2015 NETL Workshop on Multiphase Flow Science

Driving for High-Density Operation for both CFB Riser and Downer

- an Introduction of the Western's Particle Technology Research Centre

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Particle Technology Research Centre

The University of Western Ontario

(Western University)

Particle Technology Research Centre at the University of Western Ontario (2007)

Zhu Research Group

2009

2010

2011

2012 Graduate Students and Post Doc Fellows

Large Lab Area

Large Fluidized Bed Units

Pilot Study on London City's Wastewater Plant

Sponsored by industry, city, province and NSERC (federal)

OUTLINE

汇报提纲

1. Introduction
2. Hydrodynamics in HDCFB
3. Reactor Performance of HDCFB
4. Conclusion

CFB Applications

CFB boiler

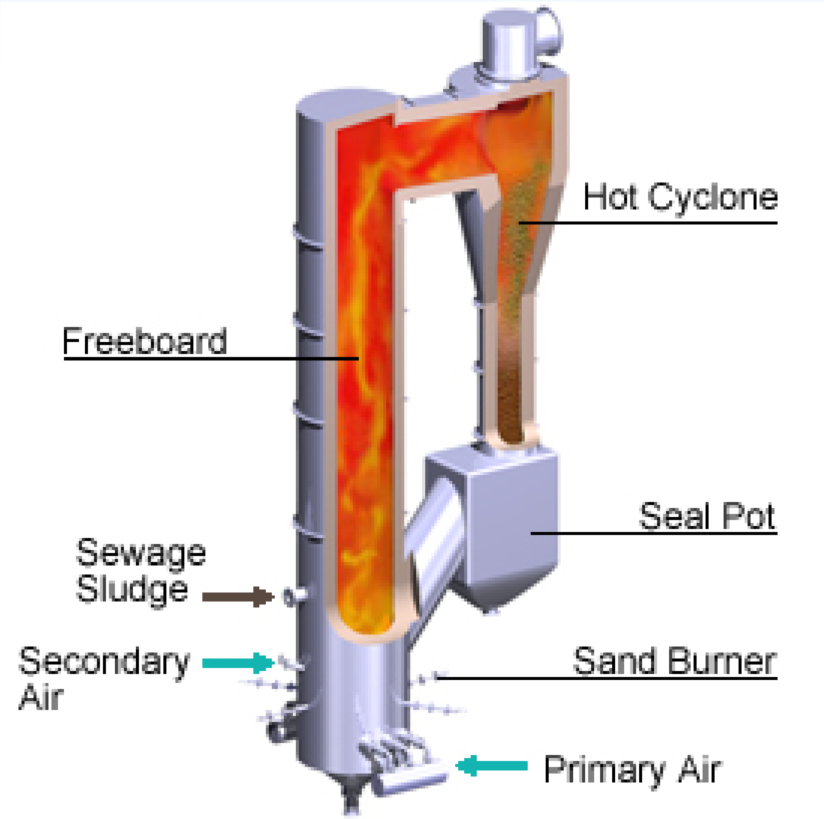
Fluid catalytic cracking unit

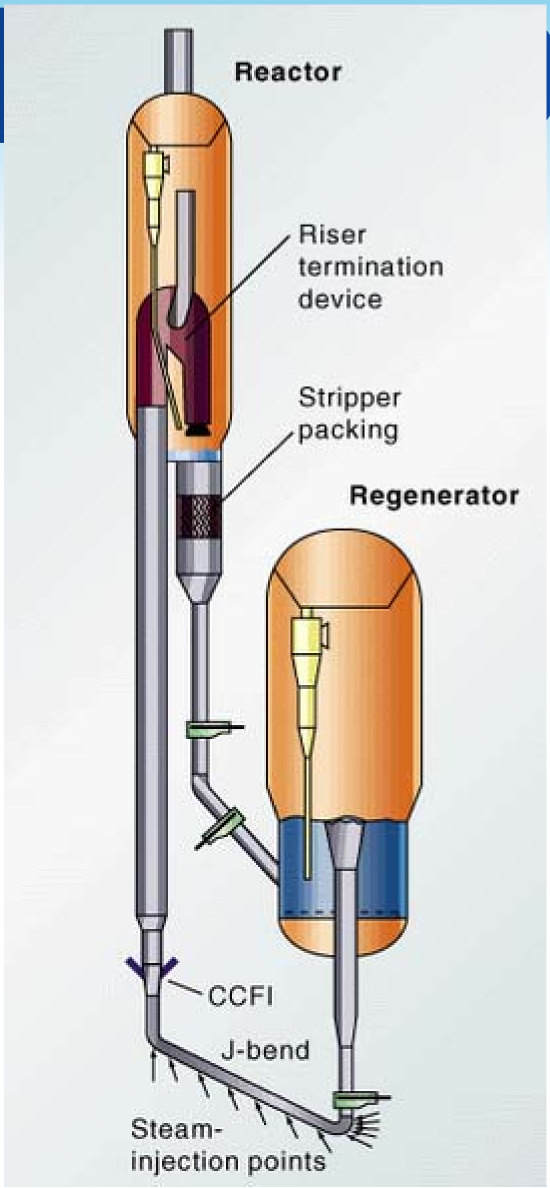
CFB

CFB gasification

Solids waste incinerator

CFB applications





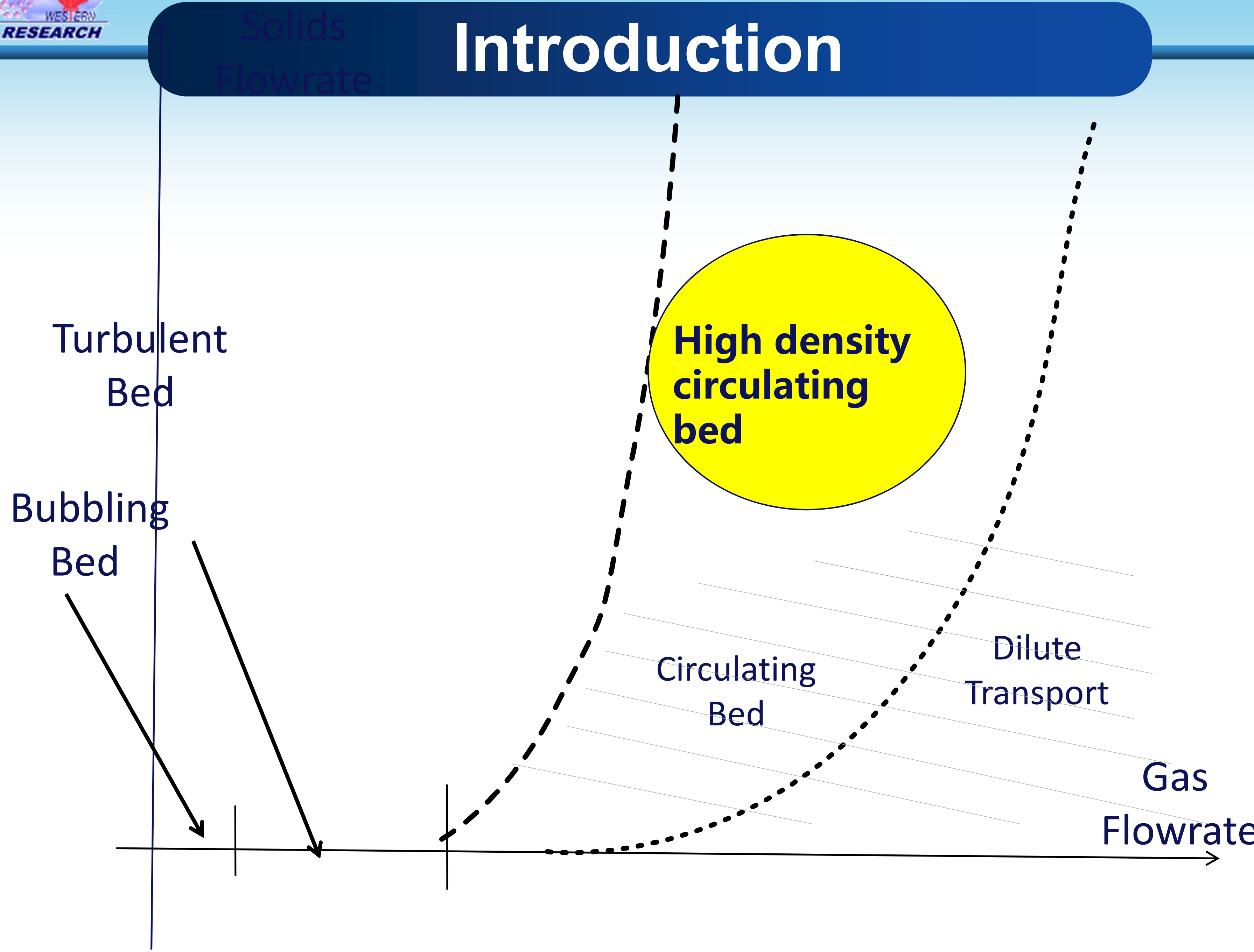
CFB combustor

FCC unit

FCC riser vs CFB combustor

Parameter	FCC Riser reactor	CFB combustor
Particle density, kg/m^3	1100-1500	1800-2600
Mean particle diameter, μm	60-80	100-300
Geldart powder group	A	B
Superficial gas velocity, m/s	4-20	5-9
Net solids flux, kg/m^2s	400-1200	10-100
Solids concentration	3%	<1%
Height to diameter ratio	>20	<5-10

Introduction



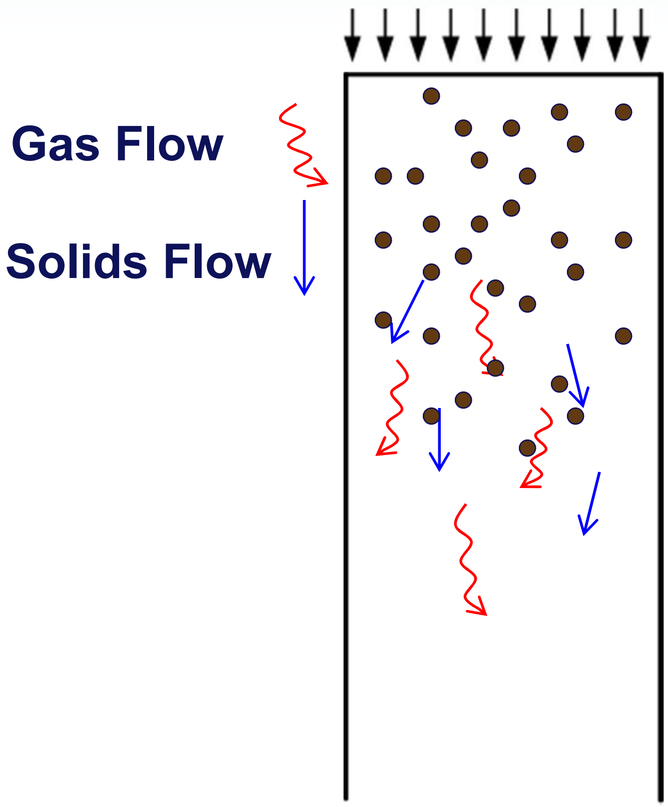
Introduction

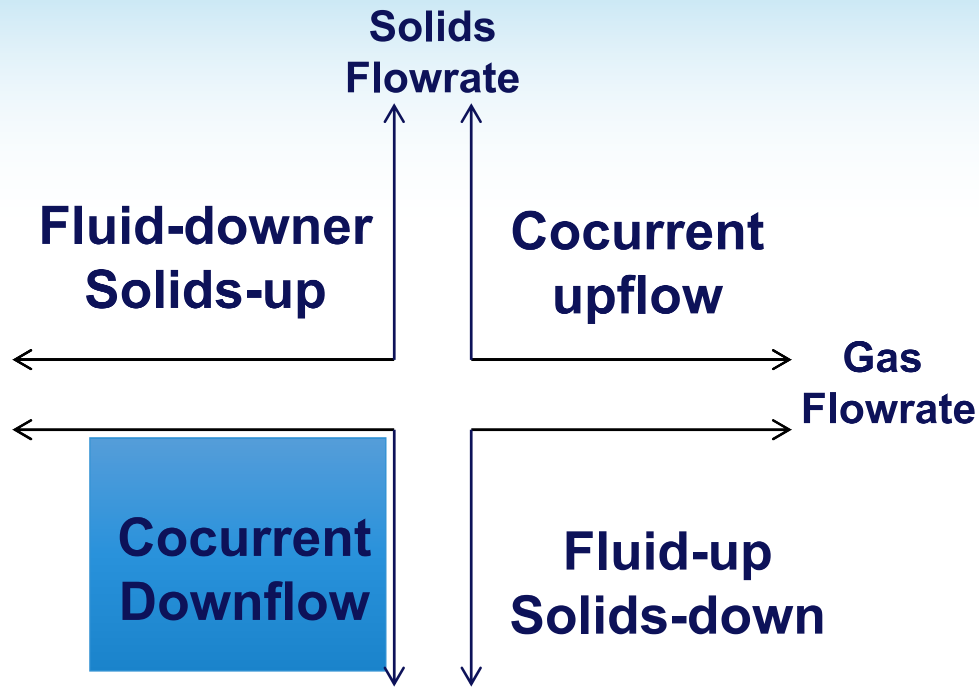
2. Research background ——High density CFB

Current state	Industrial
Low G_s(< 300 kg/m^{2}s)	High G_s(> 500 kg/m^{2}s)
Low U_g(< 10 m/s)	High U_g(8~28 m/s)
Low ε_s(< 5%)	High ε_s(> 10%)
Nonuniform flow structure	Intensive gas-solids mixing
Backmxing	Plug-flow characteristics

Introduction

Downer



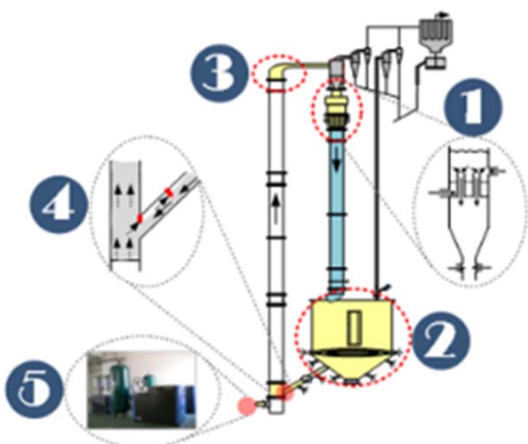


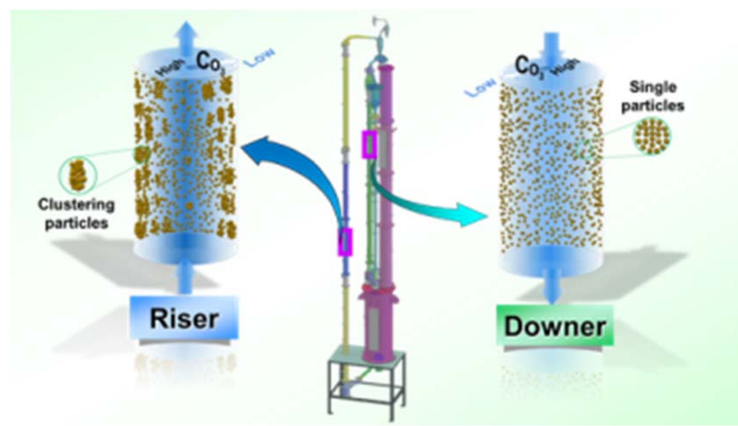
- No backmixing
- Short contacting time
- Narrow RTD
- More uniform distribution
- **Dilute (ε_s < 1%)**

Introduction

2. Research Objectives

- Achieving high density operation
- Studying hydrodynamic characteristics
- Investigating reactor performance



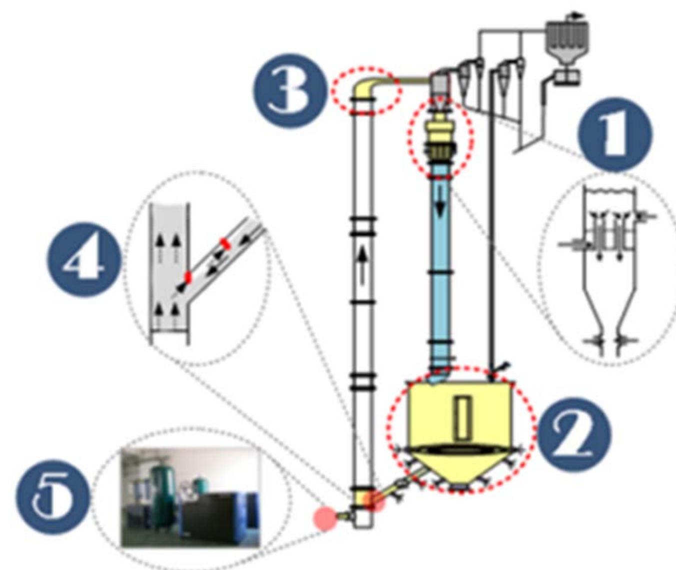


Hydrodynamics

——HDCFB riser

Conditions required for HDCFB operation

- Sufficient blower capacity and pressure
- High solids inventory
- High static bed height in standpipe
- Appropriate unit structure
  - Large downcomer to riser diameter ratio
  - Low solids feeder resistance
  - Low separator pressure drop
- Small particles to avoid slugging or classical choking



Wang et al, 2014; CES

Hydrodynamics

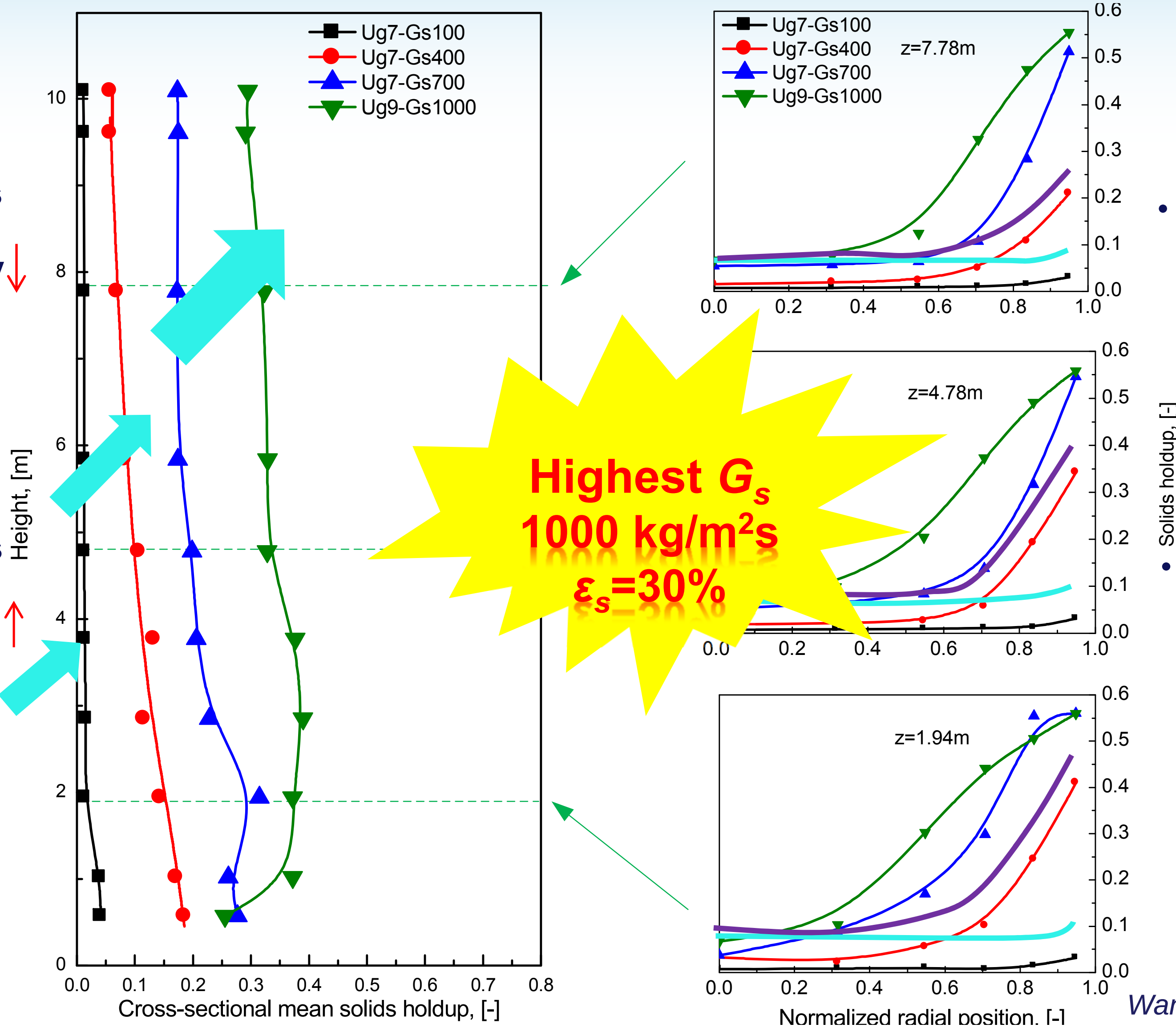
——HDCFB riser

- G_s<700kg/m²s

G_s ↑ uniformity ↓

- G_s>700kg/m²s

G_s ↑ uniformity ↑



- G_s<700kg/m²s

Core-annulus

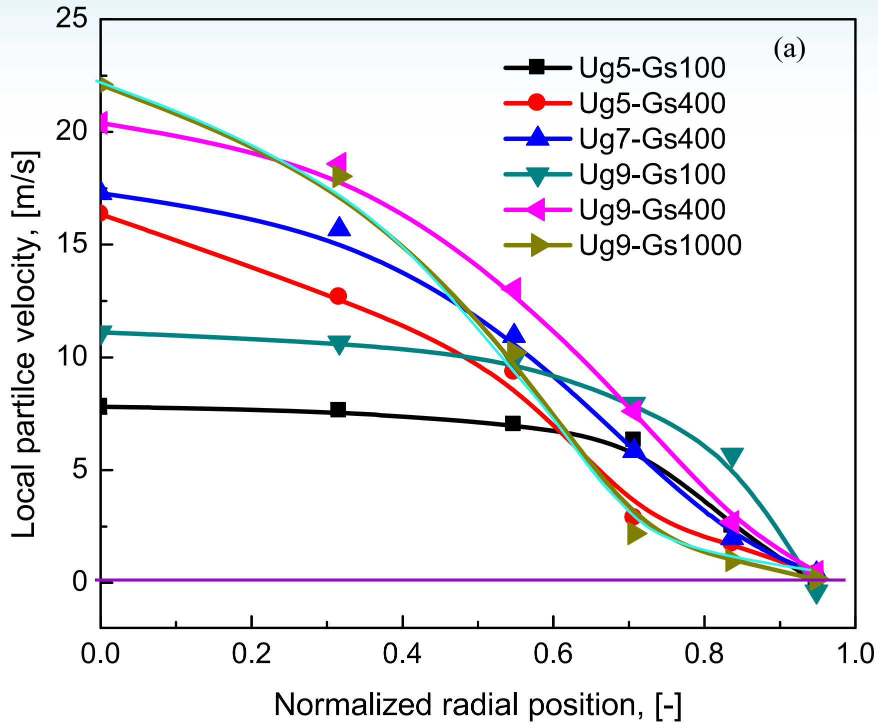
- G_s>700kg/m²s

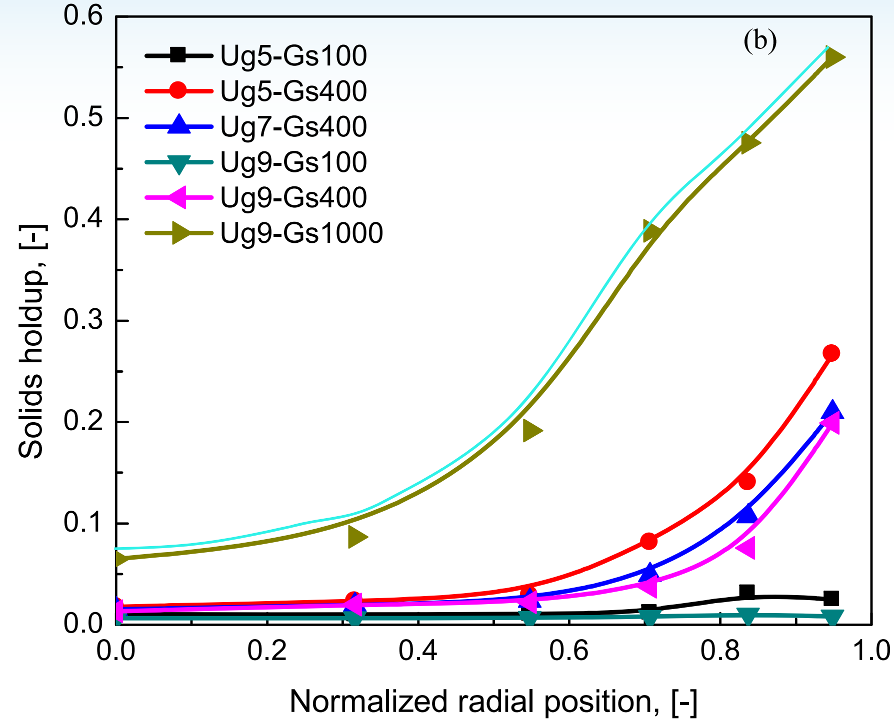
Parabolic shape

Wang et al, 2014a; CES

Hydrodynamics

——HDCFB riser





r/R ↑ **V_p** ↓

U_g ↑ **V_p** ↑

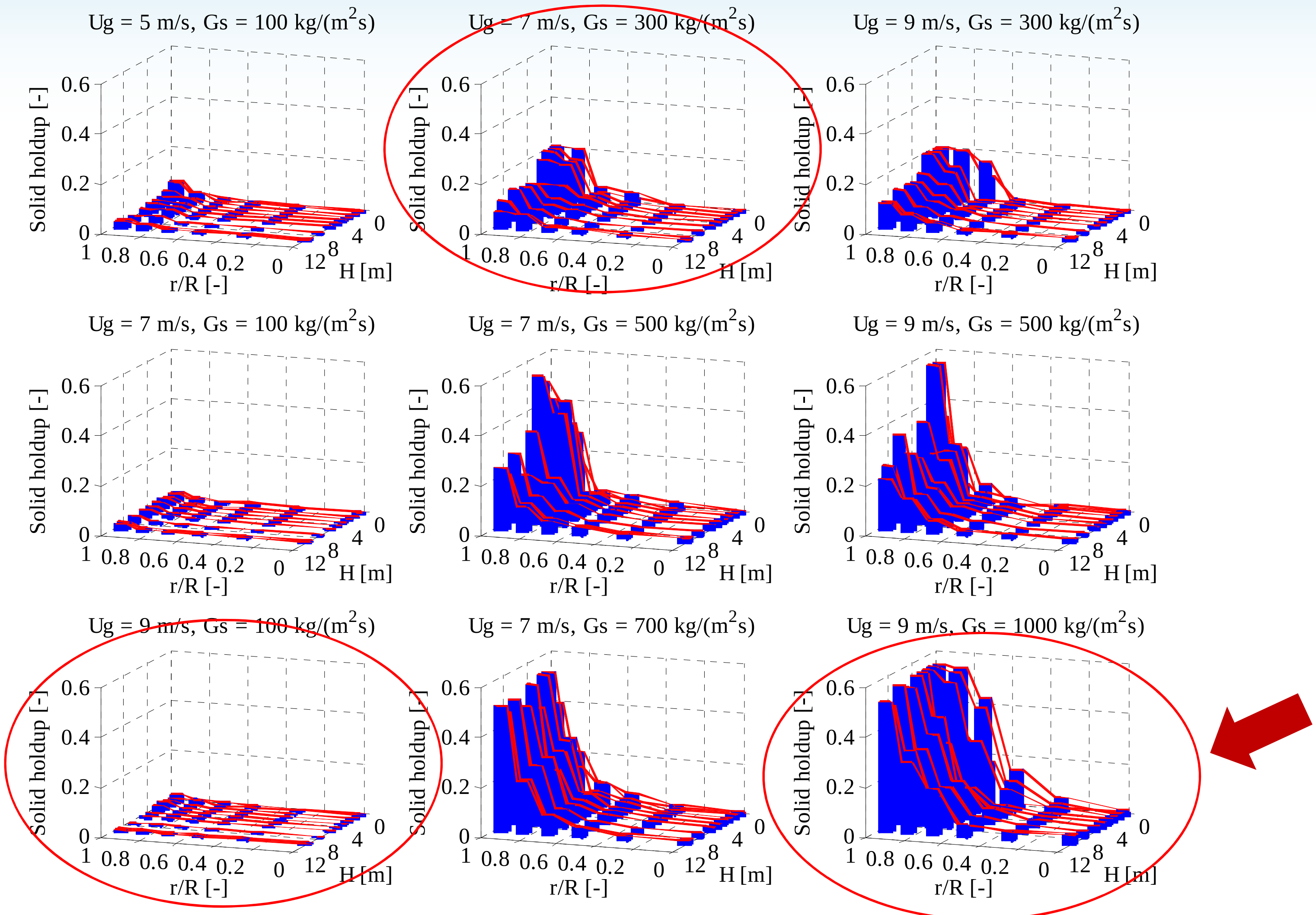
G_s ↑ **V_p** ↑**(r/R=0~0.2),** ↓

No net downwards flow

Wang et al, 2014b; CES

Hydrodynamics

——HDCFB riser



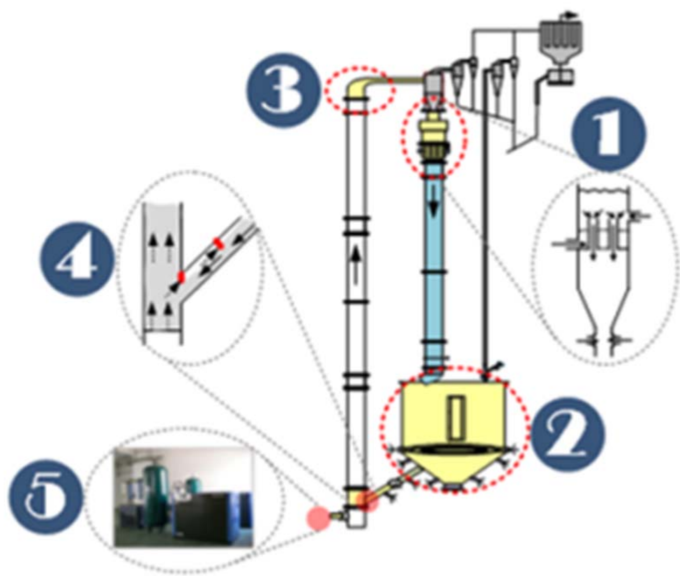
Nonuniform flow

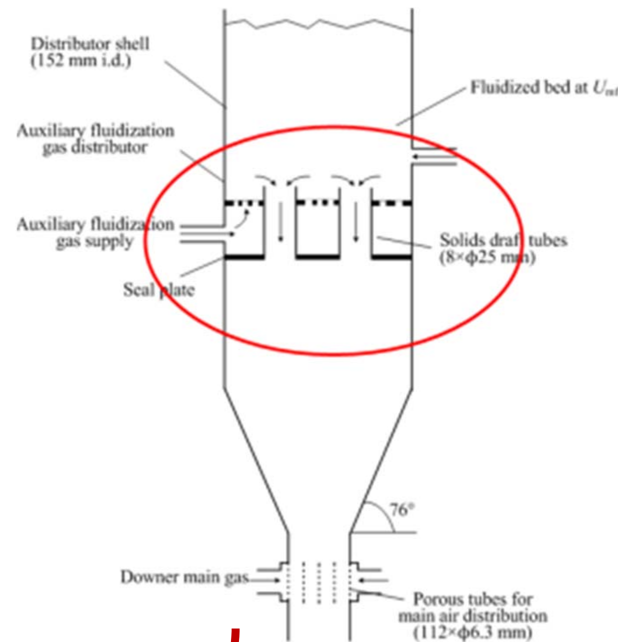
Wang et al, 2014a; CES

Hydrodynamics

——HDCFB downer

Conditions required for HDCFB operation

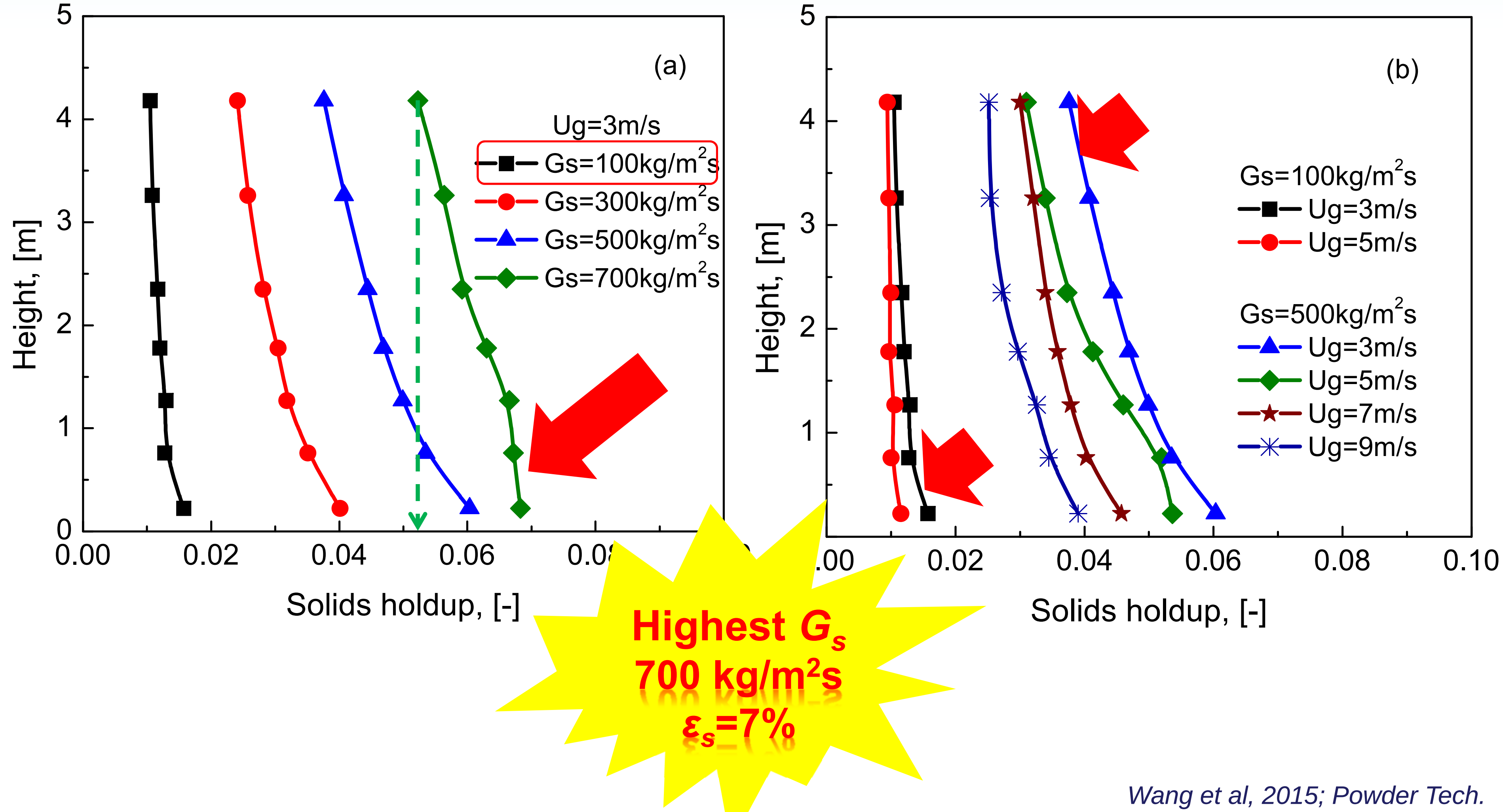




700kg/m^{2}s

Hydrodynamics

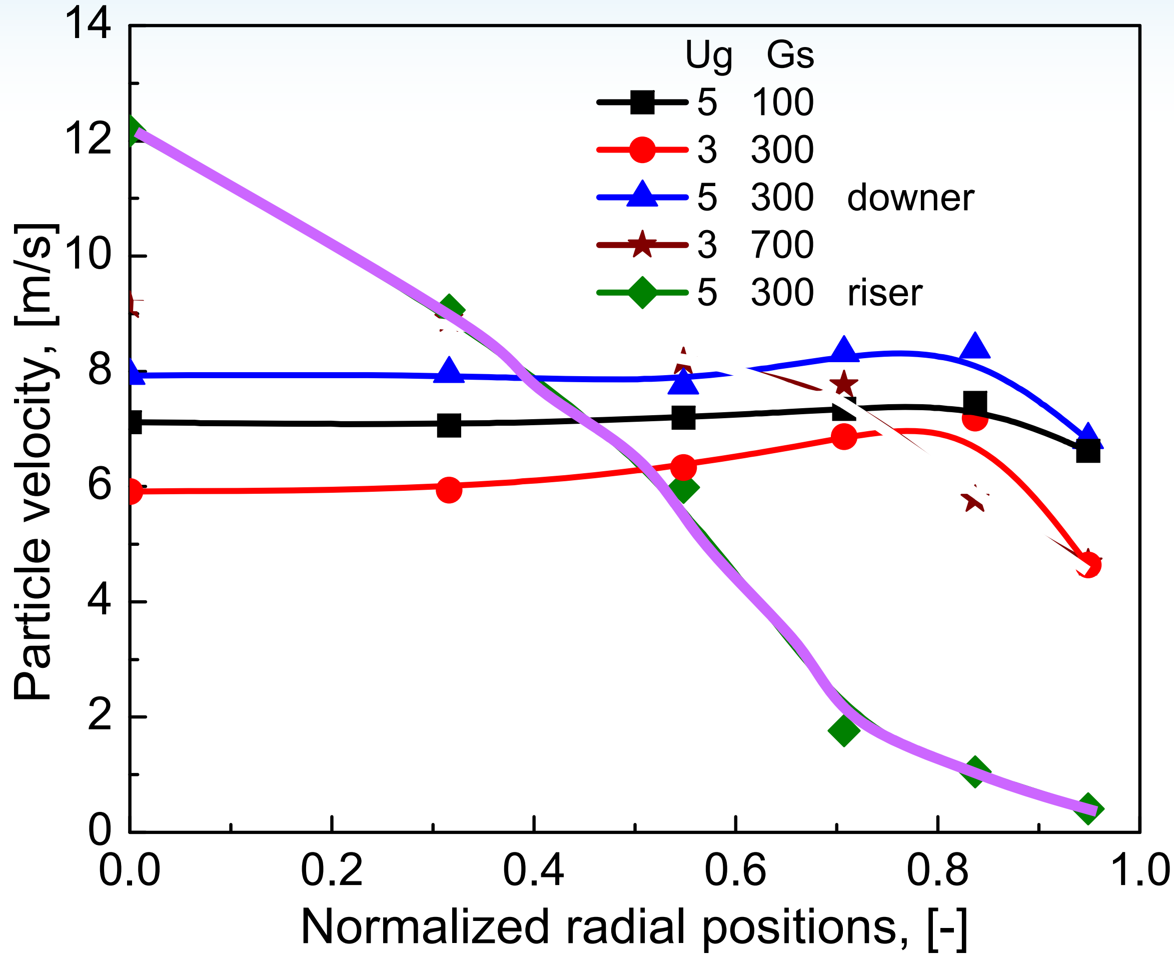
——HDCFB downer



Wang et al, 2015; Powder Tech.

Hydrodynamics

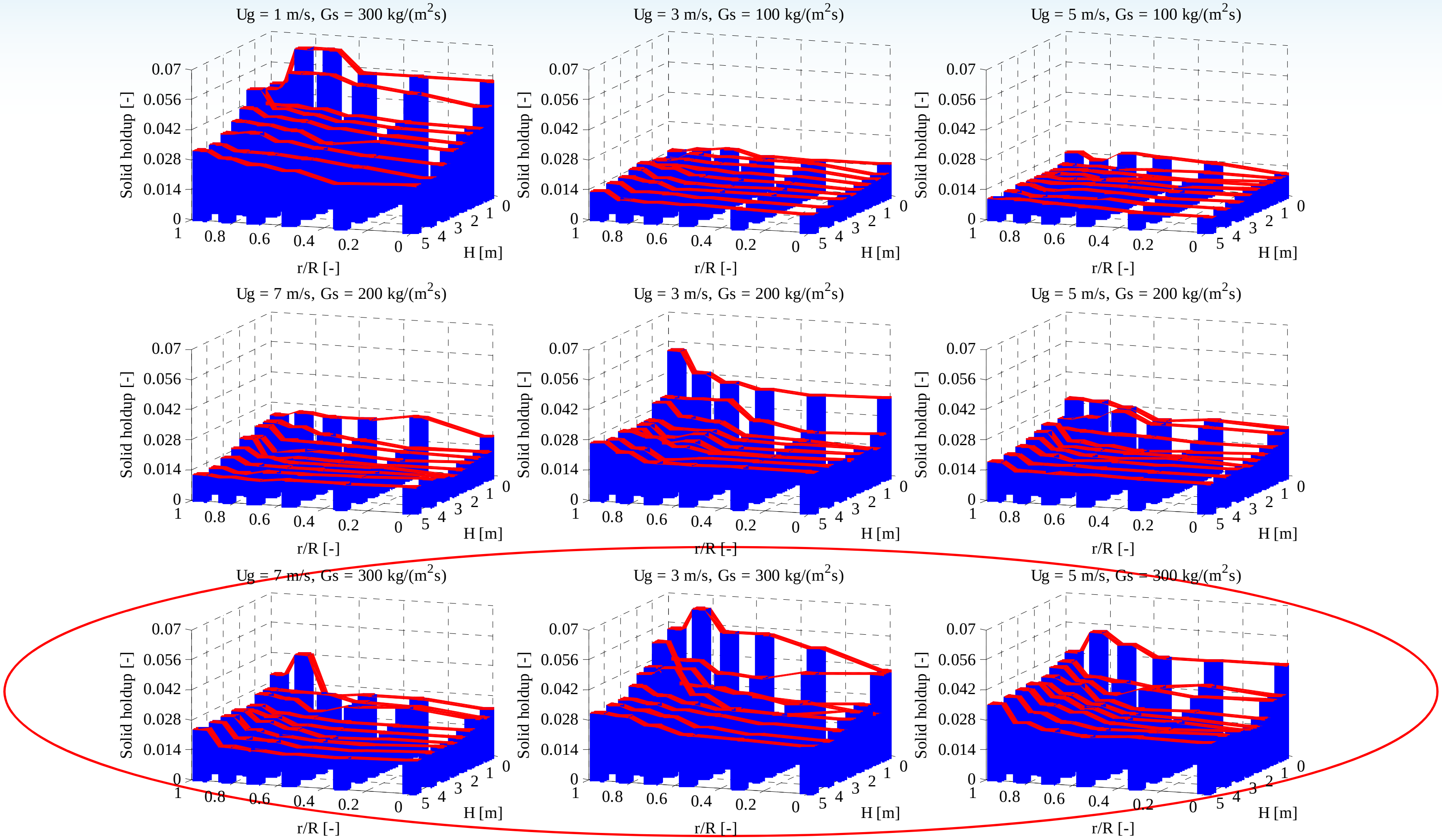
——HDCFB downer



Wang et al, 2015; AIChE

Hydrodynamics

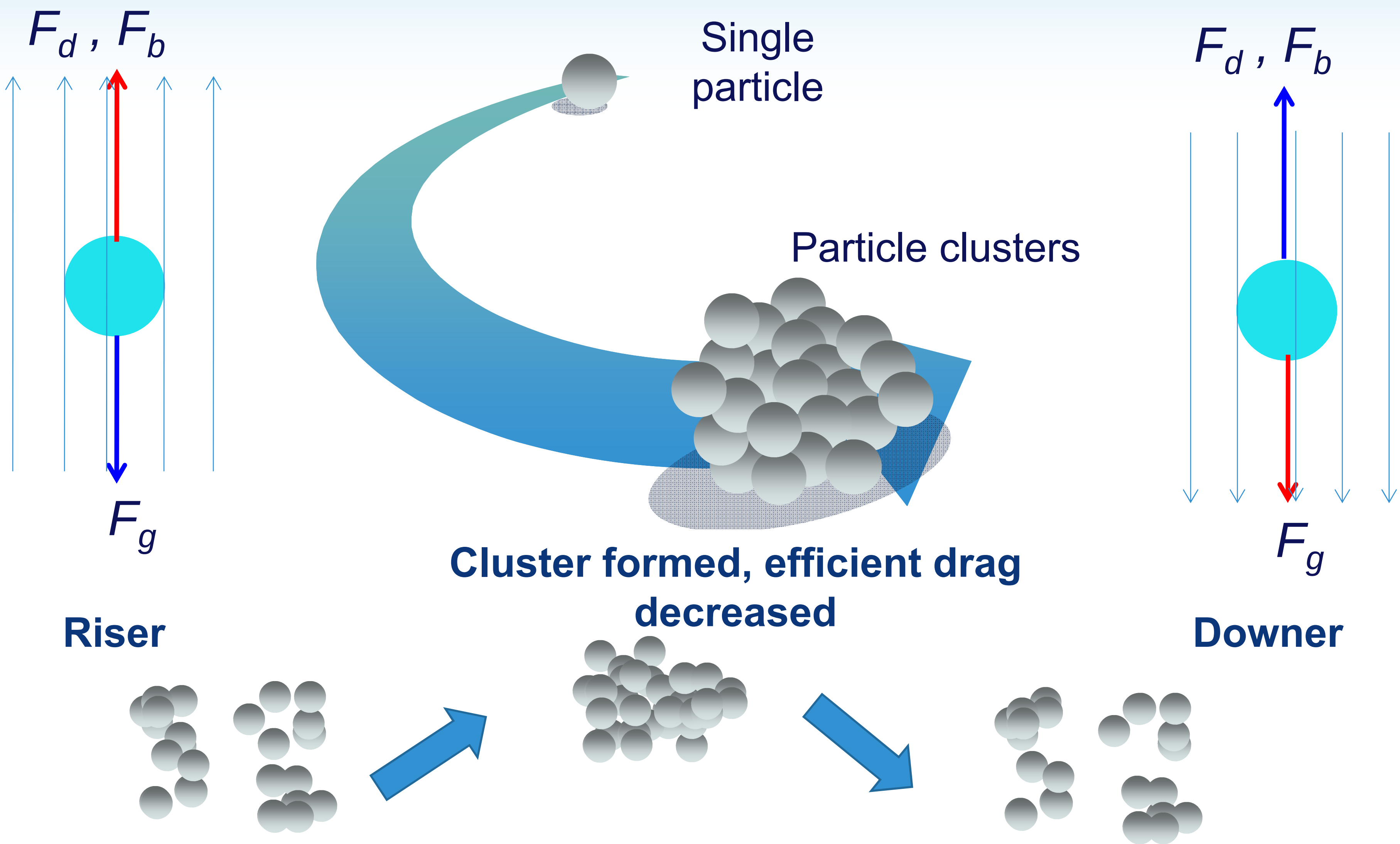
——HDCFB downer



Wang et al, 2015; CEJ

Hydrodynamics

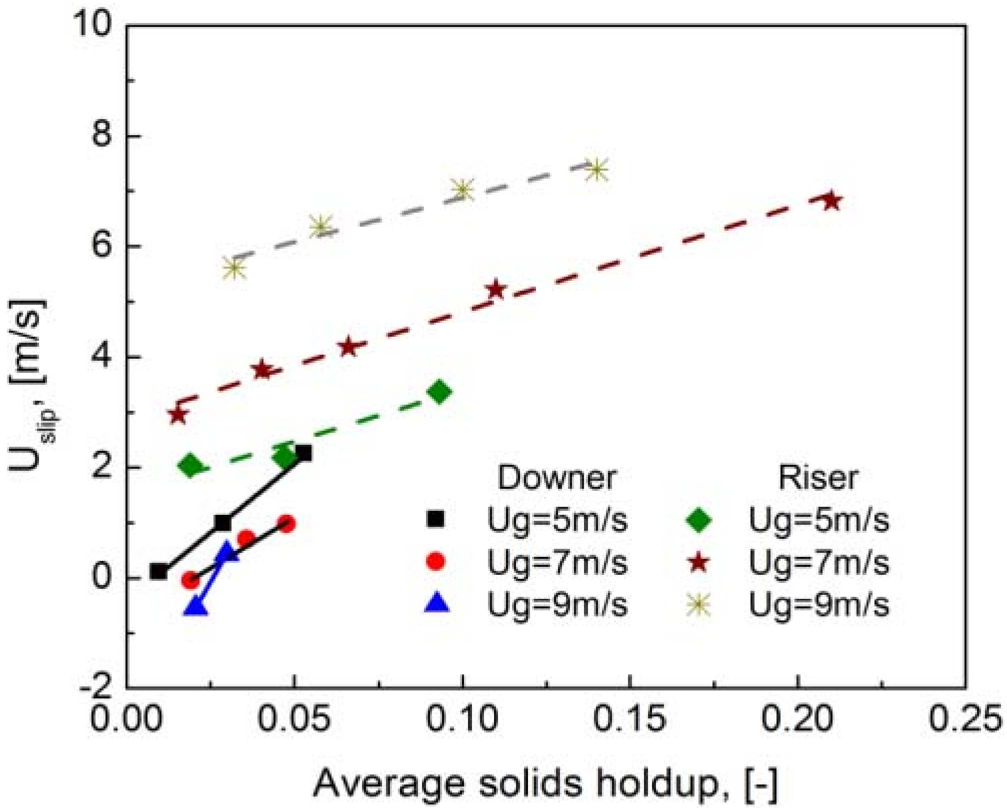
——HDCFB riser v.s. downer



Hydrodynamics

——HDCFB riser v.s. downer

Slip velocity——quantitative description of cluster



ε_s↑, Uslip↑, clusting↑

Riser :
Ug ↑, Uslip ↑
Uslip≈2-8 m/s
More cluster forming

Downer :
Ug↑, Uslip↓
Uslip≈-0.5-3 m/s
Less cluster forming

Riser : $U_{slip} = V_g - V_p = \frac{U_g}{1-\varepsilon_s} - \frac{G_s}{\rho_p \varepsilon_s}$

Downer : $U_{slip} = V_p - V_g = \frac{G_s}{\rho_p \varepsilon_s} - \frac{U_g}{1-\varepsilon_s}$

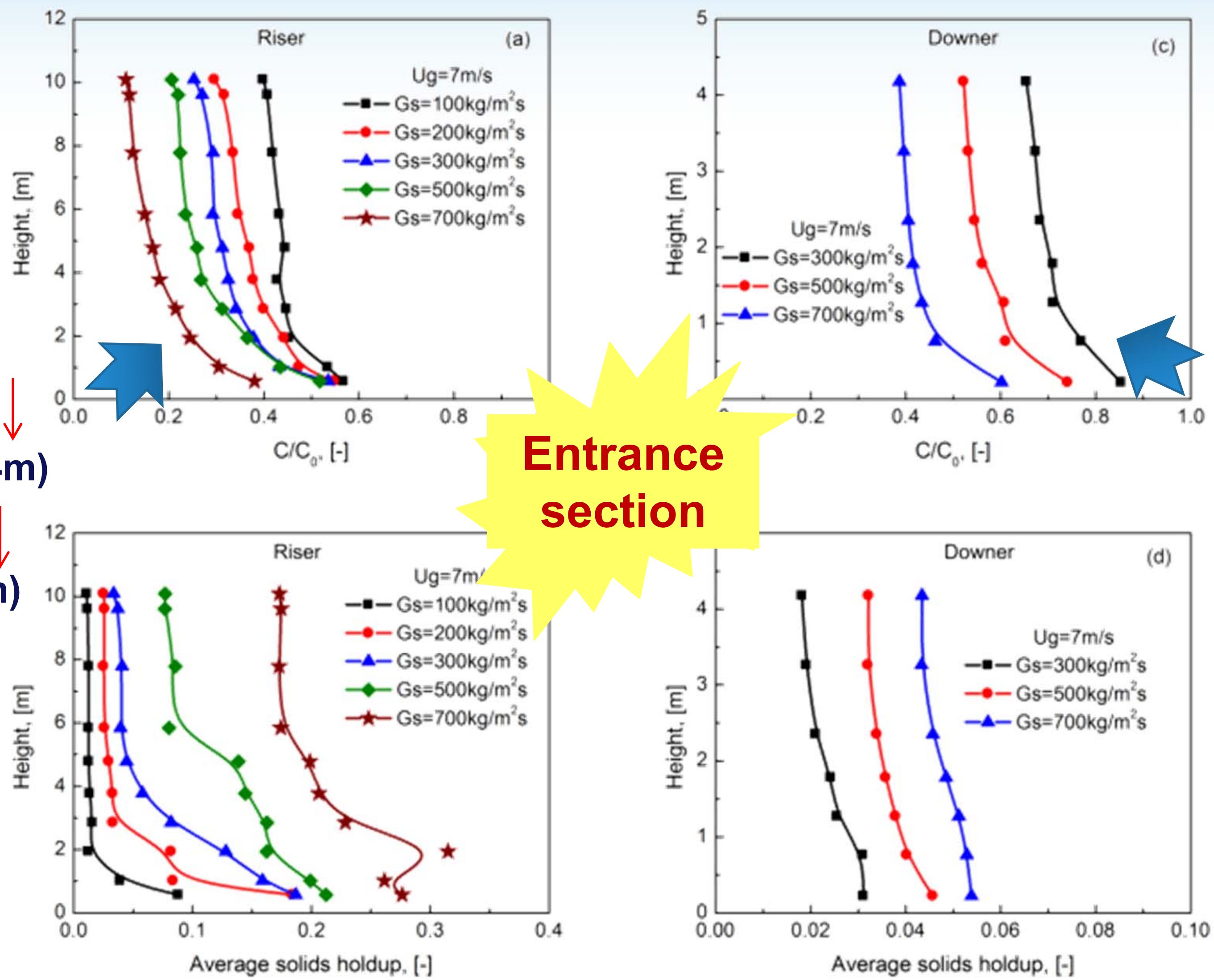
Wang et al, 2015; AIChE

Reactor Performance

——HDCFB riser v.s. downer

H ↑ C/C_0 ↓↓
(z ≤2~4m)

C/C_0 ↓
(z >4m)



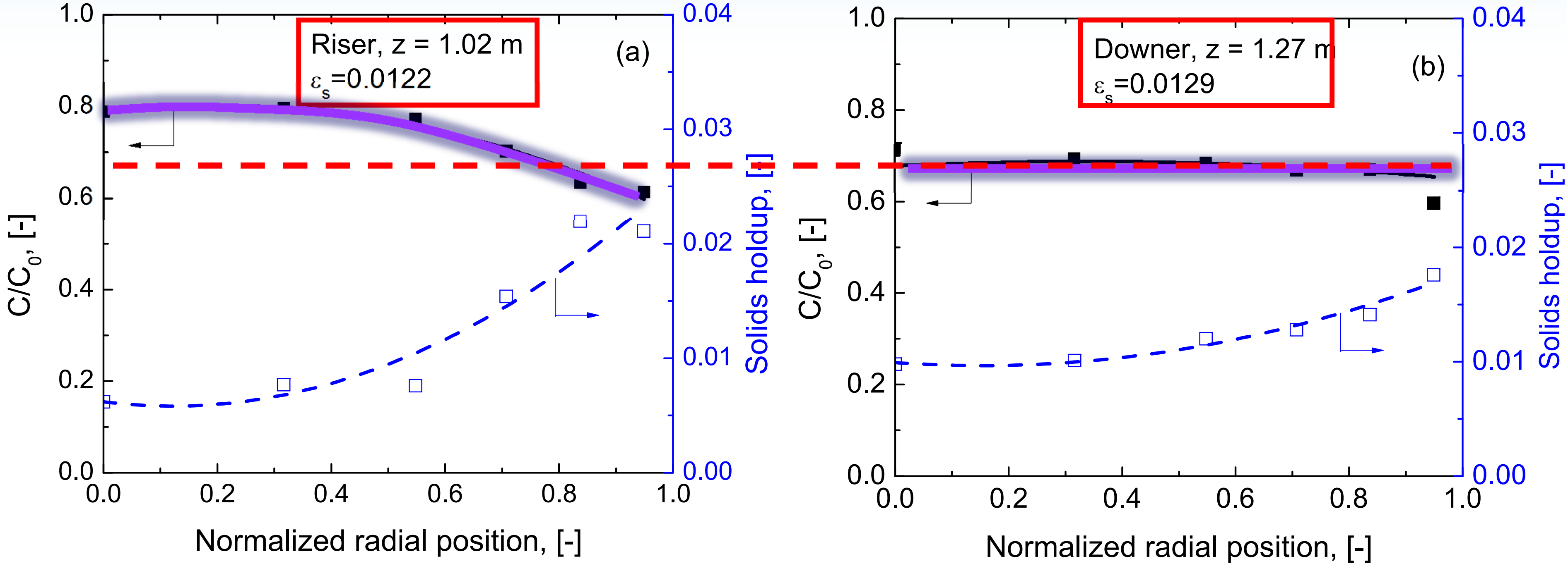
H ↑ C/C_0 ↓↓
(z ≤1~2m)

C/C_0 ↓
(z >2m)

Wang et al, 2015; CEJ.

Reactor Performance

——HDCFB riser v.s. downer

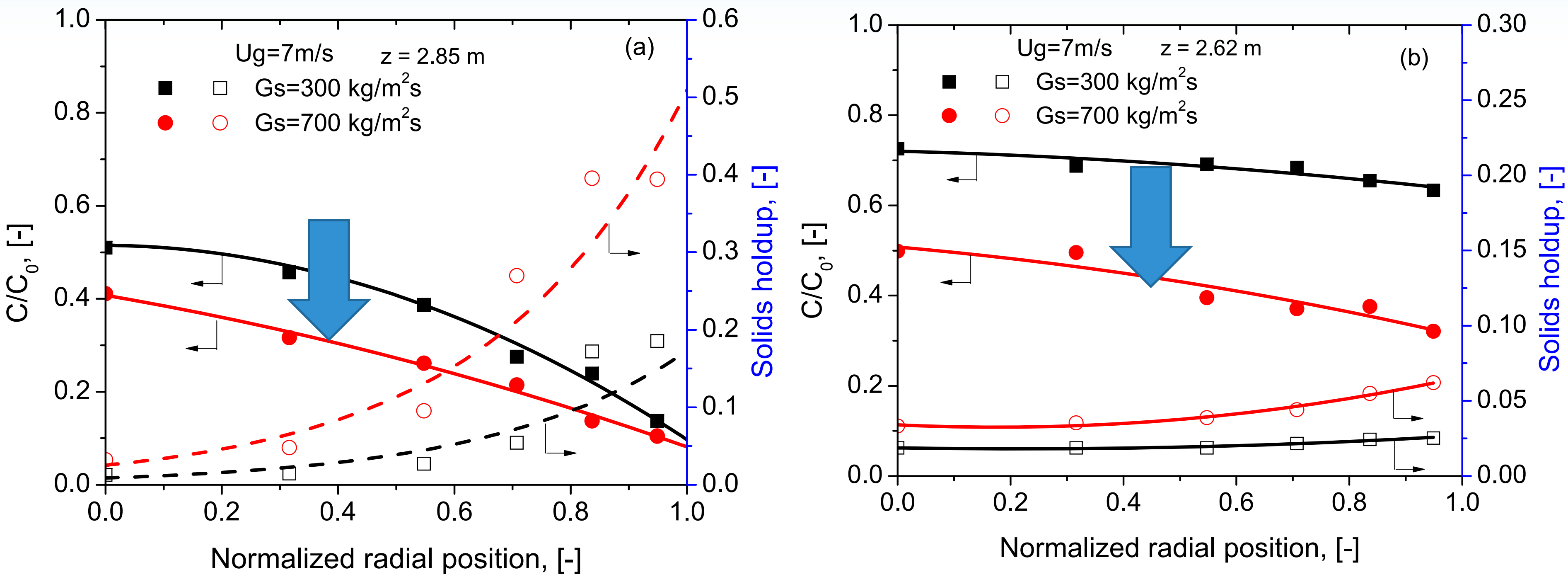


Good reactor performance

Wang et al, 2014; AIChE.

Reactor Performance

——HDCFB riser v.s. downer



$C/C_{0,max}$, r/R=0.0

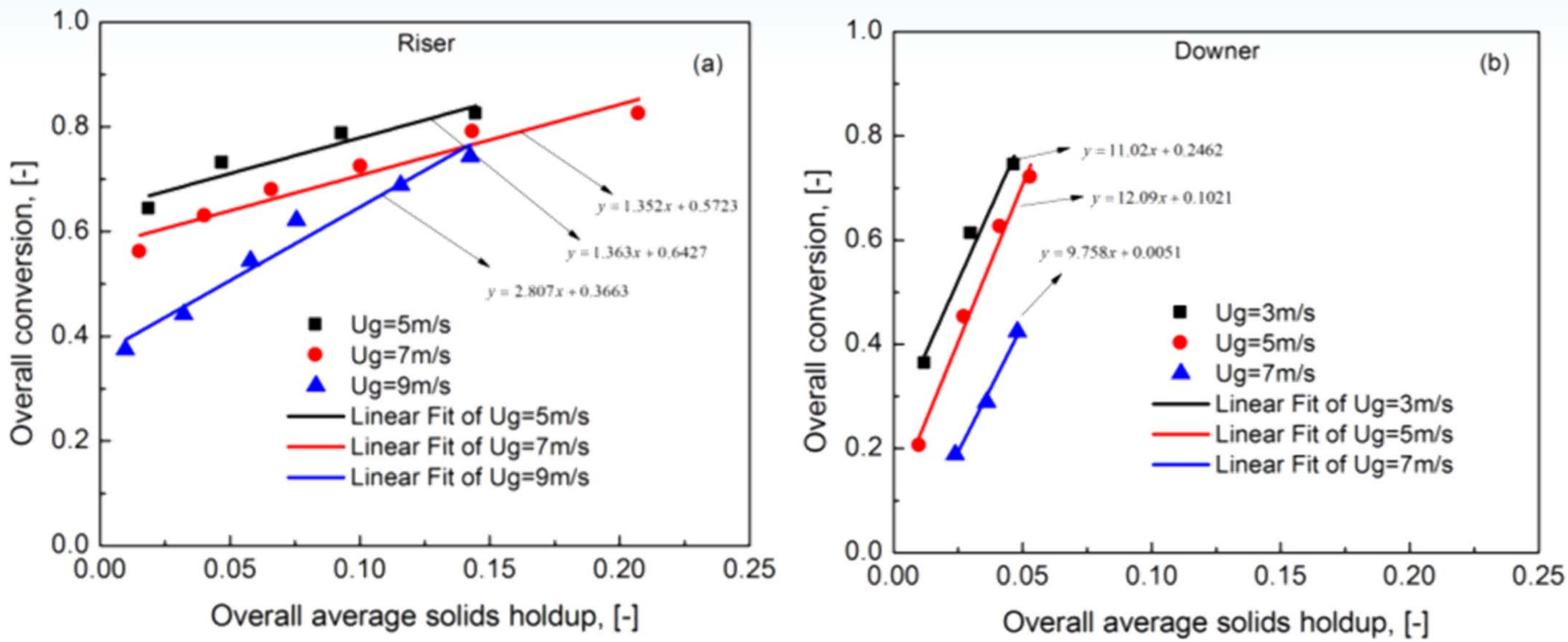
$C/C_{0,min}$, r/R=1.0

In downer: C/C_0 and ε_s profiles become flatter

Wang et al, 2015; CEJ.

Reactor Performance

——HDCFB riser v.s. downer



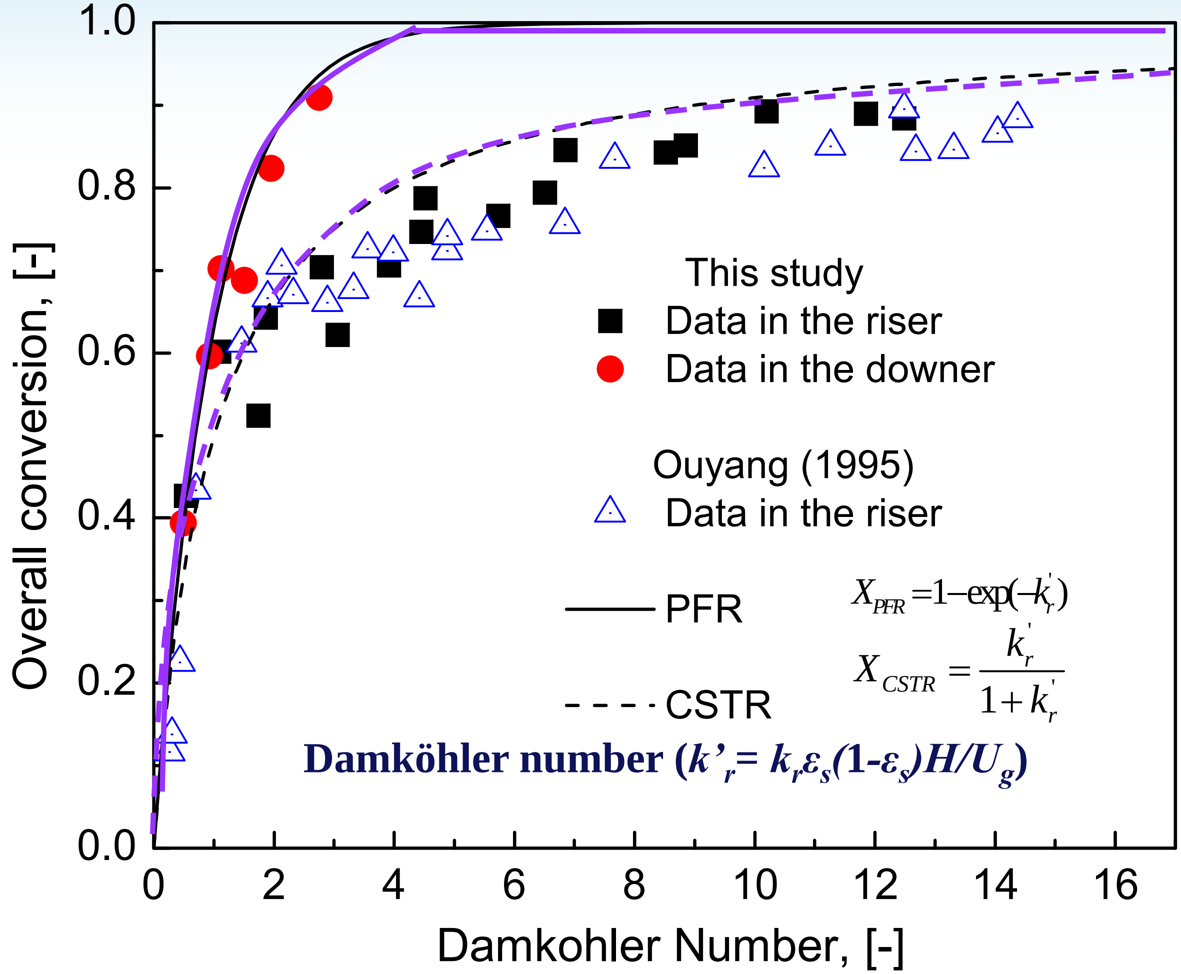
$\varepsilon_s \uparrow$ $C/C_0 \downarrow$ X $\uparrow$

$Ug \uparrow$ $C/C_0 \uparrow$ X $\downarrow$

Wang et al. 2014; I&EC Res.
Wang et al, 2015; CEJ.

Reactor Performance

——HDCFB riser v.s. downer



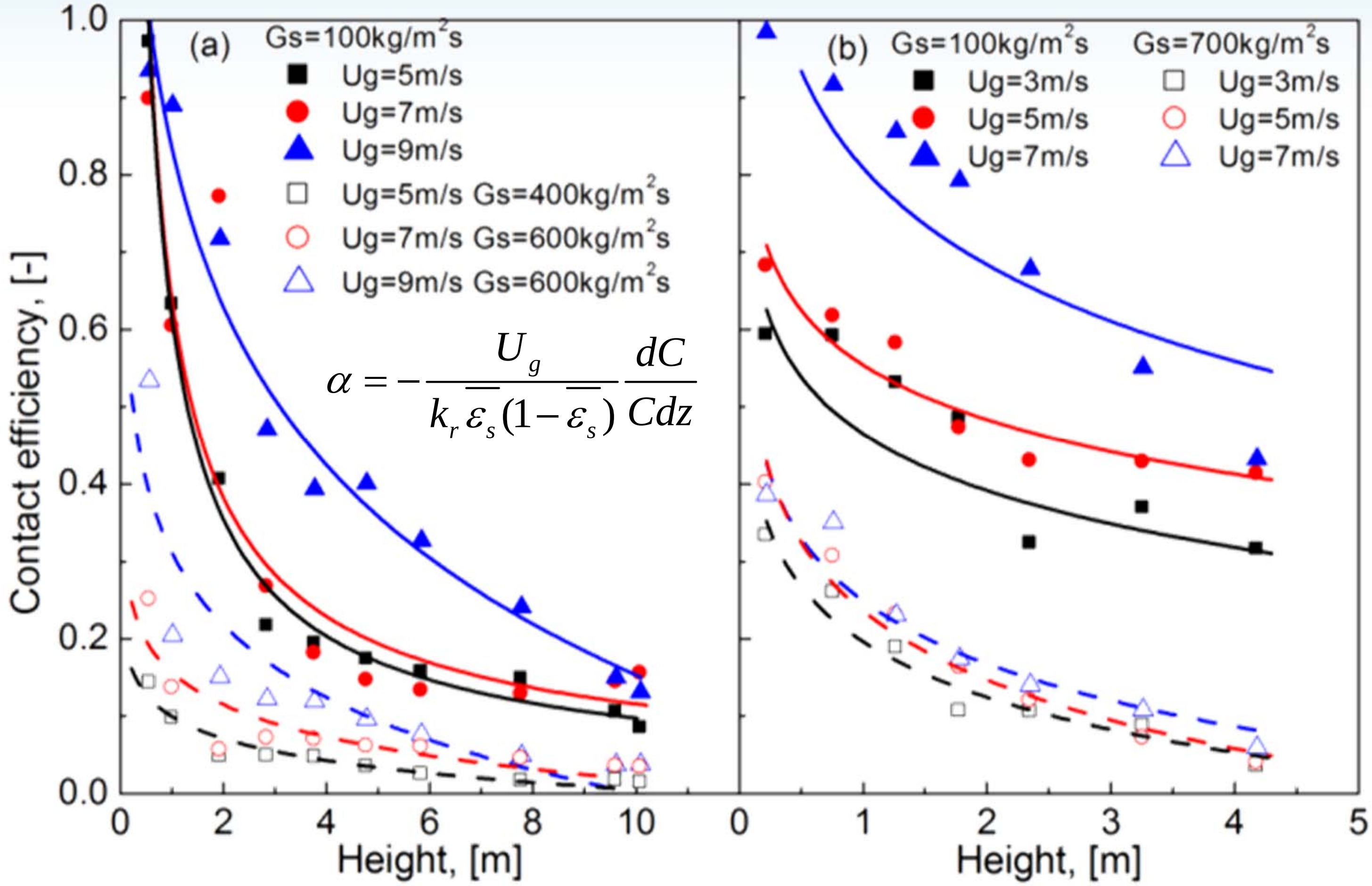
Downer: nearly plug flow reactor

Riser: far below CSTR

Wang et al, 2015; CEJ.

Reactor Performance

——HDCFB riser v.s. downer

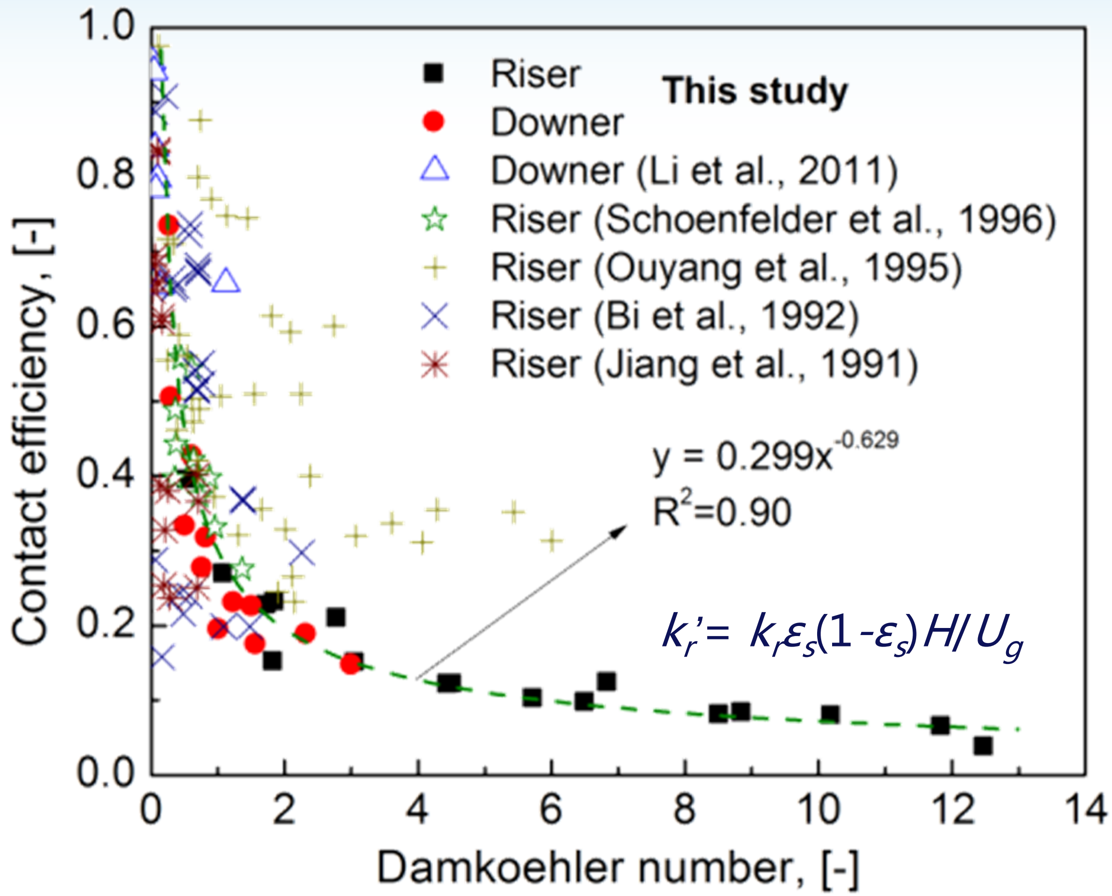


Contact efficiency in the downer is higher compared to the riser reactor at similar operating conditions.

Wang et al, 2015; CEJ.

Reactor Performance

——HDCFB riser v.s. downer



Contact efficiency obtained in this work is comparable to the results reported in the literature.

Wang et al, 2015; CEJ.

Conclusion

- A homogenous axial flow structure with εs up to 25-30% is observed in HDCFB riser.
- No net downward flow near the wall leads to a reduction of solids back-mixing.
- Solids holdup in the downer can be achieved higher than 0.06 with relatively uniform flow structure at G_s = 700 kg/m^{2}s.

Conclusion

- The slip velocity in the downer is much smaller than that in the riser for the same solids holdup indicating less particle aggregation and better gas-solids.

- Correlation between O_3 and hydrodynamics is observed in HDCFB both riser and downer reactors.

- Reactor performance is better in the downer than in the riser because of its nearly plug flow structure.

Large CFB Apparatus we have

- A riser (15m) and downer (10m) unit, both 4”, (U_g ~ 15m/s, G_s -200 kg/m^2s)
- A 10 m twin riser (3” and 8”), (U_g ~ 12m/s, G_s ~ 500 kg/m^2s)
- A 10 m ozone reactor unit - 3” riser, 2” + 3” downers, (U_g ~ 12m/s, G_s ~ 1000 kg/m^2s)
- A 2-D narrow-rectangular riser, 7 m tall, 6” wide (U_g ~ 12m/s, G_s ~ 500 kg/m^2s)

We have lots of data and are willing to share, and to collaborate with modellers