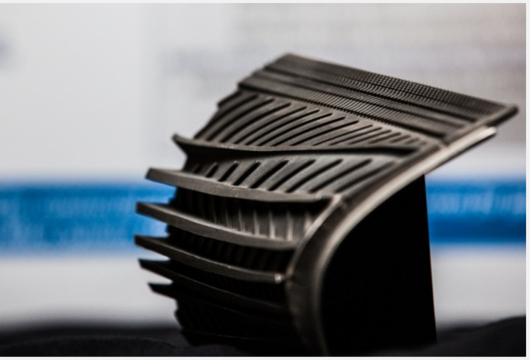
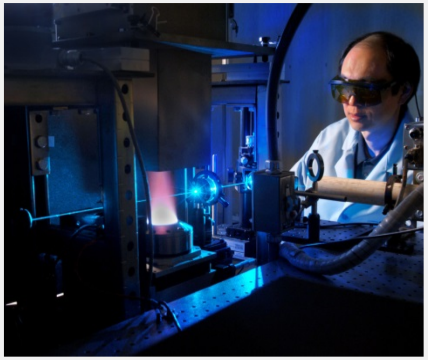
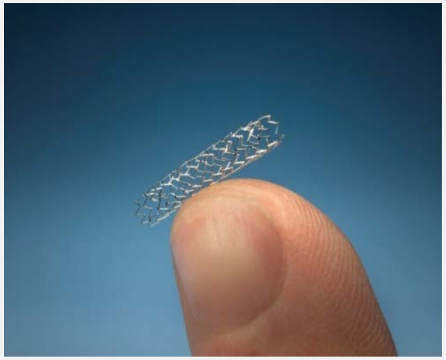
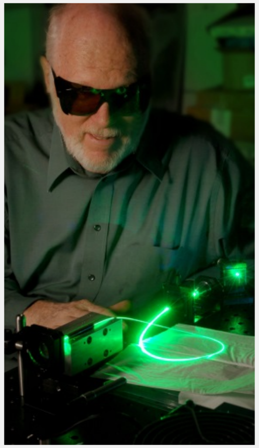
Driving Innovation ◆ Delivering Results


Development of a Carbon Stripper Particle Separation System for Chemical Looping Applications

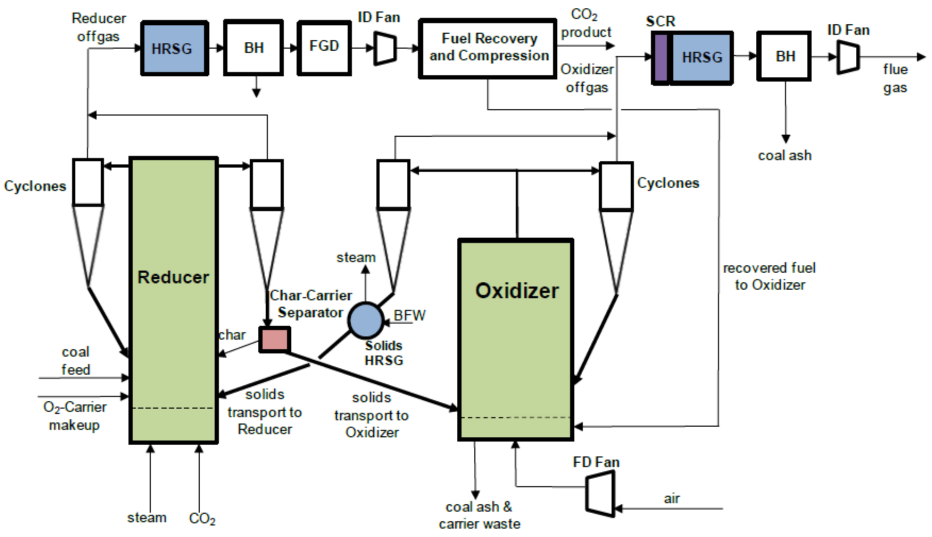
Ronald Breault, Steven Rowan, Richard Stehle, and Michael Bobek

The 41st International Technical Conference on Clean Coal & Fuel Systems

June 5-9, 2016

Chemical Looping Combustion (CLC)

- Chemical looping combustion (CLC)
- CLC Reactor Configuration.
  - Reducer (Fuel Reactor):
    - Oxygen Carrier (OC) is reduced
    - Coal is combusted
    - Concentrated CO_2 stream produced.
  - Oxidizer (Air Reactor):
    - Spent OC is re-oxidized.
- Concentrated CO_2 stream from reducer easily captured for re-use or sequestration.



*Conceptual Block Diagram of CLC Power Plant**

*Stevens, R., Newby, R., Shah, V., Kuehn, N., Keairns, D., Guidance for NETL's Oxycombustion R&D Program: Chemical Looping Combustion Reference Plant Designs and Sensitivity Studies, DOE/NETL-2014/1643. Dec. 19, 2014.

Economic Assessment of Chemical Looping Combustion

Operating Cost Comparison:

- Fe_2O_3 – 84% CPC BBR Cost
- $CaSO_4$ – 76% CPC BBR Cost

Exhibit 5-4 Cost of electricity breakdown comparison

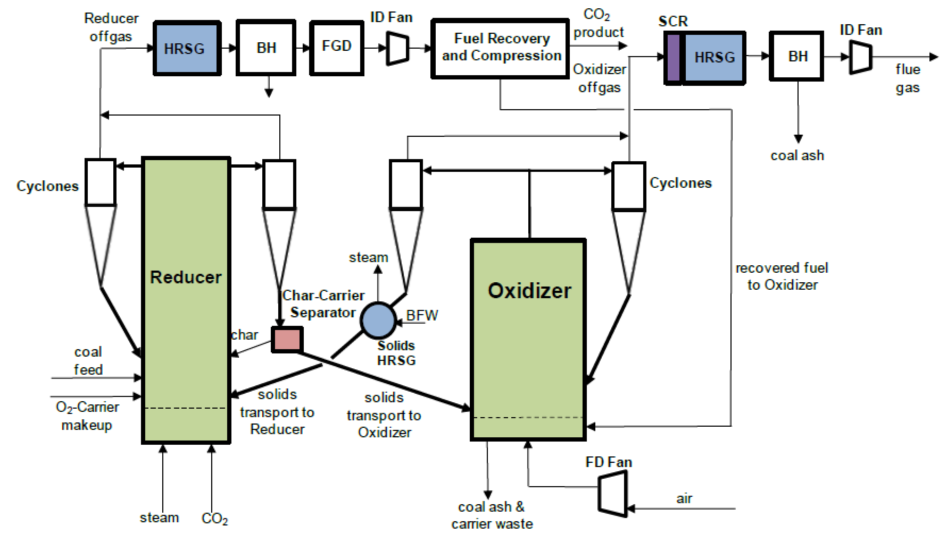
Cost	Fe_2O_3 ($/MWh)	$CaSO_4$ ($/MWh)	Conventional PC BBR Case 12
Capital	49.6	53.4	73.1
Fixed	11.3	12.2	15.7
Variable	25.7	8.4	13.2
Maintenance materials	3.2	3.5	4.7
Water	0.4	0.4	0.9
Carrier makeup*	18.7	1.1	N/A
Other chemicals & catalyst	1.9	1.7	6.4
Waste disposal	1.5	1.7	1.3
Fuel	28.6	30.8	35.3
Total	115.2	104.7	137.3

*Fe_2O_3 oxygen carrier makeup: 123 tons/day @ $2,000 per ton; Limestone carrier makeup: 425 tons/day @ $33.5 per ton

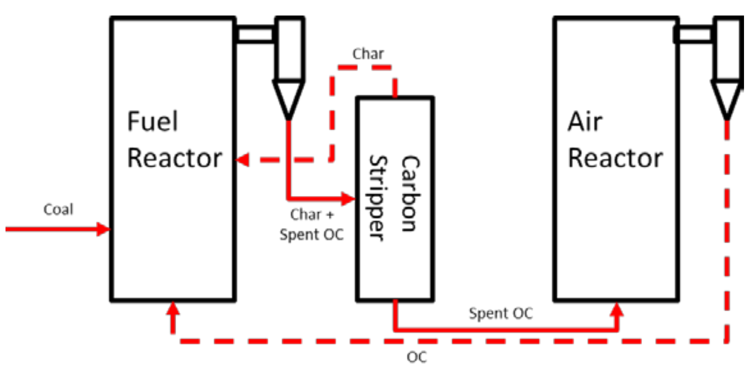
*Stevens, R., Newby, R., Shah, V., Kuehn, N., Keairns, D., Guidance for NETL's Oxycombustion R&D Program: Chemical Looping Combustion Reference Plant Designs and Sensitivity Studies, DOE/NETL-2014/1643. Dec. 19, 2014.

Technological Need or Issue

- The deployment of CLC technology is dependent upon successful development of a char-carrier separator.
- Without successful separation of char from the oxygen carrier, CO_2 will not occur*.
- The char-carrier separator:
  - Separates char from spent carrier.
  - Returns recovered char to Reducer.
  - Feeds Carrier to Oxidizer.



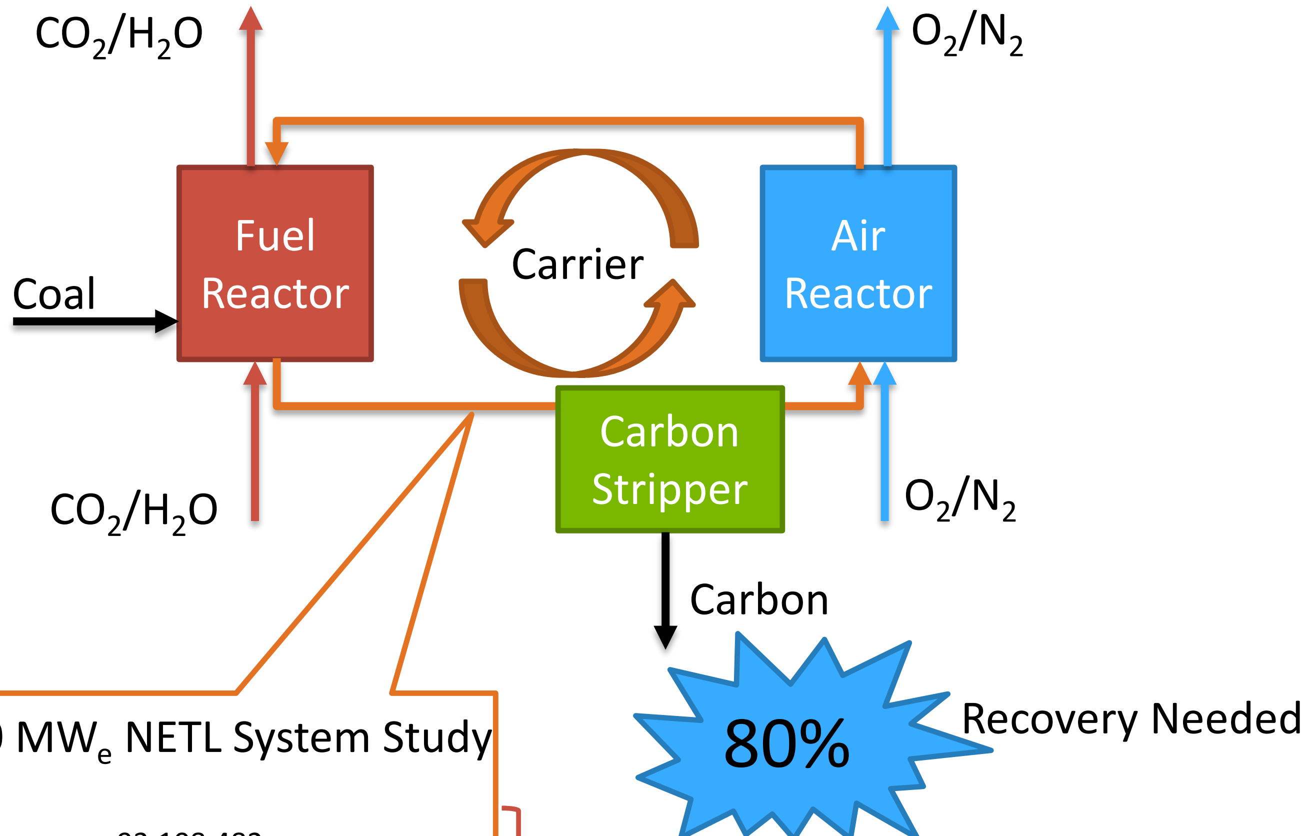
*Conceptual Block Diagram of CLC Power Plant**



Conceptual Diagram of CLC Reactor System with Carbon Stripper Unit

*Stevens, R., Newby, R., Shah, V., Kuehn, N., Keairns, D., Guidance for NETL's Oxycombustion R&D Program: Chemical Looping Combustion Reference Plant Designs and Sensitivity Studies, DOE/NETL-2014/1643. Dec. 19, 2014.

Char-Carrier Separator Requirements



550 MW_e NETL System Study

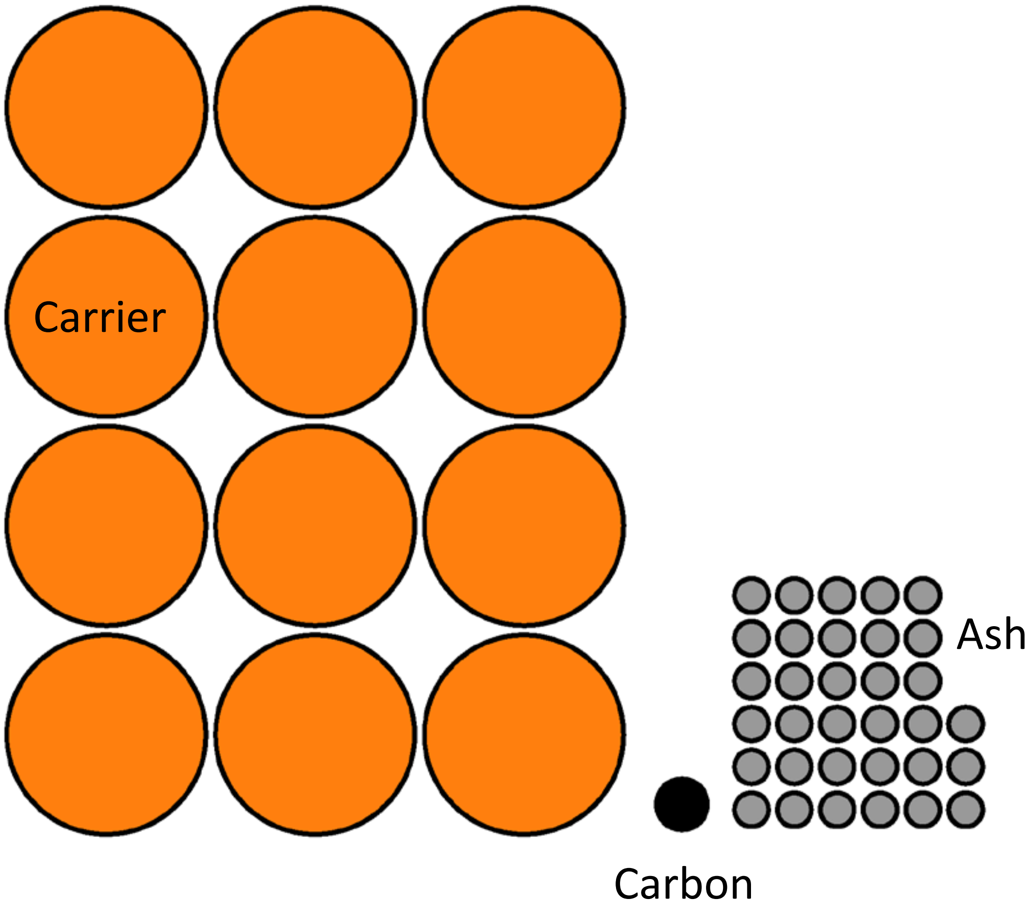
Carrier	93,108,482	
Carbon	58,332	
Ash	449,186	
Total	93,616,000	lbs/hr

$0.06\%_w$ Carbon!

$0.14\%_v$

Lets put it into perspective

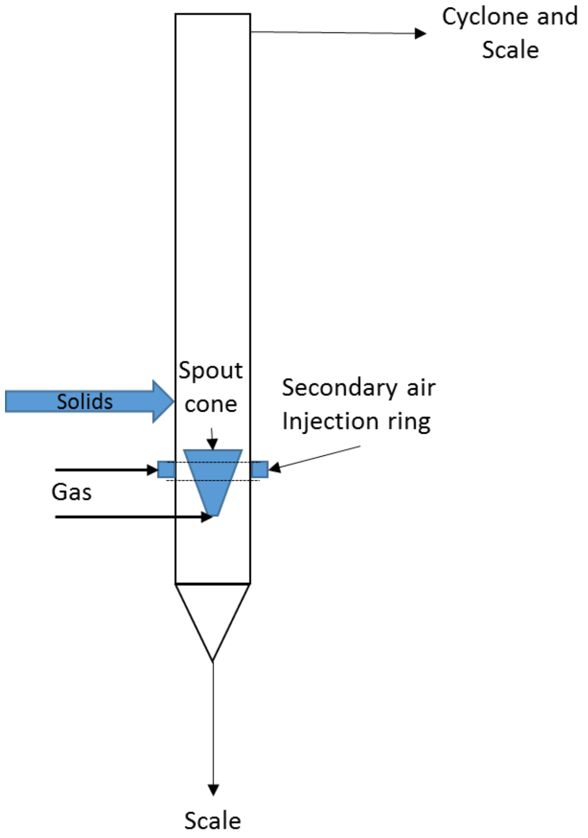
- **Need to collect**
  - 46,668 lbs out of 58,332 lb carbon going to Air reactor
  - 46,669 lbs out of 93,569,003 lbs of all material
  - Or 8 out of every 10 carbon particles going to the air reactor.



Spouted Bed Carbon Stripper

A Spouted Bed Carbon Stripper is under development at NETL.

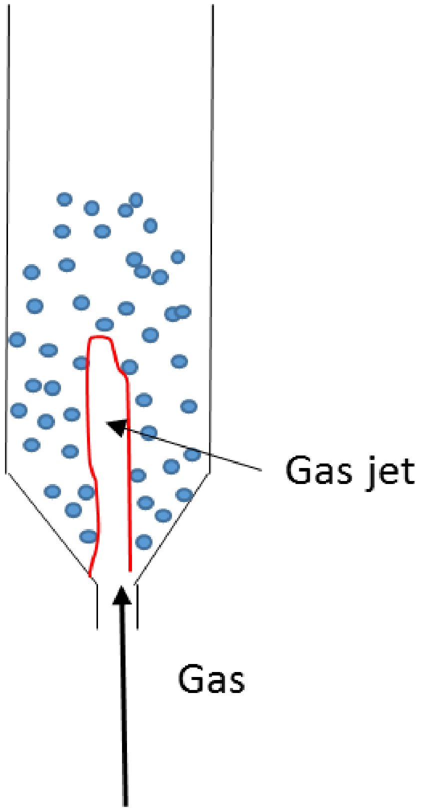
- System Highlights:
  - Spouted bed
  - Annular gap between inner wall and spout cone for carrier extraction.
  - Sweep gas within annular gap aids in separation.
  - Char removed via elutriation.



Carbon Stripper System Diagram

Spouted Bed Fundamentals

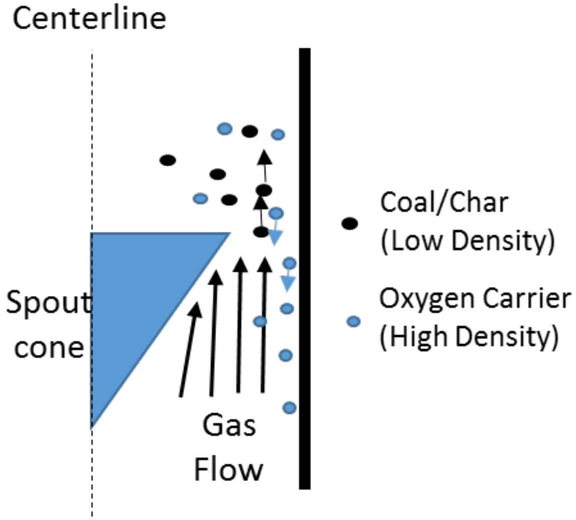
- **General Spouted Bed Features:**
  - For not easily fluidized materials
  - Gas jet pushes particles upwards.
  - Particles ejected into freeboard.
  - Particles outside gas jet move down until entrained upwards.
  - Particles ejected from bed either fall back into bed or are carried out with gas, depending upon particle terminal velocity.



Conceptual diagram of spouted bed showing gas jet.

Separation Mechanism

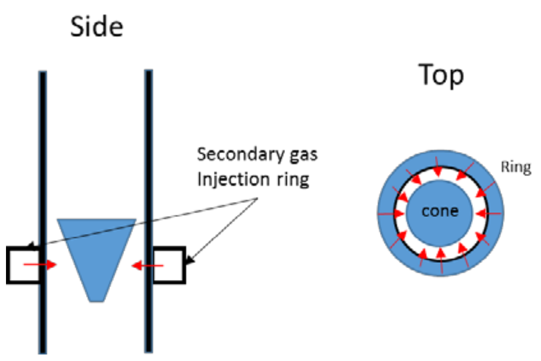
- **Particle Separation Mechanism (annular gap + sweep gas):**
  - Spouting will cause particles to move towards the annular gap.
  - Velocity of sweep gas in gap is between the terminal velocity of the oxygen carrier and char particles.
  - The oxygen carrier particles fall through gap.
  - The char particles blown out of gap and can be entrained out of the bed.



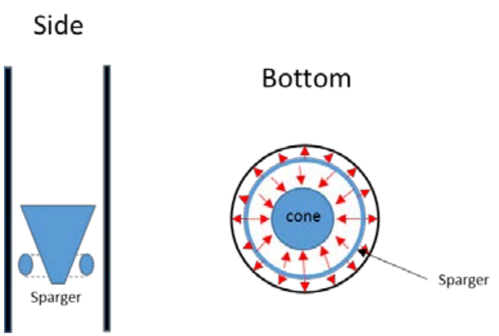
Particle separation mechanism

Possible System Configurations

- **Planned Configurations:**
  - Sweep gas injected radially inward through riser walls. (top)
  - Sweep gas injected through ring-shaped sparger located within the riser. (bottom)



Injection ring as secondary gas source (gas flow shown in red)



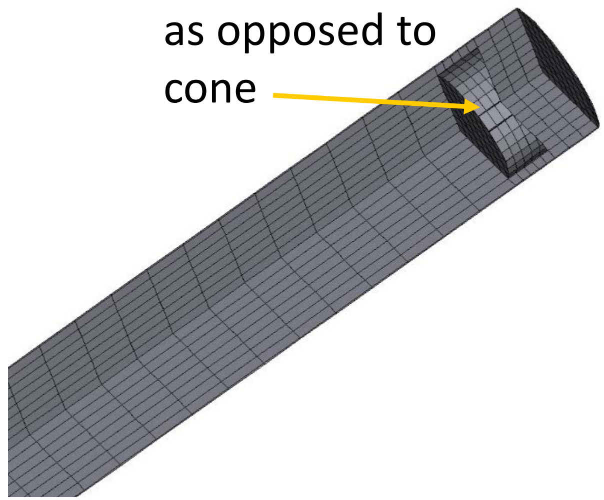
Sparger as secondary gas source (gas flow shown in red)

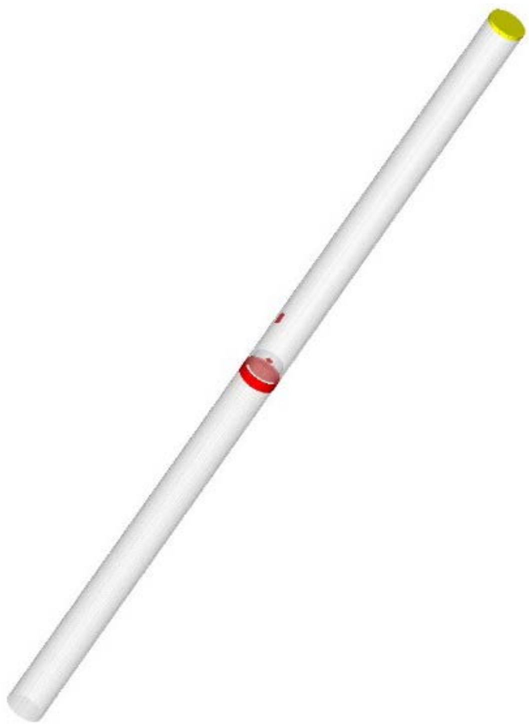
Quick – Simple Concept Validation

- **Set-up a simple Barracuda Model**
- **Look at the effect of**
  - Spout Velocity
  - Annulus Velocity
  - Particle Size

Barracuda Model – Geometry and Boundary Conditions

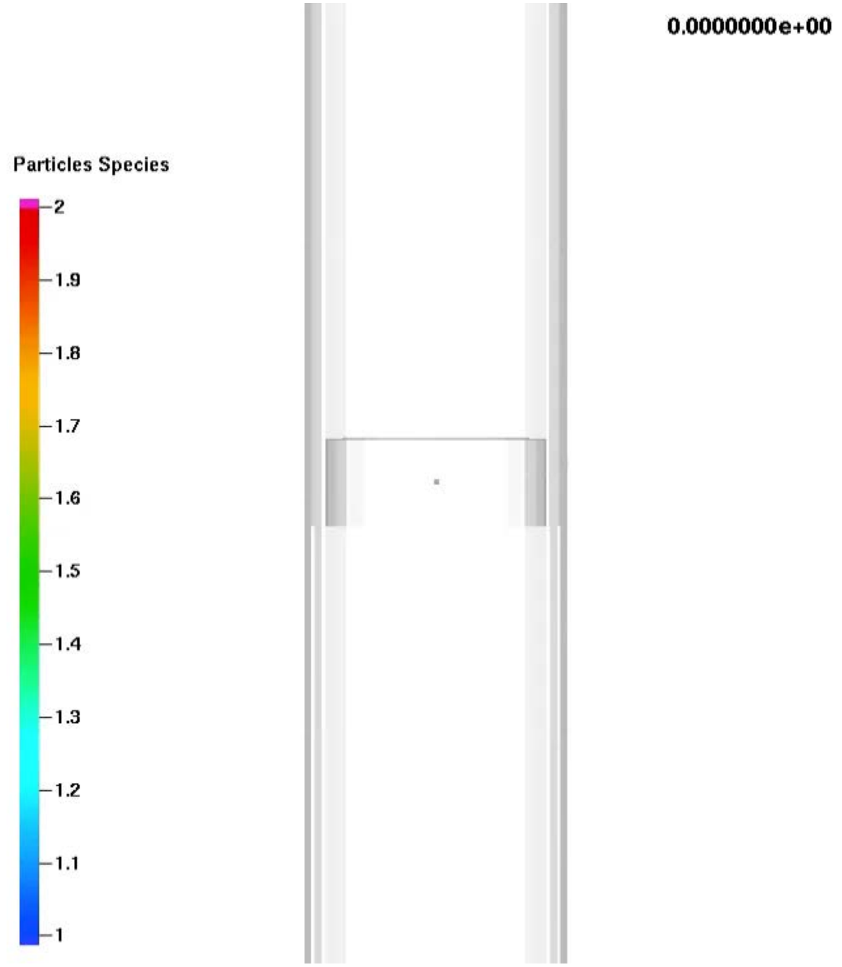
Simple cylinder as opposed to cone





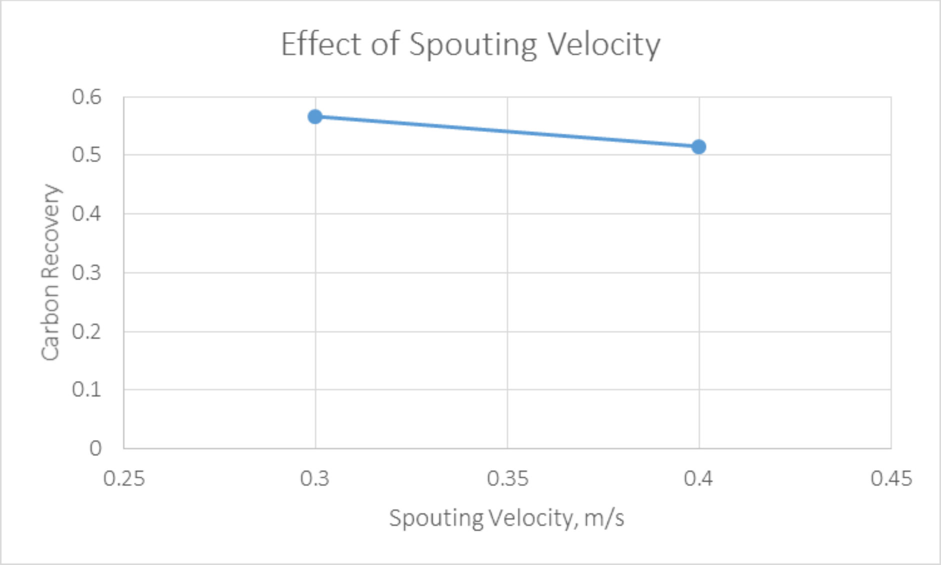
Simulation Operation/Results

- **Solids feed flows toward observer**
- **About 50% carbon recovery with this simplified geometry**



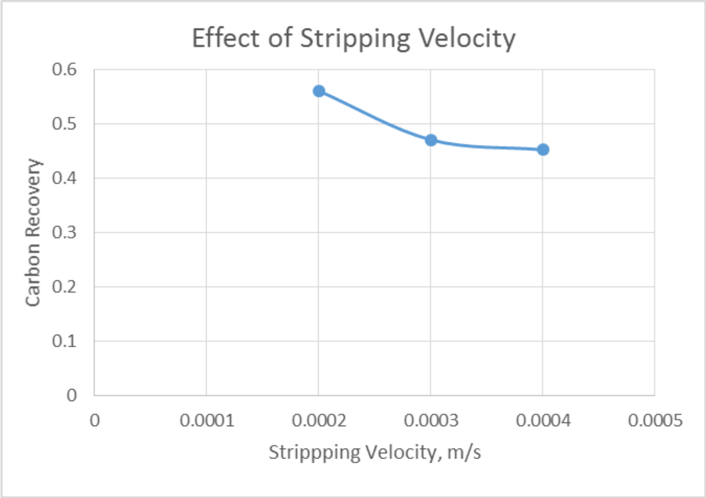
Simulation Results – Spout Velocity

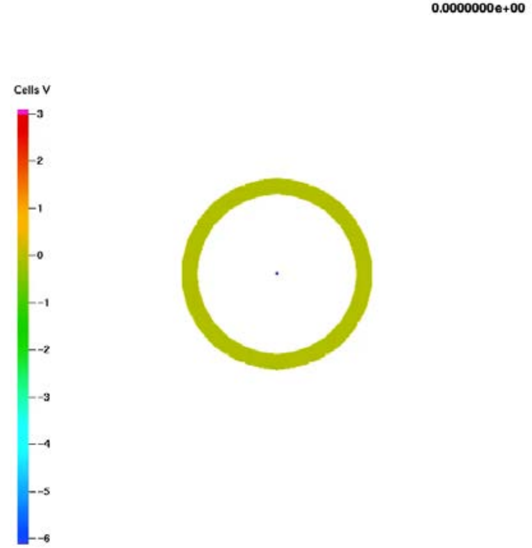
- **Increasing the spouting jet velocity decreases the carbon recovery**
  - Increased jet flow broadens the central spout diameter
  - This pushes all solids towards the wall
  - Resulting in more carbon falling through the annulus.



Simulation Results – Stripping Velocity

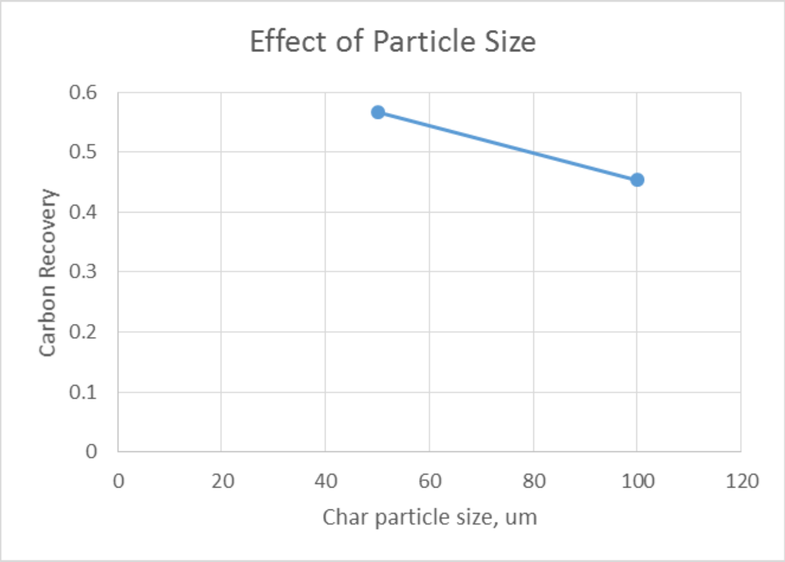
- **Counter to expectations – carbon recovery decreased with increasing gas flow**
- **This observation is credited to imbalances in annulus gas flow**
- **Correcting the flow imbalance should reverse this behavior**





Simulation Results – Char Size

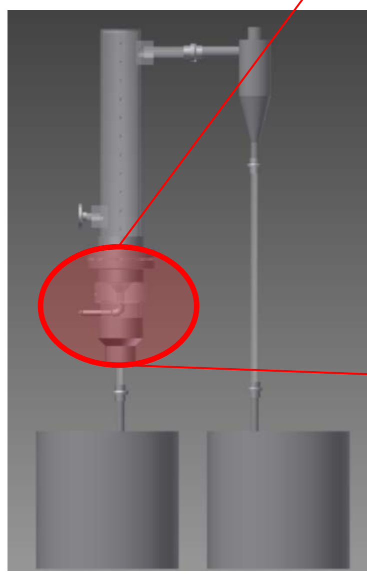
- **Increasing the carbon particle size reduces the effective carbon recovery at a fixed annulus stripping gas velocity.**
- **Additional modeling and or experiments will be conducted to assess the stripping gas flow rate.**



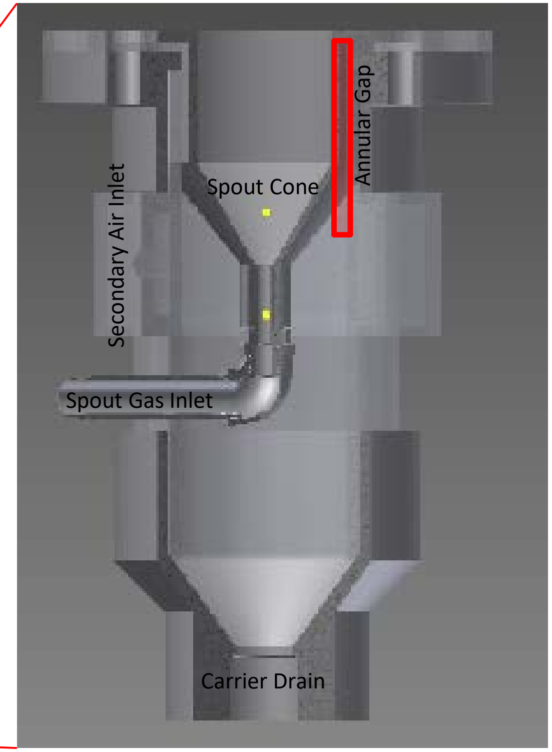
Experimental Prototype

A cold flow prototype is current under construction and will be use to study the effects of the following:

- Spout Velocity/Superficial Gas Velocity Ratios.
- Sweep Velocity
- Spout Cone Geometry
- Annular gap size
- Spout jet diameter



Carbon stripper unit.



Cutaway rendering of spout cone/separation region.

Summary

- Simulations in a simplified geometry show that about 60% recovery is possible
- Correcting imbalances in the stripping gas flow though the annulus should improve carbon recovery
- Testing is scheduled to begin in August

Disclaimer

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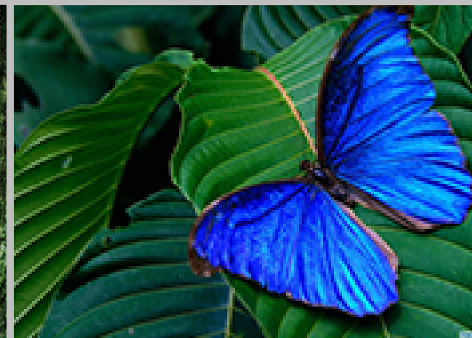
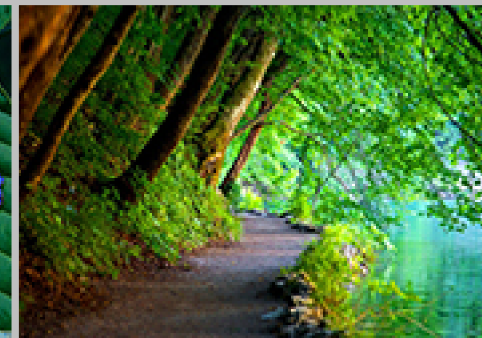

Questions

NETL