A novel CLC Configuration with Independent Solid Flow Control

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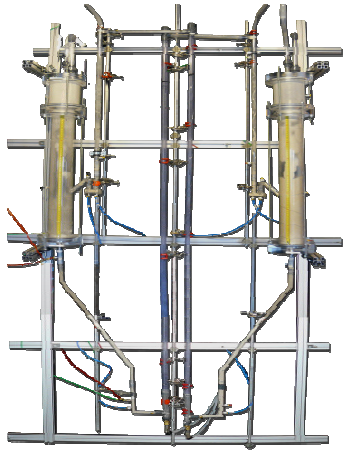
CLC Context

Verification cold flow prototype:

- Design validation
- Study of solid circulation
- Investigation of the operation ranges

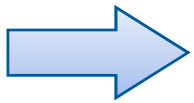


10 kW_{th} CLC pilot plant

CLC Introduction

Important parameters:

- Oxygen Carrier
- Solid flow rate control:
  - Control of thermal balance
  - Control of oxygen flow



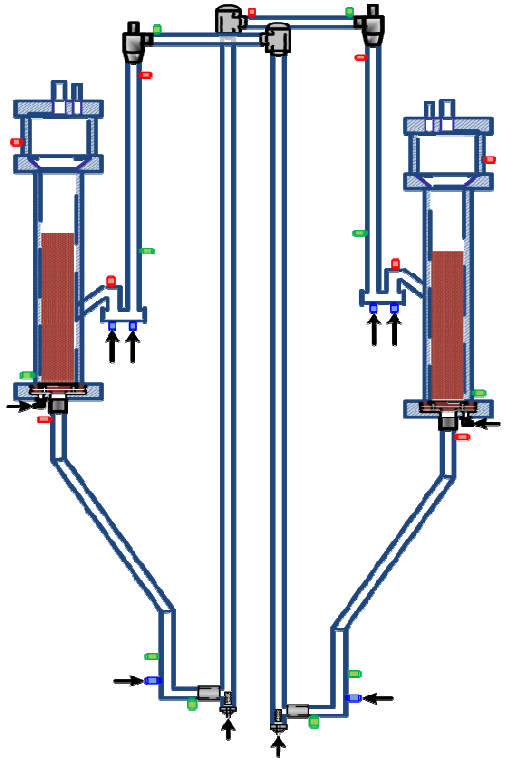
Operation flexibility
(produced power, different OC)

- Gas tightness:
  - Avoiding gas carry over with solids

Experimental

Design aspects:

- Reactors:
  - Two bubbling fluidized bed reactors
- Solid flow control:
  - Non-mechanical L-valve (high temperature)
  - Independent from the air/fuel flow rates
- Gas tightness
  - Loop seals



Experimental

Particles:

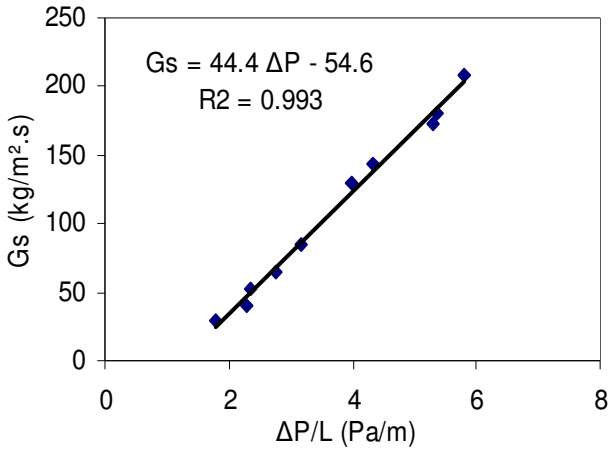
- Silica Sands I & II
- Ilmenite

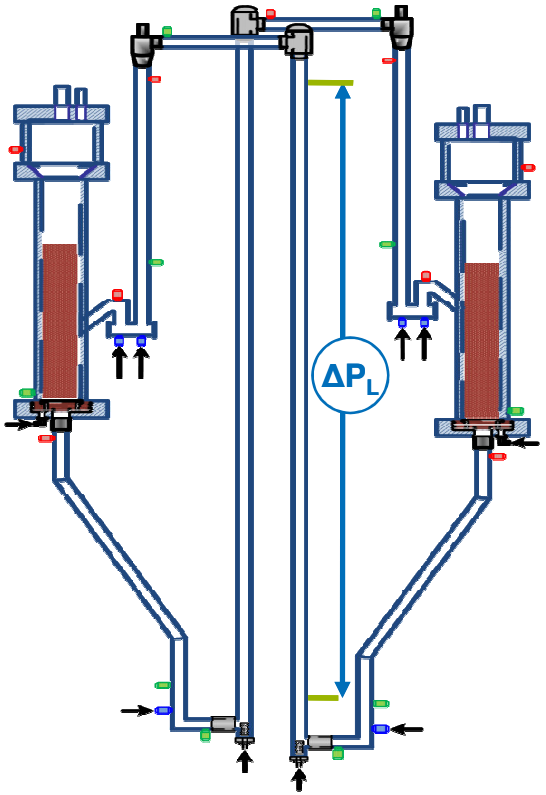
Solid	$\rho_{s,real}$ (kg/m^3)	$d_{harmonic}$ (µm)	d_{50} (µm)	U_{mf} (m/s)	U_t (m/s)	ε_{mf}	ε_s (free settled)	Φ
Sand I	2650	197	205	0.038	1.37	0.513	0.463	0.86
Sand II	2650	289	353	0.068	1.95	0.514	0.457	0.76
ilmenite	4750	107	129	0.013	0.82	0.455	0.434	0.61

Solid Flow Rate Measurement

Continuous Operation:

- $W_s = f(DP_L)$



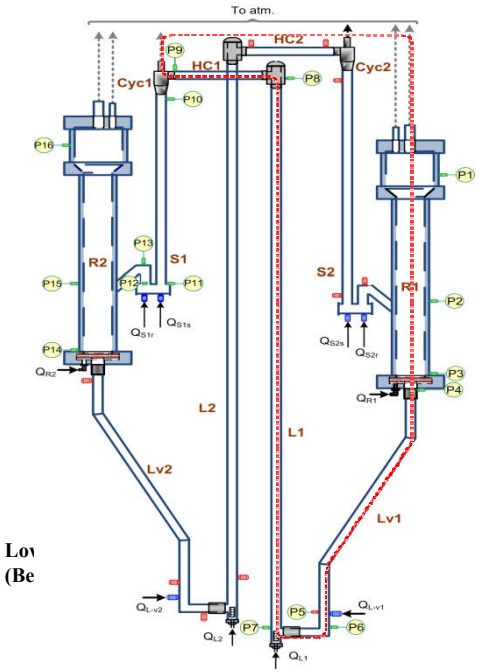


$U_{g,L} = 6.8$ m/s

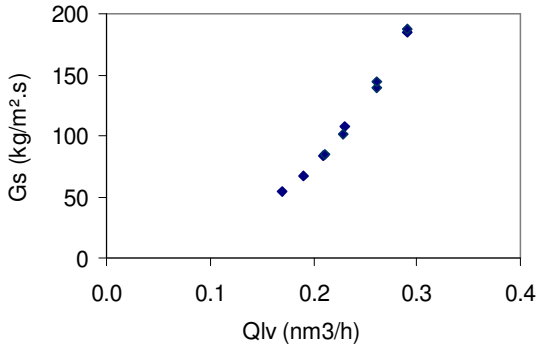
L-valve Operation

Solid flow rate in the L-valve:

- $W_s = f(Q_{lvH})$
- $Q_{lvH} = Q_{lv} \pm Q_{lvv}$
- $Q_{lvv} = f(\Delta P_{lv,v})$
  - Ergun equation
- $\Delta P_{lv,v}$
  - variable: from the overall pressure loop
  - $U_r = U_s - U_g$



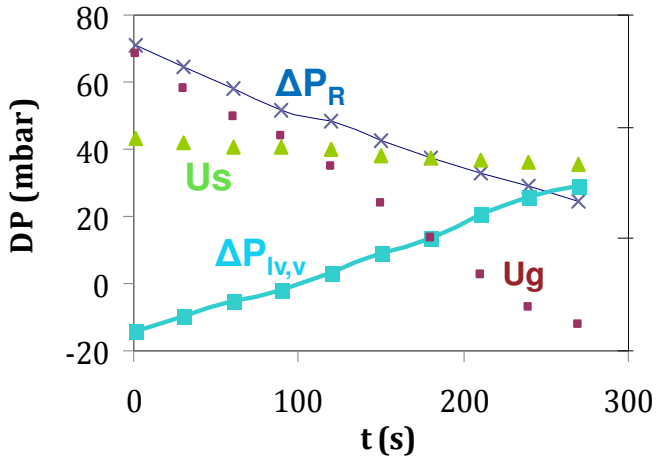
Resulting solid flow rate control:



L-valve Operation

Vertical arm of the L-valve:

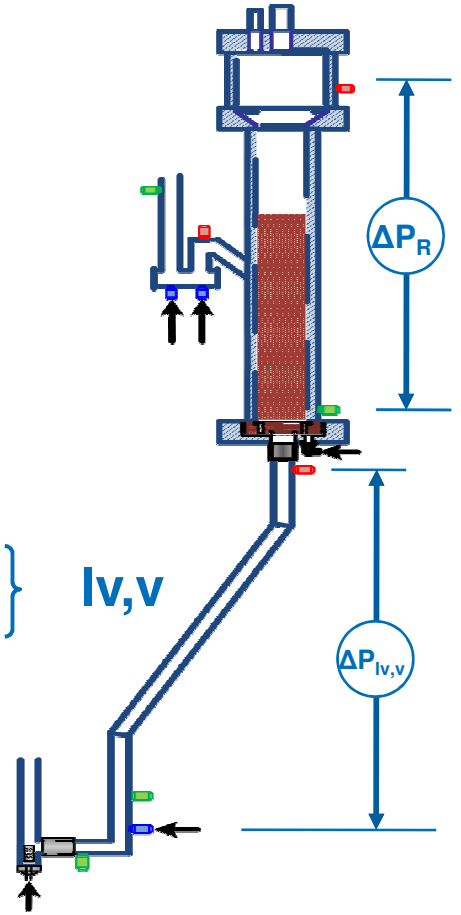
Variations imposed by change of the ΔP_R:



Q_{lv}=0.22 Nm^3/h

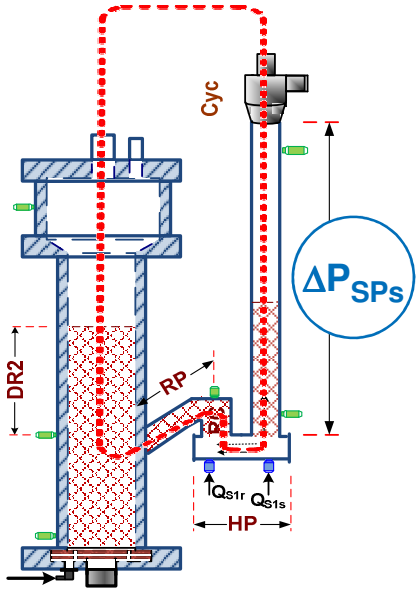
$U_g = Q_g/A$
$U_s = W_s/A.\rho$

lv,v



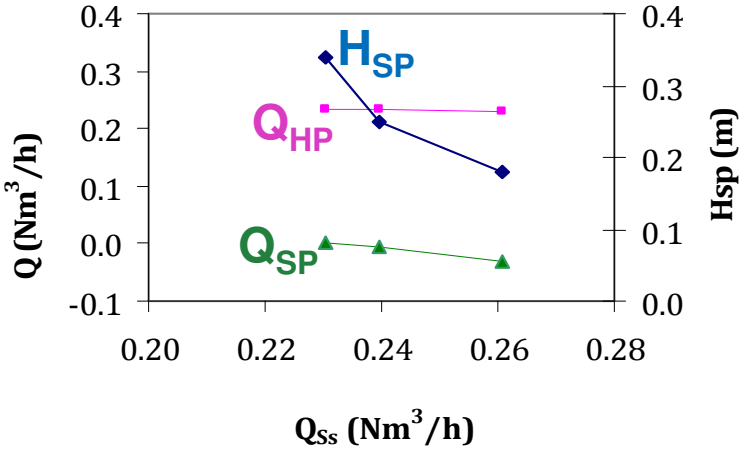
Loop-seal Operation

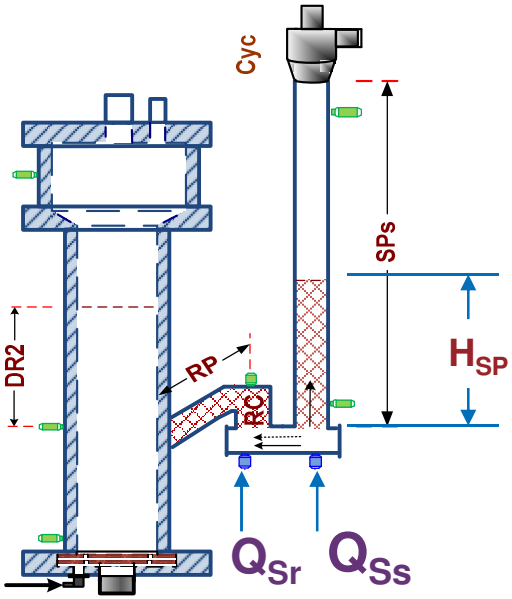
- $Q_{Ss} = Q_{SPs} + Q_{HP}$
  - Solid flow rate (W_s) = imposed
  - Solid height in dipleg (H_s) = variable
- ΔP_{SPs} :
  - From pressure balance
  - Varies to adjust the pressure balance
  - Absorbs the pressure by 2 mechanisms:
    - Variation of H_{SPs}
    - Variation of $\Delta P_{SPs}/L$ through relative gas-solid velocity



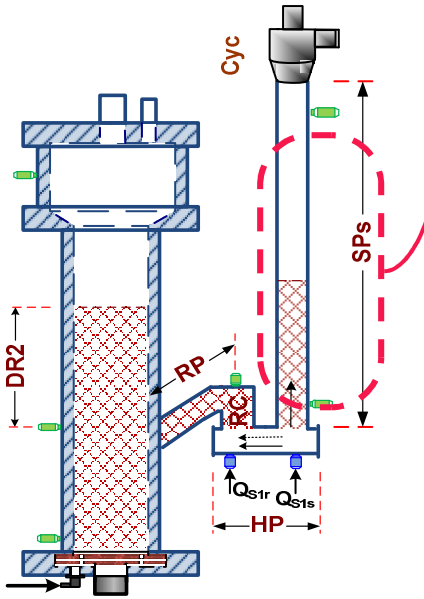
Loop-seal Operation

- **Effect of loop-seal aeration (Q_{Ss}):**
  - Solid Flux (G_s) = 145 kg/m².s
  - ΔP_{SPs} = 18.3 mbar





Loop-seal Operation



gastight

Q_{SPs} : ↑/↓ **leakage**

maximum gastightness at:

$Q_{Ss} \geq Q_{HP}$

Limit to:

$v_r = v_s - v_g < v_{mf}$

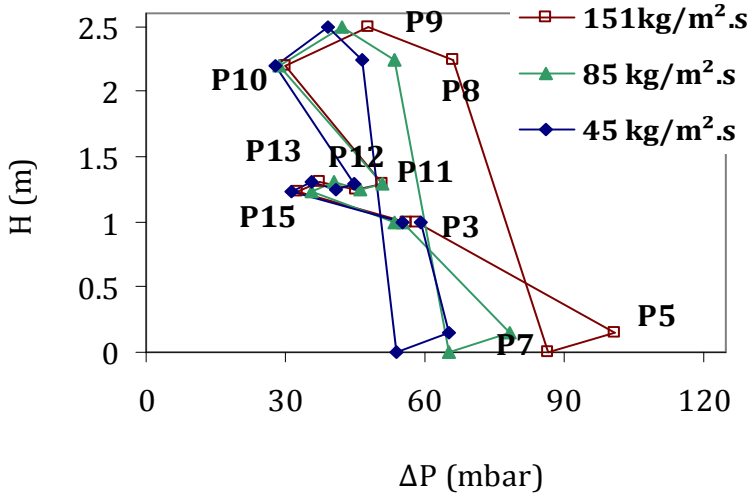
Fluidized standpipe:

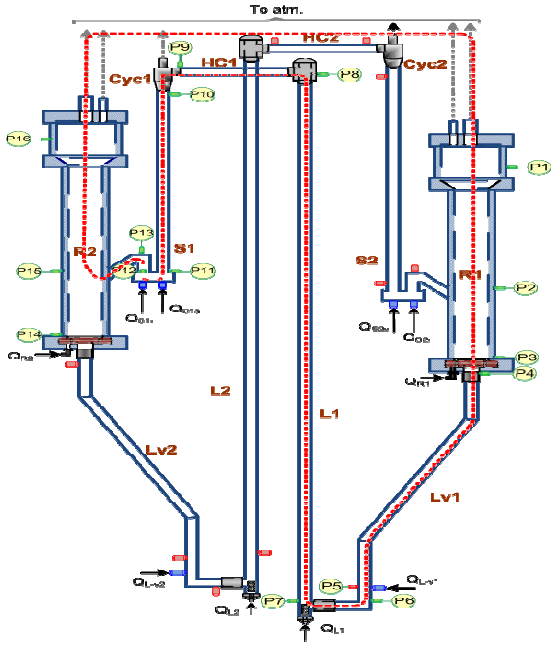
- No operational limit
- SP can absorb pressure just through the solid level variation and not the relative gas-solid flow

Steady State Operation

- Stable continuous operation
- Pressure variation is balanced over the circulation loop

$$\Sigma\Delta P = \Delta P_{R1} + \Delta P_{lv,v} + \Delta P_{lv,H} + \Delta P_L + \Delta P_{Tb} + \Delta P_{HC} + \Delta P_{Cyc,s} + \Delta P_{SC} + \Delta P_{HP} + \Delta P_{RC} + \Delta P_{RP} + \Delta P_{DR2} = 0$$





Conclusions:

- Design approved
- Independent control of solid circulation (l-valves)
- Gas-tightness achieved by loop-seals
- Investigation of gas-solid circulation in the system

- Development of a solid circulation model
- Gas and solid residence time distribution (RDT)

Thanks for your attention