Recirculating fluidized bed reactor for chemical-looping

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RECIRCULATING FLUIDIZED BED REACTOR FOR CHEMICAL-LOOPING

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Fluidization XV, Quebec, Canada.  
OUTLINE OF PRESENTATION

- Chemical-Looping Combustion (CLC)
- Existing reactor arrangements for CLC
  - Single reactor arrangement
  - Interconnected reactor arrangement
- Issues related to the existing reactor arrangements
- Re-Circulating Fluidized Bed (RCFB) Reactor design for CLC
- How RCFB overcomes the issues related to the existing reactor designs?
- Conclusions
CHEMICAL LOPIXING
COMBUSTION (CLC)

Reaction Equations in CLC

Air Reactor

\[ Me + \frac{1}{2} O_2 \rightarrow MeO \]

Fuel Reactor

\[ (2n + m)MeO + C_n H_{2m} \rightarrow (2n + m)Me + mH_2O + nCO_2 \]
REQUIREMENTS FOR CLC

- Split the combustion in oxidation and reduction cycles by introducing metal oxides
- Air reactor is a high velocity reactor – for the transfer of bed material within the reactors
- Fuel reactor is a low velocity reactor – for higher residence of bed material
- Wear and tear resistant metal oxide and reactors
- Reactive metal oxide – for higher fuel conversion
- Good solid circulation rate – for proper transfer of heat and reactants within the reactors
REQUIREMENTS FOR CLC

- Reactor system with low gas bypassing – required for the purity of the CO$_2$ capture
- Low particle agglomeration – required for proper particle flow and uniform temperature in the reactors
- Regimes of fluidizations
VARIOUS REACTOR CONFIGURATIONS

• Single reactor configuration
• Interconnected reactor configuration
SINGLE REACTOR ARRANGEMENT
Externally heated low velocity batch fluidized bed reactor of quartz.
Batch fluidized bed reactor of stainless steel working in the low velocity and high velocity cycles.

INTERCONNECTED REACTORS ARRANGEMENT (CONTINUOUS MODE)
Circulating Fluidized Bed

- The setup involves two separate reactors and of course a cyclone.

- Particles from the riser escape out on increasing the fluidization velocity.

- Cyclone collects the particles.

- Collected particles are diverted into the standpipe.

- Standpipe is also fluidized to make the particles flow back into the riser.

- To avoid the gas bypassing from the riser into the standpipe, a certain bed height is maintained in the standpipe.

- Bed in the standpipe adds on to the overall pressure drop.
TWO COMPARTMENT FLUIDIZED BED REACTOR (1 AIR REACTOR, 2 DOWNCOMER, 3 FUEL REACTOR, 4 SLOT, 5 GAS DISTRIBUTOR, AND 6 WIND BOX).

(KRONBERGER, B.; JOHANSSON, E.; LÖFFLER, G.; MATTISSON, T.; LYNGFELT, A.; HOFBAUER, H. A TWO COMPARTMENT FLUIDIZED BED REACTOR FOR CO$_2$ CAPTURE BY CHEMICAL-LOOPING COMBUSTION, CHEMICAL ENGINEERING AND TECHNOLOGY. 2004. 27(12), 1318-1326.)
DUAL CIRCULATING FLUIDIZED BED REACTOR ARRANGEMENT.

SOME OF THE ISSUES THAT CAN CROP-UP IN THE CLC

- Low residence time of bed material in the air reactor.
- High attrition of bed material in the cyclone.
- Cluster formation in the air reactor.
- Complex operation involving loop-seals.
- High heat losses as bed material leaves the air reactor and moves to cyclone.
- Gas bypassing.
RE-CIRCULATING FLUIDIZED BED REACTOR
ADVANTAGES OF RCFB REACTOR

- Cyclone separator is not present in RCFB reactor.
- Bed particles do not leave the reaction site hence less heat losses.
- RCFB is an excellent mixing device.
- No complex loop seal in case of a single reactor operated in reduction and oxidation cycles.
CLC REACTOR CONFIGURATION USING RCFB REACTOR(S)

- Two interconnected RCFB reactors
  - A single RCFB reactor alternatively working in oxidation and reduction cycles.
- A single RCFB reactor where central draft tube act as air reactor and the downcomer act as fuel reactor.
VARIABLES DURING THE COLD MODEL EXPERIMENTS

- Bed Inventory (4 kg, 6 kg, 8 kg, 9 kg, 10 kg).
- Particle size (Sand Grade I, II, III).
- Spacer section (3 cm, 8 cm, 15 cm).
- Jet tube diameter (2.5 cm and 3 cm).

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<th>Sr. No.</th>
<th>Sand Grade</th>
<th>Geldart’s Classification</th>
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<td>(1 mm – 0.5 mm)</td>
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<td>3.</td>
<td>Grade III</td>
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<td>(0.5 mm – 0.09 mm)</td>
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<td>Test Series</td>
<td>Jet tube diameter (m)</td>
<td>Spacer section (m)</td>
<td>Sand Grade</td>
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## Scheme of Cold Model Experiments

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IMPORTANT PARAMETERS FOR CLC

- Regime of Fluidization for air reactor and fuel reactor – affect the residence time.
- Operating Voidage – heat transfer
- Residence time – fuel conversion
- Particle Size – conversion
- Solid circulation rate – uniform bed temperature
Operating Voidage Variation in the Riser

2.5 cm jet tube section

- Sand Grade I
  - 0.83
  - 0.84
  - 0.85
  - 0.86
  - 0.87
  - 0.88
  - 0.89
  - 0.9
  - 0.91
  - 0.92
  - 0.93
  - 0.94

- Sand Grade II
  - 0.82
  - 0.83
  - 0.84
  - 0.85
  - 0.86
  - 0.87
  - 0.88
  - 0.89
  - 0.9

3 cm jet tube section

- Sand Grade I
  - 0.6
  - 0.7
  - 0.8
  - 0.9

- Sand Grade II
  - 0.9
  - 1
OPERATING VOIDAGE VARIATION IN THE RISER

Sand Grade III

2.5 cm jet tube section

3 cm jet tube section

Operating Voidage in the riser

Inventory (kg)

Operating Voidage in the riser

Inventory (kg)
OPERATING VOIDAGE VARIATION IN THE DOWNCOMER

2.5 cm jet tube section

Sand Grade I

3 cm jet tube section

Sand Grade II

Graphs showing operating voidage in the downcomer for Sand Grade I and Sand Grade II with 2.5 cm and 3 cm jet tube sections, with different spacer sizes (3 cm, 8 cm, 15 cm) plotted against inventory (kg) and operating voidage in the downcomer.
OPERATING VOIDAGE VARIATION IN THE DOWNCOMER

2.5 cm jet tube section

3 cm jet tube section

Sand Grade III
SOLID CIRCULATION RATE VARIATION

2.5 cm jet tube section

3 cm spacer section

3 cm jet tube section

8 cm spacer section

Solid Circulation rate (kg/s)

Inventory (kg)

Sand Grade I
Sand Grade II
Sand Grade III

Solid Circulation rate (kg/s)

Inventory (kg)

Sand Grade I
Sand Grade II
Sand Grade III

Solid Circulation rate (kg/s)

Inventory (kg)

Sand Grade I
Sand Grade II
Sand Grade III

Solid Circulation rate (kg/s)

Inventory (kg)

Sand Grade I
Sand Grade II
Sand Grade III
SOLID CIRCULATION RATE VARIATION

2.5 cm jet tube section

3 cm jet tube section

15 cm spacer section
SUSPENSION DENSITY VARIATION IN THE DOWNCOMER/FUEL REACTOR

2.5 cm jet tube section

Sand Grade I

3 cm jet tube section

Sand Grade II
SUSPENSION DENSITY VARIATION IN THE FUEL REACTOR/DOWNCOMER

2.5 cm jet tube section

3 cm jet tube section

Sand Grade III

![Graph showing suspension density variation in the fuel reactor for different spacers and inventory levels. The graphs compare 2.5 cm and 3 cm jet tube sections.]
CONCLUSIONS

- Existing interconnected reactor arrangements for CLC have some issues
- To overcome some of these issues, RCFB reactor has been proposed
- RCFB can be used as
  1. An interconnected reactor arrangement
     - Single reactor working in cycles of air reactor cycle and fuel reactor cycle with N₂ bubbled in between the cycles
  2. A single RCFB where the riser is acting as air reactor and downcomer as fuel reactor
     - In this configuration a permanent seal is required on the top downcomer section
CONCLUSIONS

- The draft tube in the RCFB ensures good solid mixing & solid circulation, longer residence time which results in maintaining uniform temperature throughout the reactor and better distribution of bed inventory and fuels.

- The construction of the RCFB reactor is not complex as it does not have cyclone separator and complex loop seals, which makes it less expensive with flexible operating conditions.

- Further experimental studies are needed to verify the claims made.
THANK YOU