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High-Efficiency Post Combustion Carbon Capture System
National Carbon Capture Center Test

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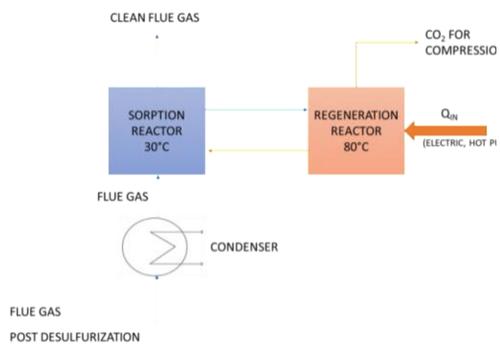
Summary:

The current report details work done at the National Carbon Capture Center in Wilsonville Alabama as part of SBIR Phase 2 project DE-SC0017221 High-Efficiency Post Combustion Carbon Capture System during March 9- March 12, 2020 by contractor Precision Combustion Inc.
In this reporting period, a bench-scale Post Combustion Carbon Capture System was installed in the Bench-Scale (0.05 MWe, 500 lb/hr) test bay and shakedown was successfully performed with simulated flue-gas mixtures. Two complete cycles of carbon capture and thermal desorption were performed on the assembly.
Pending availability of flue gas and lift of travel restrictions under a current Phase II A effort , the team from PCI will continue testing according to a pre-established test matrix. Results will be integrated with a full-scale computational fluid dynamics and performance model as well as economic model of CO_2 capture cost.

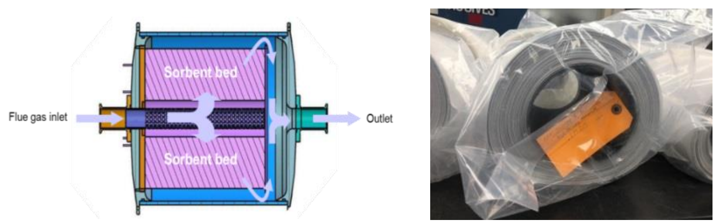
Introduction:

PCI's innovation is a compact, modular Post Combustion Carbon Capture System (PCCCS) utilizing high internal volume nanosorbents, for carbon capture, supported on a tailorable mesh substrate. Our system enables low pressure drop, high volumetric utilization and high mass transfer, and is suitable for the rapid heat transfer and low temperature regeneration operating modes needed for cost-effective carbon capture (Figures 1-2). Capital and operating costs are reduced based on lowered energy demand due to a combination of enhanced CO_2 capture efficiency in addition to a reduction in projected large-scale material costs.

The modular cartridge form factor enables low-cost retrofit to existing systems. For the high space velocity sorbent structure, PCI has developed and patented a short contact time mesh-based substrate, trademarked Microlith® [i,ii], coated with the densified nanostructured sorbent. The combination enables higher surface areas per unit volume, decreased bed volumes with equivalent effectiveness to other types of monolithic or loose packing, without pressure drop penalty. Additionally, up to twenty times higher mass and heat transfer coefficients are obtainable as compared to other sorbent systems such as monoliths and pellets, due primarily to boundary layer minimization and break-up, boosting CO_2 removal rates with greater sorbent bed utilization and less bypass inherent to packed beds or monoliths. Individual Microlith elements have very low thermal mass and low axial conductivity, and consequently quickly transfer heat from the gas phase to the sorbent. Our sorbent manufacturing technology allows for adherent and durable sorbent coatings (as well as other high surface area sorbents) on the Microlith substrate. The sorbent and Microlith structure and coating operate synergistically.



<u>Figure 1:</u> Schematic of the PCCCS unit with a two-module temperature swing system. One module is adsorbing while a second one is in regeneration mode. Recovered CO_2 can be used as purge gas for regeneration. Low-grade thermal energy or waste heat recovered from flue gas cooling or the CO_2 compression train can be used in the regenerator.



<u>Figure 2:</u> Left, an example design of sorption/desorption module with Microlith coil around an axial-flow gas distribution system (other options include planar arrangement with flow-through). Right, Microlith coils coated with sorbent holding approximately 200 sq ft of coated mesh.

The focus of the work is to evaluate the operability and regenerability of the PCCCS unit and to obtain test results in a real flue-gas environment (Figure 3). Testing planned at the National Carbon Capture Center should provide multiple PCCS unit regenerations that will indicate if the performance is consistent after thermal cycles under realistic conditions. The regeneration strategy and frequency will be evaluated throughout the duration of the test, and any modifications will be made by adjusting system control. Additional observations and improvements required for the system will be documented for future PCCCS design and development. Data will be recorded and reported. During installation, shakedown, initial startup and testing, PCI provided the necessary technical support and troubleshooting on-site (March 2020 testing campaign).

The specific objectives of the field trial testing are to demonstrate:

- Operability and regenerability of the PCCS unit
- Low pressure-drop and low power consumption for operation and for regeneration
- Acquire data for full scale-modelling of PCCS unit and balance of plant components.

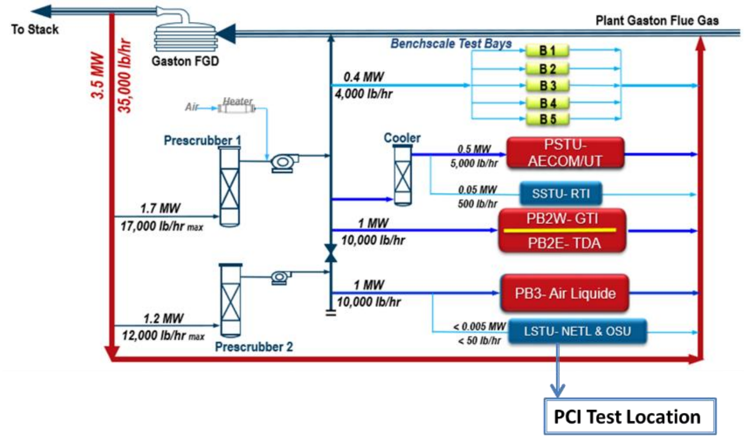


Figure 3: PCI test location in NCCC facility.

Results:

Skid Design and Installation

The adsorber module consists of a coil of Microlith mesh coated with sorbent, with the fluid flow being delivered through the center of the coil towards the outlet (Figure 4).

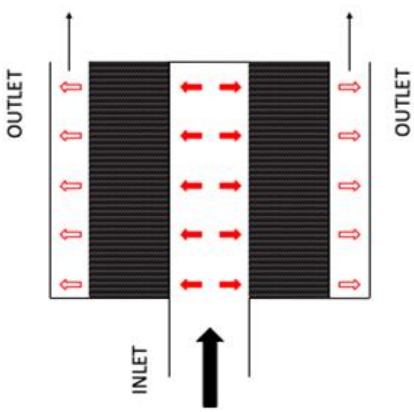


Figure 4: Schematic of adsorber module flow pattern and coated mesh assembly

A heating coil has been integrated directly into the sorbent bed to provide rapid heat-up to desorption temperature during thermal swing operation.
The unit was fitted with all BOP components including the dehumidifier, sorbent housing, flow meters, heater controls, bypass, thermocouples, valves etc. Figure 5 shows the process flow schematic for the system. Figure 6 is a photograph of the skid during on-site shakedown testing at NCCC. Table 1 details the sorbent bed geometry.

Process Control functions:

Flue Gas flow to targeted flow rate during adsorption stage
Purge gas flow to targeted flow during purge stage
Purge gas temperature to targeted desorption temperature during purge stage and for cooling bed after desorption
Bed temperature warmup to targeted desorption temperature during purge stage
Adsorbent bed pressure control for pressure maintenance
Switching between flue gas and purge gas during stage changes
CO_2 monitor of exhaust gas

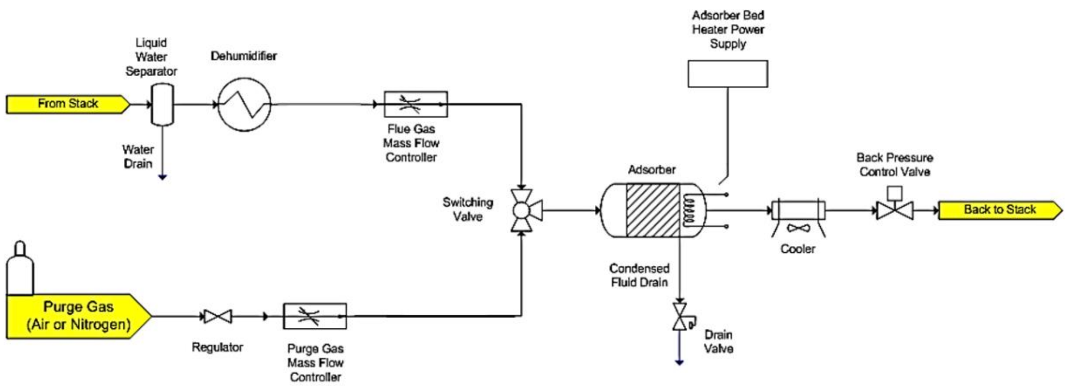


Figure 5: Flow Schematic of NCCC CO_2 Capture Test.

Figure 6: PCI test skid installed on the flue gas flow stream at the National Carbon Capture Center.

Table 1: Sorbent bed geometry.

Component	**ID (in)**	**OD (in)**	**Height (in)**
Base Tube	2.94	3.00	11.25
Inner Roll	3.50	7.13	10.00
Outer Roll	11.65	14.50	10.00
Inlet Pipe	2.88	3.00	6.00
Inlet Fitting	0.75	0.85	1.25
Exhaust Pipe	2.87	3.00	1.50
Exhaust Fitting	0.75	0.85	2.78
Outer Housing	16.94	17.25	16.00

Data and Other Pertinent Information:

In the March of 2020 testing campaign, the PCI team travelled to NCCC to install the test rig on the PC-4 flue gas stream. The rig has been installed, leak tested, pressure checked and all balance of plant components have been tested including heaters, mass flow controllers, pressure valves etc., in accordance with the HAZOP parametric study performed by PCI and NCCC prior to skid arrival. Before testing, the sorbent bed was preconditioned by heating the bed and flowing N_2 through in order to purge CO_2 and moisture from the bed picked up during shipment to NCCC.

For test rig shakedown, two thermal-swing cycles were performed with simulated flue gas. Flue gas was simulated by adding CO_2 to an inlet stream of ambient air to achieve a target CO_2 volume percentage. The test rig shakedown is shown in Table 2.

Table 2: Shakedown Test Matrix

TEST MATRIX FOR PRECISION COMBUSTION BENCH-SCALE PCCCS UNIT									
	Inlet Temp., °C	**Inlet Pressure, psi**	**Inlet Flowrate, SLPM**	**Inlet CO2, Vol. % (Average)**	**Inlet O2, Vol. % (Average)**	**Inlet N2, Vol. % (Average)**	**Inlet H2O, Vol. % (Average)**	**Max. Regen. Temp., °C**	**Purge gas**
1	30	2	60	8	8.1	83.9	NA	80	N2
2	30	2	60	8	8.1	83.9	NA	80	N2

Figure 6 shows the evolution of CO2 at sorber outlet during adsorption of CO2 from simulated flue gas for shake-down cycles 1 and 2 and figure 7 shows evolution of CO2 during thermal swing.

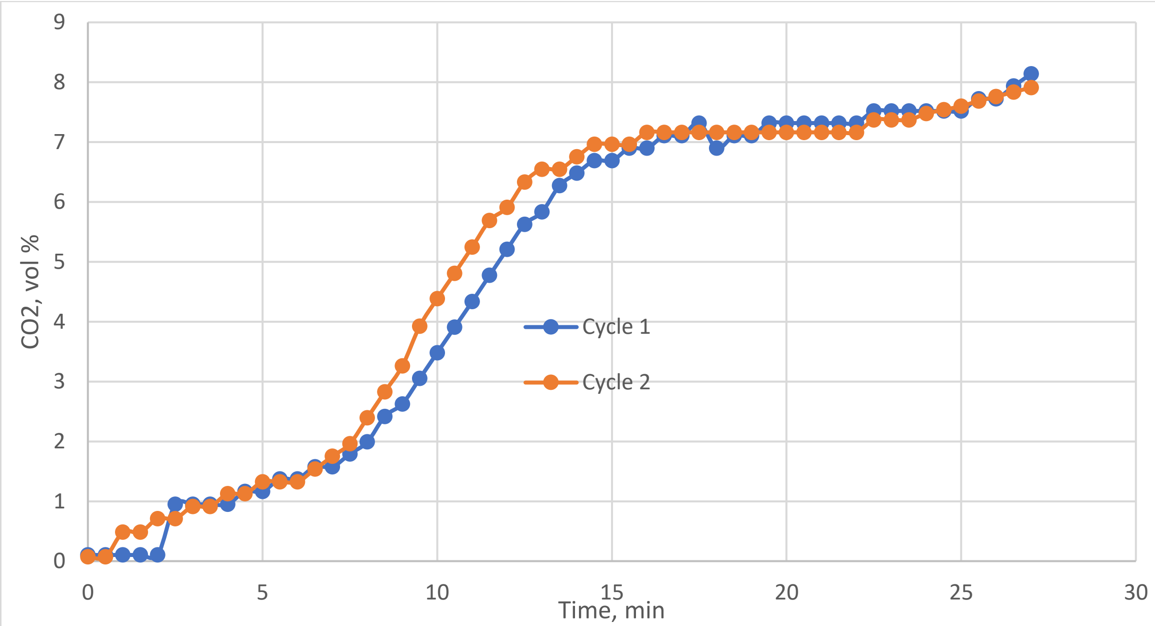


Figure 6: CO_2 evolution at sorber outlet during shake-down testing. The cycles are consistent.

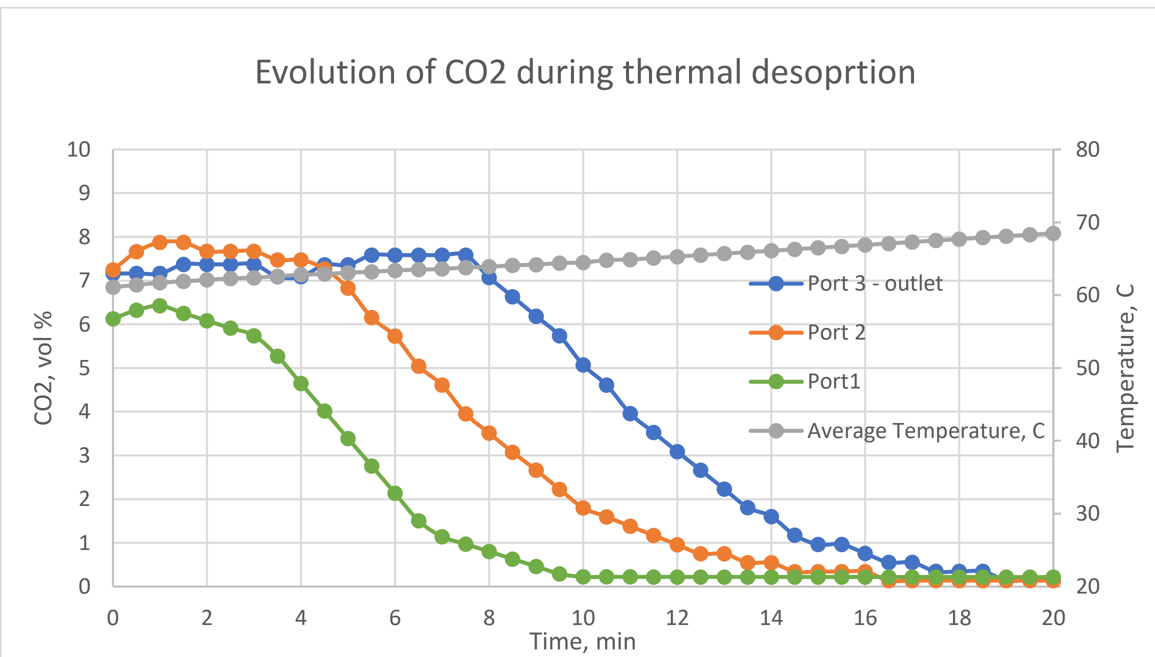


Figure 7: Evolution of CO_2 at during thermal swing regeneration – Port 1 and 2 sample the leading and mid- sorbent bed, Port 3 samples at outlet. Temperature is an average of 6 independent measurements.

Table 3: Shake-down test results.

Cycle	Cycle time, min	Flue gas inlet, l/min	Amount of sorbent, kg	Capacity, cc/g	Capacity, mmol/g	Capacity, wt. %	CO_2 capture rate %	Power input, kWh/kg CO2 recovered
1	27	60	2.3	25.7	1.1	4.7	44	0.5
2	27	60	2.3	24.3	1.0	4.5	41	0.5

The test skid will be optimized for the next campaign of testing by optimizing the configuration of the inlet and outlet flanges to direct the flow more uniformly through the sorbent bed and avoid by-pass. This is expected to significantly increase the CO_2 capture rate.

The heating system will also be optimized with the heat exchanger incorporated within the sorbent bed to reduce heat up time and minimize heat losses with a target of 0.25-0.3 kWh per kg of CO_2 recovered.

Conclusions:

- PCI completed installation and shake-down of the Post Combustion Carbon capture bench-scale test unit on location at the National Carbon Capture Center.
- All balance of plant components have been tested and installed in accordance with the pre-established HAZOP study.
- Shake-down cycles of adsorption and thermal regeneration were completed with simulated flue gas mixture.
- Sorbent performance was stable through the shake-down testing.
- Options have been identified for optimizing inlet flow to avoid by-pass and heat. exchange in the sorbent bed to increase capture rate and decrease power consumption.

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[i] S. Roychoudhury, D. Walsh, and J.L. Perry, *SAE*, 2005-01-2866 (2005).
[ii] S. Roychoudhury, D. Walsh, and J. Perry, *SAE Int.*, 2004-01-2442 (2004).