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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.

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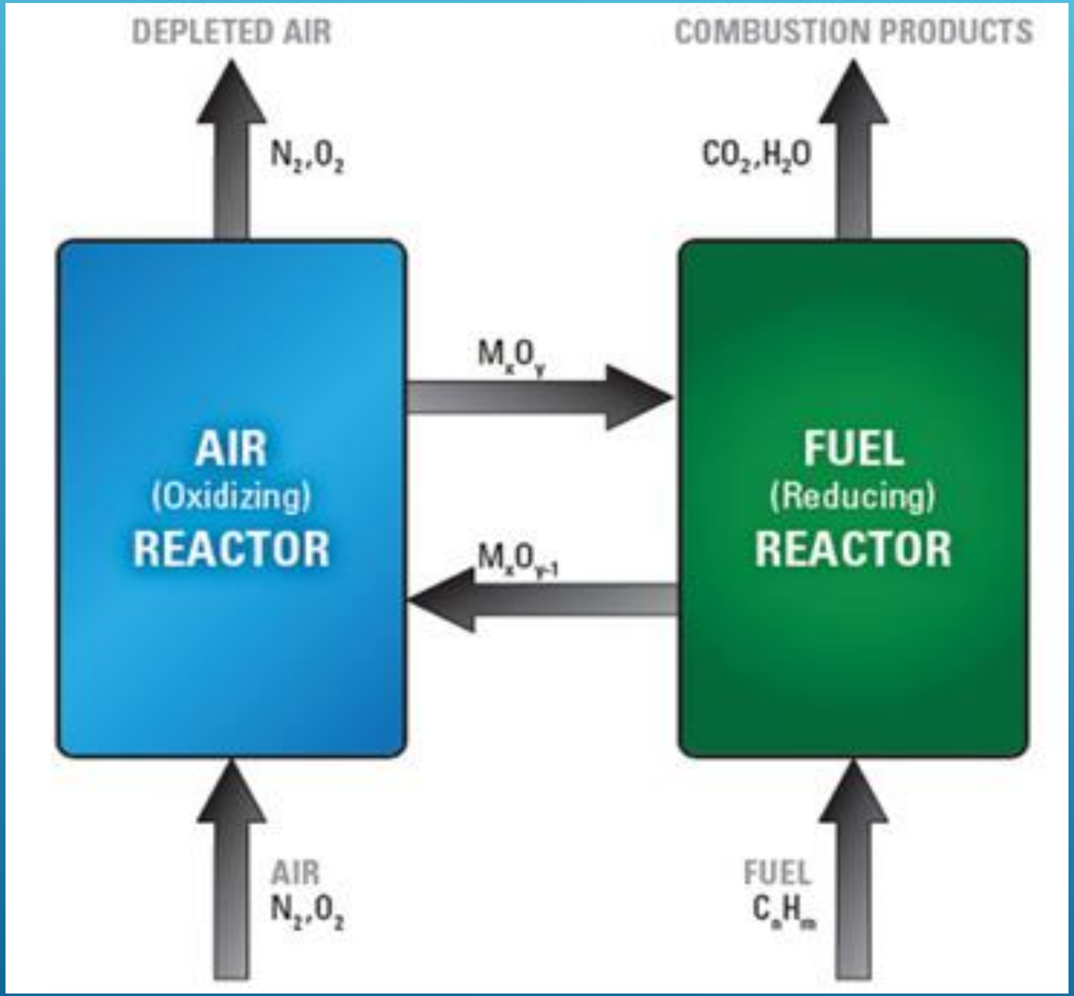
OUTLINE OF PRESENTATION

- 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 LOOPING COMBUSTION (CLC)



Reaction Equations in CLC

Air Reactor

$$Me + \frac{1}{2} O_2 \rightarrow MeO$$

Fuel Reactor

$$(2n+m)MeO + C_nH_{2m} \rightarrow$$
$$(2n+m)Me + mH_2O + nCO_2$$

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

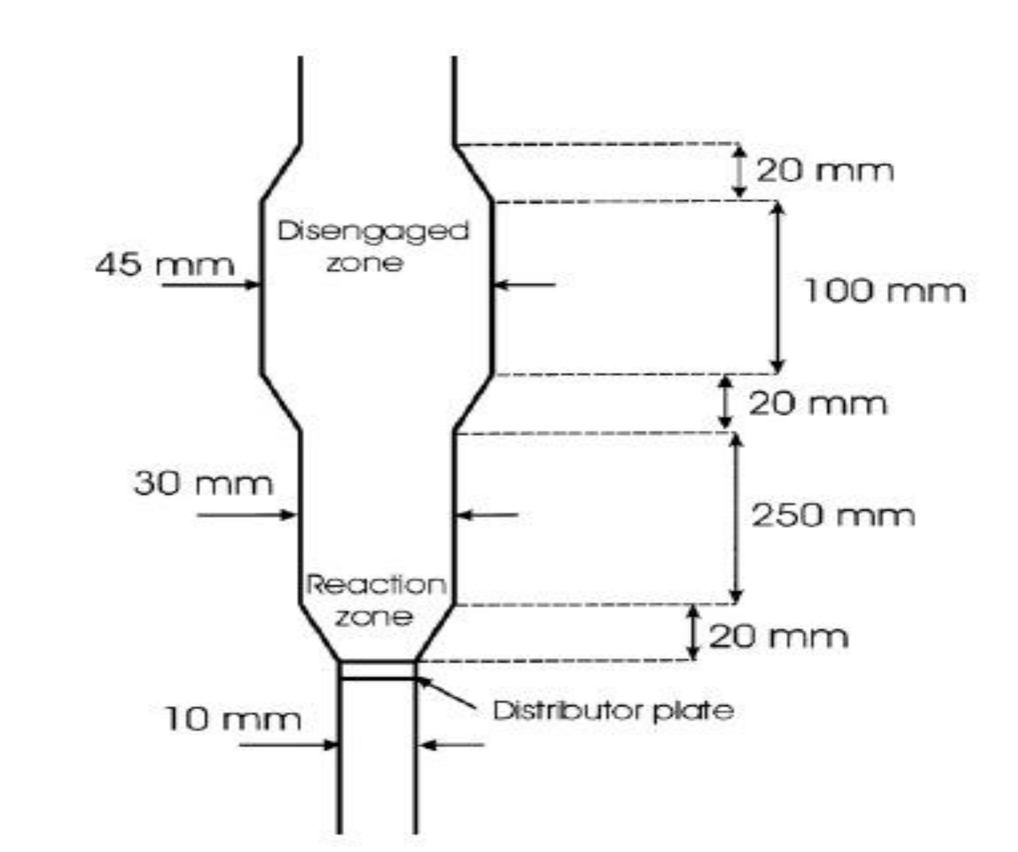
- Reactor system with low gas bypassing – required for the purity of the CO_2 capture
- Low particle agglomeration – required for proper particle flow and uniform temperature in the reactors
- Regimes of fluidizations

VARIOUS REACTOR CONFIGURATIONS

- Single reactor configuration
- Interconnected reactor configuration

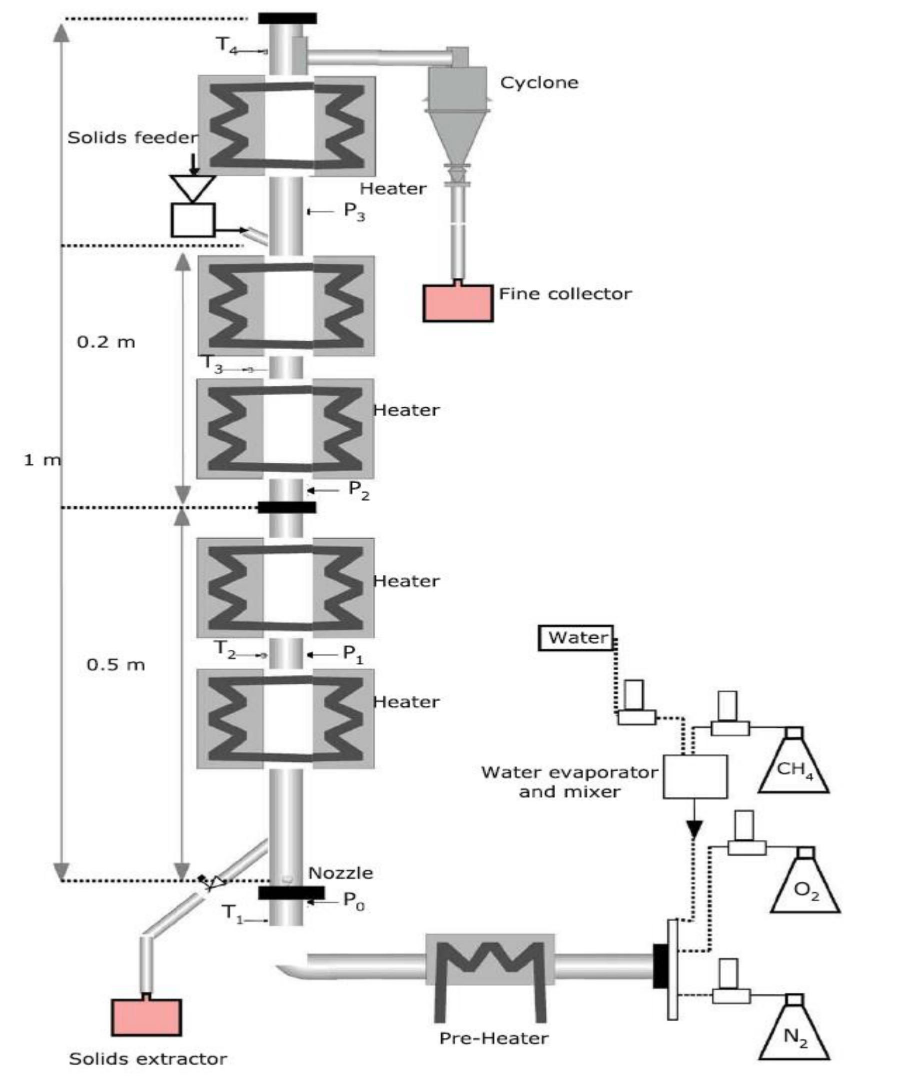
SINGLE REACTOR ARRANGEMENT

SINGLE REACTOR CONFIGURATION



Externally heated low velocity batch fluidized bed reactor of quartz.

(Leion, H.; Mattisson, T.; Lyngfelt, A. The use of petroleum coke as fuel in chemical-looping combustion, *Fuel*. 2007, 86, 1947-1958)

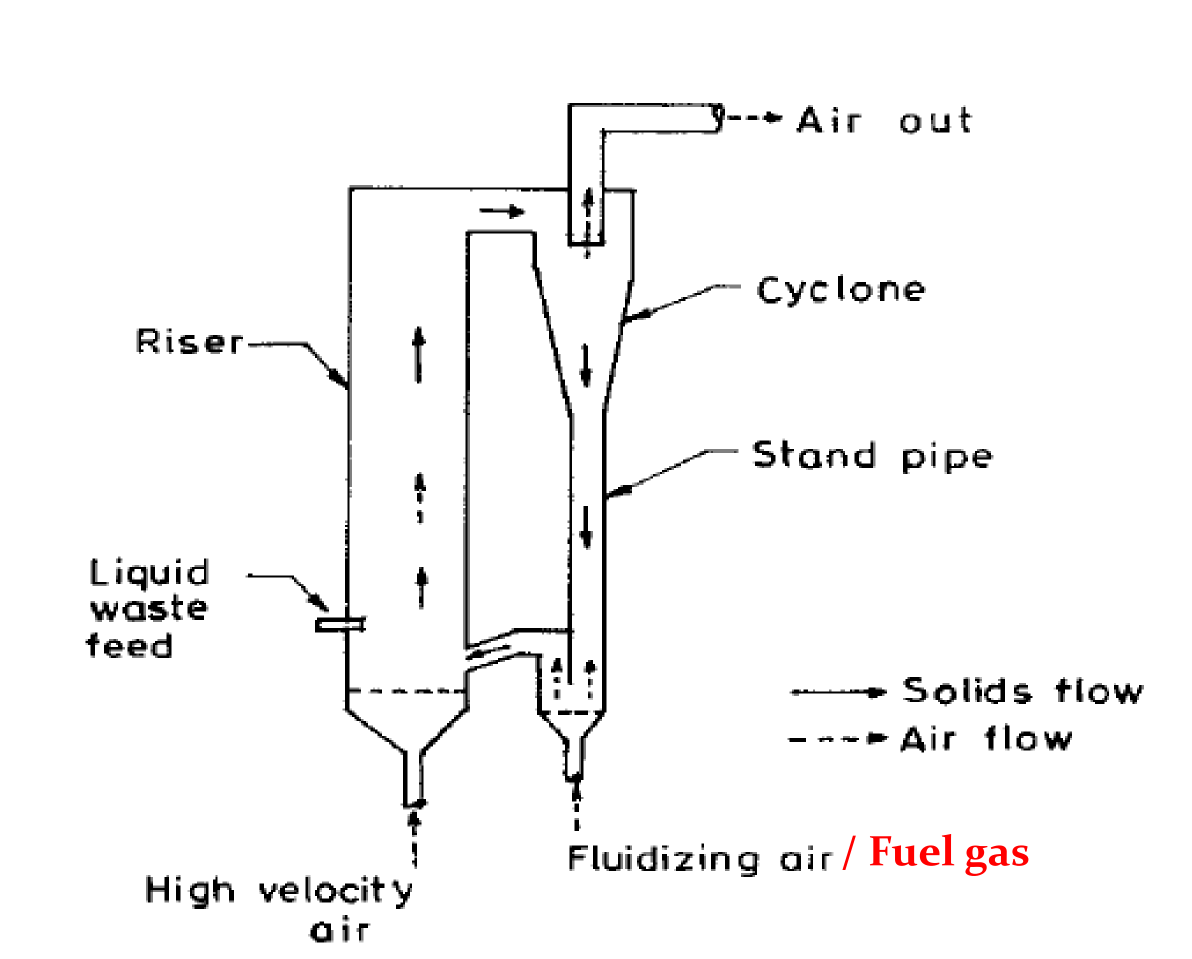


Batch fluidized bed reactor of stainless steel working in the low velocity and high velocity cycles.

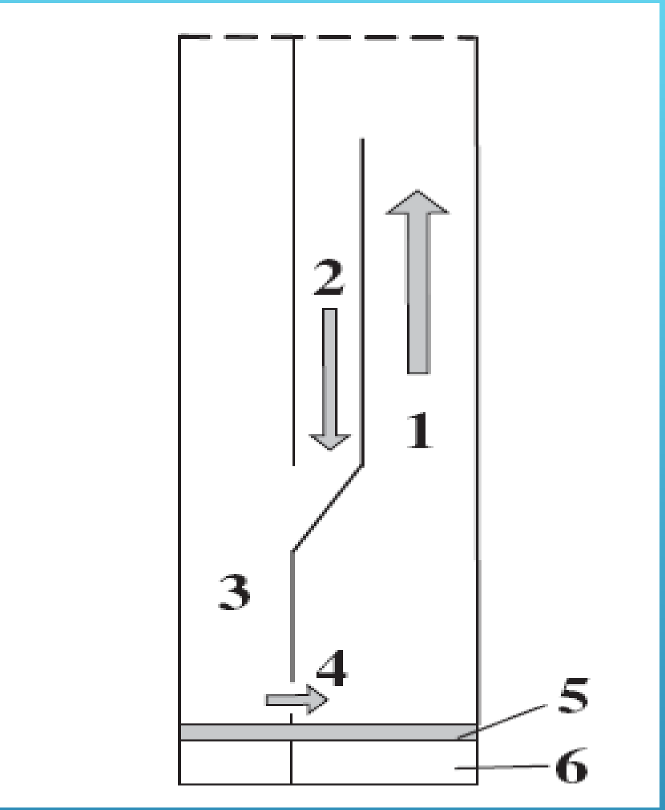
(Hoteit, A.; Chandel, M.K.; Durécu, S.; Delebarre, A. Biogas combustion in chemical looping fluidized bed reactor, *International Journal of Greenhouse Gas Control*. 2009, 3, 561-567)

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 to 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 add 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.
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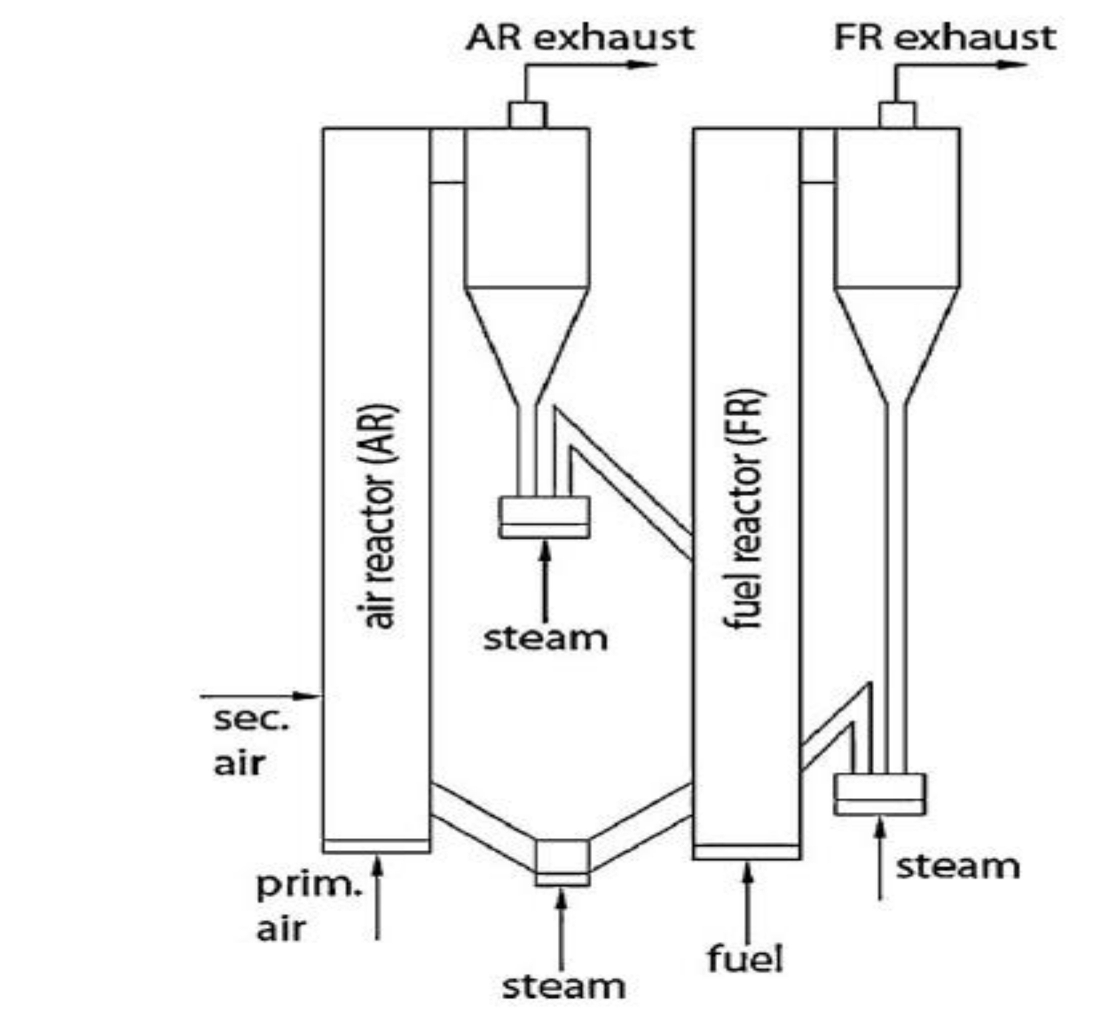


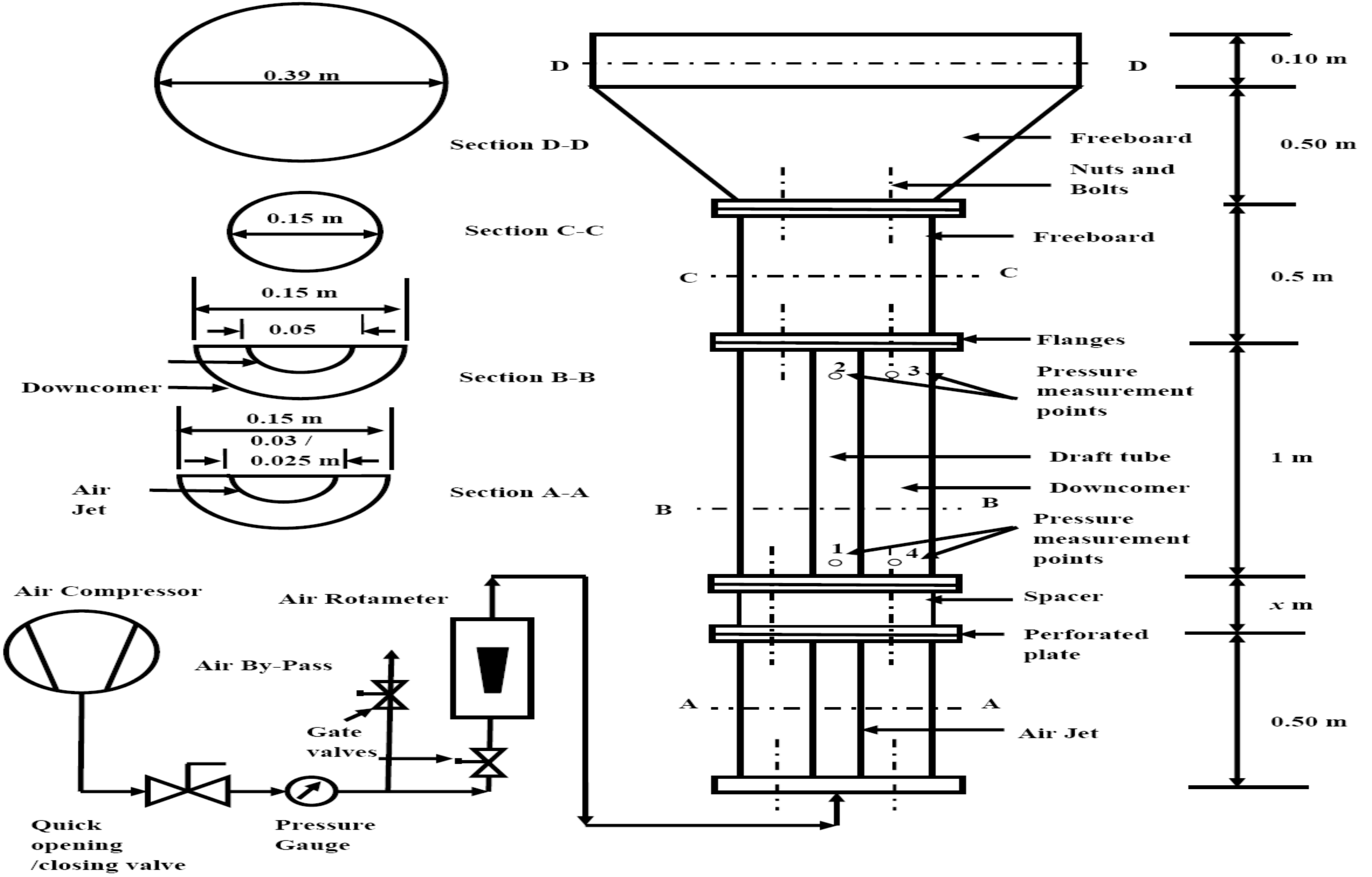
DUAL CIRCULATING FLUIDIZED BED REACTOR ARRANGEMENT.

(KOLBITSCH, P.; PRÖLL, T.; BOLHÀR-NORDENKAMPF, J.; HOFBAUER, H. DESIGN OF A CHEMICAL LOOPING COMBUSTOR USING A DUAL CIRCULATING FLUIDIZED BED REACTOR SYSTEM, *CHEMICAL ENGINEERING AND TECHNOLOGY*. 2009, 32(3), 398-403.)

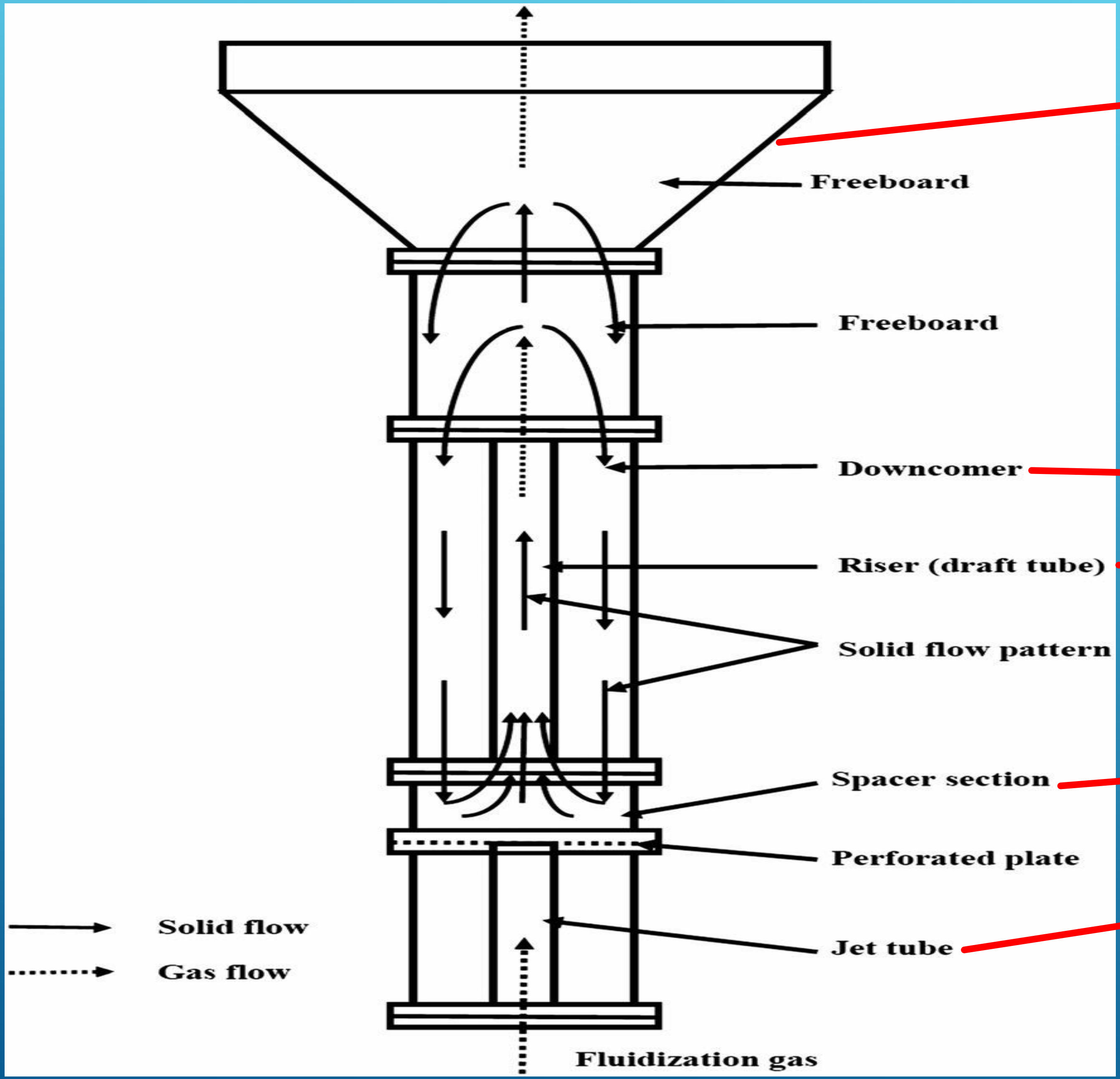
SOME OF THE ISSUES THAT CAN CROP-UP IN THE CLC

- 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.

EXPERIMENTAL SET UP



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).

Sr. No.	Sand Grade	Geldart's Classification	Average Particle Size (mm)
1.	Grade I (2mm – 1mm)	D	1.3
2.	Grade II (1 mm – 0.5 mm)	B	0.5
3.	Grade III (0.5mm – 0.09mm)	B	0.35

SCHEME OF COLD MODEL EXPERIMENTS

Test Series	Jet tube diameter (m)	Spacer section (m)	Sand Grade	Inventory (kg)
1	0.025	0.03	I	4, 6, 8, 9
2	0.025	0.08	I	6, 8, 9
3	0.025	0.15	I	8, 9, 10
4	0.025	0.03	II	4, 6, 8, 9
5	0.025	0.08	II	6, 8, 9
6	0.025	0.15	II	8, 9, 10
7	0.025	0.03	III	4, 6, 8, 9
8	0.025	0.08	III	6, 8, 9

SCHEME OF COLD MODEL EXPERIMENTS

9	0.025	0.15	III	8, 9, 10
10	0.03	0.03	I	4, 6, 8, 9
11	0.03	0.08	I	6, 8, 9
12	0.03	0.15	I	8, 9, 10
13	0.03	0.03	II	4, 6, 8, 9
14	0.03	0.08	II	6, 8, 9
15	0.03	0.15	II	8, 9, 10
16	0.03	0.03	III	4, 6, 8, 9
17	0.03	0.08	III	6, 8, 9
18	0.03	0.15	III	8, 9, 10

IMPORTANT PARAMETERS FOR CLC

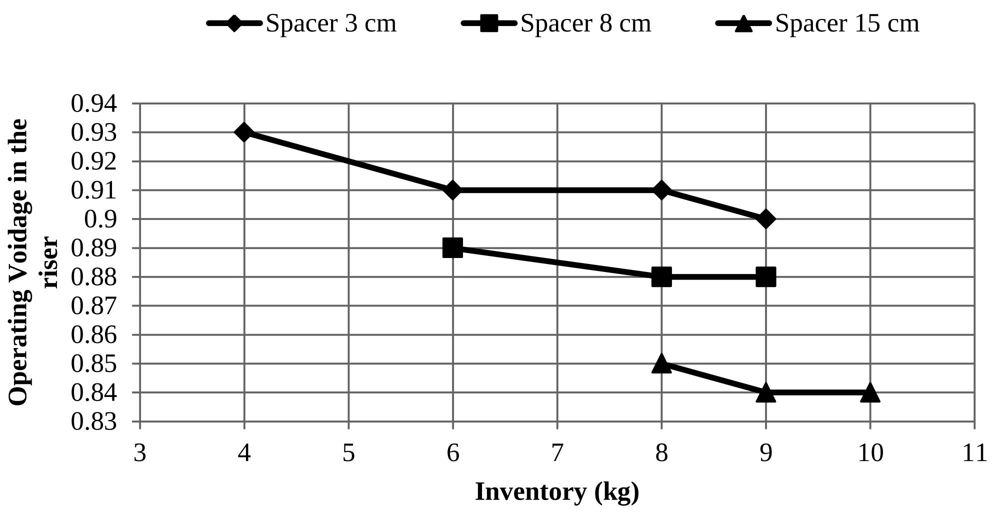
- Regime of Fluidization for air reactor and fuel reactor – affect the residence time.
- Operating Voidage – heat transfer
- Residence time – fuel conversion
- Particle Size – conversion
- Solid circulation rate – uniform bed temperature

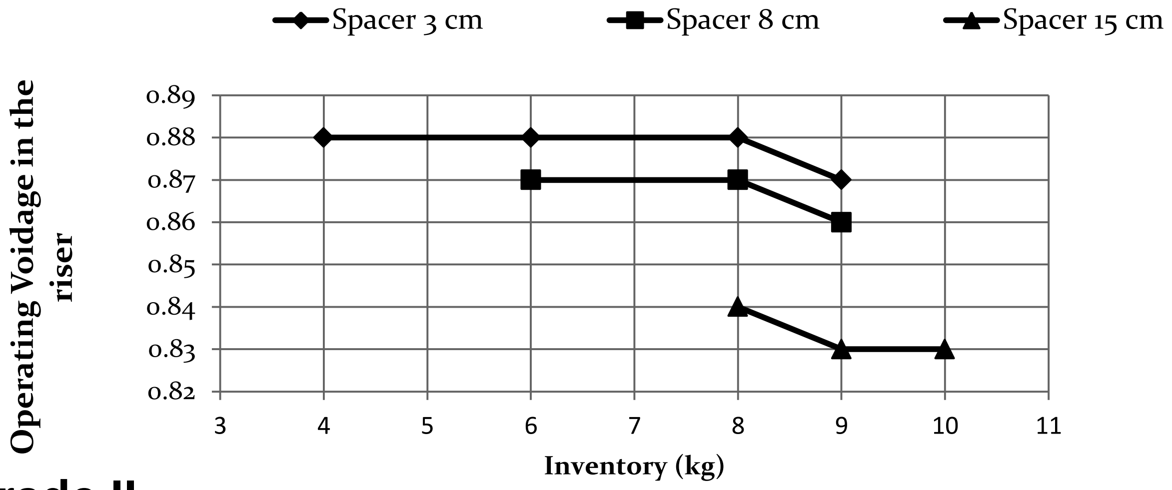
OPERATING VOIDAGE VARIATION IN THE RISER

2.5 cm jet tube section

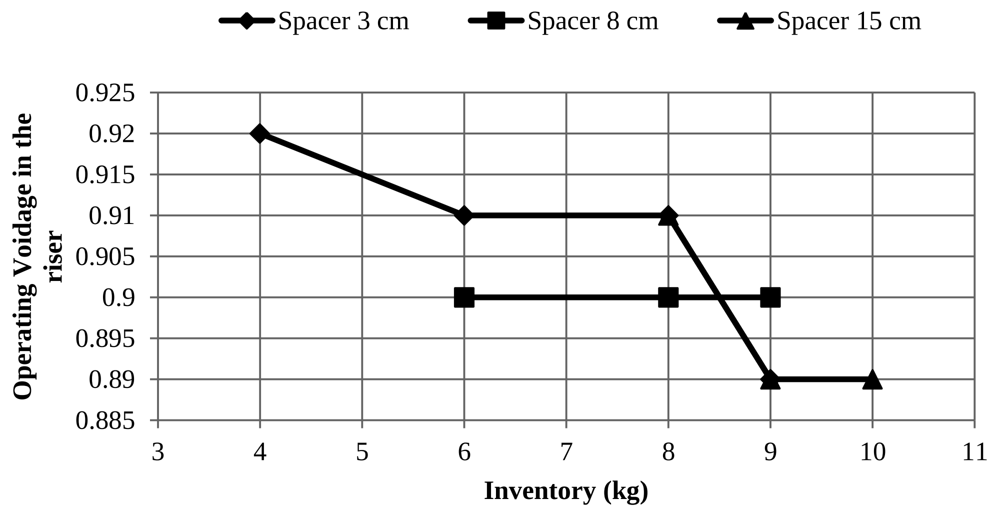
Sand Grade I

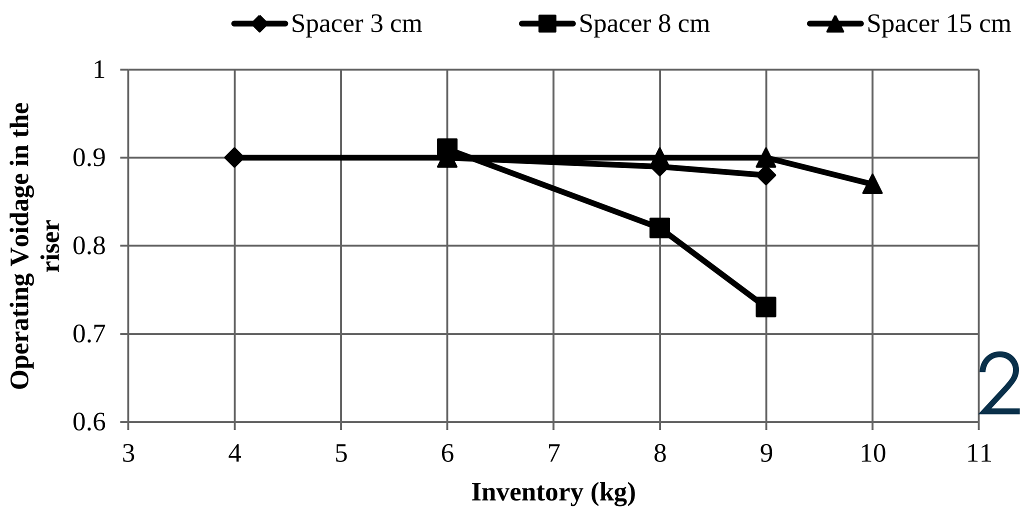
3 cm jet tube section





Sand Grade II



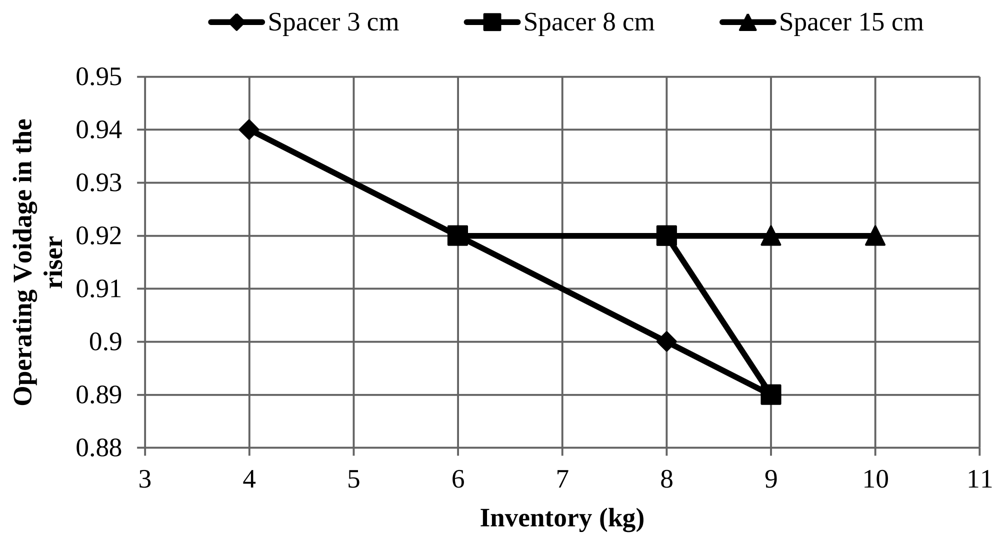


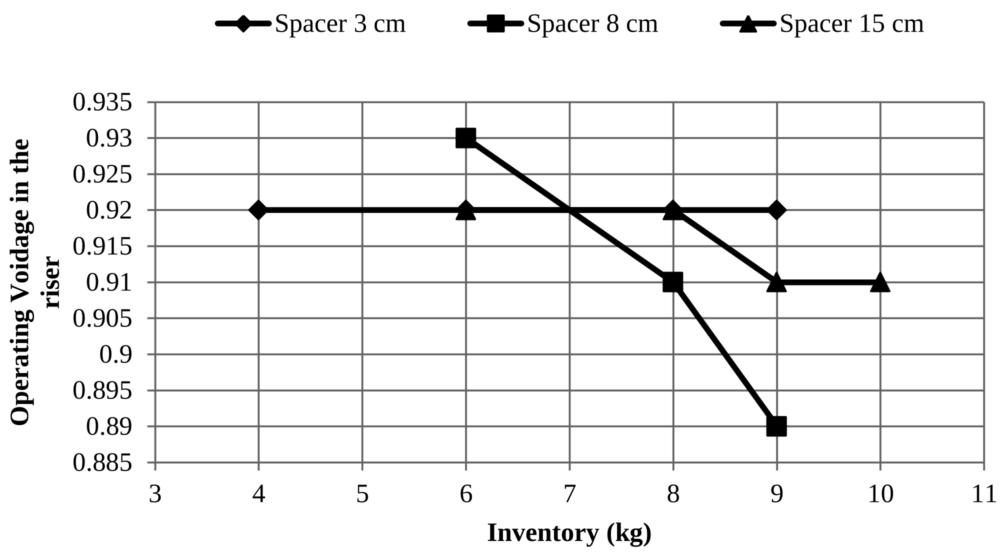
OPERATING VOIDAGE VARIATION IN THE RISER

2.5 cm jet tube section

3 cm jet tube section

Sand Grade III



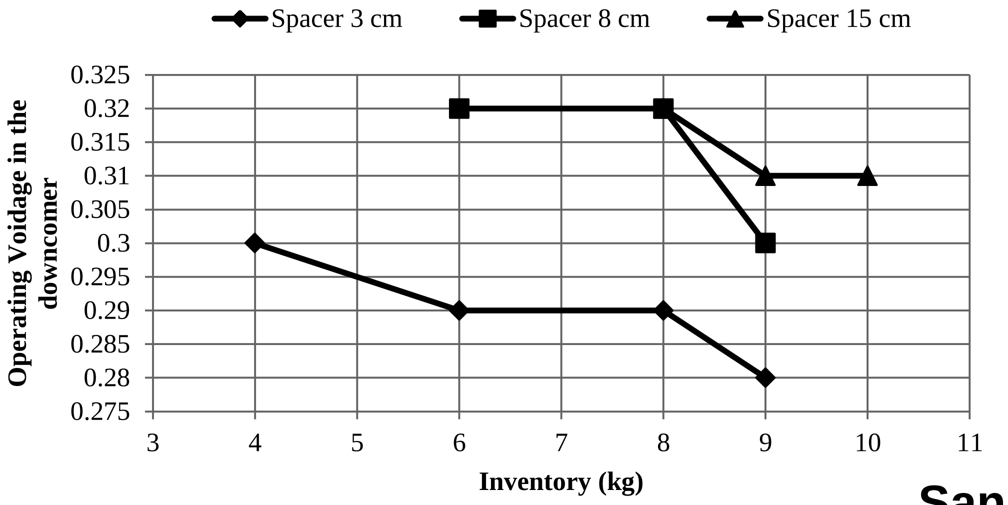


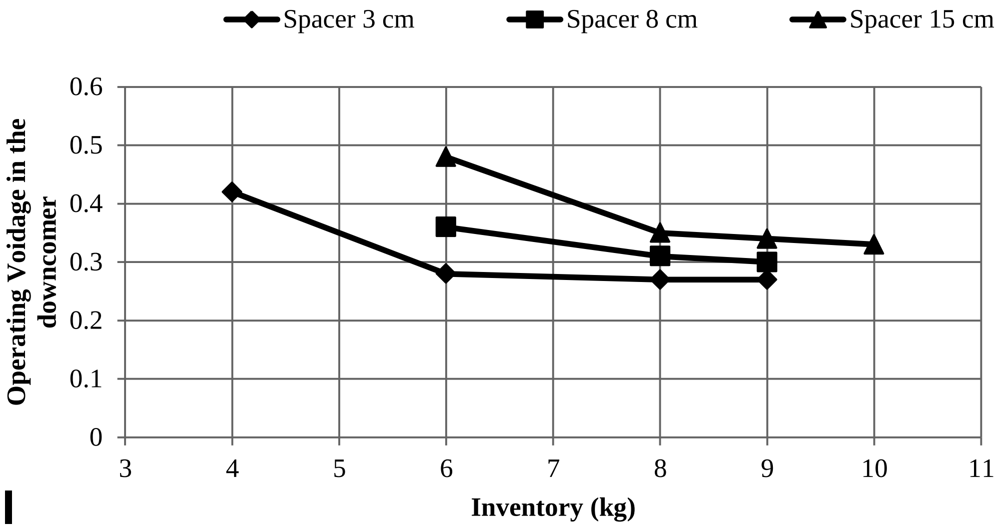
OPERATING VOIDAGE VARIATION IN THE DOWNCOMER

2.5 cm jet tube section

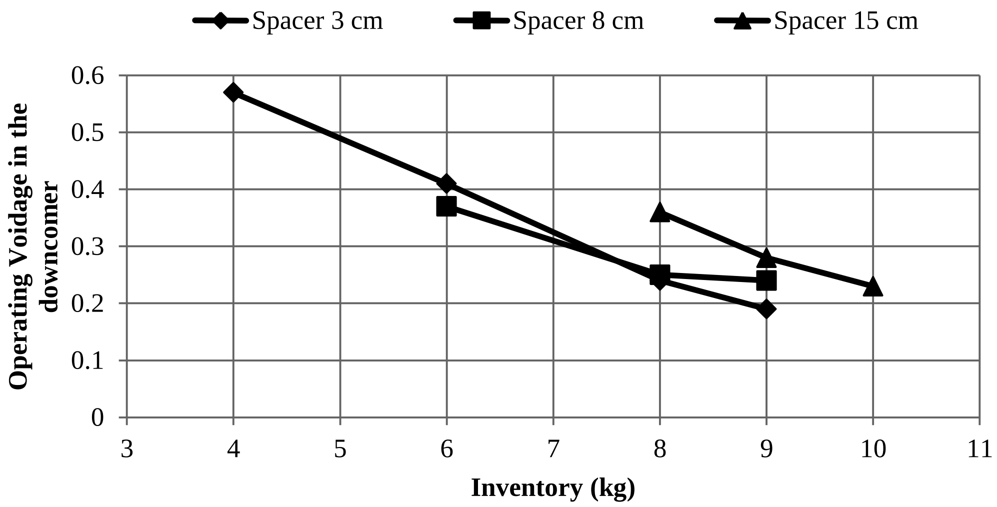
Sand Grade I

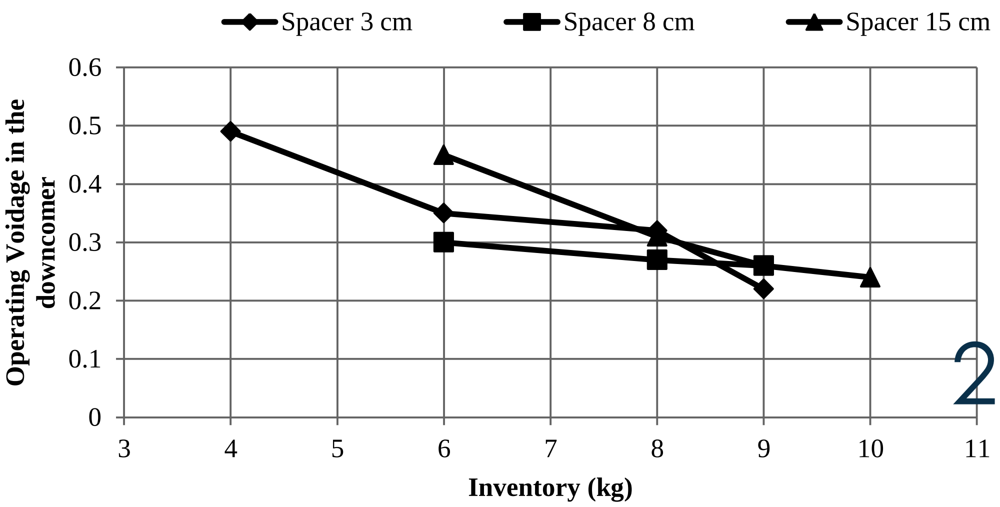
3 cm jet tube section





Sand Grade II



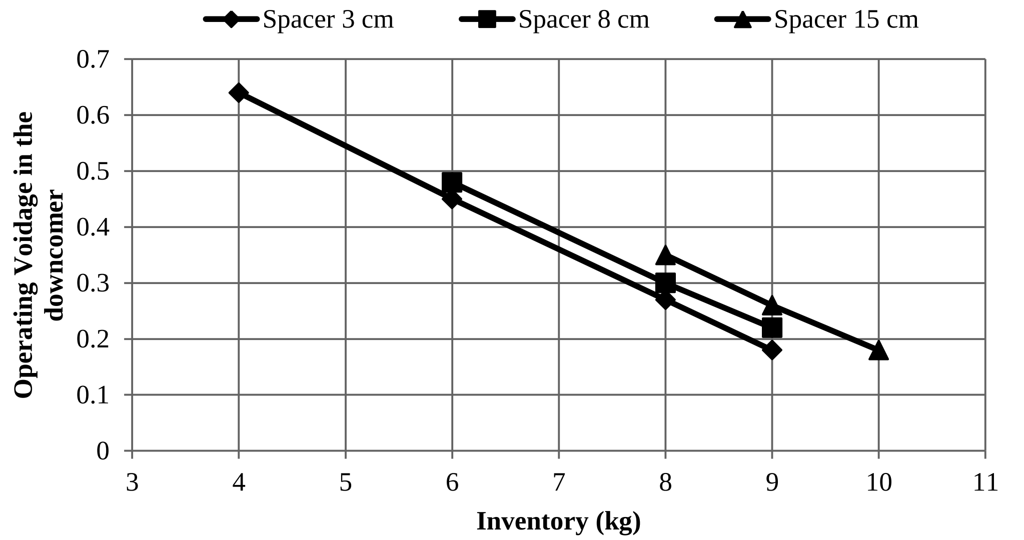


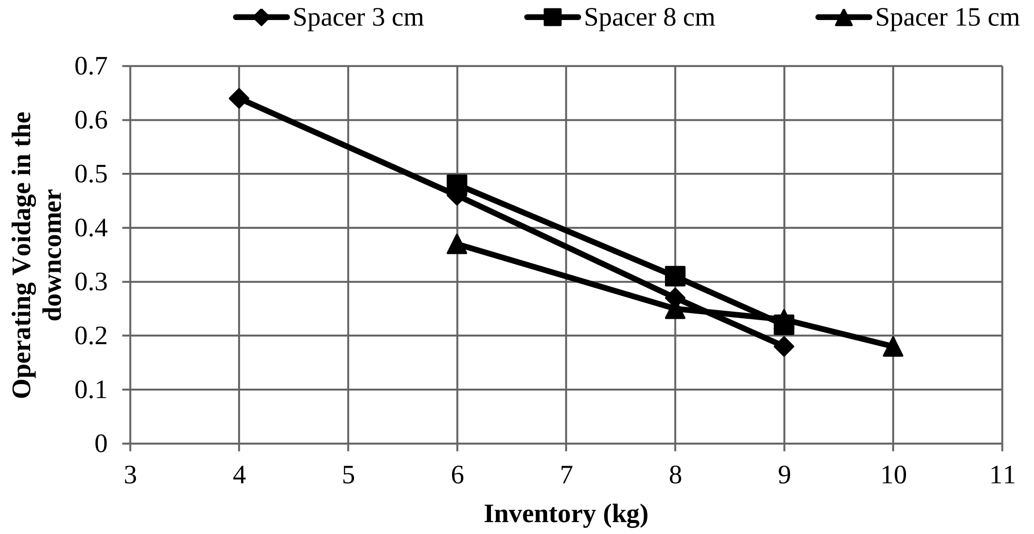
OPERATING VOIDAGE VARIATION IN THE DOWNCOMER

2.5 cm jet tube section

3 cm jet tube section

Sand Grade III



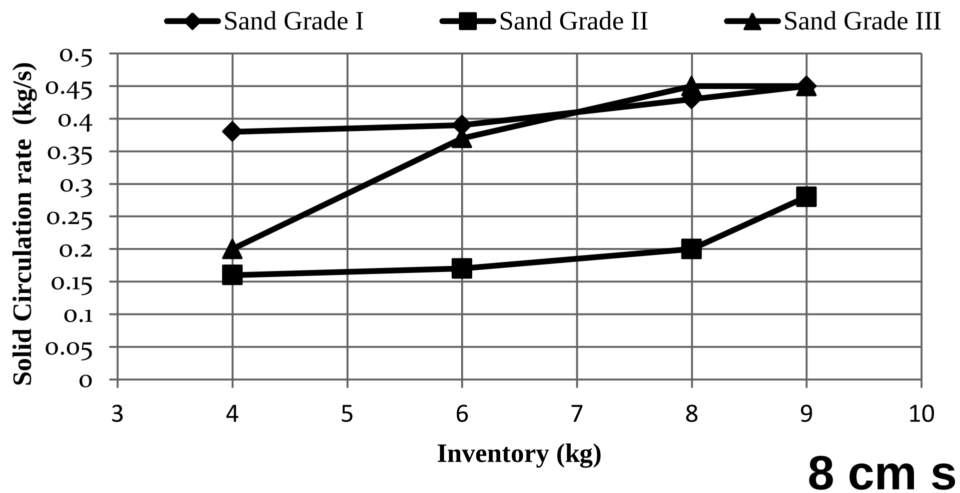


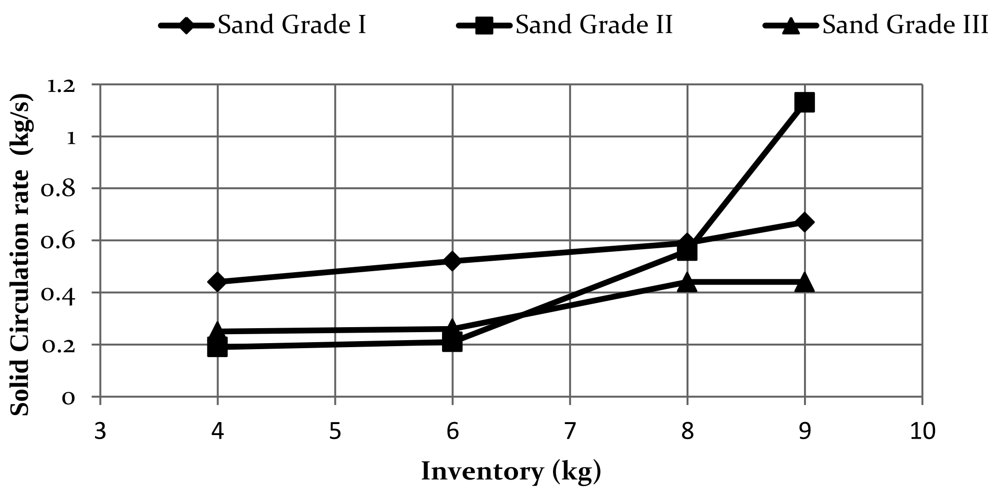
SOLID CIRCULATION RATE VARIATION

2.5 cm jet tube section

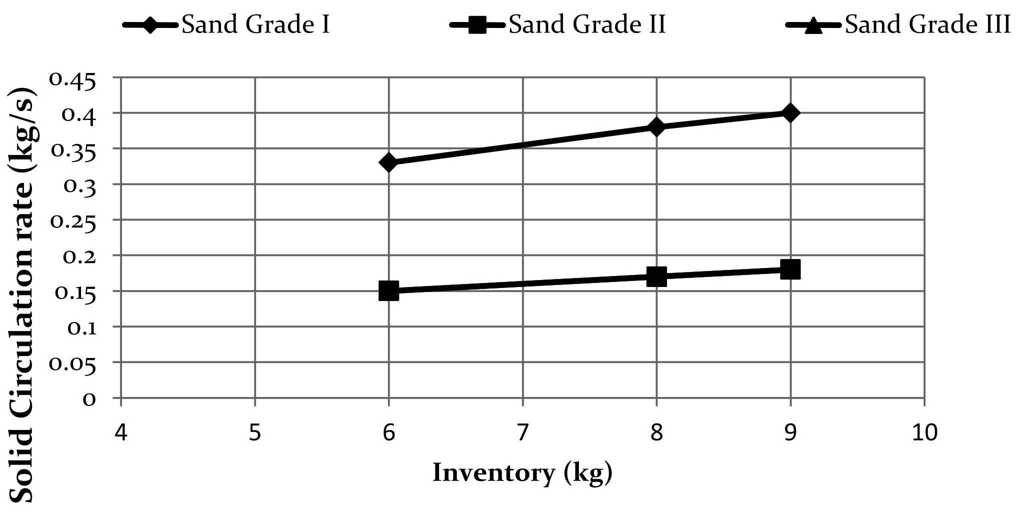
3 cm spacer section

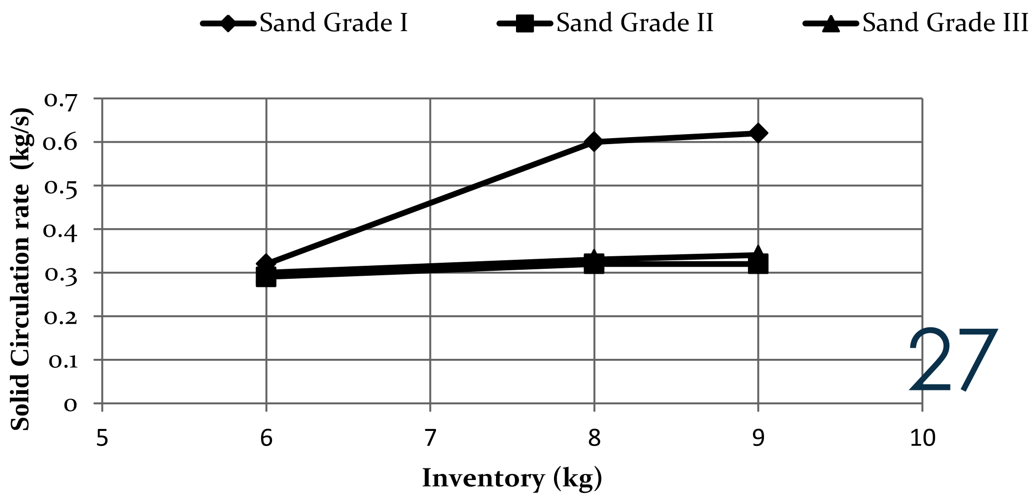
3 cm jet tube section





8 cm spacer section



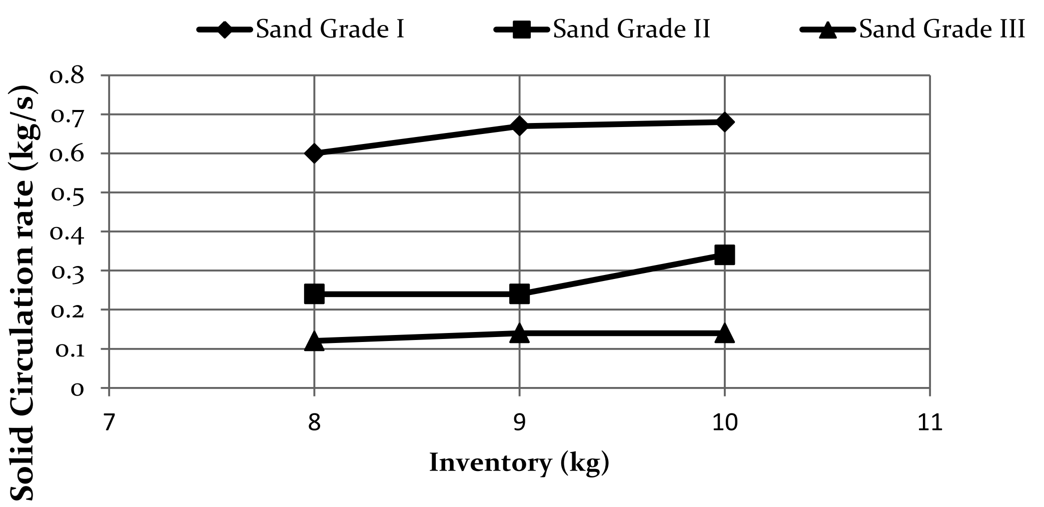


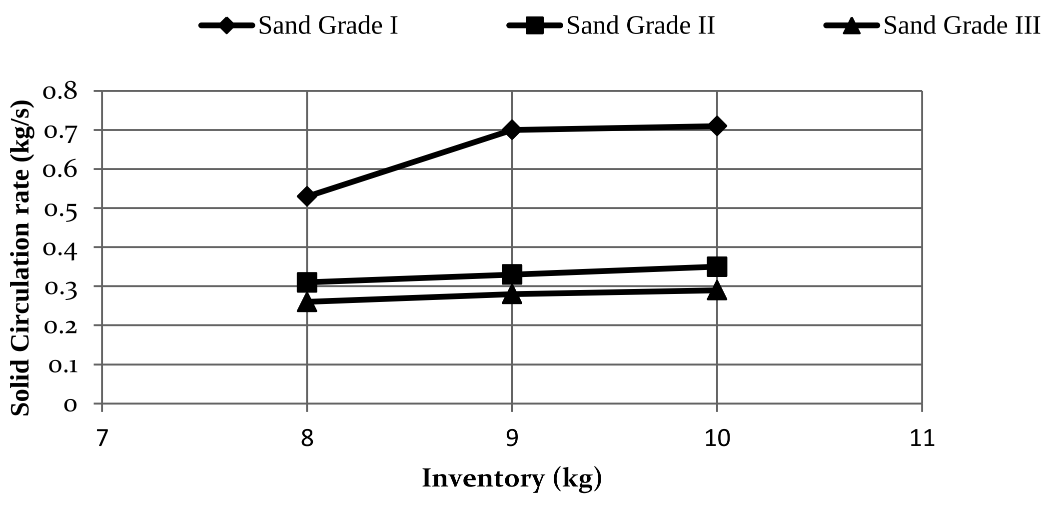
SOLID CIRCULATION RATE VARIATION

2.5 cm jet tube section

3 cm jet tube section

15 cm spacer section



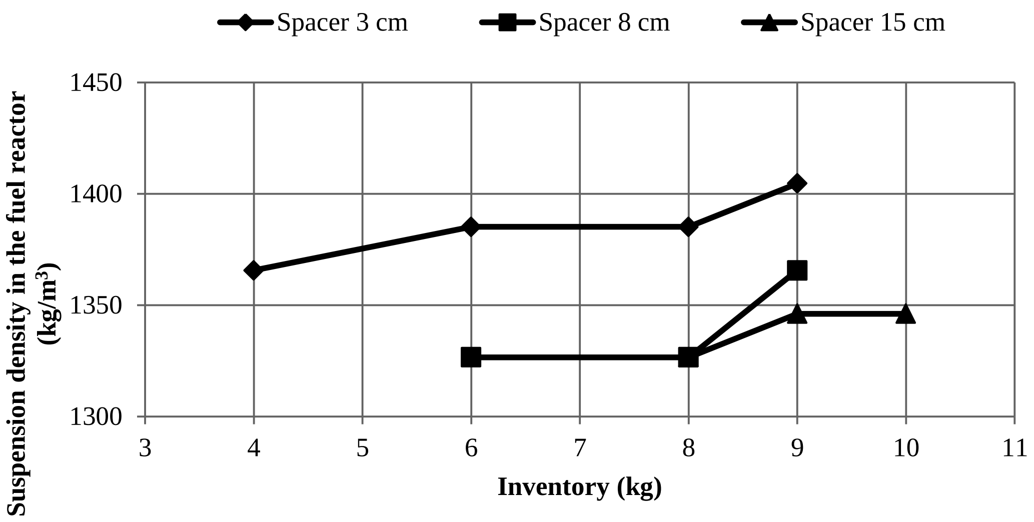


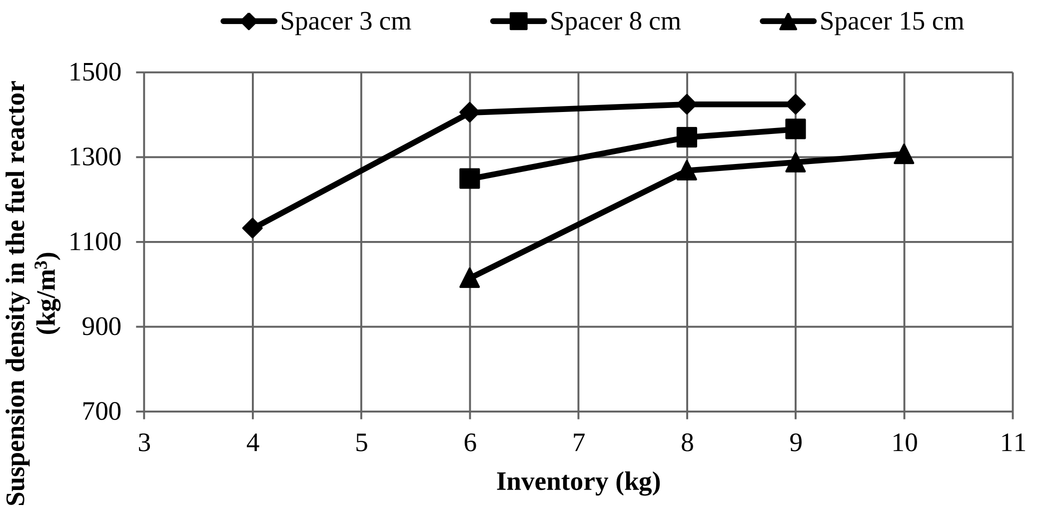
SUSPENSION DENSITY VARIATION IN THE DOWNCOMER/FUEL REACTOR

2.5 cm jet tube section

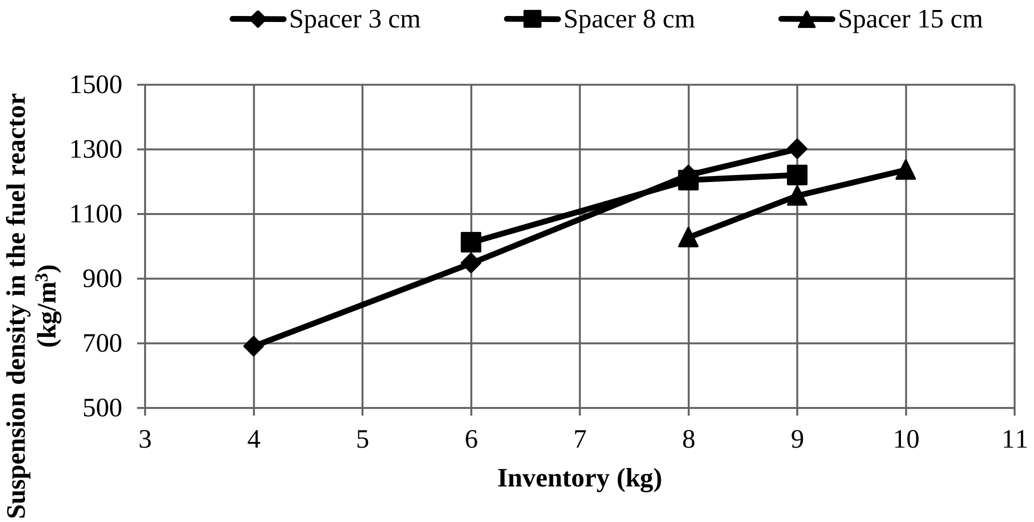
Sand Grade I

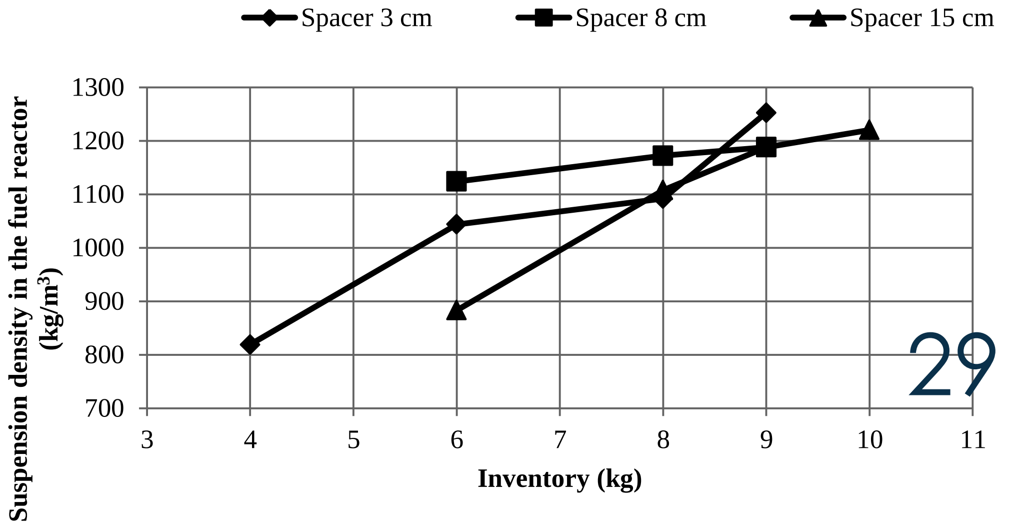
3 cm jet tube section





Sand Grade II



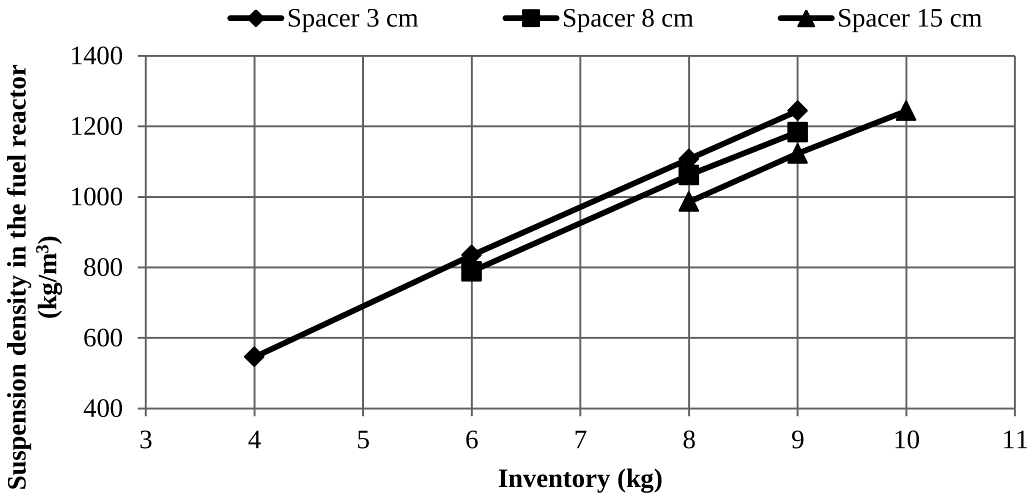


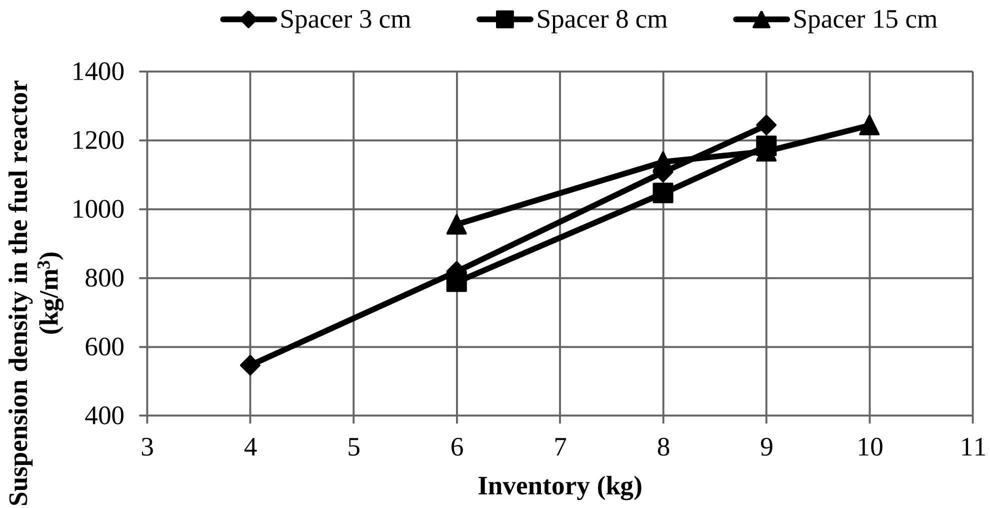
SUSPENSION DENSITY VARIATION IN THE FUEL REACTOR/DOWNCOMER

2.5 cm jet tube section

3 cm jet tube section

Sand Grade III





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 N_2 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