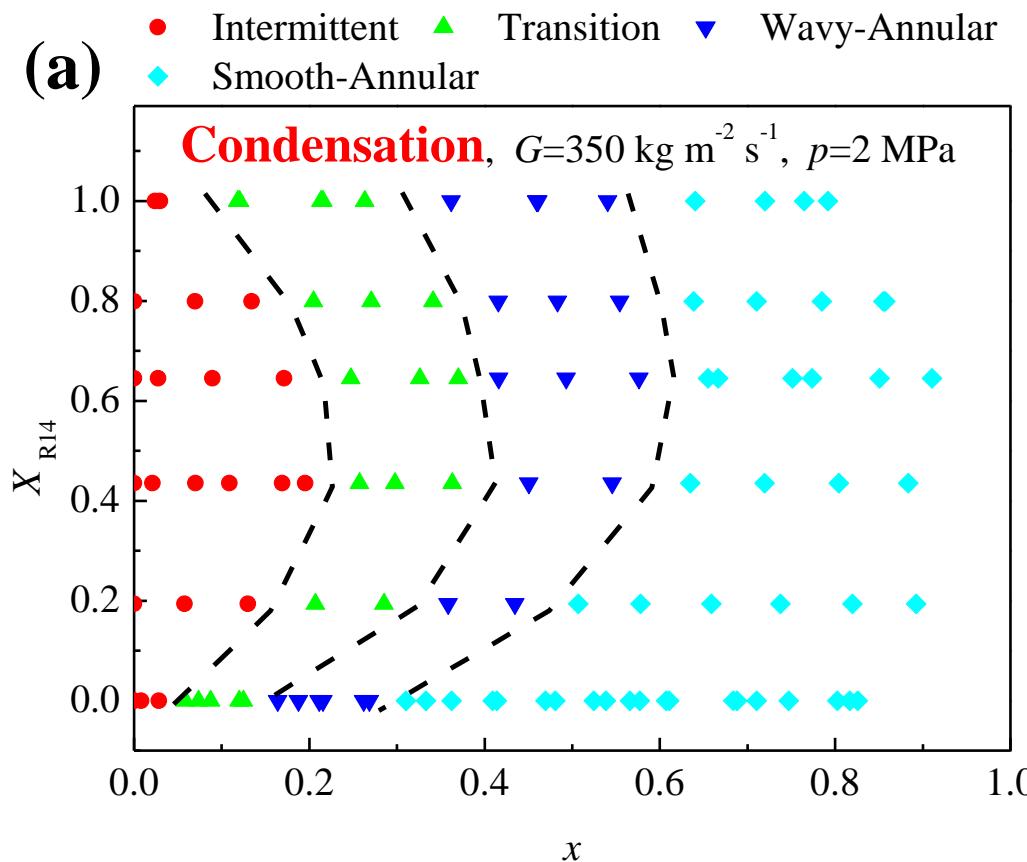
Condensation flow patterns

□ Mass transfer influence



Condensation flow patterns

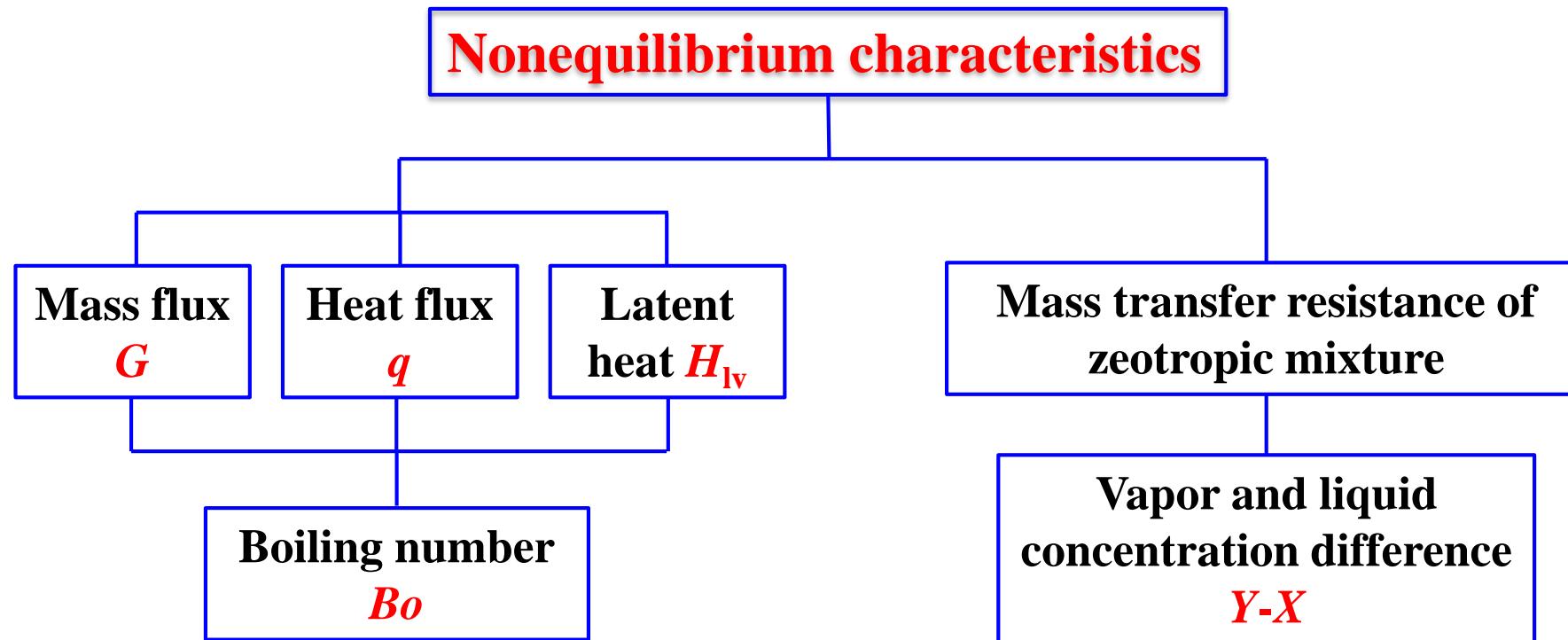
◆ Compared with adiabatic flow



- Condensation transition vapor qualities **increase first** and then **decrease**
- While adiabatic transition vapor qualities **increase unchangeably**

Condensation flow patterns

◆ New flow pattern map



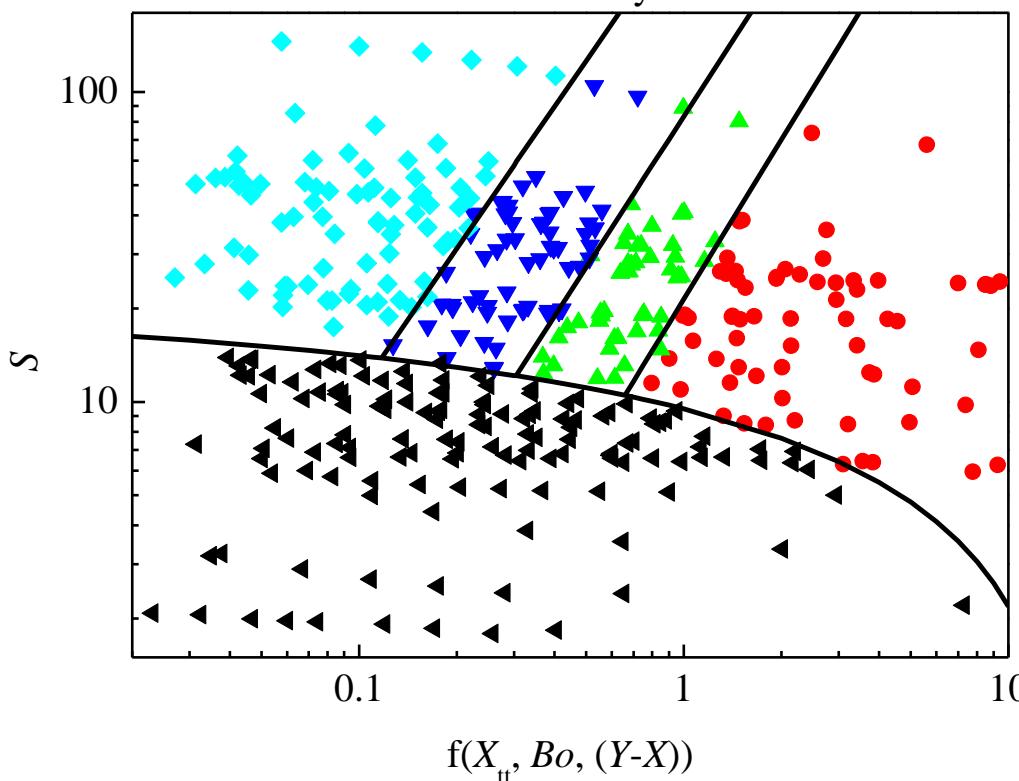
$$f(X_{tt}, Bo, (Y - X)) = \frac{X_{tt}}{1 + 8 \times 10^5 \times Bo^2 \times [1 + (Y - X)^{0.4}]}$$

Condensation flow patterns

◆ New flow pattern map

$$f(X_{tt}, Bo, (Y - X)) = \frac{X_{tt}}{1 + 8 \times 10^5 \times Bo^2 \times [1 + (Y - X)^{0.4}]}$$

- Intermittent ▲ Transition ▼ Wavy-Annular
- ◆ Smooth-Annular ◀ Wavy-Stratified



WS:

$$S < 22 - 12.5[f(X_{tt})]^{0.2}$$

I to T:

$$S = 21.45[f(X_{tt})]^{1.71}$$

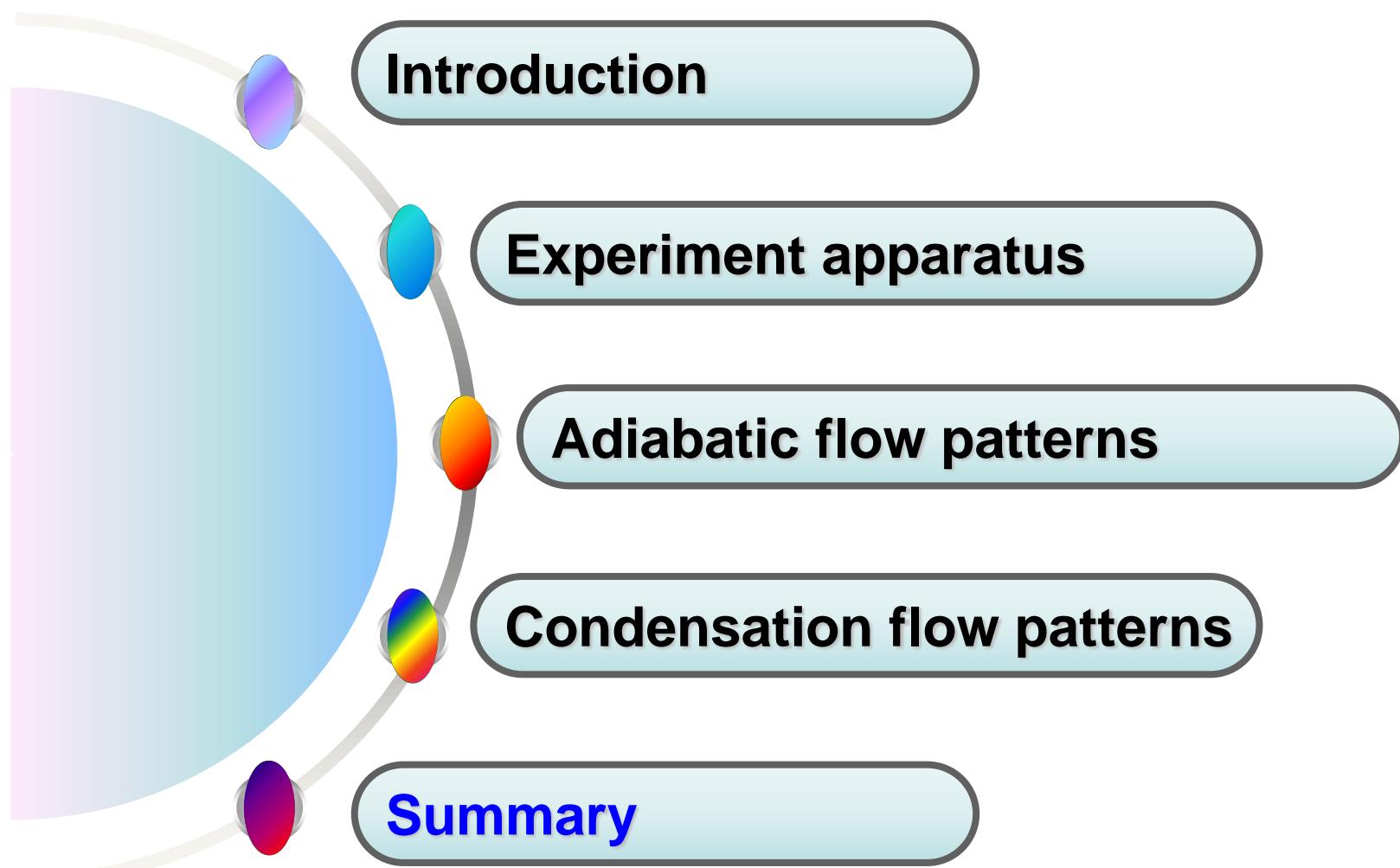
T to WA:

$$S = 83.4[f(X_{tt})]^{1.62}$$

WA to SA:

$$S = 360.6[f(X_{tt})]^{1.52}$$

Main Content



- Flow visualization experiments of **R14/R170 mixtures** under **adiabatic** and **condensation** conditions were presented.
- The effects of **mass flux**, **saturation pressure**, **concentration** and **heat flux** on flow pattern transitions were analyzed.
- Both **modified adiabatic and condensation flow pattern map** were developed.



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Thanks for your attention!

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