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Design and performance of a full scale Cold Flow Model of an innovative Chemical Looping Combustion reactor system

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Chemical Looping Combustion R&D @ SINTEF/NTNU

- Full scale Cold Flow Model (CFM)
- 150kW$_{th}$ Atmospheric rig
- Pressurized rig

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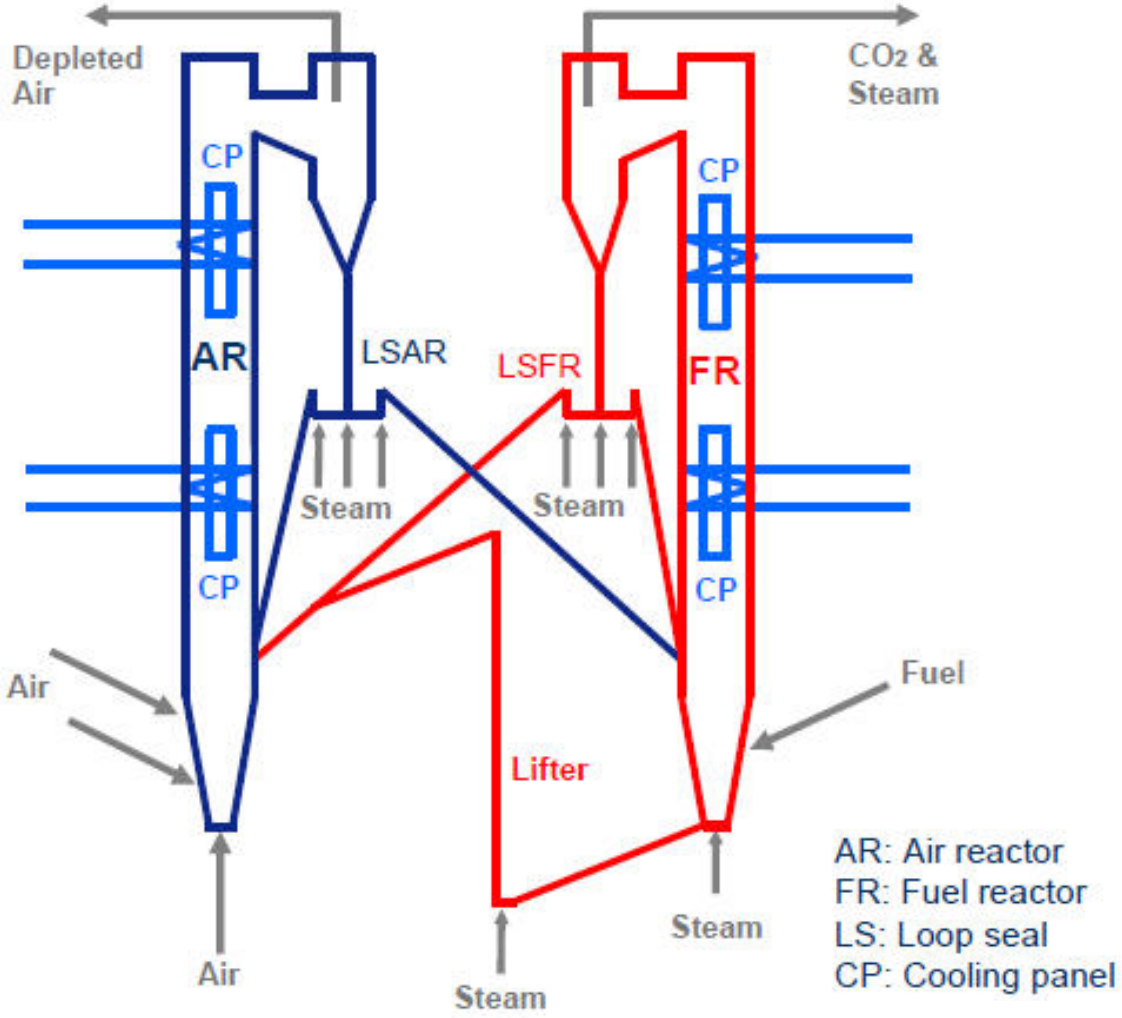
Double Loop Circulating Fluidized Bed (DLCFB)



Design criteria

- High flux
- Flexibility of configuration:
  - Height of reactor
  - Relative position of reactor
  - 1 loop, 1.5 loop, 2 loops
- Compactness
- Choose industrial solutions wherever possible

"Design of a Double Loop Circulating Fluidized Bed reactor system for Chemical Looping Combustion with focus on industrial applicability and pressurization", Bischi et al., submitted for publication in the International Journal of Greenhouse Gas Control.

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Cold Flow Model (CFM) scaling strategy

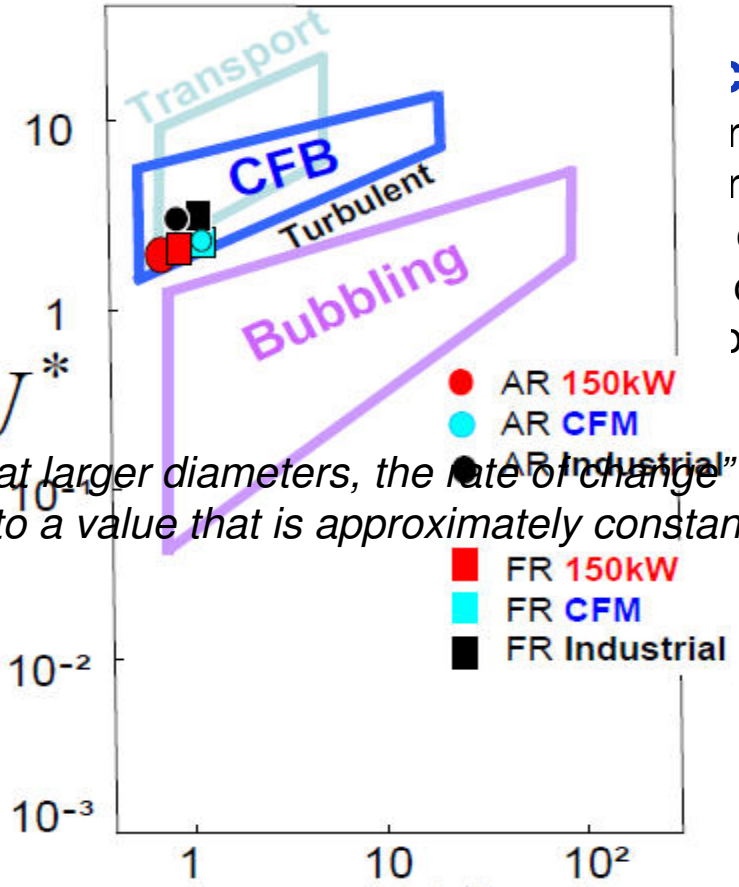
Industrial Application

Glicksman dimensionless param

- Archimedes number (Ar)
- Froude number (Fr)
- Gas/particle density ratio
- Gas-particle Reynolds numb
- Reactor/particle diameter rati
- Reactor height/diameter ratio
- Dimensionless solid flux
- Dimensionless sphericity
- Particle Size Distribution (PS

ess parameters:

rating temperature
rating pressure
composition
cles Geldart classification
A)



1:1 scale because ….*"at larger diameters, the rate of change" of hydrodynamic parameters "levels off to a value that is approximately constant"* T.M. Knowlton

Cold Rig

Hot Rig

Lim, Zhu and Grace (1995)

- Particles Geldart classification (group A)

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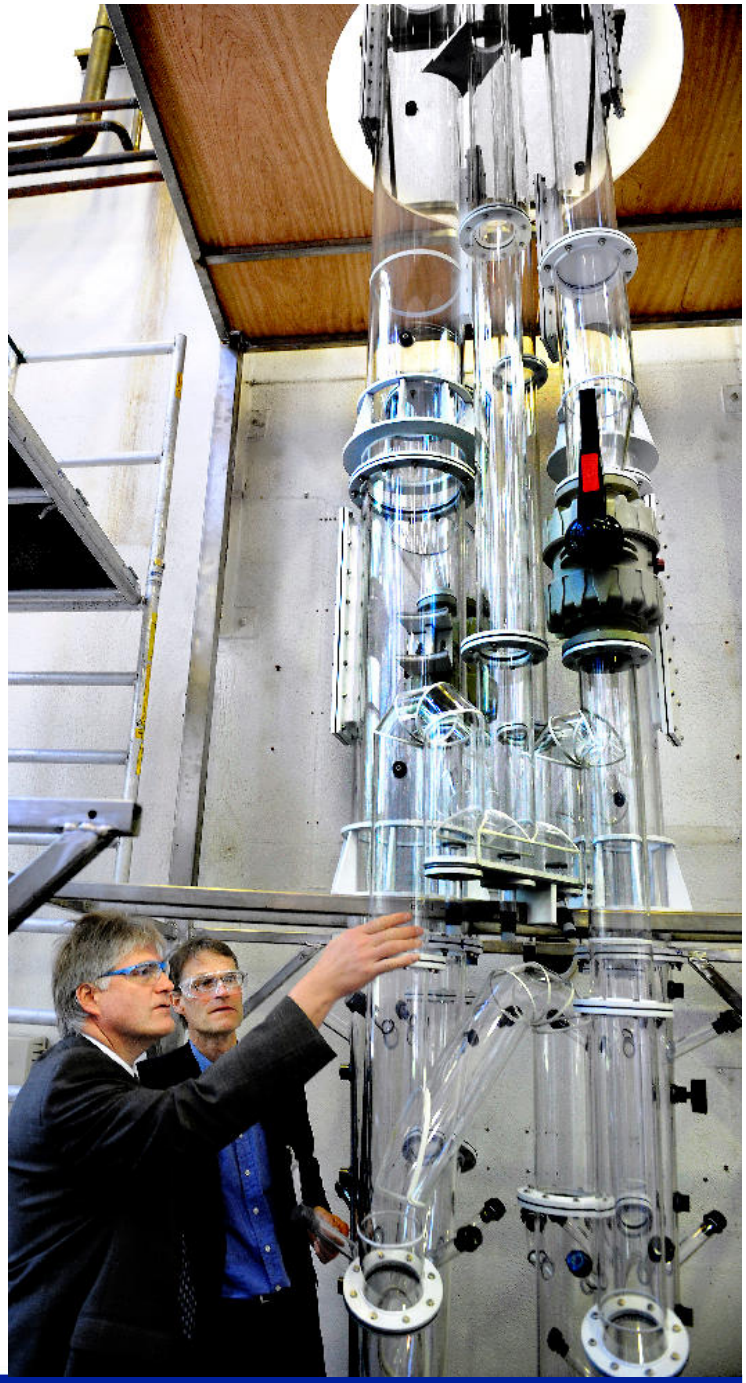
Experimental set-up

Test rig

- Polycarbonate Air Reactor CFM:
  5m height & **0.23m** internal diameter
- Nominal AR air flow:
  ~4500Nl/min (1.9m/s at 20ºC)
- Polycarbonate Fuel Reactor CFM:
  5m height & **0.144m** internal diameter
- Nominal FR air flow:
  ~1800Nl/min (1.9m/s at 20ºC)
- 14 Mass flow controller Brooks® 5853

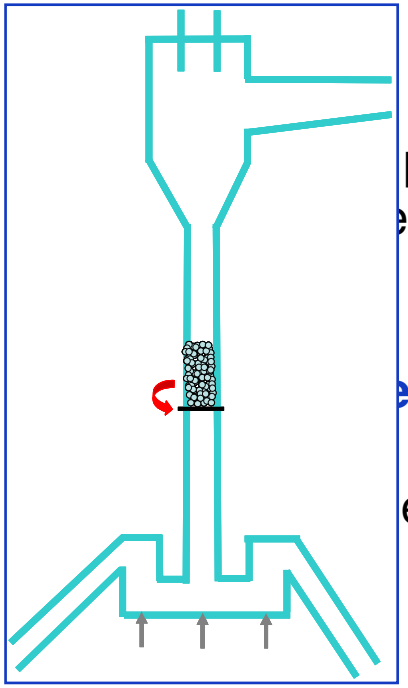
Powder

- Fe-Si powder
- d_{50}: **34micrometers**
- Density: **7000kg/m³**
- System inventory:**140+kg**
- Irregular shape



Cold rig at SINTEF ER/NTNU.
To the left: President of Climate Technologies at SINTEF Nils A. Røkke.
To the right: Trygve Riis, CLIMIT program, Norwegian Research Council (funding the project)

Measurement procedures



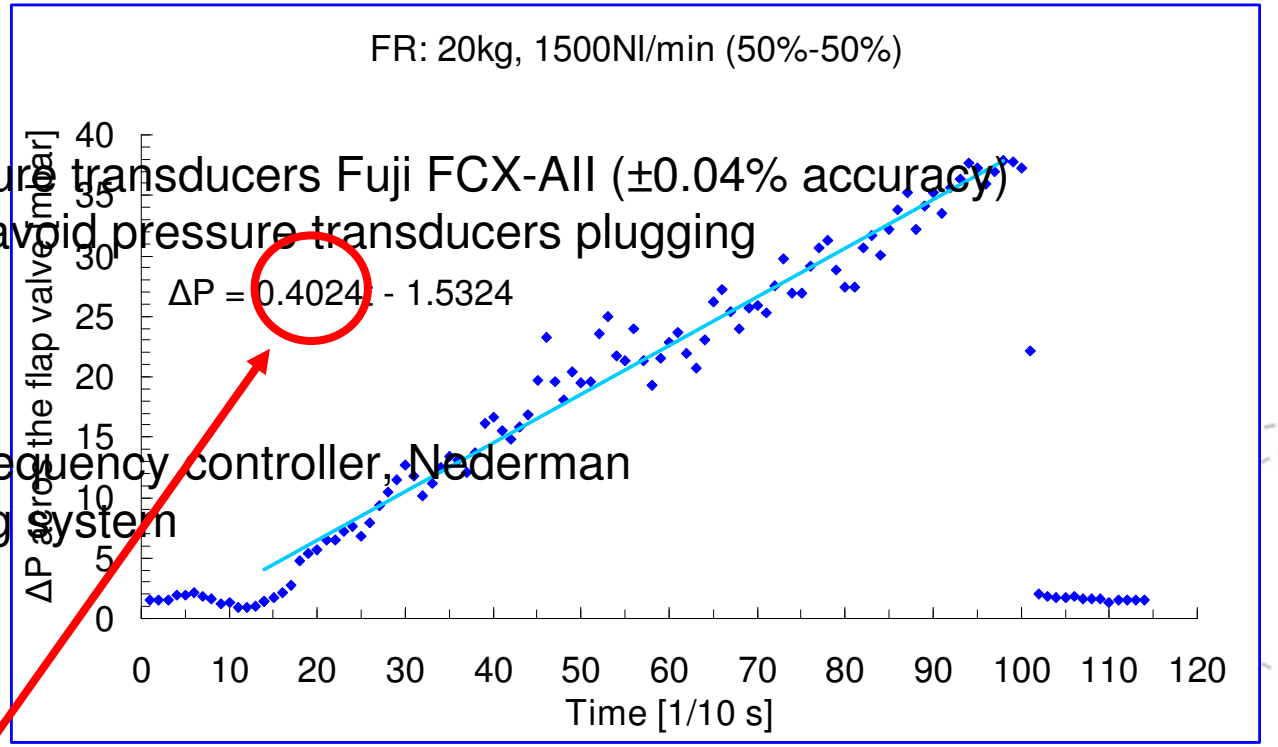
pressure transducers Fuji FCX-AII (±0.04% accuracy)

em to avoid pressure transducers plugging

ency:

fan frequency controller, Nederman

eaning system



Solid flow/flux (G_s):

2 automated flap valve located in the cyclones down-comers

- Visual measurement of the solids accumulation without LS fluidization (all)
- ΔP(time) across perforated flap valve (some, calibration phase):

$$G_s = \frac{d\Delta P}{dt} \cdot \frac{1}{g} \cdot \frac{A_{downcomer}}{A_{riser}}$$

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Preliminary mapping of the operational window

1. **Run separately the AR**
2. **Run separately the FR**

- **recirculating 100%** of entrained flow (0% exchange)
- varying the **total air flow** and the **mass inventory** aiming:
  - to operate the reactors in Circulating Fluidized Bed (CFB) regime
  - a "good" cyclone efficiency **(>99+%)**
  - a stable achievement of the maximum design solids flows

AR 2kg/s
FR 1kg/s + 1kg/s in the bottom lifter

3. **Run AR & FR coupled**

- **exchanging 100%** of entrained flow (0% recirculation) up to **2kg/s**
- coupling AR & FR according to the operating conditions which gave the desired performance separately

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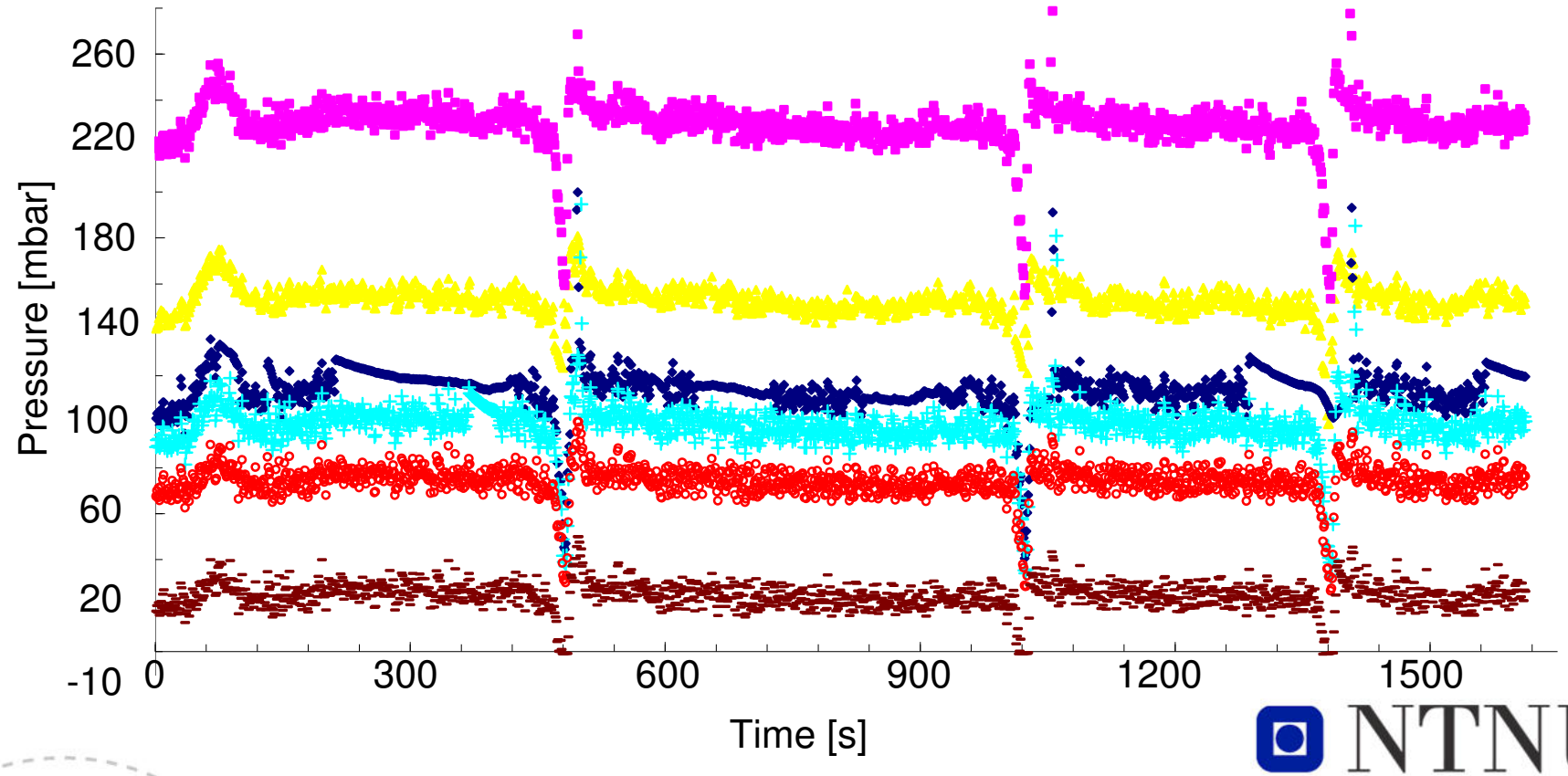
Steady state - FR

- Upstream FR primary nozzle
- Bottom FR
- Border lower & upper part FR
- FR exit
- FR cyclone exit
- Bottom Loop Seal AR



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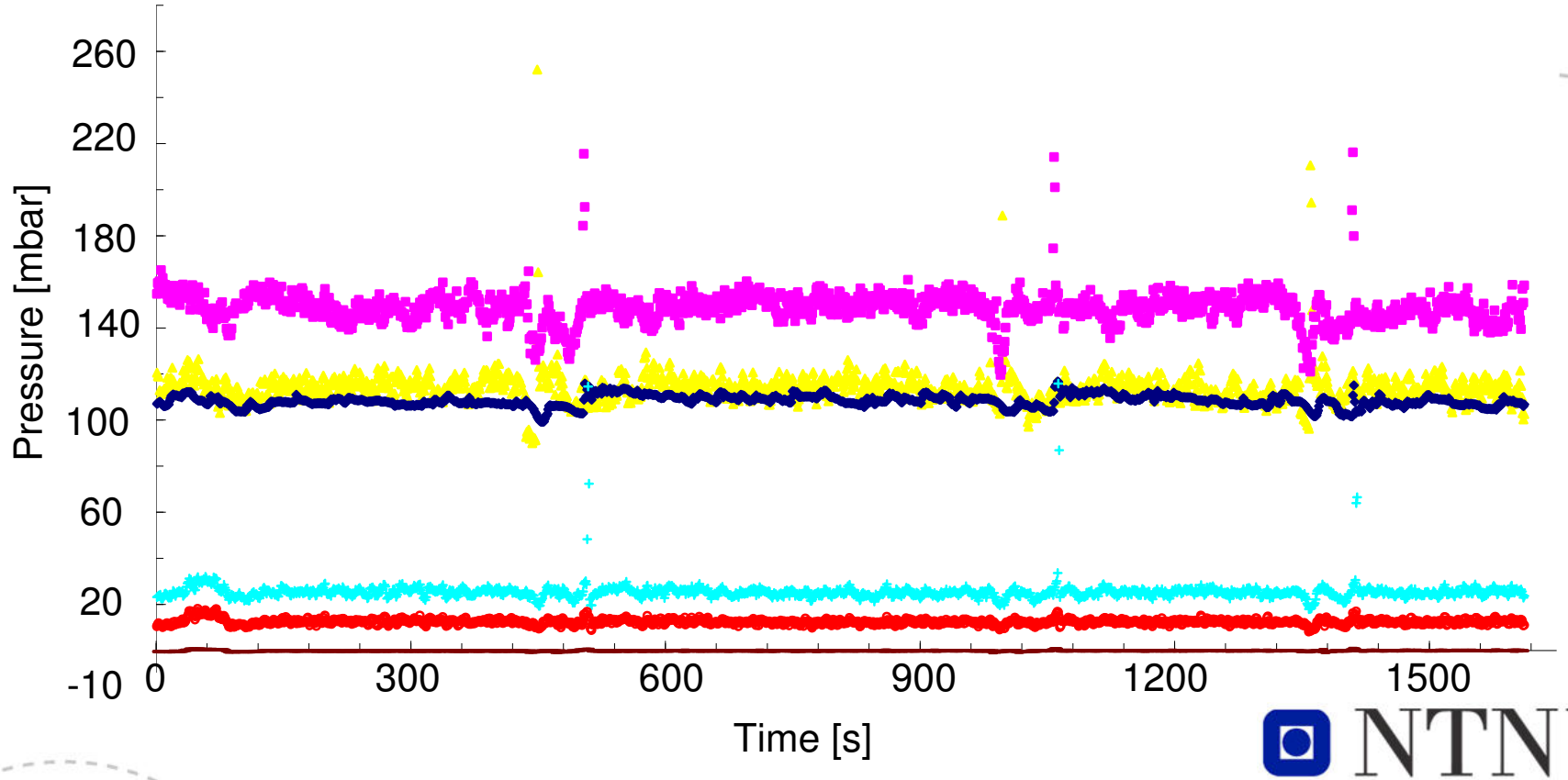
Steady state - AR

- Upstream AR primary nozzle
- Bottom AR
- Border lower & upper part AR
- AR exit
- AR cyclone exit
- Bottom Loop Seal FR



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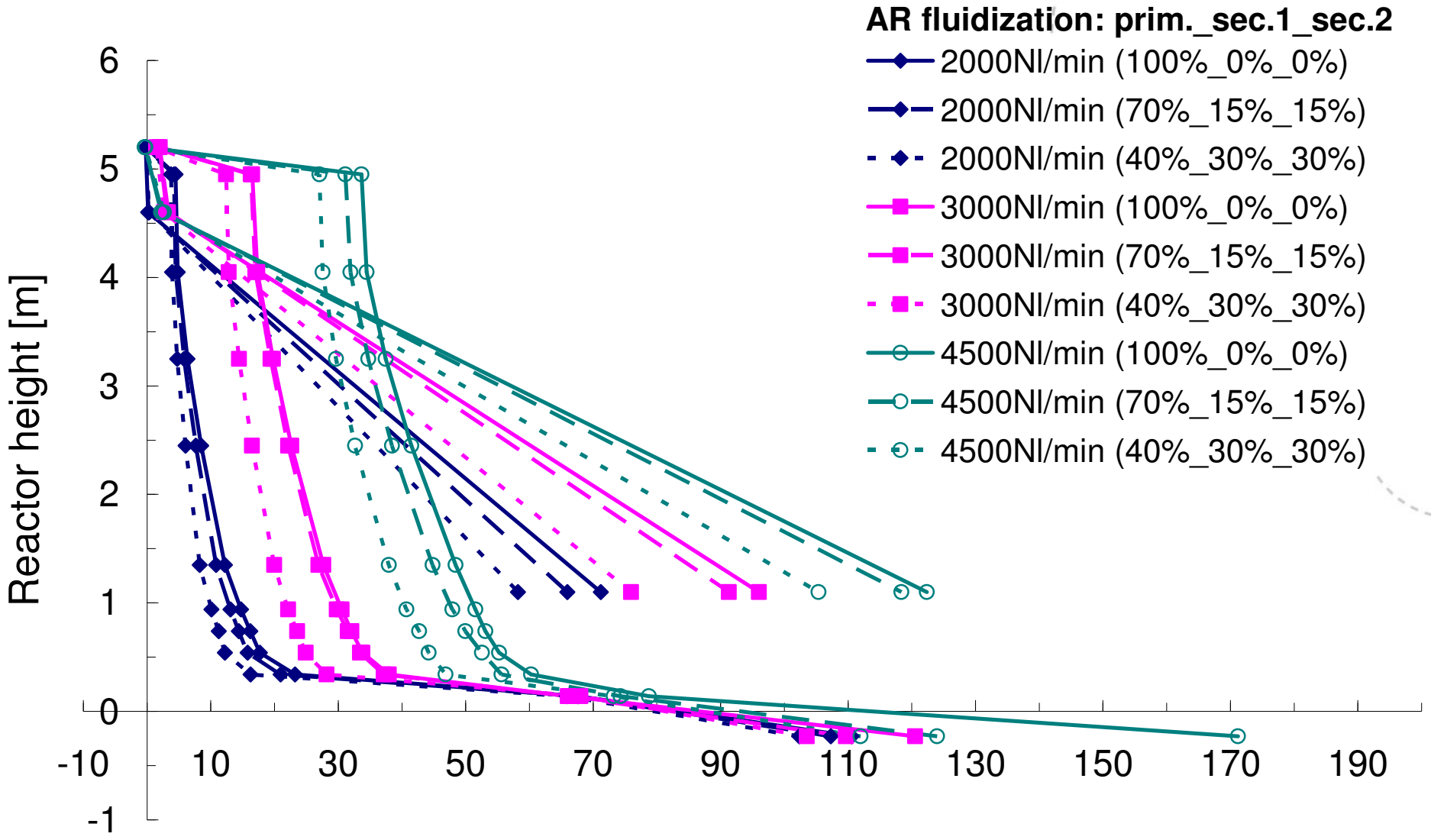
AR Pressure behaviour, 20kg inventory



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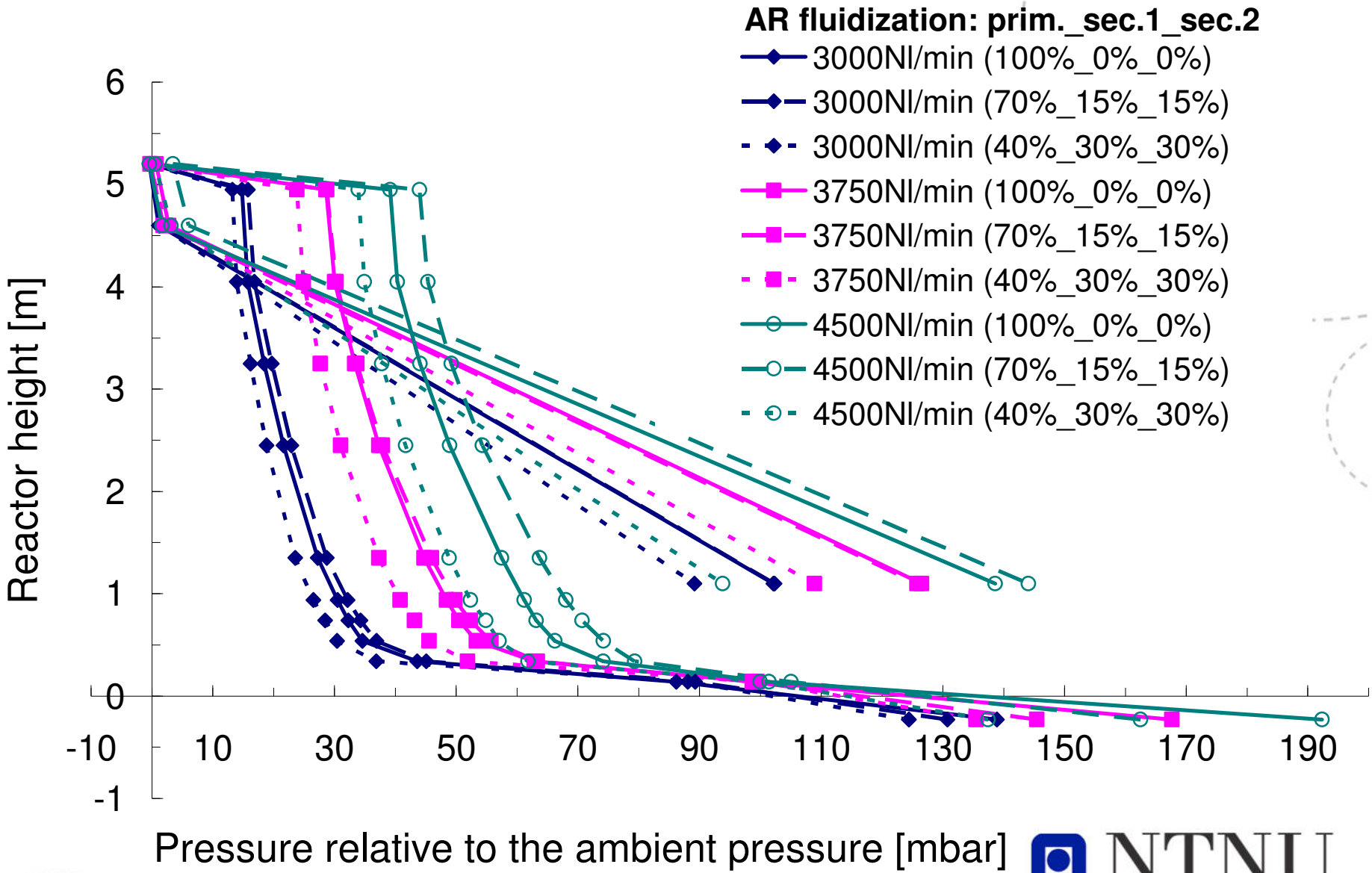
AR Pressure behaviour, 30kg inventory



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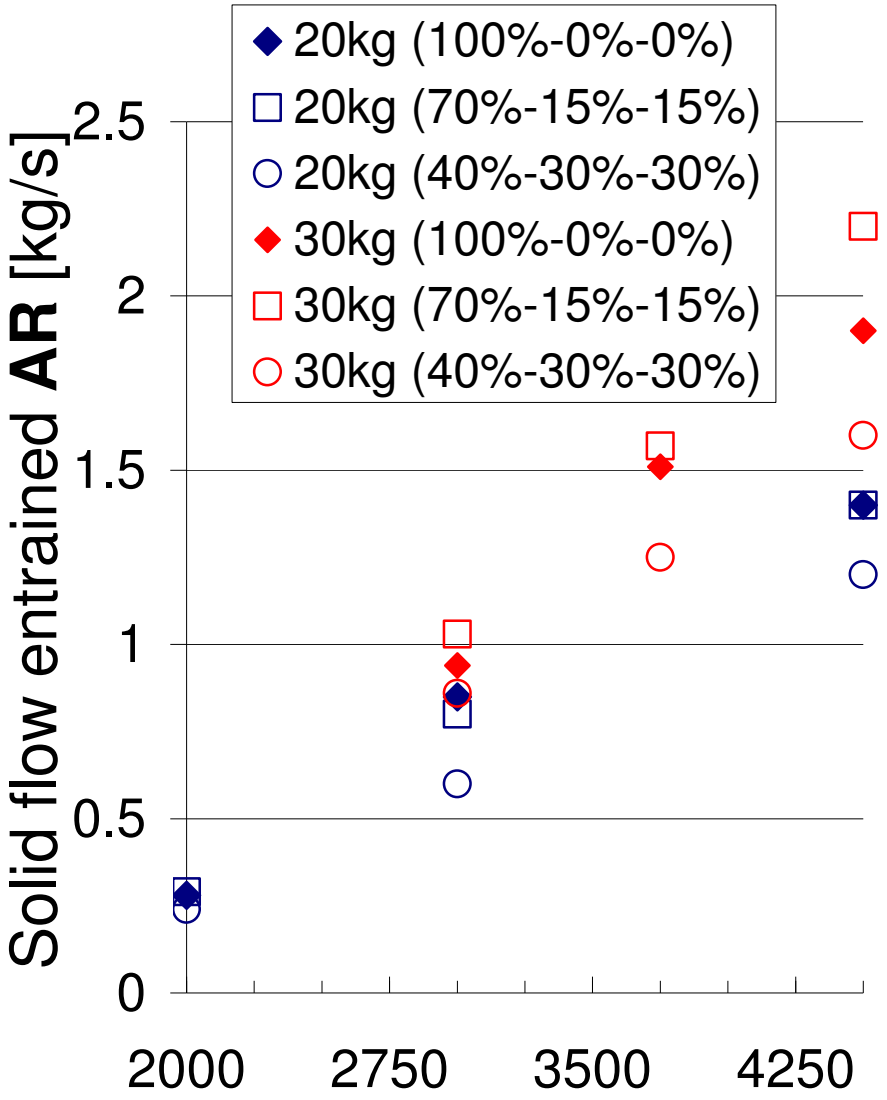
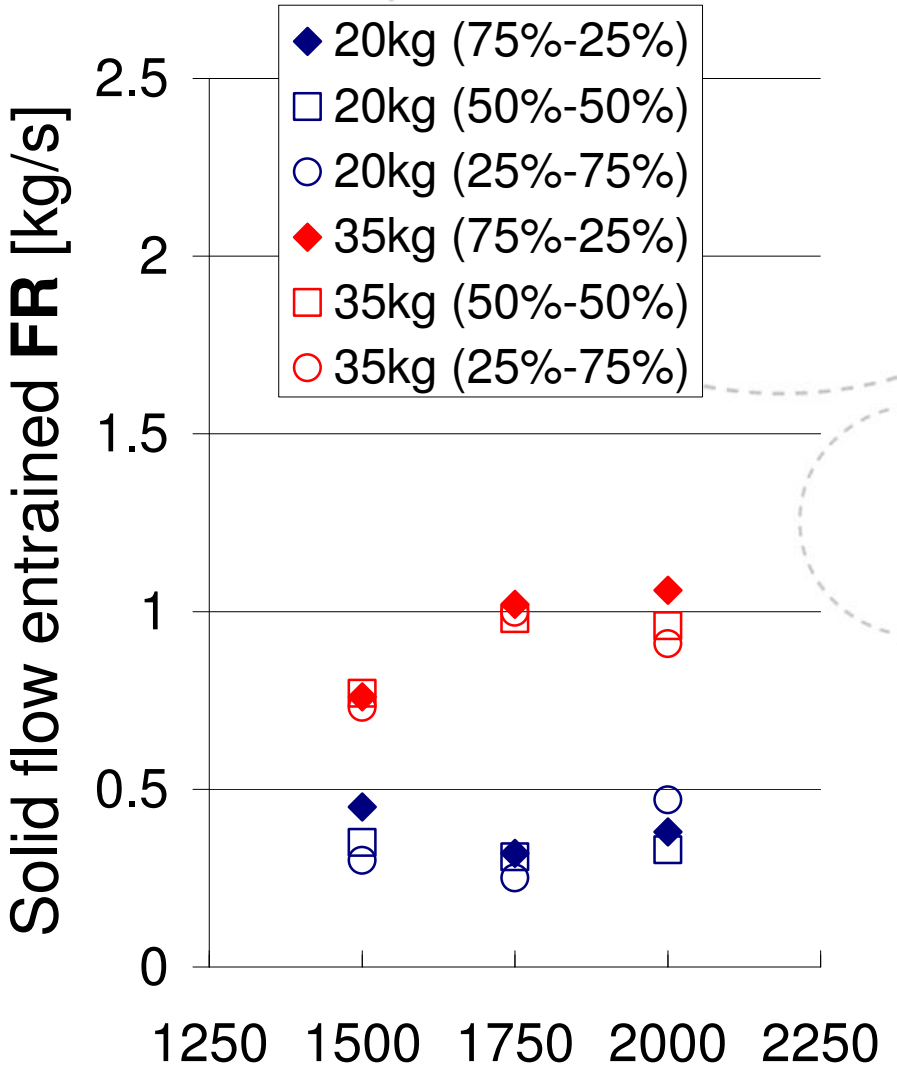
AR & FR performance separately – Solids flow measurement





Air flow [Nl/min]

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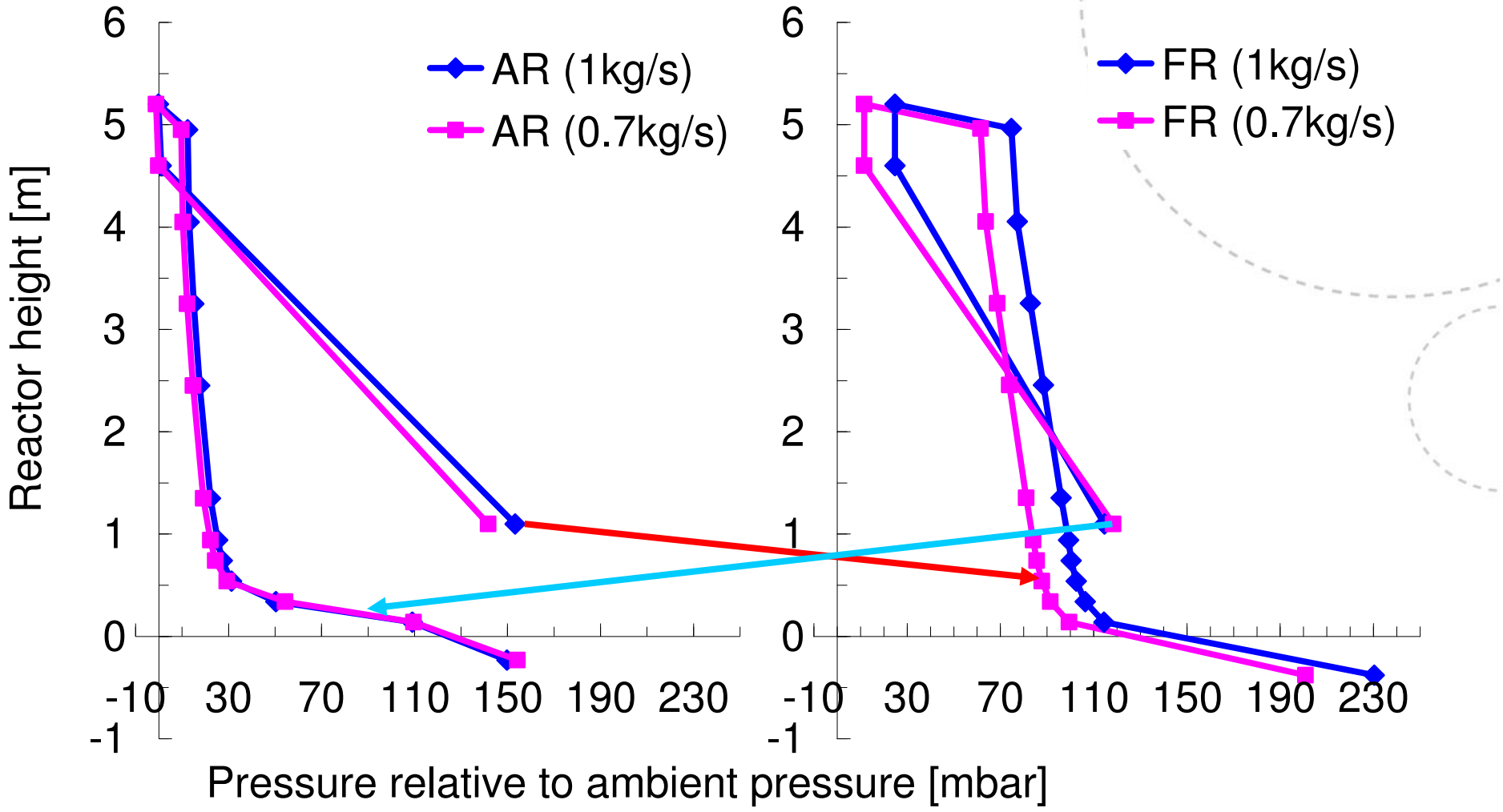
AR & FR performance coupled



0.7kg/s AR:30kg & 3000Nl/min FR:30kg & 2000Nl/min
1kg/s AR:30kg & 3200Nl/min FR:30kg & 2200Nl/min

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Conclusions

1. **Achievement of the AR & FR operation separately according to the design target**
   - Extensive mapping to find further combinations

2. **High cyclone efficiency over 99+%**
   - Further experiments with on line detailed monitoring

3. **Achievement of the 1 loop CFB reactor system operation up to a mass exchange of 1.4kg$_{solids}$/s**
   - Pressure control valve (reactors exit)
   - Optimize Loop Seals operation + vertical fluidization

4. **Divided Loop Seal for 1.5 & 2 loops operation**
   - Test LS recirculation between 0 and 100% solid flow
   - Optimize pressure distribution between reactors to maximize the solid transfer

5. **Integration of lessons learnt and components performance in the 150kW rig under finalization**

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Thank you

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