ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds

Project Overview

Funding
- DOE Funding: $2,900,000
- Non-DOE Funding: $725,000
- Total Value: $3,625,000

Overall Project Performance Dates
- Project duration: 30 months

Project Participants
- Gas Technology Institute (GTI)
- Clean Carbon Solutions Ltd. (CCSL)
- National Carbon Capture Center (NCCC)

Overall Project Objectives
- DOE's cost target of ≤$30/tonne CO_2
- Achieving ≥95 % product CO_2 purity

Major participants (collaborative projects):

The Project Team is comprised of GTI, CCSL and NCCC. The proposed program utilizes each Team Member's unique expertise.

GTI has expertise is in bench-scale and pilot-scale research and development (R&D) plus scoping economic analysis. We bring over 75 years of performing applied R&D for DOE and other governmental agencies as well as industry and bringing technology to the market to the effort.

CCSL is an early stage process technology venture with commercially proven products and process licensing with technologies for industrial decarbonization commercial while reducing the environmental impact of man-made emissions. Their focus is to provide the most cost-effective CO_2 capture and CO_2 treating technology with patented chemistry and engineering know-how at more than 25 sites globally.

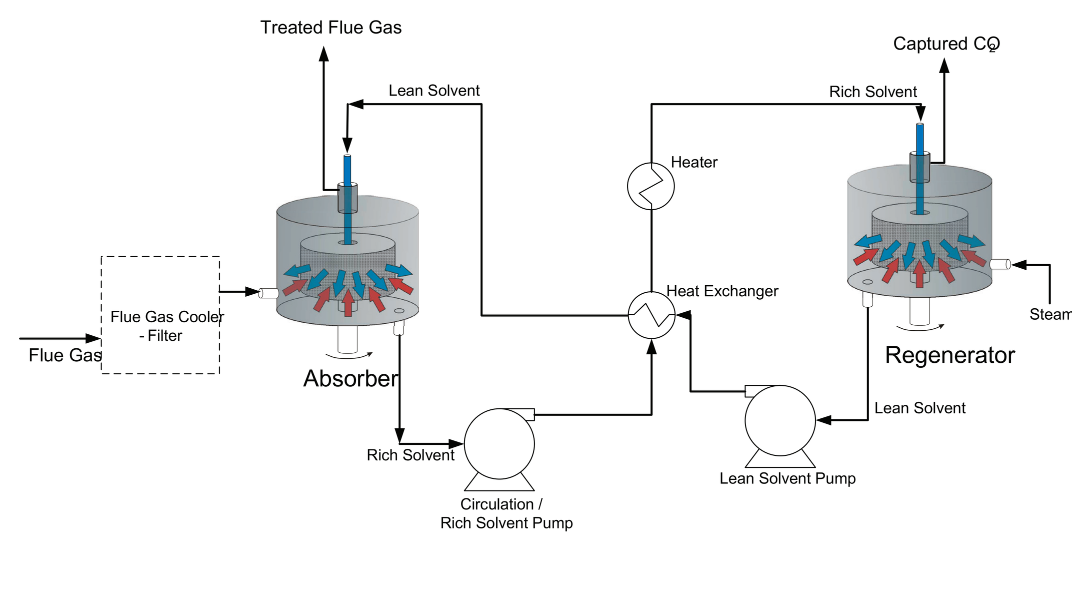
NCCC specializes in evaluation of developing technologies using coal-derived gas with the concomitant impurities, providing critical information on material and process suitability for scale-up to commercial applications.

Technology Background

The objective of this project is to develop and validate a transformational carbon capture technology—**ROTA-CAP**. This will be achieved by the design, construction, testing, and simulation modelling of novel rotating packed bed (RPB) absorbers and regenerators in an integrated, process-intensified carbon capture system using advanced solvents at bench-scale. The performance of the integrated hardware and solvent will be assessed under a range of operating conditions with simulated flue gases and GTI's natural gas burner flue gas to optimize the process, ahead of long-term testing with coal-fired flue gas at the National Carbon Capture Center (NCCC).

How the technology works

ROTA-CAP will utilize the RPB in combination with an advanced solvent technology in an effort to validate a significant breakthrough in reducing the capital and operating expenditure of carbon capture system to meet or exceed DOE's cost targets for carbon capture from low percentage CO_2 sources, such as pulverized coal (PC)-fired power plant flue gas or natural gas-derived flue gas. These targets are for a new coal-fired power plant with CO_2 capture to achieve ≥90 % of the CO_2 from the flue gas. The product CO_2 is to have a purity of ≥95 % and a cost of electricity at least 30% lower than that of a supercritical PC with CO_2 capture or approximately $30 per tonne of CO_2 by 2030.

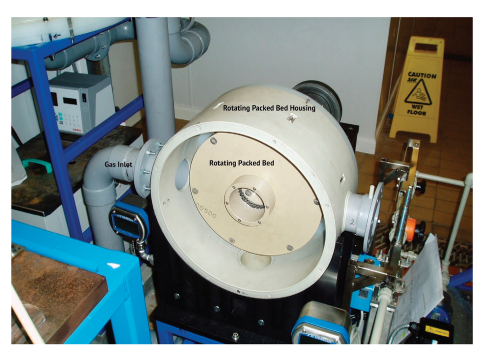


ROTA-CAP System Process Flow Diagram

The fundamental science

The RPB absorber is a type of high gravity reactor (HIGEE), originally developed in the 1930's. It replaces the conventional gas-liquid contactor towers used in for gas processing.

- Rotating disk of a packing material that generates a high gravity centrifugal force.
- Solvent flows from the inner edge of the rotating disk radially towards the outer edge.
- Incoming countercurrent flue gas contacts the solvent.



Laboratory Scale Rotating Packed Bed Absorber

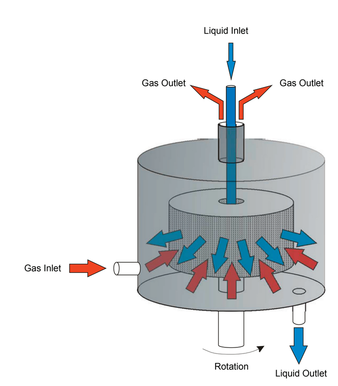
Rotation (~600–1,000 rpm) generates high centrifugal forces that provide:

- High liquid shear.
- Improved CO_2 mass transfer efficiency.

Highly concentrated solvents can be used in small reactors to absorb similar quantities of gas that require tall contacting columns and high solvent circulation rates. This leads to higher CO_2 loadings and greater process efficiency.

Other process benefits:

- Reduced sizing requirements of heat exchangers, pumps, and coolers by up to 50%.
- Lower residence time of the solvent in the absorber.
- Reduced oxidative and thermal degradation.
- Decreased solvent top-up requirements by approximately 77%.
- Reduced waste handling and disposal cost by up to 92%.

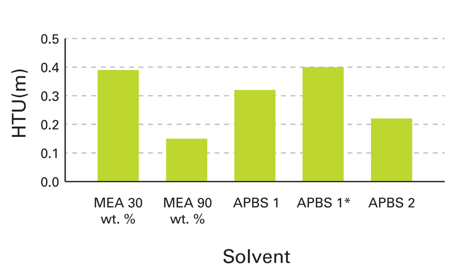


Rotating Packed Bed Reactor

The use of RPB absorber technology is anticipated to reduce the size and therefore cost of the absorber. Similarly, we expect the size reduction of the RPB regenerator relative to the conventional, static stripper columns would be comparable to that of the analogous absorber technology.

Development efforts to date

In 2016, Carbon Clean Solutions Limited (CCSL) completed an research and development (R&D) program with the Newcastle University, UK and the University of Hull, UK. In the project, a bench-scale prototype Rotary Packed Bed Absorber (RPBA) was evaluated in CO_2 capture applications using CCSL's solvent (APBS 2) and the industry standard solvent, monoethanolamine (MEA) at various concentrations. Results show close to 50% smaller height of transfer unit (HTU) for APBS 2 solvent compared to 30% MEA solvent for same absorption rate.



Height of a Transfer Unit (HTU) for MEA and APBS Solvents Tested in a Prototype RPB Absorber

ROTA-CAP Technology Background (continued)

Technical and economic advantages

- The ROTA-CAP technology holds potential to provide economical, efficient carbon capture capabilities, allowing the continual use of fossil fuels to generate clean, low-cost electricity for generations to come.
- A simulation process model for integrated RPB carbon capture systems will be developed, which can be used in future larger-scale deployments.
- A high-level techno-economic analysis (TEA) will prove the value of the ROTA-CAP technology in the carbon capture market. It will also evaluate how ROTA-CAP aligns with DOE's cost target of ≤$30/tonne CO_2, while achieving ≥95 % product CO_2 purity.
- RPB reactors offer higher efficiencies and are non-selective to the solvent used, making them easier to scale up than conventional contactors.

Technical and economic challenges

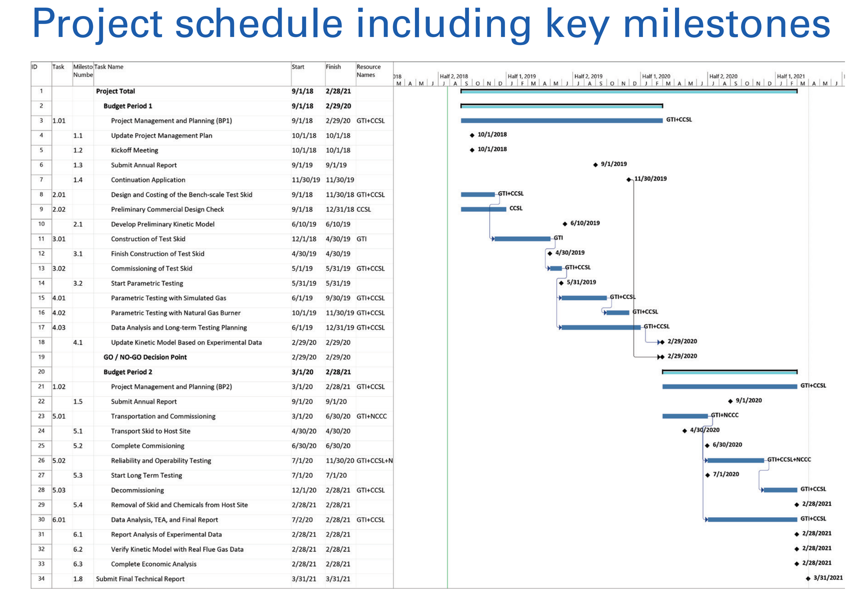
- The integrated use of RPBs as both absorber and regenerator in a single system.
- The mechanical design parameters of rotating equipment.
- Solvent performance during operation.
- Integrating and achieving required solvent regeneration using an RPB regenerator.
- Scaling up of the RPBs may be challenging. We will allow for design limitations of rotating equipment sizing and investigate the modular design approach by designing, building, and testing an integrated RPB absorber and regeneration unit that will work with CCSL's solvent (APBS 2).
- During testing we will determine the solvent performance and modify it as needed to achieve 90% CO_2 removal rate.
- We will allow for design limitations of rotating equipment sizing and investigate the modular design approached to overcome RPB scaling challenges.

Technical Approach/Project Scope

Experimental design and work plan

GTI and Clean Carbon Solutions Ltd. (CCSL) will develop a compact carbon capture system that uses a RPB contactor absorber and rotating bed contactor regenerator. The two sections of the system need to be connected together and operated continuously to validate and optimize the equipment as a cost and energy effective carbon capture system. Ultimately, the system is indifferent to the solvent used. Combining ROTA-CAP with CCSL's proprietary solvent formulation solvent will further improve capture efficiency. Together with CCSL, GTI will develop both the absorber and regenerator through bench scale with testing at GTI and perform reliability and long term testing at NCCC.

Project schedule including key milestones



Project success criteria

Decision Point	Date	Success Criteria
Go/No-Go decision points	03/01/2020	• Complete design for bench scale ROTA-CAP skid utilizing continuous absorption-regeneration operation. • Viable design for a commercial scale unit verified. • Successful testing of the ROTA-CAP bench scale skid with RPB absorber and regenerator using simulated gas and natural gas burner flue gas: –Continuous operation with absorber and regenerator coupled together. –Quick startup and shutdown duration for the skid.
Completion of the project	03/01/2021	• Successful long duration testing: • Cumulative 1000 hr testing with real flue gas. • Minimal solvent carryover and degradation.

Project risks and mitigation strategies

Description of Risk	Probability*	Impact*	Risk Management Mitigation and Response Strategies
Technical Risks:			
Scale up of rotating packed bed reactor is too problematic	Low	Moderate	• Previous experience in design of lab scale equipment and commercial equipment manufacturers available for consultation • GTI's experience on evaluation of high-efficiency gas-liquid contactors for natural gas processing including RPB reactors
Energy use by RPB reactors is too high	Low	Moderate	• Reactor design will balance the size of reactor and energy use to achieve economic scale up
Flue gas contaminants degrade solvent or solvent aerosols form on RPB reactor exit	Moderate	Low	• Solvent analysis to monitor degradation • Liquid carryover measurement will be done at the exit of the RPB reactor
Not high enough capture efficiency	Low	Moderate	• Previous work with CCSL solvent APBS matched MEA performance • Solvent concentration can be adjusted to achieve the desired efficiency
Safety Risks:			
Rotating Equipment	Low	High	• CCSL has previous experience with designing rotating packed bed equipment. All necessary mechanical engineering calculations will be verified by a commercial equipment manufacturer.
Chemical	Low	High	• HAZOP reviews will be conducted prior to skid fabrication and again prior to initiation of the testing to identify and mitigate any safety risks associated with handling methane and potential reaction products.
Resource Risks:			
Minimal: GTI, CCSL, and NCCC have qualified personnel and equipment in place. GTI has the laboratory space and equipment available for the project and NCCC has committed to providing a test site for the long-term testing.			
Management Risks:			
Minimal: GTI, CCLS, and NCCC have Project Management systems in place to minimize management risks.			

Progress and Current Status

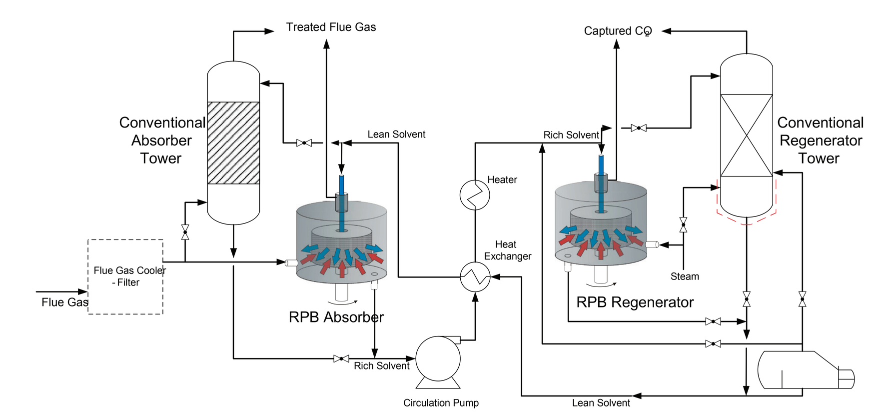
Description of test equipment

GTI will build a 50kWe (1000kg/day CO_2 removal) equivalent scale integrated carbon capture skid. The skid will have a flue gas cooling and filtration section available to be used when necessary and will be designed to be able to operate with either RPB contactors or conventional columns or a combination of each.

The key variables will include:

- Rotating packed bed rotational speed 500–2000 RPM
- Absorber Liquid/Gas ratio 0.5–5.0 kg/m3
- Solvent circulation rate 30–150 kg/h
- Solvent concentration/viscosity 40–80 wt.% (5–100 cP)
- Regenerator operating pressure/temperature 0.0–1.0 bar(g) (100–130°C)
- Flue gas composition (synthetic, natural gas-fired, coal-fired).

The task duration for testing of the bench-scale ROTA-CAP skid at GTI is planned to be 5 months. This includes 3 months for simulated gas testing and 1 month natural gas burner flue gas testing with 1 month of testing that can be used for either. Long-term testing at NCCC is planned to be a cumulative 1000 hr test.



Integrated Bench-Scale Rota-Cap Test Skid with Conventional Tower Sections

Future Plans

The project aims to increase the technology readiness level (TRL) of the existing technology, with respect to carbon capture, from its current level of TRL 3 to TRL 5 on completion of the project. Through validation of the technology, both experimentally and through process simulation, ROTA-CAP will take strides towards providing an economically viable carbon capture system for industrial flue gas sources.

This project will lead to continued development of rotating pack bed based carbon capture technology to higher TRLs.

Contact: Mr. Osman Akpolat
osman.akpolat@gastechnology.org