

Supersonic Post-Combustion Inertial CO₂ Extraction System

primary project goals

Orbital ATK, Inc. (OA) developed an inertial carbon dioxide (CO₂) extraction system (ICES) that converts CO₂ from flue gas to solid CO₂ (dry ice) using supersonic expansion followed by inertial separation. The project included bench-scale testing of the system with simulated flue gas.

technical goals

- Demonstrate ICES at bench-scale including condensation, migration, CO₂ removal, and diffusion of the CO₂-depleted flue gas to atmospheric pressure.
- Develop approach to obtain condensed CO₂ particle size required for effective migration and separation.
- Demonstrate pressure recovery efficiency of system consistent with economic goals.
- Demonstrate CO₂ capture efficiency.

technical content

Orbital ATK, Inc. designed an inertial CO₂ extraction system (ICES) that aims to achieve an overall reduction in total carbon capture cost for post-combustion CO₂ capture. The ICES system, shown in Figure 1, is derived from aerospace applications and is based on supersonic inertial separation technology. Compressed flue gas is directed to a converging-diverging nozzle and undergoes supersonic expansion (high velocity, low pressure and temperature), which results in CO₂ desublimation. Turning the supersonic flow in the curved flow path causes inertial separation of the dense, solid CO₂ particles, which are collected in a CO₂-rich stream through a duct in the wall into a cyclone separator where the CO₂ solids are collected. The CO₂-depleted stream is diffused and sent to the stack.

Factors for improved performance of the ICES system included controlling and increasing CO₂ particle size to increase migration and capture, pre-cooling of the flue gas to enable subsonic condensation and promote heterogeneous nucleation for larger particles, and efficient pressure recovery. The compact design, along with efficiencies in CO₂ capture, reduces costs of the carbon capture system. An initial techno-economic assessment by Worley Parsons estimated a \$41.80/tonne CO₂ captured for an ICES plant, with cost savings coming from lower capital costs (smaller equipment), lower operating costs (no moving parts, chemicals or media), and improved capture efficiency compared to a typical amine solvent-based plant. However, further studies found that more compression is required due to lower pressure recovery than predicted and, therefore, a cost of >\$50/tonne CO₂ captured is anticipated. ICES is expected to have comparatively favorable economics for applications requiring less capture and/or applications with lower CO₂ concentration since compression costs scale with these parameters.

technology maturity:

Bench-Scale, Simulated Flue Gas

project focus:

Supersonic Inertial CO₂ Extraction System

participant:

Orbital ATK, Inc.

project number:

FE0013122

predecessor projects:

N/A

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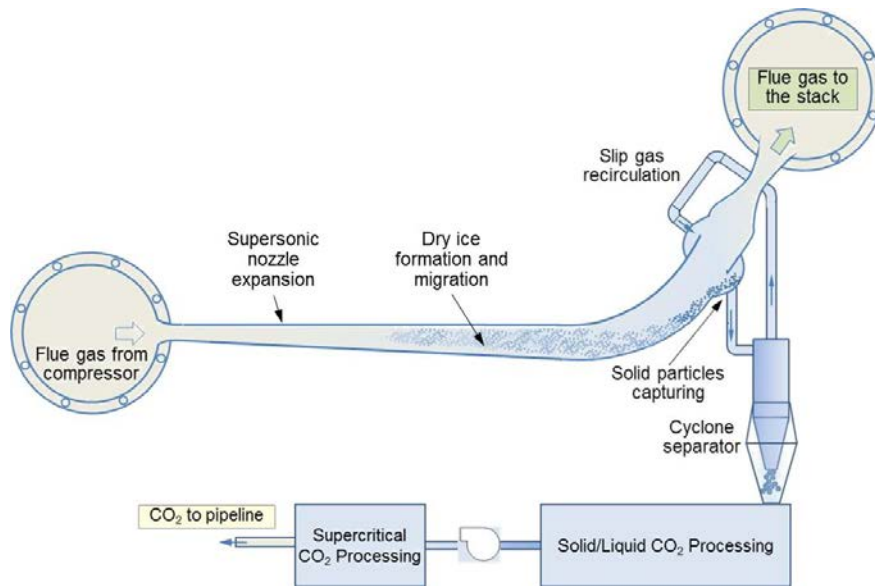


Figure 1: ICES system

Lab-scale testing of the system in a previous project has shown that CO_2 particles of $>2.5 \mu\text{m}$ is required to ensure efficient inertial migration. Initial test results also proved that CO_2 only condenses on solid or liquid media in the flow (heterogeneous condensation). This led to the conclusion that solid CO_2 seeding is the most viable path to 90 percent CO_2 capture by causing flue gas CO_2 to condense on particles that are already $>2.5 \mu\text{m}$. Preliminary testing on a bench-scale apparatus (Figure 2) using a liquid throttle to inject CO_2 of a controlled particle size in the duct demonstrated >50 percent capture of solid CO_2 and indicated a higher amount of CO_2 captured with a lower inlet temperature. An approach was developed to recirculate a fraction of the collected liquid CO_2 back to the inlet to achieve additional cooling at the inlet along with the creation of large “seeded” particles to promote heterogeneous nucleation capable of migration. However, compression requirements would further increase with this method since more energy would be needed to accelerate the added mass of the recycled CO_2 to high speed. Based on thermodynamic analyses, a method for pre-cooling of the flue gas using captured CO_2 as a “cold sink” was determined to be the best approach. This pre-cooling enables subsonic condensation of a small quantity of CO_2 (and trace water) resulting in “in situ” seeding without the need to recirculate solid CO_2 . Testing of a subsonic ICES system with pre-cooling by liquid nitrogen showed that a significant amount of CO_2 condensed into large CO_2 particles with an average size of $30\text{--}40 \mu\text{m}$.



Figure 2: Bench-scale ICES test apparatus illuminated with laser sheet

Scaling the technology for use in a full-scale power plant involves combining multiple ICES units for increased capacity. The compactness of the group of ICES units, as shown in the proposed plant configuration in Figure 3, leads to substantial reductions in the footprint capture plant compared to a similar capacity capture plant using amine solvent capture technology ($8,000 \text{ m}^2$ vs. $20\text{--}30,000 \text{ m}^2$). Stacking the ICES nozzles and compressors further reduces the footprint.

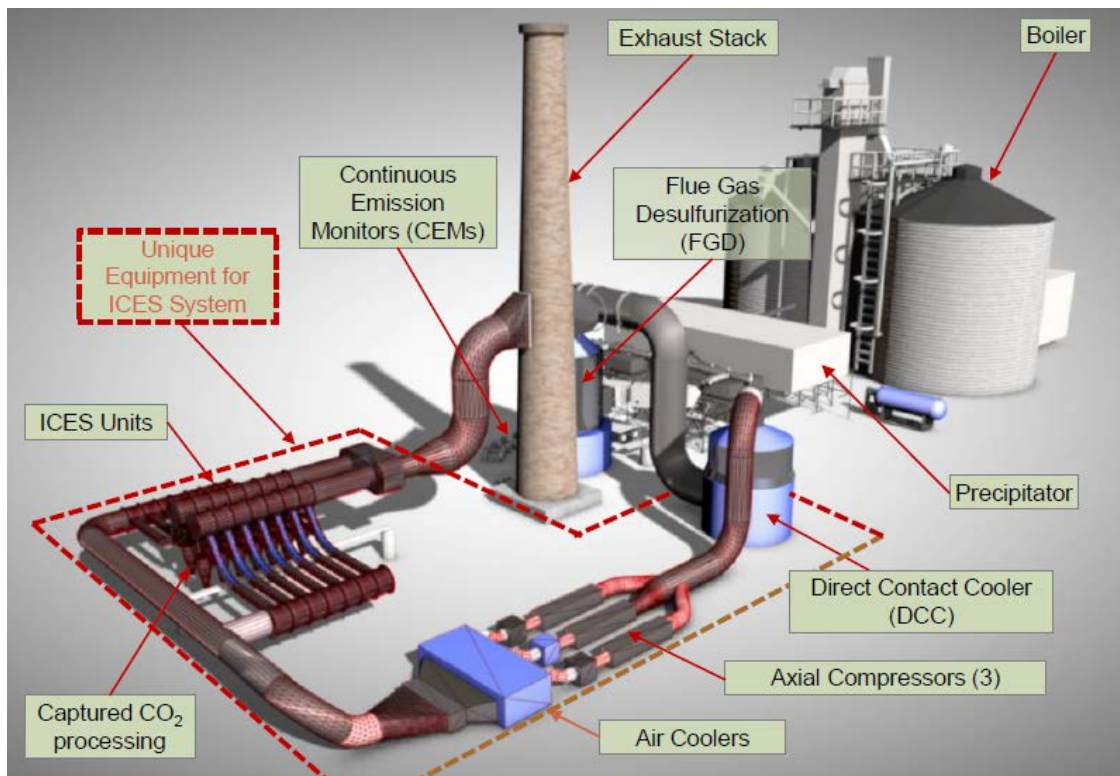


Figure 3: ICES plant layout and footprint

Definitions:

Inertial Separation – Method that uses a rapid change in air direction and principles of inertia to separate particulate from an air stream.

Heterogeneous nucleation – Process that occurs in the formation of a crystal from a solution, liquid, or vapor, in which particles become arranged in a pattern characteristic of a crystalline solid, forming a site upon which additional particles are deposited as the crystal grows.

technology advantages

- No moving parts, chemicals/additives, or consumable media.
- No refrigeration expense—low temperatures from supersonic expansion.
- Inexpensive construction based on sheet metal and concrete.
- Small equipment footprint.
- “Cold sink” available from accumulated solid CO₂.
- Costs driven by flue gas compression.

R&D challenges

- Development of optimized supersonic contour to maximize particle size and migration and minimize pressure losses.
- Minimization of slip gas that is removed with solid CO₂.
- CO₂ purity—condensable flue gas impurities removed along with CO₂.
- Solid CO₂ processing.
- Optimization of flow path pressure recovery.

status

Testing of a bench-scale capture duct/diffuser system achieved ≥ 50 percent CO₂ capture. Testing of a subsonic ICES test article demonstrated large CO₂ particle formation through partial subsonic condensation enabled by pre-cooling of the flue gas. The pre-cooling approach addresses the increase in compression requirements that evolved from thermodynamic modeling efforts. Future work will continue optimization of the ICES for a range of CO₂ concentrations and/or CO₂ capture levels to identify the most favorable operating conditions.

available reports/technical papers/presentations

"Supersonic Post-Combustion Inertial CO₂ Extraction System," Final Report, April 2017.

<https://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/post-combustion/Final-Report-ATK-FE0013122-April-2017.pdf>

Castrogiovanni, A., Balepin, V., Robertson, A., Calayag, B., "Supersonic Post-Combustion Inertial CO₂ Extraction System," presented at the 2016 NETL CO₂ Capture Technology Meeting, Pittsburgh, PA, August 2016.

<https://www.netl.doe.gov/File%20Library/Events/2016/c02%20cap%20review/3-Wednesday/T-Castrogiovanni-ACENT-Supersonic-Inertial-CO2-Extraction.pdf>

Balepin, V., Castrogiovanni, A., Robertson, A., Tyll, J., "Supersonic Post-Combustion Inertial CO₂ Extraction System," presented at the 2015 NETL CO₂ Capture Technology Meeting, Pittsburgh, PA, June 2015.

<https://www.netl.doe.gov/File%20Library/Events/2015/co2captureproceedings/A-Castrogiovanni-AL-Supersonic-CO2-Extraction.pdf>

Balepin, V., Castrogiovanni, A., Robertson, A., Calayag, B., "Supersonic Post-Combustion Inertial CO₂ Extraction System," presented at the 2014 NETL CO₂ Capture Technology Meeting, Pittsburgh, PA, July 2014.

<http://www.netl.doe.gov/File%20Library/Events/2014/2014%20NETL%20CO2%20Capture/A-Castrogiovanni-ATK-Supersonic-Post-Combustion.pdf>

"Supersonic Post-Combustion Inertial CO₂ Extraction System," Kickoff Presentation, November 2013.

<http://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/post-combustion/11-14-2013-NETL-ICES-Kickoff-Nonproprietary.pdf>