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Cold flow investigations of a Circulating Fluidized Bed Chemical Looping Combustion system as a basis for up-scaling to an industrial application

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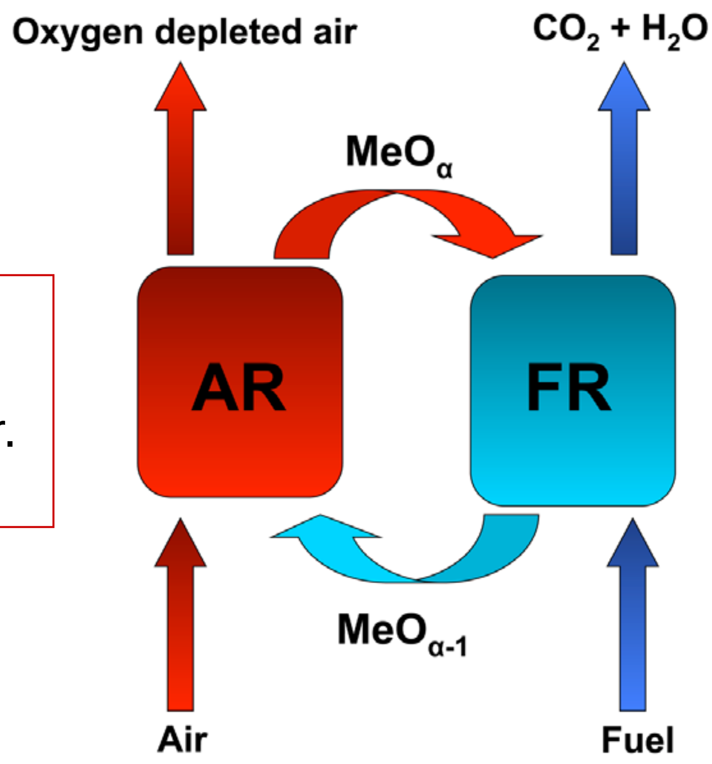
Contents

Chemical Looping principle

Air Reactor (AR)
Oxidation of the metallic oxygen carrier. Exothermic.



Fuel Reactor (FR)
Reduction of the metallic oxygen carrier. Endothermic or slightly exothermic.

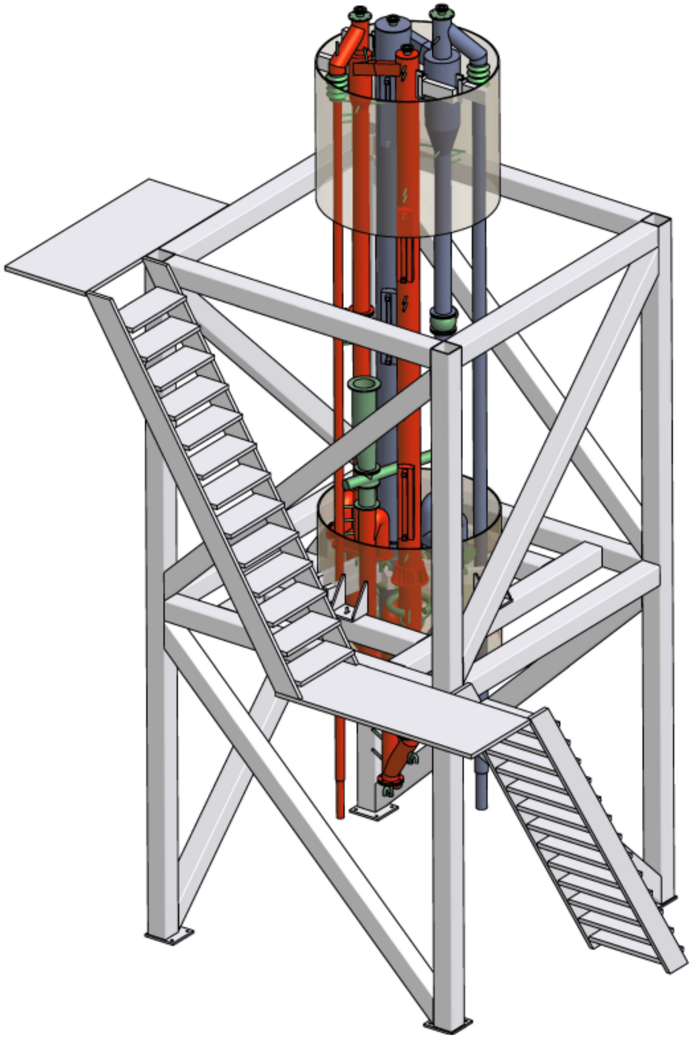
Chemical Looping Combustion (CLC):
A divided combustion process with intrinsic CO_2 separation. An oxy-fuel process without the need of an oxygen plant (potential lower costs and higher net power efficiency)

The BIGCLC project

A subproject within the larger BIGCO2/BIGCCS project framework

Reactor system:
1. **Cold Flow Model (CFM)** construction, commissioning and testing for validation of the 150kW$_{th}$ atmospheric rig design
2. **150kW$_{th}$ atmospheric rig** construction, commissioning and test campaigns
3. Pressurized conditions

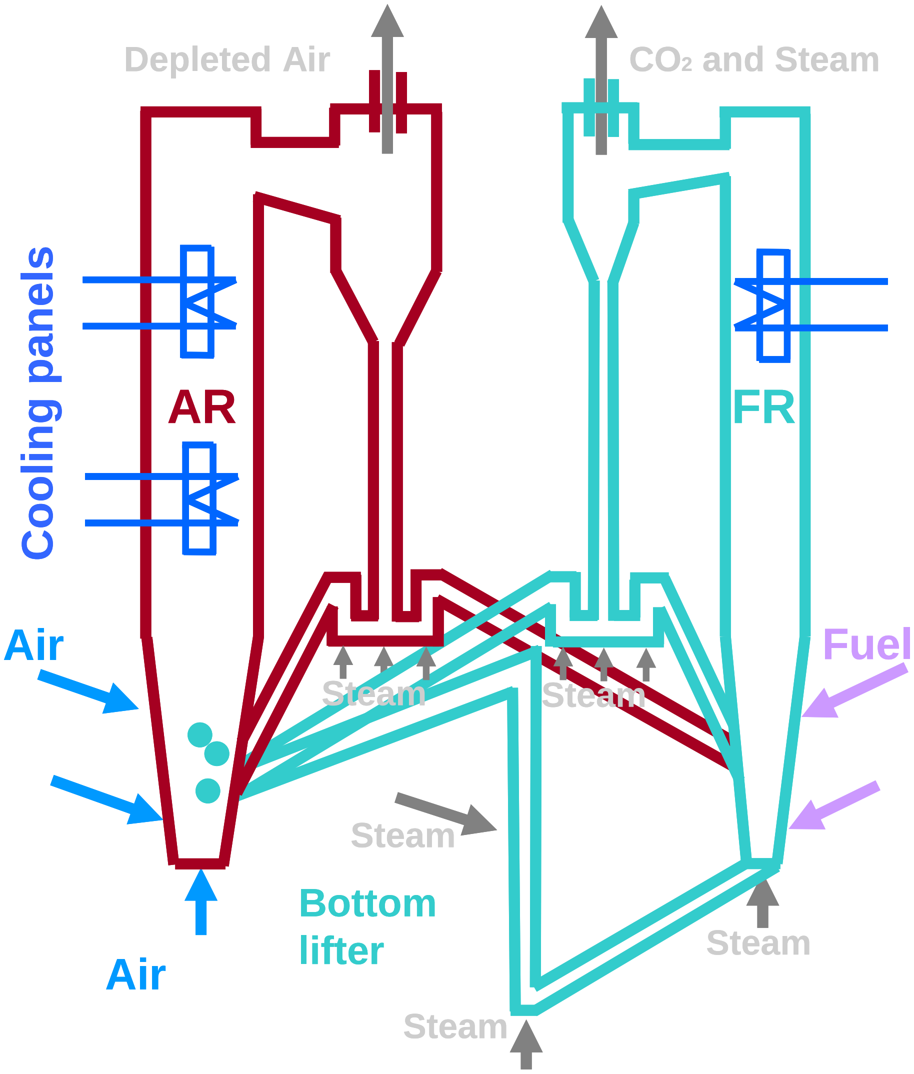
Bischi et al.,
"Design study of a 150kW$_{th}$ Double Loop Circulating Fluidized Bed reactor system for Chemical Looping Combustion with focus on industrial applicability and pressurization"
International Journal of Greenhouse Gas Control.



Oxygen carrier materials:
1. Screening and preliminary investigation
2. Selection and TGA testing (Mn-ore + Ca & Ti)
3. Fabrication by industrial methods
4. Testing in a small continuous FB process

Fossdal et al.,
"Study of inexpensive oxygen carriers for chemical looping combustion"
International Journal of Greenhouse Gas Control.

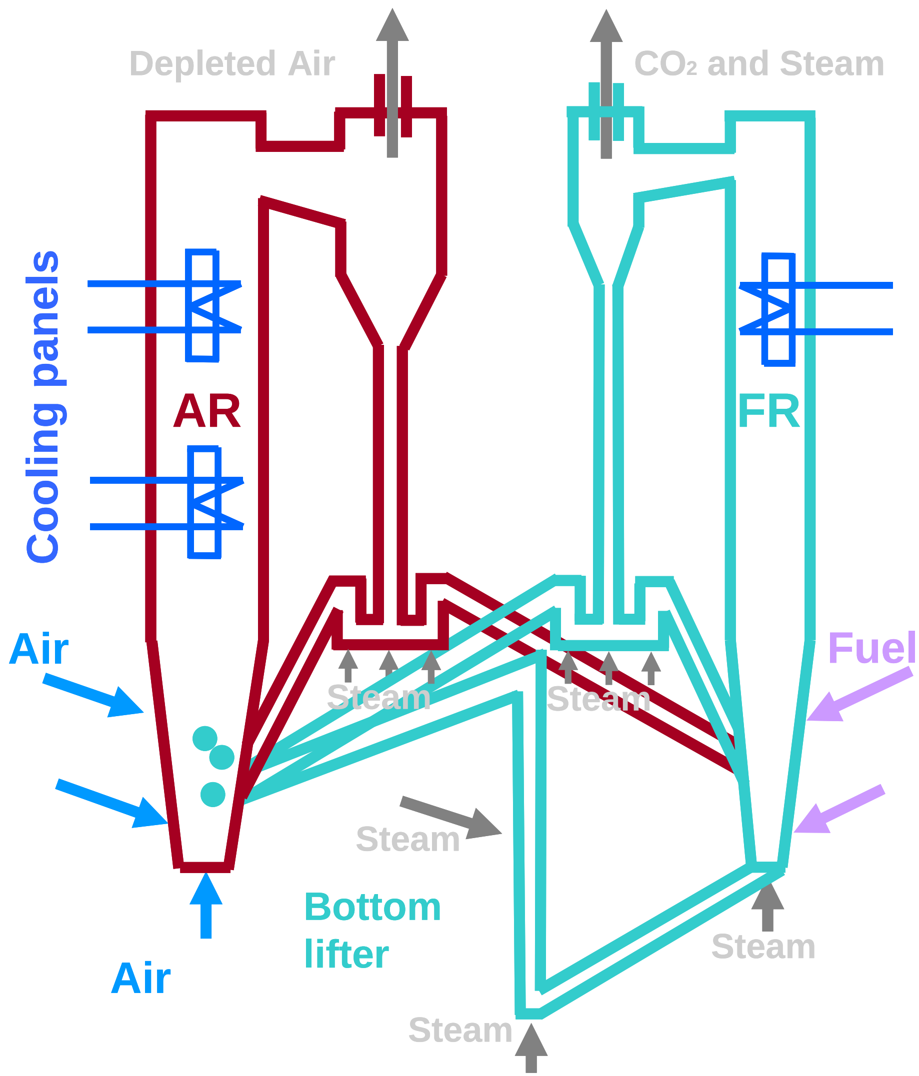
Double Loop Circulating Fluidized Bed (DLCFB)



Design criteria

- High gas–solids contact
- High solids exchange
- Flexibility of configuration
- Compactness
- Choose industrial solutions wherever possible
- Continuous operation

Double Loop Circulating Fluidized Bed (DLCFB)



Design parameters

Design parameter		AR 150kW$_{th}$	FR 150kW$_{th}$
u_o	[m/s]	~4	~4
D	[m]	0.25	0.15
L	[m]	5	5
ρ_p	[kg/m³]	2000	2000
ρ_f	[kg/m³]	0.268	0.249
d_{50}	[μm]	100	100
μ	[Ns/m²]	4.84E-05	4.29E-05
T	[°C]	1000	1000
P	[Pa]	100000	100000

- Geldart Group A particles
- Fast fluidization flow regime (CFB regime)

Scaling criteria for fluidized bed hydrodynamics

Glicksman scaling laws

- Simulating the hydrodynamics of a high temperature FB reactor with a smaller cold flow model
- Based on non-dimensional particles and fluid equations of motion
- A set of scaling parameters to be matched between actual reactor and model

→ May impose different Geldart Group of particles and different flow regime

Scaling criteria for fluidized bed hydrodynamics

Knowlton scale-up

1. Select operating regime
2. Construct a pilot plant (typical diameter 150 – 300 mm for group A particles)
   - Continuous operation for significant time
   - Industrial concerns can be addressed
   - Reduced wall effects
3. Construct a large cold-flow model (generally larger than the pilot)
4. Construct a demonstration plant
5. Construct a commercial plant

→ Flow regime and particle Geldart Group should be kept the same

Cold Flow Model (CFM) scaling strategy

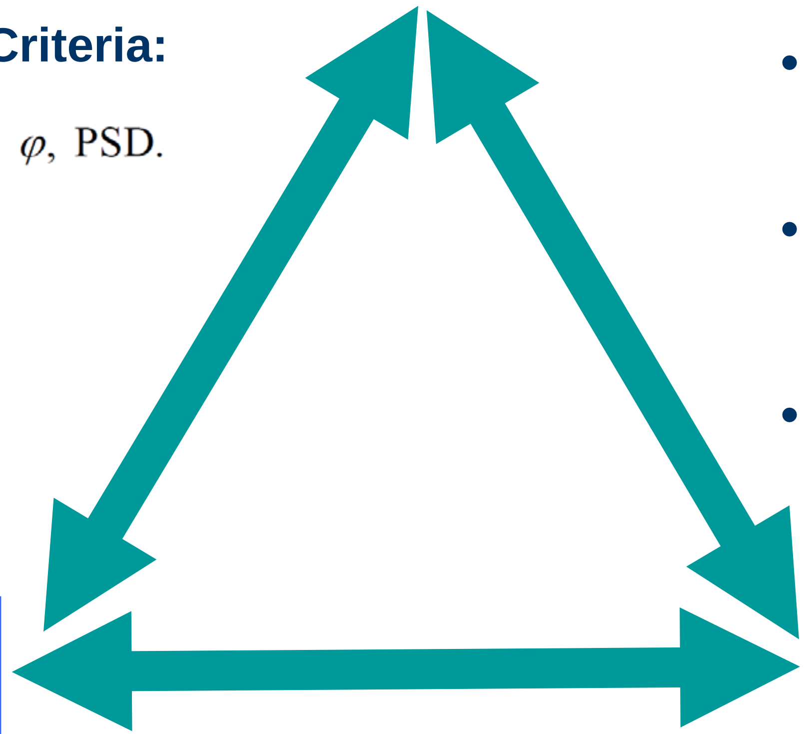
Industrial Demo ~30MW

- **Simplified Glicksman Criteria:**

$$\frac{u_0^2}{g \cdot D},\ \frac{\rho_p}{\rho_g},\ \frac{L}{D},\ \frac{u_0}{u_{mf}},\ \frac{G_s}{\rho_p u_0},\ \varphi,\ \text{PSD.}$$

- **Geldart A particles**
- **Fluidization regime:**
  Ar & Re_p

- **Process parameters:**
  T, P, gas composition
- **Same Particles:**
  Density, PSD, φ
- **Fluidization regime:**
  Ar & Re_p



Cold Flow Model

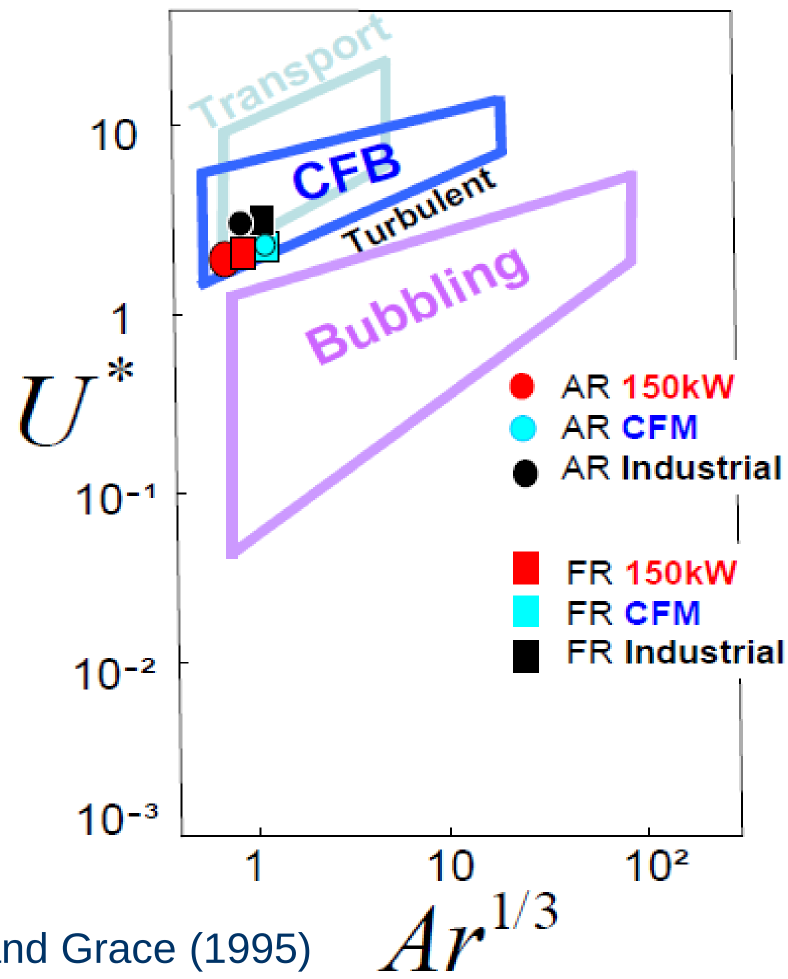
Hot Rig 150 kW

- **Geometrical identity**
- **Geldart A particles**
- **Fluidization regime:**
  Ar & Re_p

Cold Flow Model (CFM) scaling strategy

Industrial Demo ~30MW

Cold Flow Model



Hot Rig 150 kW

Lim, Zhu and Grace (1995)

Experimental set-up

Cold Flow Model, full scale:

Air Reactor (AR):

- **5m** h, **0.23m** id
- Nominal air flow: **~5500Nl/min** (2.4m/s at 20ºC)

Fuel Reactor (FR):

- **5m** h, **0.14m** id
- Nominal air flow: **~2400Nl/min** (2.6m/s at 20ºC)

Air Reactor Loop-seal:

- Nominal air flow: **~165Nl/min**

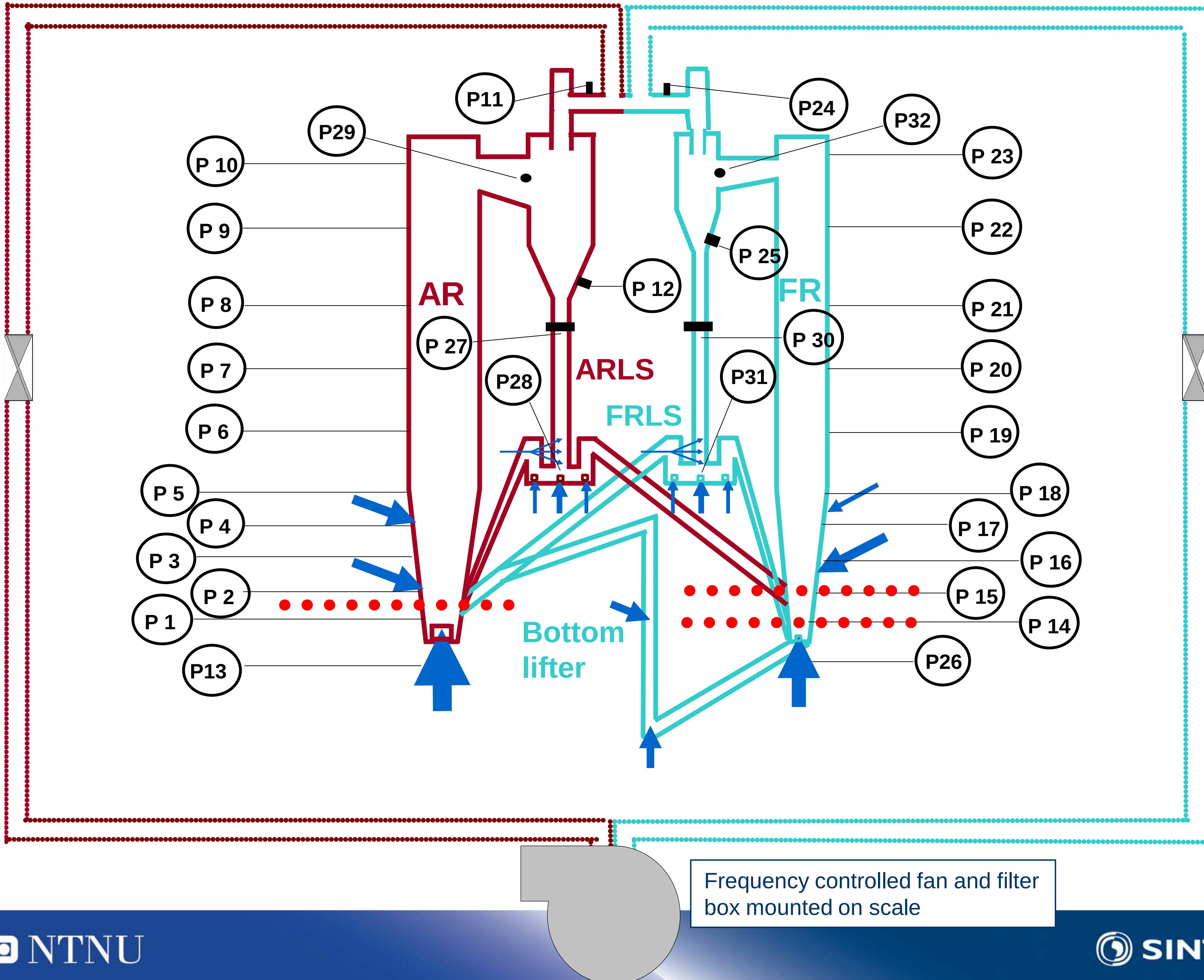
Fuel Reactor Loop-seal:

- Nominal air flow: **~95Nl/min**

Fe-Si Powder:

Geldart group A

- Starting d_{50}: **34micrometers**
- Density: **7000kg/m^3**
- Total Solids Inventory (TSI): **~ 120kg**



P11
P24
P29
P32
P 10
P 23
P 9
P 22
P 25
P 12
AR
FR
P 8
P 21
P 27
P 30
P 7
P 20
ARLS
P28
P31
FRLS
P 6
P 19
P 5
P 18
P 4
P 17
P 3
P 16
P 2
P 15
P 1
P 14
Bottom
lifter
P13
P26
Frequency controlled fan and filter
box mounted on scale

Experimental campaign overview

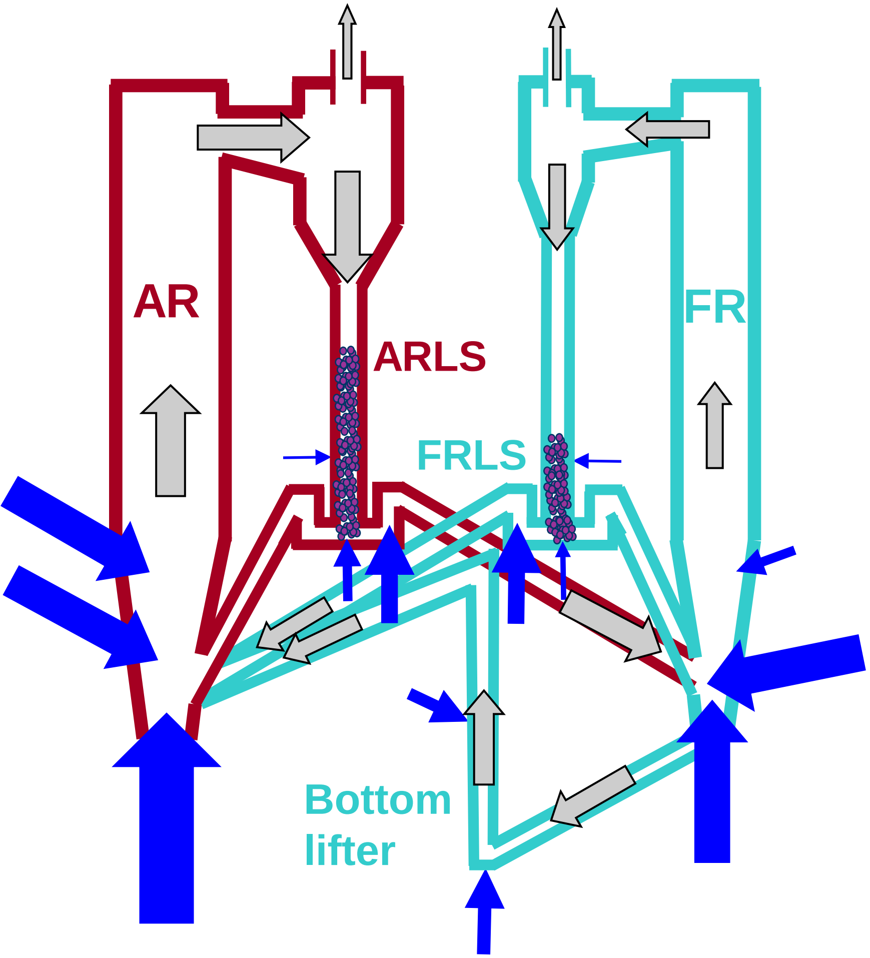
Design condition performance

- Operational performance and stability
- Validate design solutions

"Off-design" tests

- FR increased flux/concentration
- Part-load (50%)
- Simulate reforming conditions

Design conditions



AR: 5500 Nl/min (**2.4**m/s)

Primary	Secondary 1	Secondary 2
55%	**22.5%**	**22.5%**

FR: 2400 Nl/min (**2.6**m/s)

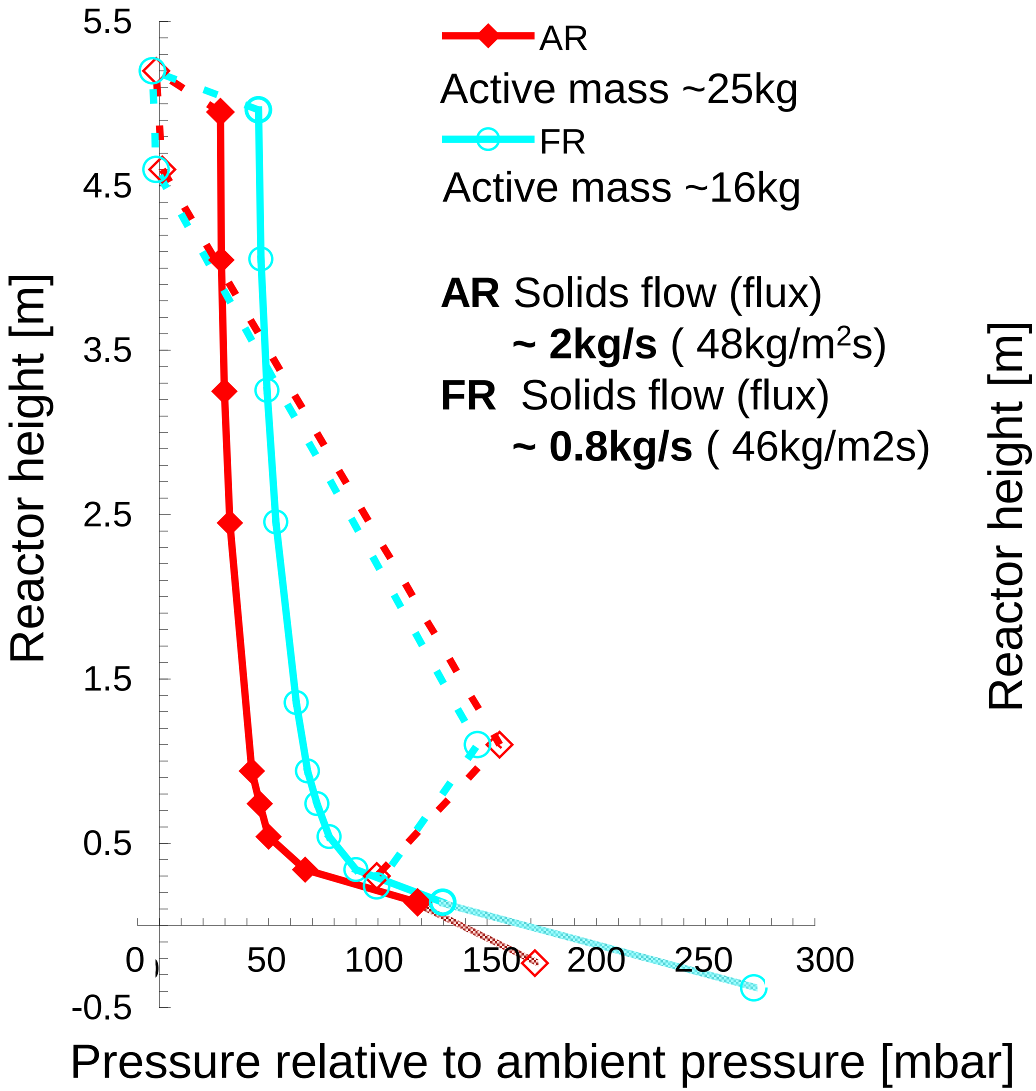
Primary	Secondary 1	Secondary 2
50%	**42%**	**8%**

Lift: 700 Nl/min (**1.5**m/s)

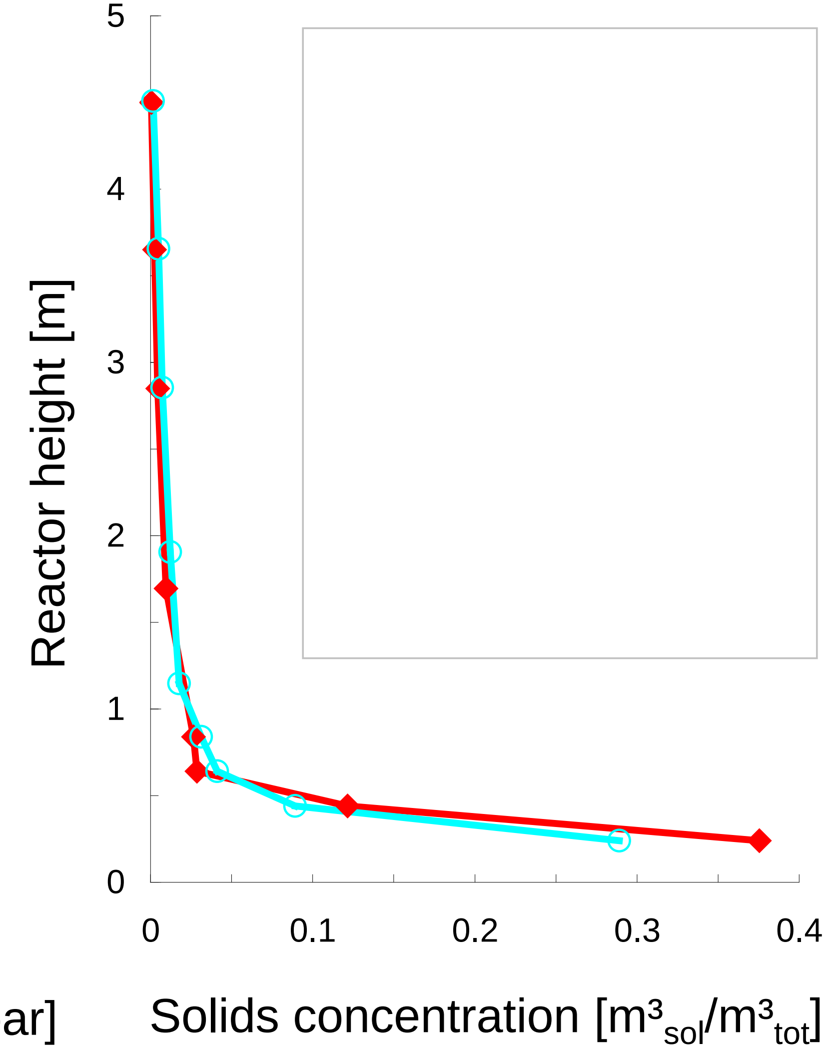
Primary	Secondary
~70%	**~30%**

Design conditions

Pressure loop

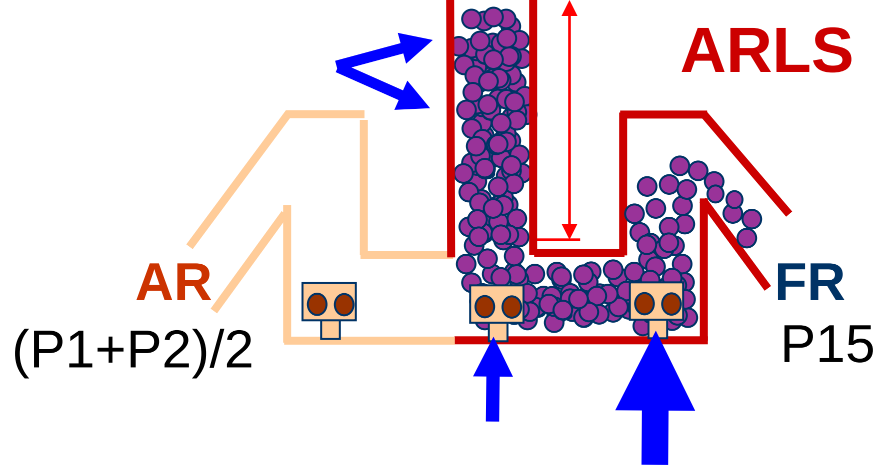


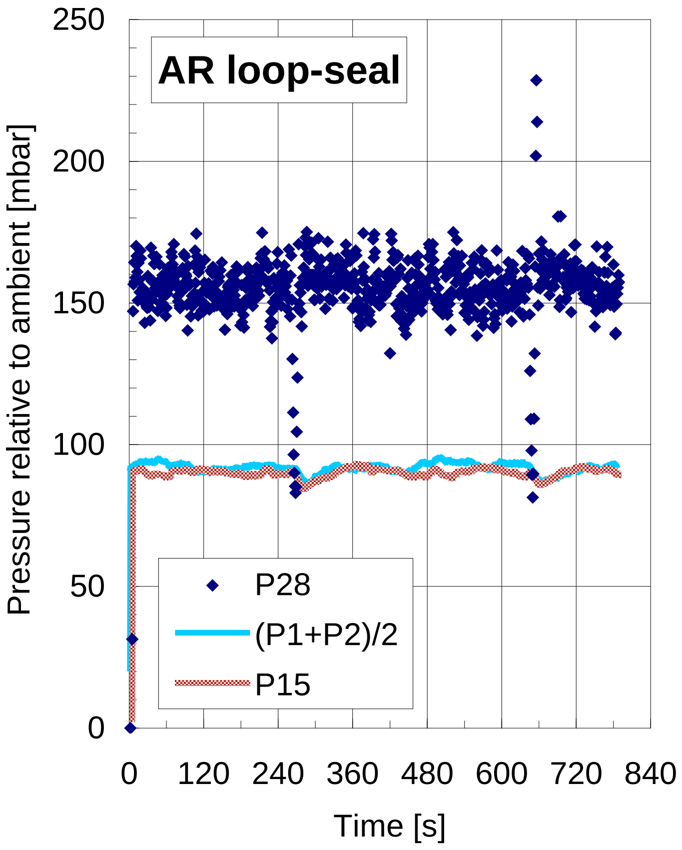
Solids concentration

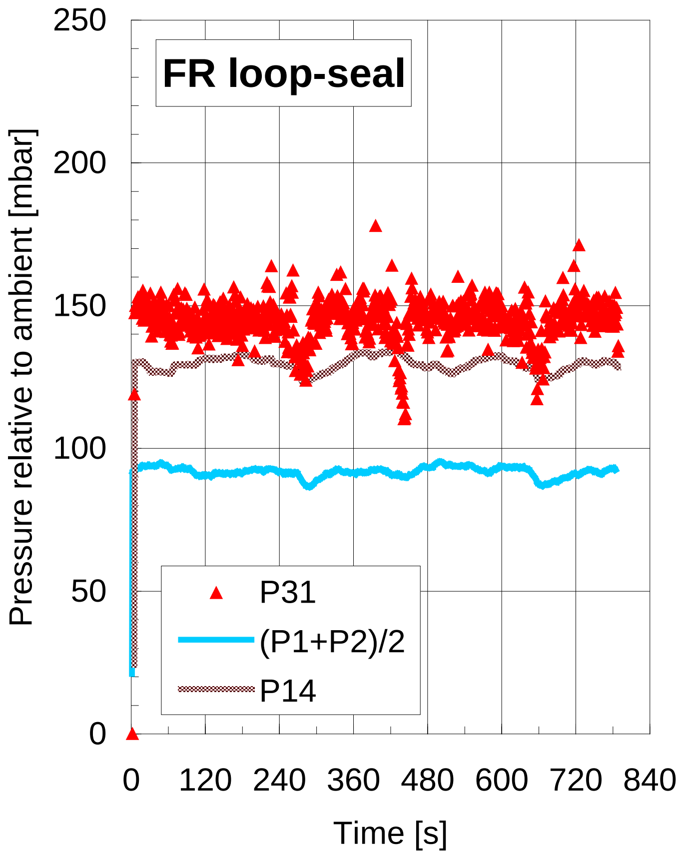


Design conditions

Pressure balance
between loop-seals & return points

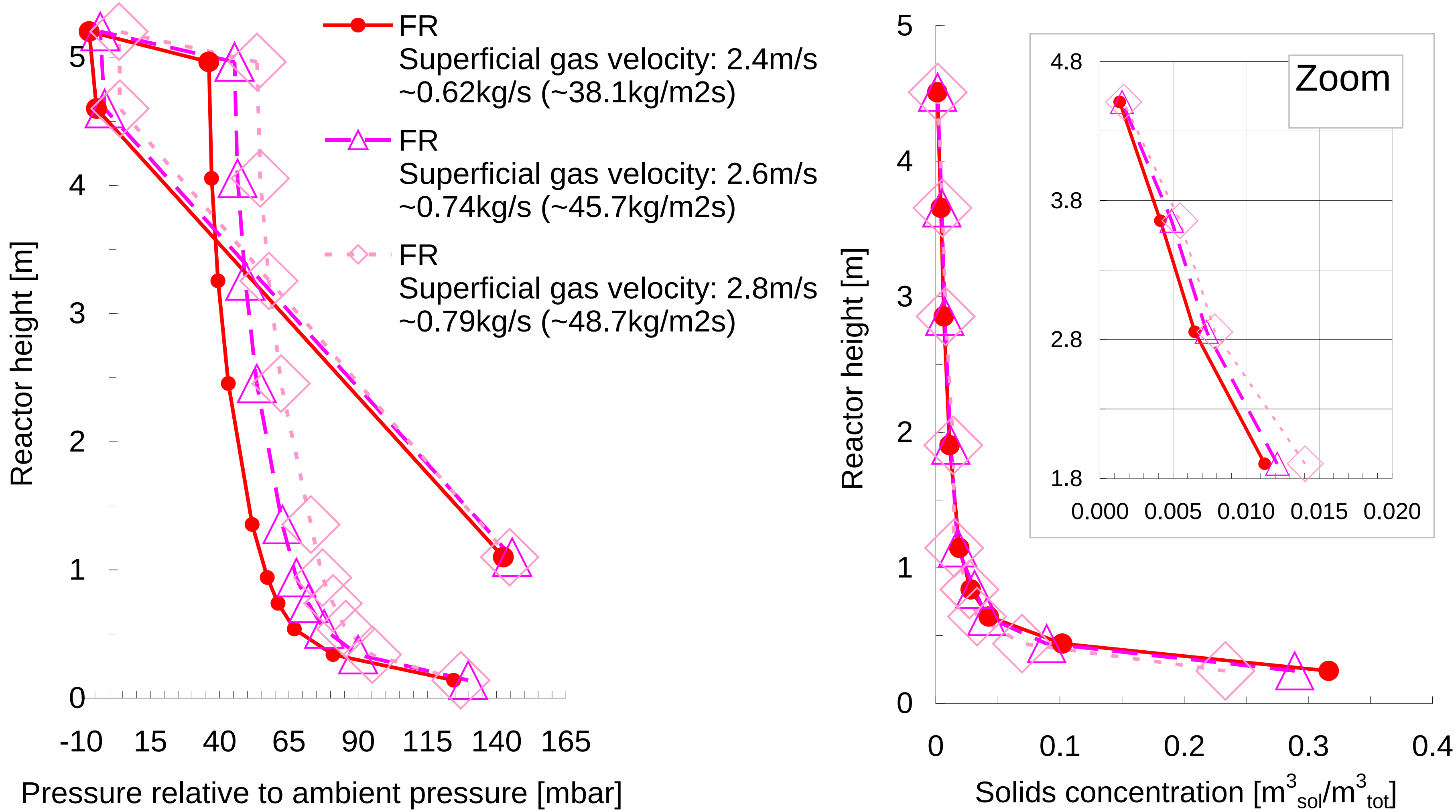






Design conditions

Fuel Reactor (FR) sensitivity



Conclusions & Outlook

1. **Achievement of stable operation at design conditions of the DLCFB cold flow model:**
   - Solids flow above **2 kg/s** → Solids flux (AR) 48 kg/m^2s

2. **Stable operation achieved at some defined off-design conditions:**
   - Increased FR solids concentration/entrainment
   - Part load conditions
   - Simulated reforming conditions

3. **Integrate lessons learnt in the final design of the 150kW_{th} hot rig**
   - Return leg height
   - Increase in FR solids concentration/entrainment

4. **Scaling strategy incorporating elements from both Glicksman and Knowlton;** the 150 kW_{th} hot rig (i.e. the next step of the BIGCLC project) and the existing large CFM will together give valuable guidelines and process and design validation for further up-scaling

Thank you

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