Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Capture Technologies (2)

Production of Concentrated CO_2 from Flue Gas Using Dry Regenerable Carbonate Sorbents in a Thermal-Swing Process

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Outline

- Project Background and Past Research
- Process Design
- Bench-scale Testing of Process Components
- Bench-scale Integrated Process
- Preliminary Economics

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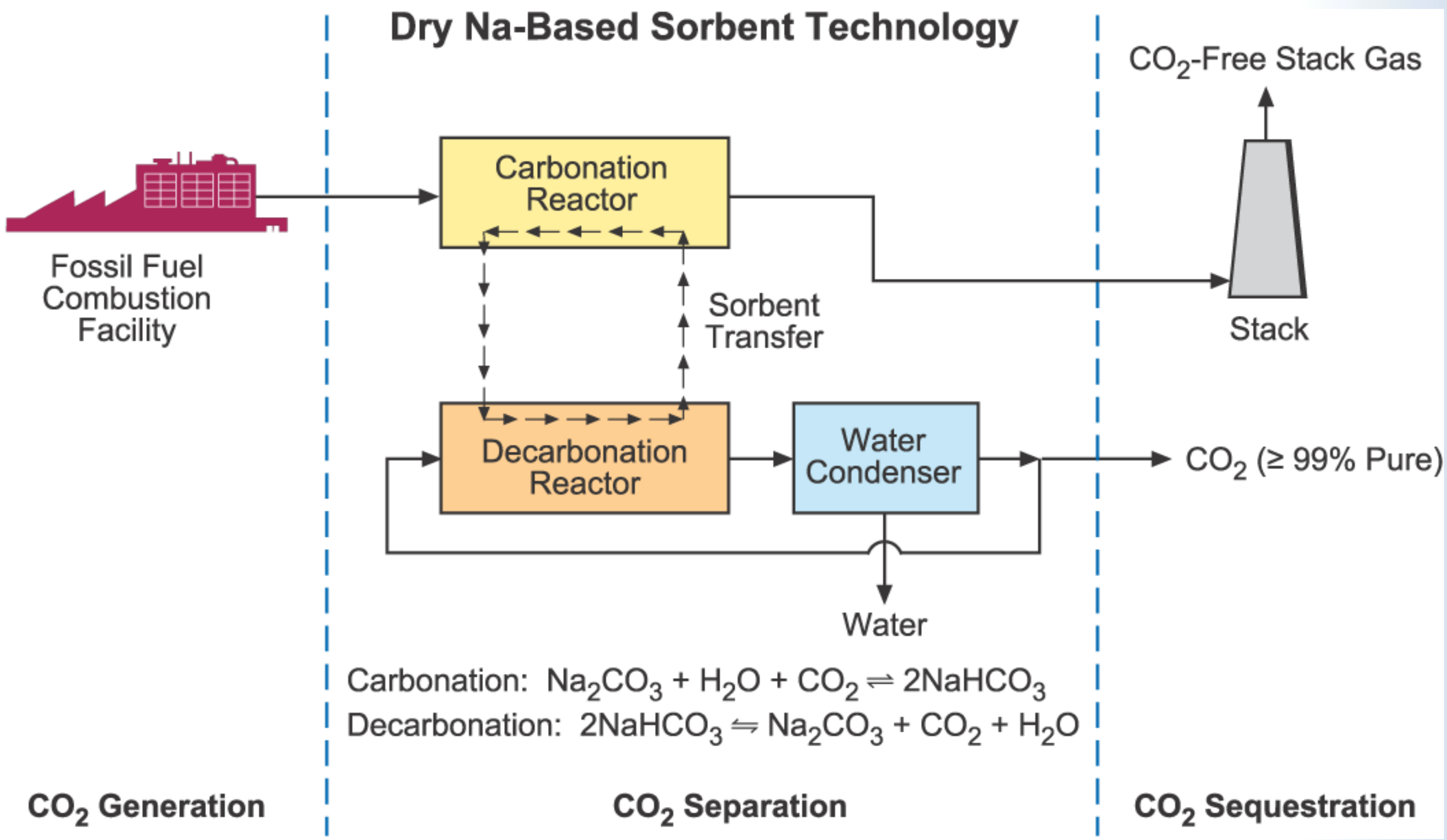
Project Objectives

To develop a carbon dioxide capture technology that is

- Based on a solid, regenerable, carbonate sorbent
- Applicable to flue gases of both coal- and natural gas-fired power plants
- Intended for retrofit in existing plants
- Less expensive and less energy intensive than current technologies (MEA)
- Of relatively simple process design

Concept of the "Dry Carbonate" Process

CO_2 Capture from Flue Gas



Past Research

Concept Evaluation

- First order reaction kinetics with H_2O & CO_2
- CO_2 absorption temperature: < 80ºC
- Sorbent regeneration temperature: ≥ 120ºC
- Sorbent is fully regenerable in pure CO_2
- Effect of SO_2 and HCl in flue gas

$$Na_2CO_3\,(s) + SO_2\,(g) + \tfrac{1}{2}O_2\,(g) \rightarrow Na_2SO_4\,(s) + CO_2\,(g)$$

$$Na_2CO_3\,(s) + 2HCl(g) \rightarrow 2NaCl\,(s) + CO_2\,(g) + H_2O\,(g)$$

- Hg, O_2 and NO_x – No reaction with sorbent

Past Research

Sorbent Development and Reactor Studies

- Sorbent Development
  - Calcined sodium bicarbonate (SBC)
  - Calcined trona
  - Supported sorbents:
    - 10 - 40 wt% Na_2CO_3 on support
    - better reactivity
    - better attrition-resistance

- Fixed- and Fluidized-bed Reactor Studies
  - >90% carbon dioxide removal achieved for SBC and supported sorbent
  - Removal activity (90%) maintained over multiple cycles
  - Sorbent bed temperature increased dramatically during CO_2 capture causing decline in removal rates (exothermic reaction)

$Na_2CO_3(s) + CO_2(g) + H_2O(g) \rightarrow 2NaHCO_3(s)$ $\Delta H = -30.8$ Kcal/gmol CO_2

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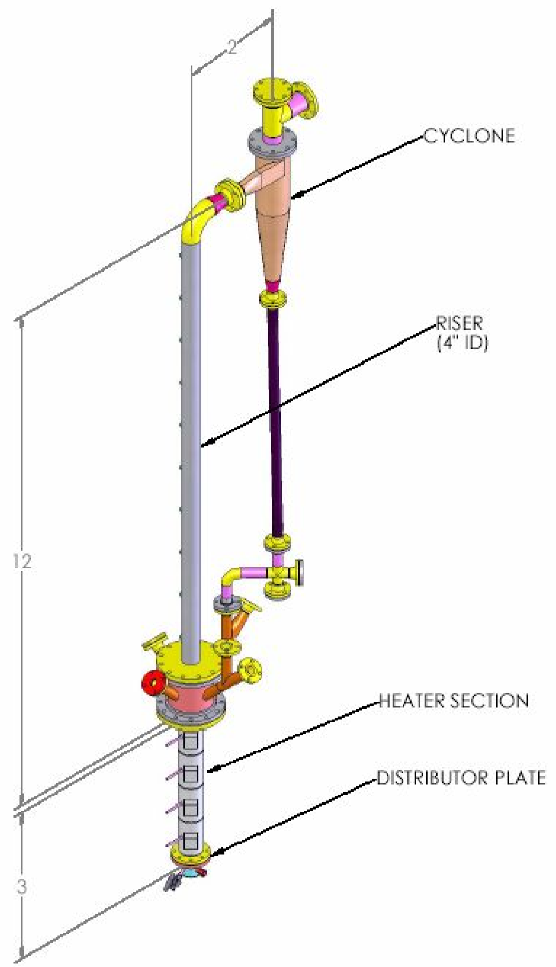
Past Research

Entrained-bed Testing at CANMET

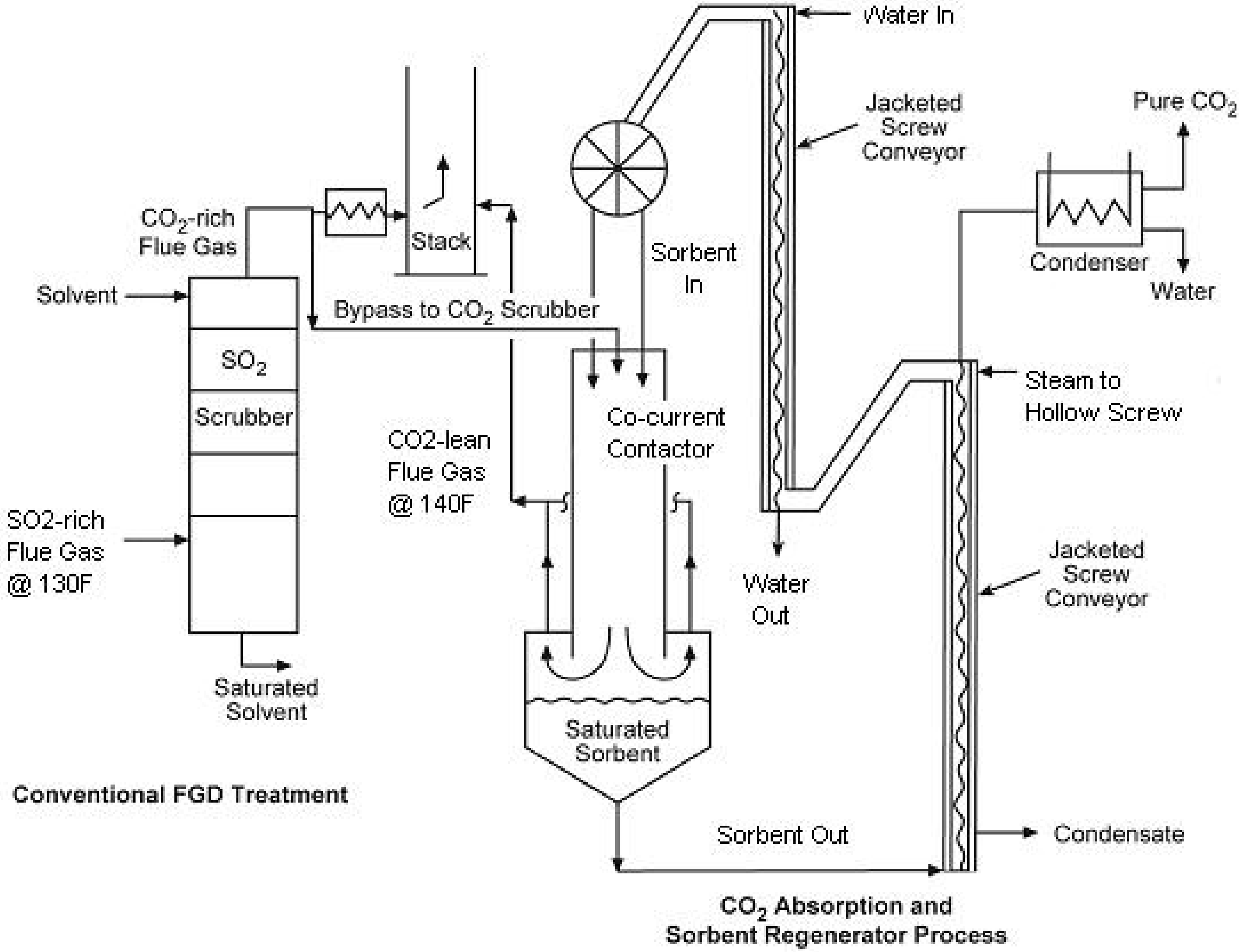


- CANMET (Ottawa) is part of Natural Resources Canada
- Highlights:
  - RTI supported sorbent
  - >90% CO_2 removal in 10 – 20 seconds of sorbent residence time
  - Temperature rise (due to exothermic reaction) limited to ~10ºC
  - Sorbent fully regenerated upon heating to 120ºC
  - Negligible sorbent attrition over 7 absorption + regeneration cycles

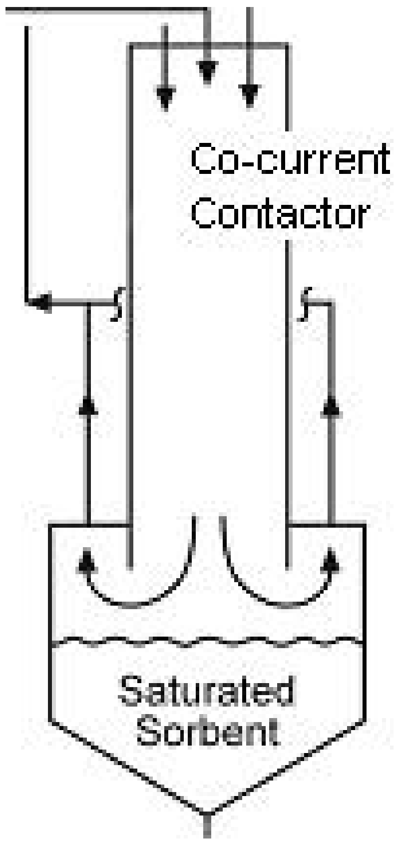
Process Engineering Challenges

- Low discharge pressure of power plant flue gas stream
  - Need to minimize additional power requirements of induced draft fan
- Sorbent transfer
  - Sorbent must be moved efficiently between absorber and regenerator
- Heat integration
  - Use of low-grade, low-value heat from steam cycle will be beneficial
- Power consumption
  - Need to minimize parasitic power consumption

Process Concept



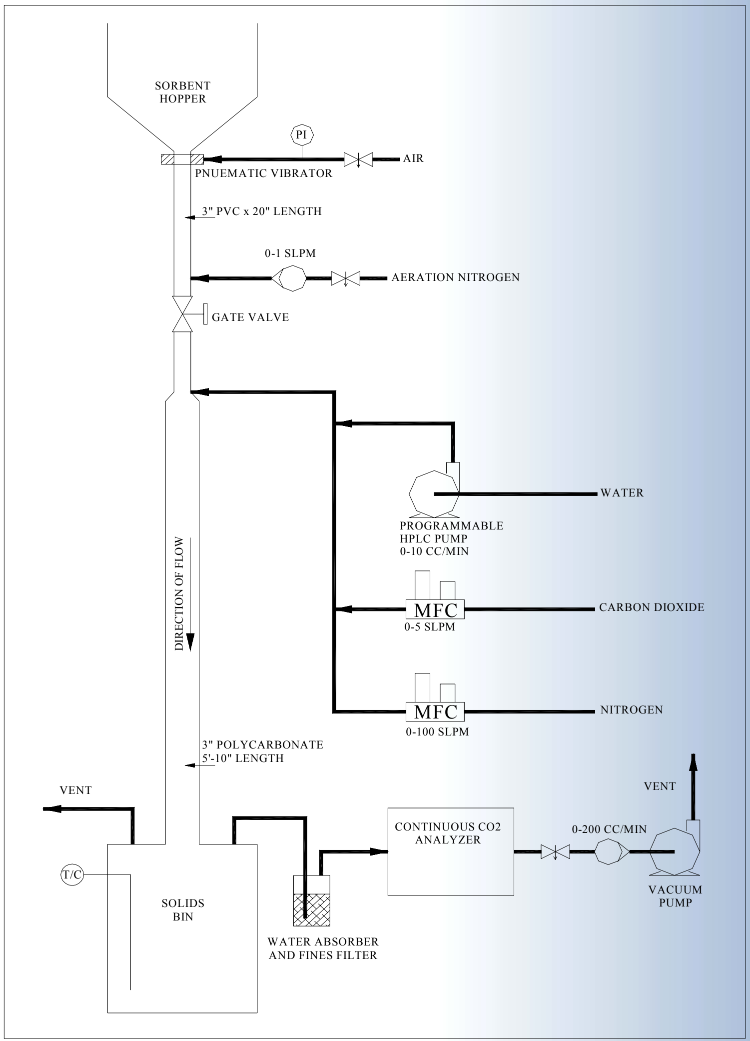
Down-flow Contactor



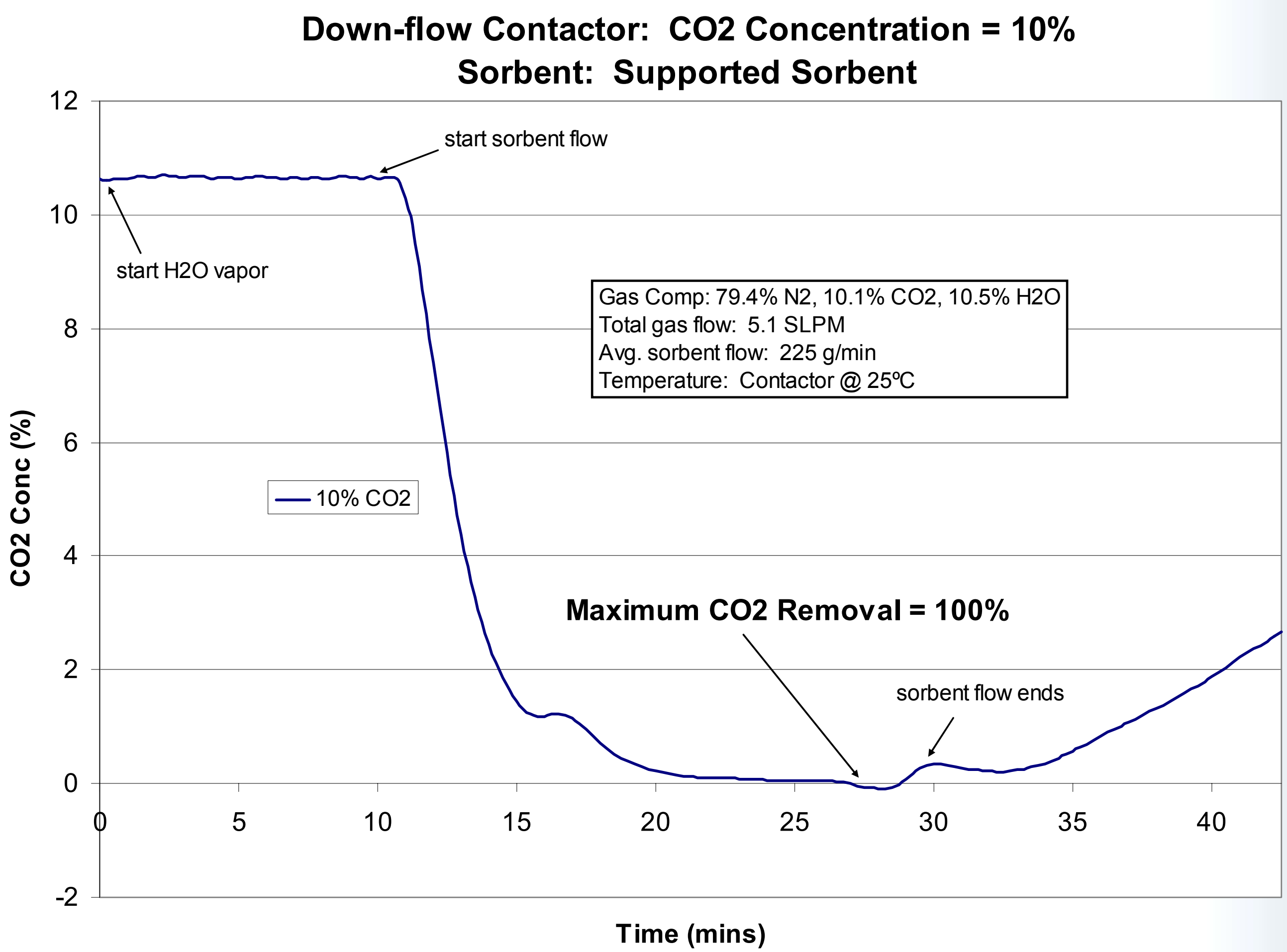
- Flue gas enters contactor after wet FGD
- Solids enter from surge bin following sorbent regeneration and cooling
- Co-current gas/solids flow
- "CO_2-lean" gas is sent to exhaust stack
- Reacted sorbent sent to regenerator

Down-flow Contactor Tests at RTI

- Is 90% CO_2 capture possible?
- Can pure sodium bicarbonate be used?
- What can we learn about contactor design?



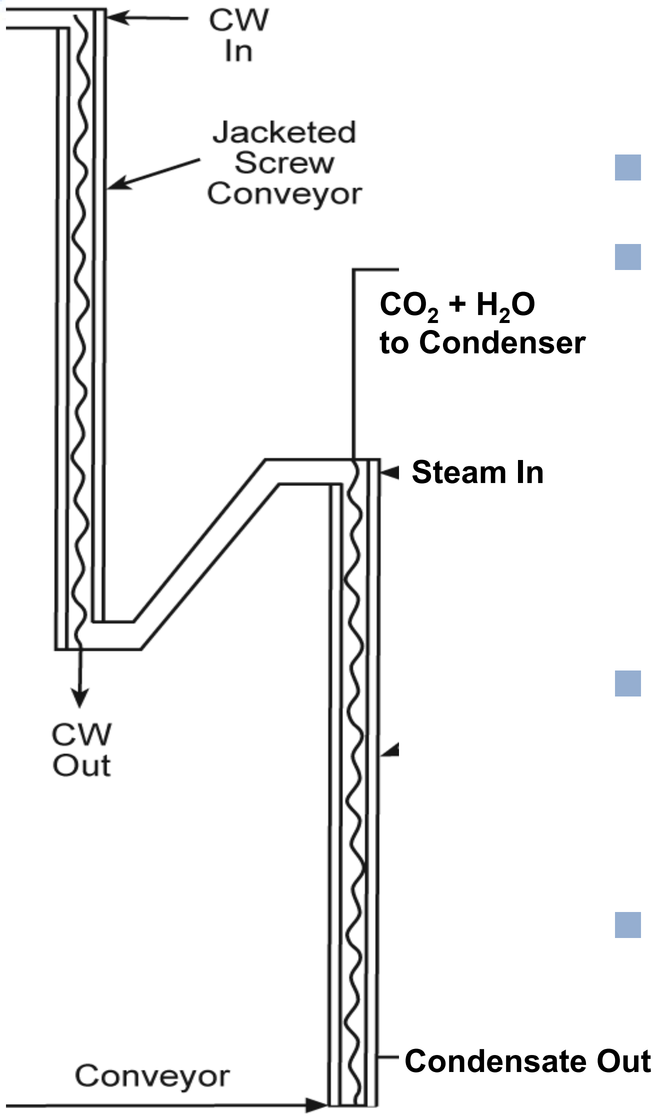
Down-flow Contactor Tests at RTI



Down-flow Contactor Tests at RTI
Summary

- Built bench-scale co-current, down-flow contactor at RTI for evaluation of contacting concept
- 90% CO_2 removal was achieved in flue gas with 10% and 15% CO_2 using RTI supported sorbent
- 90% CO_2 removal is possible using pure sodium bicarbonate. Most tests showed 60-70% removal in flue gas with 10% and 15% CO_2
- Gained insights into better contact designs
  - tangential gas injection
  - contactor with staggered baffles to improve gas/solid contact

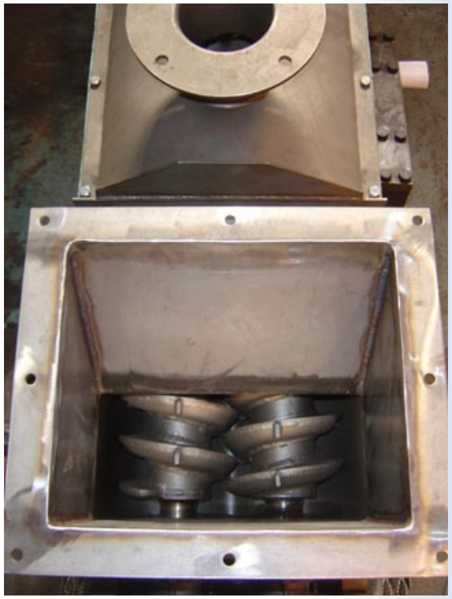
Sorbent Regenerator



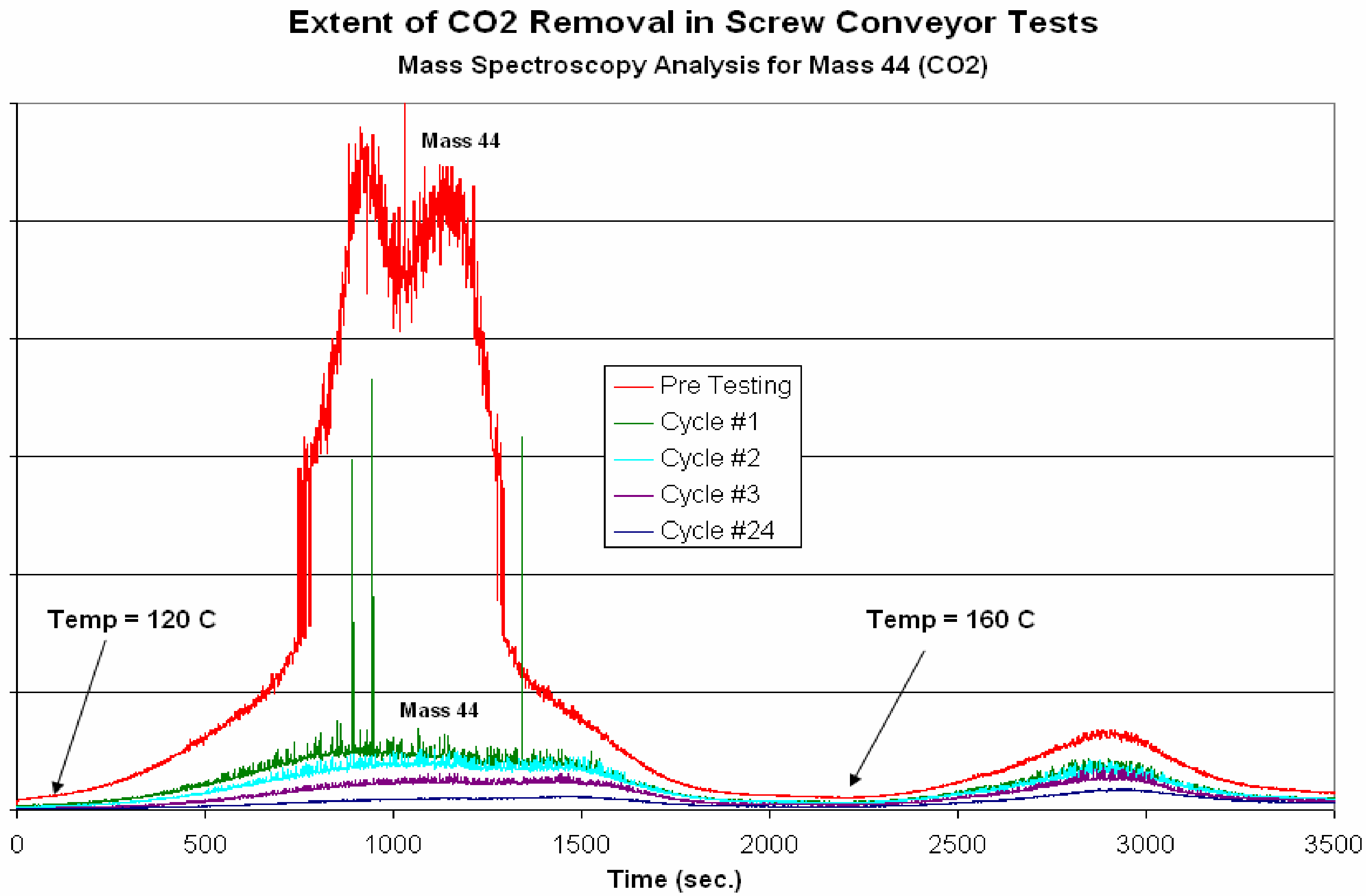
- Dual screw conveyor system
- Heated screw conveyor:
  - Sorbent regeneration
  - Indirect heating with low grade steam (35 psig)
  - Regeneration gas (CO_2 + H_2O) sent to condenser
- Cooled screw conveyor:
  - Cools sorbent to absorption temperature
  - Returns sorbent to contactor
- Expected Purity
  - 99+% CO_2 stream for sequestration

Screw Conveyor Tests at Therma-Flite

- Experiments conducted in Therma-flite, Inc. (Benicia, CA) bench-scale, horizontal test unit
- Sorbent used: RTI supported sorbent loaded with CO_2
- Objectives: Sorbent heating, regeneration, and attrition testing

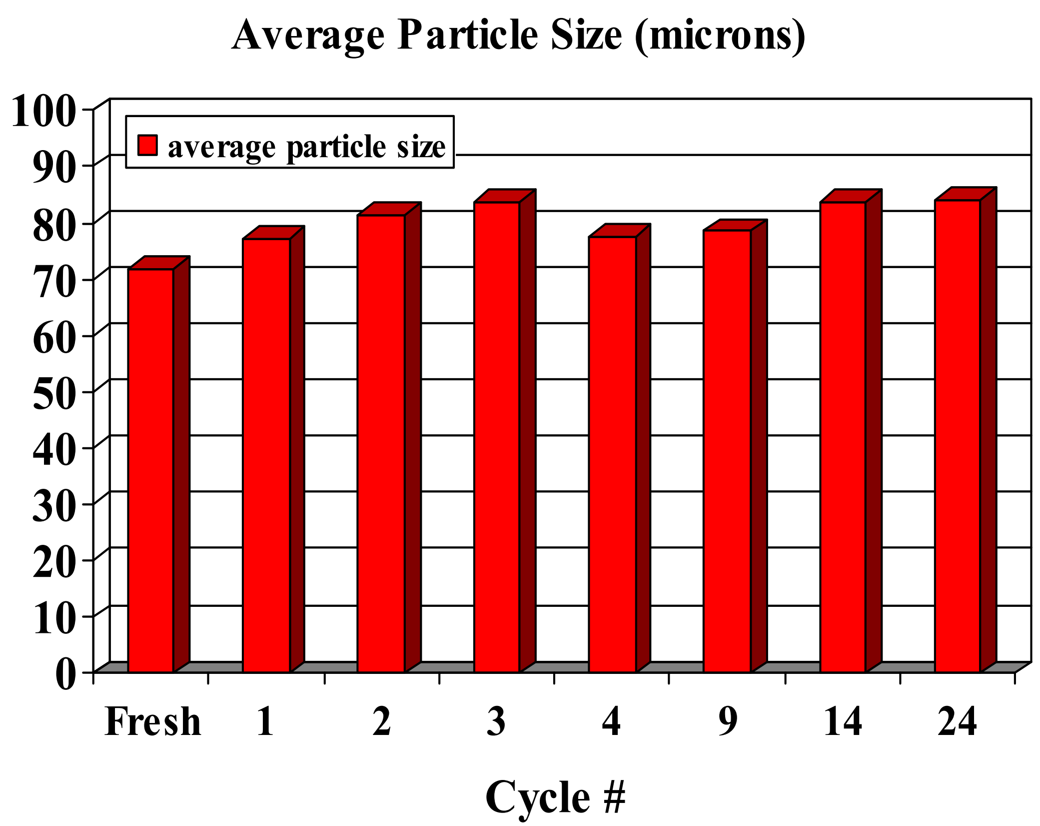


Screw Conveyor Tests at Therma-Flite Regeneration



Screw Conveyor Tests at Therma-Flite

Attrition

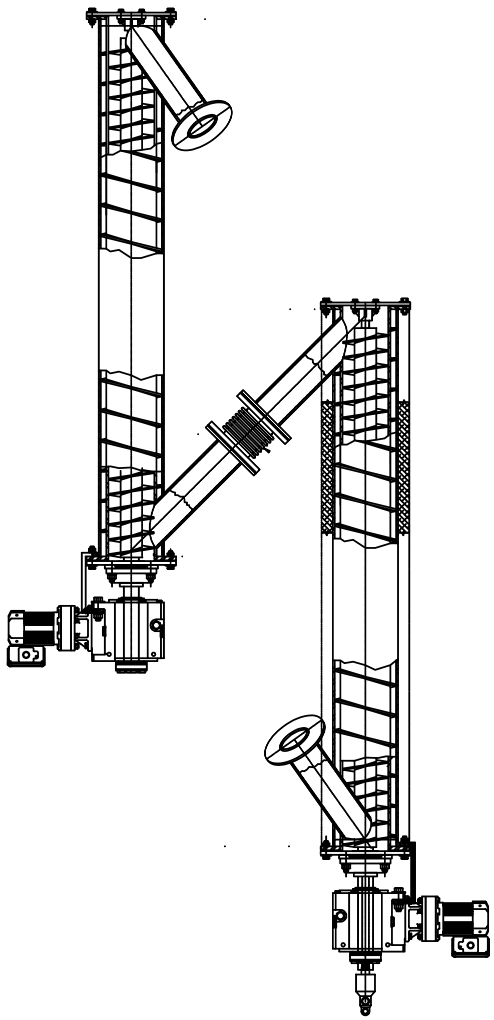


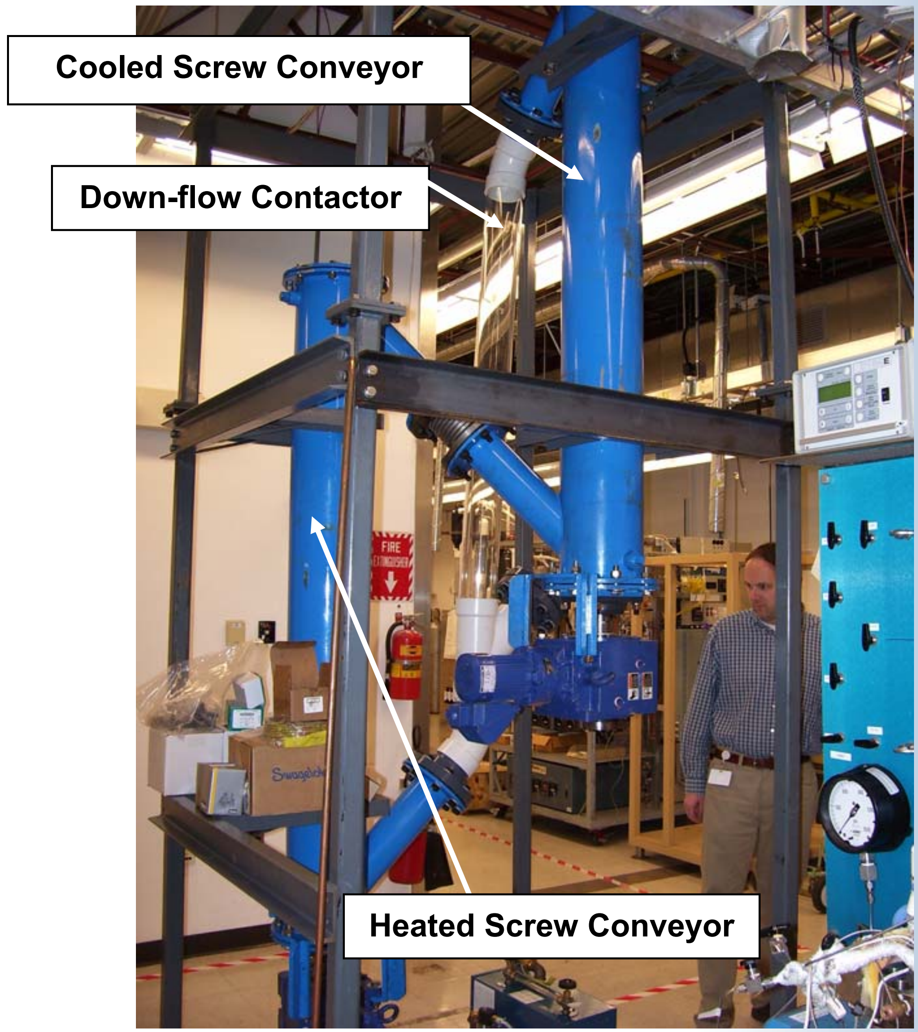
Particle size analyzer: SympaTec HELOS laser diffraction analyzer

Screw Conveyor Tests at Therma-flite
Summary

- Screw conveyor test unit (horizontal) was able to heat sorbent to regeneration temperature (~120ºC)
- Mass spectroscopy analysis of test samples showed nearly complete regeneration after one pass
- Particle size analysis of test samples showed no attrition of supported sorbent after 24 cycles

Integrated System Testing at RTI



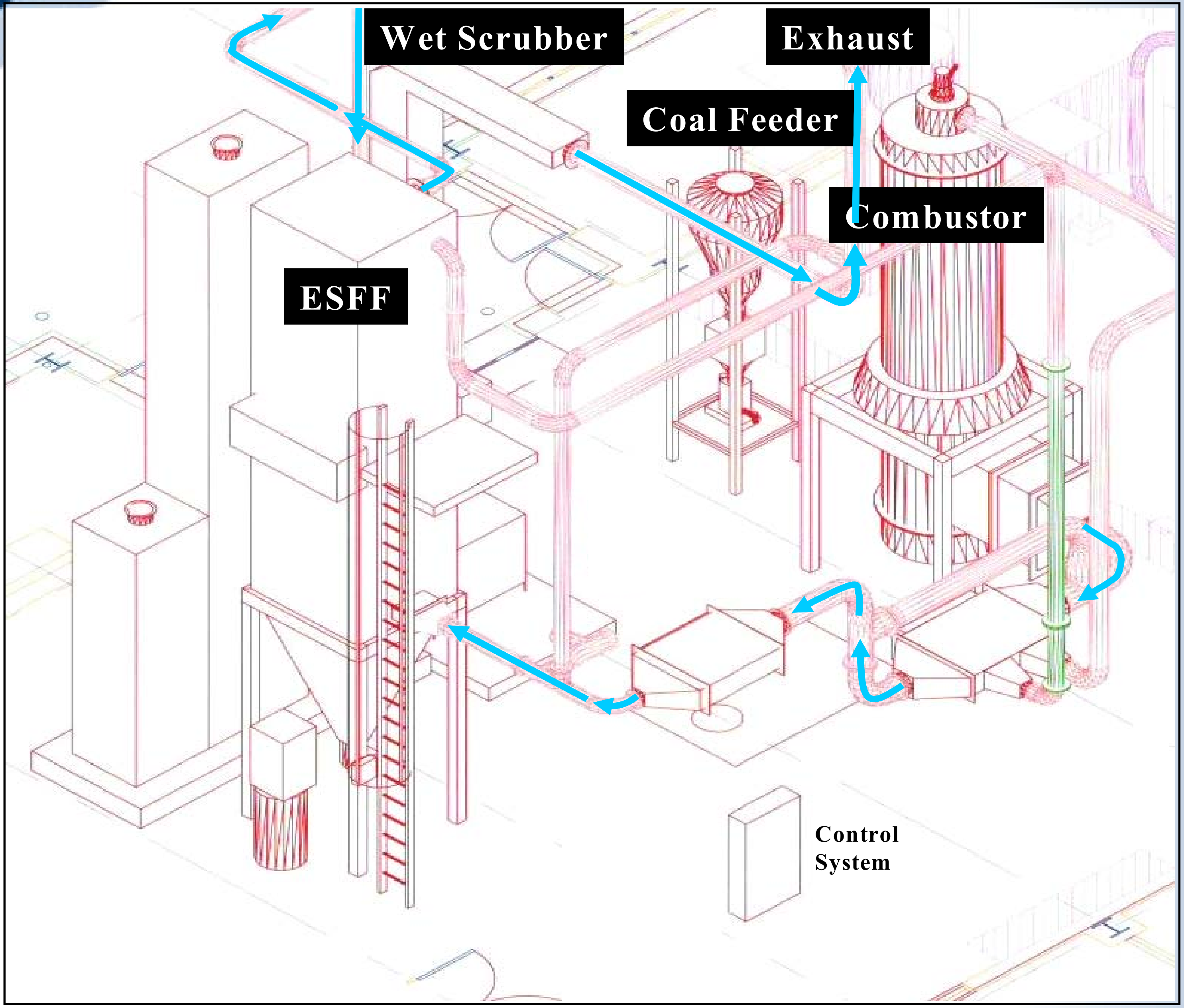


Integrated System Testing at RTI

- Bench-scale screw conveyors fabricated by Therma-flite, Inc.
  - 8” diameter and 6’ length each
  - Heated screw conveyor is rated to 80 psig (155ºC saturated steam)
  - Variable frequency drive motors – range of 25 – 250 lb/hr. sorbent circulation
- Designed to process up to 200 SLPM of flue gas
- Objectives:
  - Show that two process components can be effectively integrated
  - Prove that indirect heating with low grade steam is sufficient for sorbent regeneration
  - Prove that indirect cooling with water can return sorbent to absorption temperature
  - Show that sorbent can be transported effectively with screw conveyors
  - Show that sorbent can withstand cycling within the system
  - Finalize large-scale process design for future testing
  - Conduct detailed technical and economic analysis based on collected data

Future Test Plans

- Multi-Pollutant Control Combustion Research Facility
  - 4 Million Btu/hr (1.2 MW_t) Multi-Fuel Fired Facility
    - 340 lb/hr bituminous coal (dedicated pulverizer)
    - 4200 ft^3/hr natural gas
  - Designed for evaluation of different combinations of control technologies
- Installed multi-pollutant control technologies:
  - Selective Catalytic Reduction (SCR): NOx and Hg Oxidation
  - Lime Flue Gas Desulfurization (FGD): SO_2 and Hg Capture
  - Fabric Filter: Fine PM and Hg Capture
- Slipstream testing of RTI's CO_2 capture technology is being planned for Fall '06


Wet Scrubber
Exhaust
Coal Feeder
Combustor
ESFF
Control
System

Preliminary Power and Economic Analyses

- Based on DOE Systems Analysis Guidelines (April ’05)
- Baseline 498.3 MW_e PC power plant
  - Power plant implementing no CO_2 capture (Case 7C)
  - Power plant implementing MEA CO_2 capture (Case 7A)
  - Power plant implementing “Dry Carbonate” capture (RTI Case)
- 90% CO_2 removal by RTI’s supported sorbent
- Process streams and equipment sized accordingly
- Analyses performed:
  - Power performance
  - Capital cost
  - Operating cost
  - Overall economics

Preliminary Economics

Capital Cost Summary	No CO_2 Capture (Case 7C)	With CO_2 Capture (Case 7A)	With CO_2 Capture (Dry Carbonate)
Levelized Capital Charge Factor (%)	14%	14%	14%
Capacity Factor (%)	65%	65%	65%
Net Plant Power (KW_e)	462,058	329,294	399,216
Total Capital Requirement ($ X 1000)	$ 591,714	$ 733,000	$ 636,623
Operating Cost ($ X 1000/yr.)	$54,732	$60,714	$61,172
Capital c/kWh	3.43	5.47	3.9
Production c/kWh	2.08	3.26	2.7
Total c/kWh	5.51	8.73	6.6
$/ton CO2 Avoided	N/A	56.2	23.9

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Path Forward

- Long-term testing of bench-scale system
  - Evaluate system's reliability
  - Gain true measure of sorbent life
- Engineering evaluation of regenerator process design
- Finalize process design
- Scale-up to pilot-scale (1 ton CO_2 captured per day)
  - Evaluate at coal combustion facility

Summary

- RTI has developed an supported sorbent which is produced by a commercial catalyst/sorbent manufacturer
- RTI has developed a novel process design that is suited for retrofit in a power plant and is of relatively simple process design
- Different components of the integrated CO_2 capture system have been proven at bench-scale
- > 90% CO_2 removal has been demonstrated at all stages of the research program
- RTI has built and will thoroughly test a bench-scale, integrated system to evaluate process performance and operation
- Preliminary economic analyses shows RTI process has potential to be significantly less expensive than existing MEA systems and has potential to meet DOE economic goals for CO_2 capture

Acknowledgements

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