Process Intensification for Carbon Capture

primary project goals

Altex Technologies Corporation, in partnership with Pennsylvania State University (PSU), have previously developed the integrated temperature and pressure swing (ITAPS) carbon capture system. The ITAPS system utilizes advanced molecular basket sorbents (MBSs) on microchannel heat exchangers, which can be quickly cycled between carbon dioxide (CO_2) sorption from coal-derived syngas and desorption into low-pressure steam exhausted from steam turbines in an integrated gasification combined cycle (IGCC) power system. This would replace the typical three-stage Selexol system (for acid gas removal and pre-combustion carbon capture in the context of IGCC) with smaller and energy-efficient desorption and sorption units.

The project is currently in Phase IIB, with the goal of developing the Compact Rapid Cycling CO_2 Capture (CRC3) system that would extend the concept of using the MBSs on microchannel heat exchangers to post-combustion applications. Also, work is continuing to reduce the size (and therefore costs) of the Altex CO_2 capture system by coating both sides of the heat exchanger with a sorbent with rapid sorption-desorption kinetics. Current objectives are to design a prototype-scale system for CRC3 to improve the MBSs for higher heat- and mass-transfer rates, to fabricate and test a prototype-scale CRC3 sorbing unit on actual flue gas, and to perform techno-economic analysis (TEA) of the CRC3 system integrated into a large-scale power plant.

technical goals

- Improve sorbent capacity and sorption/desorption rates.
- Demonstrate heat integration of sorption and desorption processes.
- Conduct prototype-scale testing of a post-combustion capture-geared prototype unit on actual flue gas at 10 to 50 standard liters per minute (slpm), equivalent to 0.2 to 1.0 kilowatt-electric (kWe).

technical content

The Altex team previously developed the ITAPS process with a view to produce a low-cost CO_2 capture technology that leverages process intensification principles (i.e., process capital and energy costs of the capture systems are shared with other unit operations of the power plant). In ITAPS, Altex-developed microchannel heat exchangers were wash-coated with PSU's advanced MBSs. By wash-coating the MBS on the microchannel heat exchanger, high heat- and mass-transfer rates were obtained. These high rates allow for quick cycling between CO_2 sorption and desorption. This should allow smaller sorption units with a lower capital cost than a typical three-stage Selexol system. Operating costs are also lower than a three-stage Selexol system because the system can operate at lower pressures and does not require circulation of a liquid amine sorbent. The system can also be integrated

technology maturity:

Prototype-Scale, Actual Flue Gas (equivalent to 0.2-1.0 kWe)

project focus:

Novel Concepts/Molecular Basket Sorbents on Microchannel Heat Exchangers

participant:

Altex Technologies Corporation

project number:

SC0013823

predecessor projects:

N/A

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start date:

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percent complete:

75% (combined Phases I, II, & IIB)

with the power plant steam loop to improve energy efficiency; the heat of sorption can be used to preheat the boiler feedwater, while the heat of desorption can be used to condense about 50% of the steam turbine exhaust. In terms of process integration, Figure 1 depicts the ITAPS units' process with boiler feed water flows and steam turbine flows (for sorption and desorption modes, respectively), which would be encountered in integrating an ITAPS system within the context of an IGCC cycle or a traditional power plant.

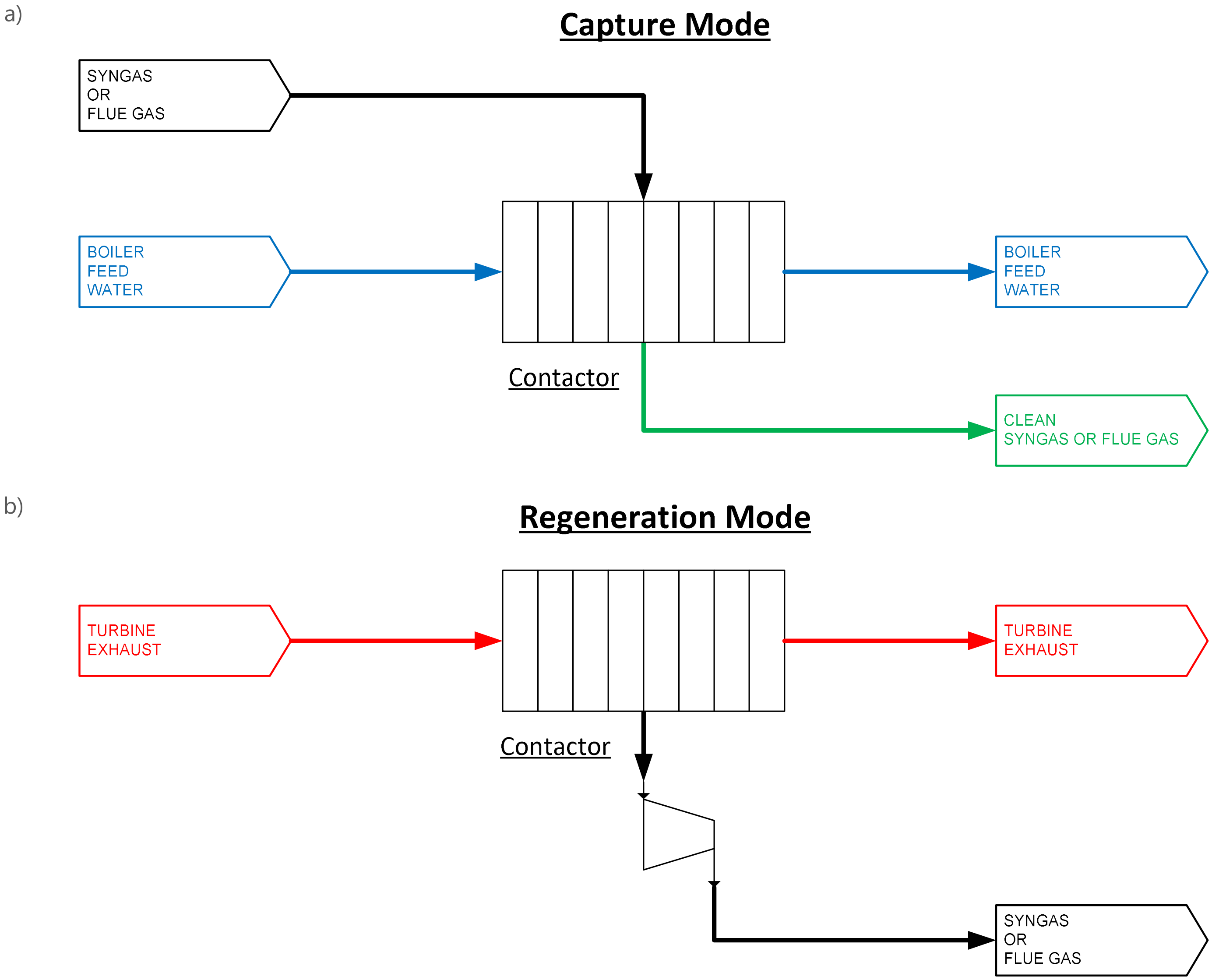

Figure 1: Simplified process flow diagram for Altex's integrated temperature and pressure swing carbon capture process. a) Capture mode – cooling provided by boiler feed water; b) Regeneration mode – heating provided by turbine exhaust.

PSU has been responsible for development of the sorbents they term as MBSs. The idea is to load CO_2-philic polymers such as polyethyleneimine (PEI) onto high-surface-area nano-porous inorganic materials such as MCM-41 and SBA-15, thereby increasing the accessible sorption sites per weight/volume of sorbent and improving the mass-transfer rate in sorption/desorption processes by increasing the gas-PEI interface. These sorbents can selectively adsorb large quantities of CO_2 compared to typical sorbents such as zeolites or activated carbons. The sorbents also pack CO_2 in a condensed form in the mesoporous molecular sieve basket and hence show a high CO_2 capacity and selectivity. The basic idea for preparation of MBS is illustrated in Figure 2.

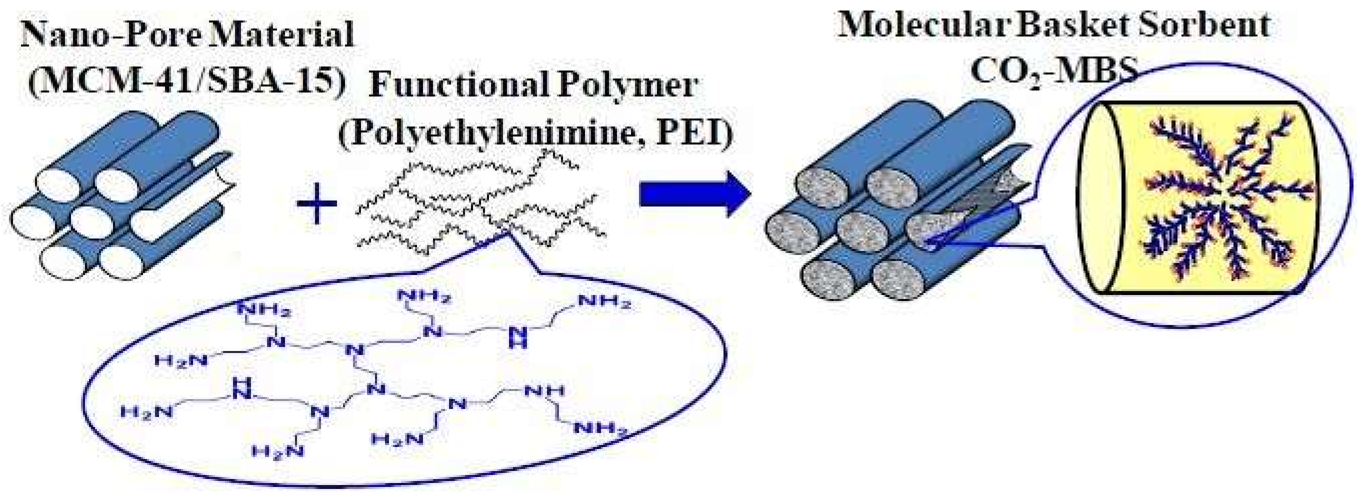

Figure 2: Principle for preparation of "molecular basket" sorbent (MBS).

The sorbents are applied by wash-coating the surfaces of microchannel heat exchangers. Altex is leveraging their expertise in design of these heat exchangers, which have been deployed in a wide range of sizes (fractions of kW to multiple megawatt [MW] capacities); materials (aluminum, copper, stainless steel, high-temperature alloys, corrosion-resistant alloys); counter-flow and cross-flow configurations; for various types of fluid flows; and in many fields, including oil and gas platform processes, separators, liquefied natural gas (LNG) processing, chillers, heat pumps, fuels reforming, waste heat power systems, and electronics cooling applications. For ITAPS, Altex developed the bench-scale prototype depicted in Figure 3. Note that finned inserts within the unit provide ample surface area onto which MBS can be wash-coated. In the pre-combustion capture case, the process stream of syngas containing CO_2 passes through the channels, and on the utility side, cooling water provides withdrawal of heat; in regeneration, steam would be passed through the channels to purge out the captured CO_2. Extensive surface area facilitates efficient heat transfer needed to accomplish the sorption and desorption steps for capture of CO_2.

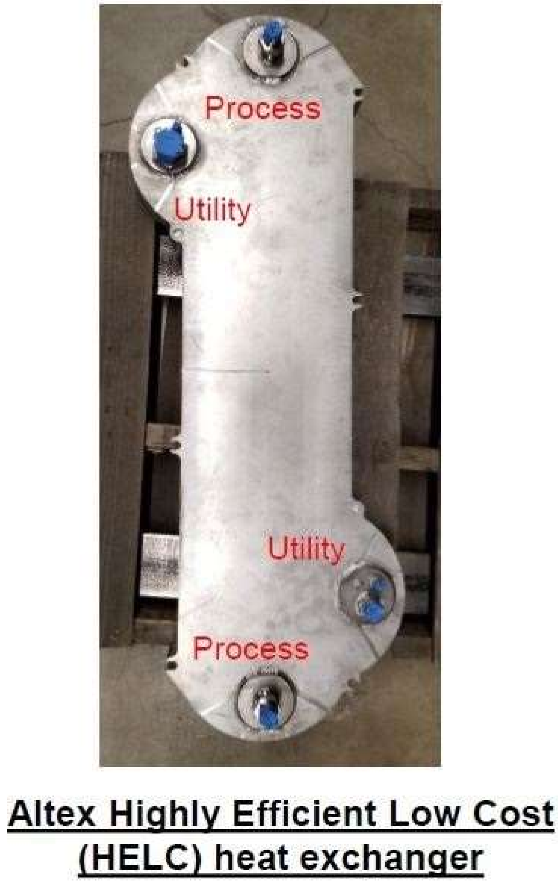

Figure 3: Illustration of ITAPS microchannel heat exchanger units/reactors.

In earlier project phases, PSU advanced the MBS material to improve the CO_2 capacity, and Altex demonstrated and established the feasibility of wash-coating this sorbent onto the microchannel heat exchanger. Advancements were made in both improving the mechanism of loading of the polymer into the solid matrix of the sorbent (low-cost fumed silica has been used in place of high-cost mesoporous silica, and sorbent performance improved by incorporating 3-aminopropyl triethoxysilane [APTES] along with PEI in the polymer formulation) and in improving the process for wash-coating the reactor (a single-step wash-coating method incorporating fumed silica, APTES, and PEI was devised, eliminating a separate impregnation step).

The bench-scale system prototype was tested for multiple cycles of CO_2 sorption/desorption, validating the feasibility of cycling and heat recovery. Data from these tests were used to determine the required wash-coat thickness needed to meet the target cost of electricity (COE) and ensure that this thickness can maintain a high effectiveness. From findings of the testing, analysis showed that the ITAPS process could significantly reduce cost of capture and COE.

Currently, the project is extending application of this technology into the area of post-combustion CO_2 capture. Figure 4 depicts the process concept for the CRC3 system, which deploys the Altex technology to capture of CO_2 from post-combustion flue gas.

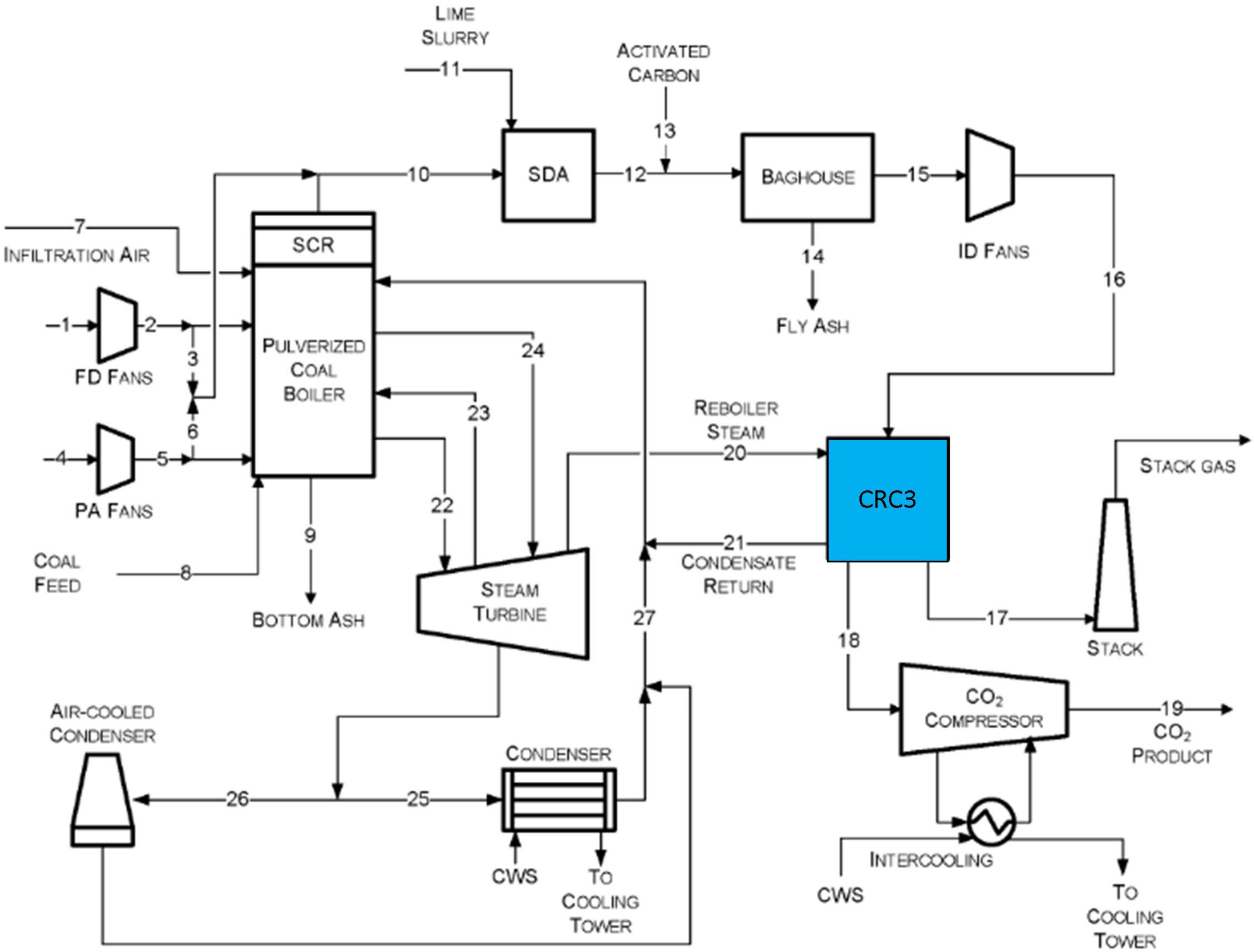

Figure 4: Process concept for the Compact and Rapid Cycling CO_2 Capture (CRC3) system.

Within this post-combustion capture context, current work is targeting better process approaches to integrate heat of sorption with the heat of desorption and to further improve sorbent performance, all of which are intended to reduce capture costs and enable the commercial potential of this technology.

technology advantages

- The CRC3 approach of applying sorbent to the high surface area, wash-coated minichannel reactor walls enables indirect heating and cooling of the sorbent.
- The sorbent on the minichannel reactor walls remains fixed in place and is not subject to particle attrition resulting from particle-particle contact, as would occur in a fluidized bed.
- The dispersion of sorbent over the high surface area of the walls of the minichannel reactor enables high mass-transfer rate of CO_2 to the sorbent.
- The pressure drop through the minichannel reactor can be reduced relative to a packed-bed absorber, much in the same way that monolith-supported catalysts reduce the pressure drop in selective catalytic reactors (SCRs) and, more commonly, in automobile catalytic converters. This will enable ITAPS to handle high gas-flow rates.

- The CO_2 MBSs developed by PSU exhibit high capacity and operate at low-desorption temperatures and with lower heat of sorption, requiring less parasitic energy draw and thereby boosting plant net efficiency.
- The MBSs are engineered with specific chemical surface functionality, which allows for high CO_2 sorption capacities in high-humidity conditions.
- Sorbent performance and the CRC3 approach enable lower round-trip energy costs for a complete sorption-desorption cycle.
- Enabling the production of CRC3 reactors at low cost and integrating a carbon capture system with existing unit operations should result in lower capital and operating costs for CO_2 capture from coal-fired power plants.

R&D challenges

- Operation at lower CO_2 partial pressures in flue gas as compared to syngas used in Phase I and Phase II.
- Implementing sorbent on both sides of the contactor and coordinating heat transfer between them.
- Operating on real flue gas.

status

Project Phase I and Phase II have been previously completed, in which ITAPS technology was developed and feasibility demonstrated for pre-combustion capture. Phase IIB is underway, in which the MBSs integrated in microchannel heat exchangers are to be improved, evaluated, and tested for post-combustion capture from flue gas.

available reports/technical papers/presentations

"Process Intensification for Carbon Capture," Altex Technologies Corporation and Pennsylvania State University, DE-SC0013823 (Phase IIB) Kickoff Meeting presentation (proprietary), September 5, 2019.

"*Process Intensification for Carbon Capture*," Phase II Final Report, Kenneth Lux, Tahmina Imam and Mehdi Namazian of Altex Technologies Corporation, Xiaoxing Wang and Chunshan Song of Pennsylvania State University, Submitted to the U.S. Department of Energy Office of Science (SBIR) / Office of Fossil Energy under Assistance Agreement Number DE-SC0013823, November 12, 2018.