Prospectus
Texas Carbon Management Program

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Please consider participating in the Texas Carbon Management Program (TxCMP) at the University of Texas at Austin (UT). The research program is focused on the technical obstacles to the deployment of CO_2 capture from flue gas by amine absorption/stripping. The primary objective is to develop and demonstrate evolutionary improvements to monoethanolamine (MEA) scrubbing for CO_2 capture from coal- and gas-fired flue gas, including power plants and other sources. The strategy is to apply chemical engineering science to understand and quantify the performance of MEA and piperazine (PZ) absorption/stripping, then to develop innovative, evolutionary improvements.

Background

Carbon capture technology is needed for coal and gas-fired power plants, OTSG boilers used in oil sands, LNG production, cement plants, and other CO_2 sources. Conventional coal-fired power plants and gas-fired combined cycles represent a large fraction of the existing capacity and capacity to be built before renewables can be deployed with acceptable power storage. Even with storage there will be a need for capacity when renewables are unavailable for more than a few hours. These conventional plants cannot be abandoned in any comprehensive strategy to address global climate change by reducing CO_2 emissions. With the availability of inexpensive natural gas, new combined cycle, gas-fired power plants will be a significant source of CO_2 emissions that must be addressed. Refineries and chemical plants require gas-fired turbines with cogeneration of steam. Alberta has an urgent need to reduce the carbon footprint from gas-fired boilers and turbines used to produce petroleum from oil sands. Cement plants and other industrial sources must also be addressed. The lean and rich partial pressure of coal-fired CCS is comparable to CO_2 capture for LNG production.

Our immediate objective is to support in Texas the commercialization of CO_2 capture by amine scrubbing on gas and coal-fired power plants and gas-fired cogen that will supply CO_2 for EOR.

Like limestone slurry scrubbing for flue gas desulfurization, CO_2 capture by scrubbing with aqueous monoethanolamine (MEA) was identified in 1991 as the technology of choice. The CCS community has been working to find a breakthrough with ionic liquids, designer solvents, adsorption, membranes, oxycombustion, gasification, and other “promising” alternatives for more than 30 years. Yet amine scrubbing is and will be THE competitive technology for CO_2 capture from natural gas and coal combustion. If we expect to impact the cost of CO_2 capture and accelerate its deployment, we must address the opportunities and remaining challenges of amine scrubbing and its immediate solvent process derivatives.

The TxCMP has demonstrated aqueous PiperaZine with the Advanced Stripper (PZAS™) at 150 °C as an attractive, representative second generation (2G) alternative to MEA. This fully disclosed, comprehensive case study of solvent and process development continues to develop fundamental understanding and applied methods that are applicable to the evaluation and development of proprietary solvents and processes.

As a representative 2G solvent unlike MEA, PZ is resistant to degradation, corrosion, and other solvent management issues, yet these challenges persist. Therefore, the first primary emphasis of the TxCMP is to safeguard amine scrubbing from the environmental and cost risks of amine oxidation and nitrosamine by developing fundamental understanding and mitigation with piperazine and other 2G solvents.

Further energy improvement is limited by the minimum work of CO_2 separation from flue gas and presents little opportunity for meaningful progress. Second generation amine scrubbing (2G) has demonstrated an energy requirement that is better than 50% thermodynamic efficiency (<2.5 GJ_t or 250 kwh_e/tonne CO_2). Therefore, the second primary emphasis is addressing capital cost reduction by evaluating and optimizing alternative equipment types and hybrid configurations for gas/liquid contactors, heat exchangers, and compressors and by addressing the poorly understood mechanisms of corrosion.

Focus of Effort

The program includes 7 PhD students, 2 faculty, 2 PhD professionals, and 3 professional staff working on solvent management, system modeling to reduce capital costs, and pilot plant testing. The effort is funded by more than $500,000/yr from 13 sponsors in the Texas Carbon Management Program and other affiliated activities including 6 process suppliers (Shell/Cansolv, MHI, Honeywell UOP, Chart, Aker, RTI), 1 power company (EPRI), 3 oil companies (Chevron, ExxonMobil, Total), three collaborators (AECOM, Trimeric, GSEC) and one equipment donor (Emerson). This support is leveraged by more than $1,800,000/yr of grant funding from the U.S. DOE for work on FEED studies, amine oxidation, and model development.

Solvent Management

Solvent management is required to minimize the environmental risks and costs of oxidation, aerosol, and nitrosamine. This effort includes fundamental studies of loss mechanisms and more applied measurements to deal with each of the mechanisms. It includes detailed case studies with PZ and MEA and screening of other amines. Ariel Plantz, Chih-I Chen, and James Obute are the PhD students performing this research.

Amine Oxidation is being elucidated by comprehensive analysis of degraded samples from pilot plants and bench-scale experiments. The solutions are analyzed by cation and anion chromatography, HPLC, mass spectrometry, UV/VIS spectrometry, and NMR to determine and quantify the parent amine and degradation products including aldehydes, organic acids, amino acids, and amides. A simple bench-scale experiment with intensive exposure to oxygen for 1 to 3 weeks is used to screen amines at absorber conditions. T cycling in another apparatus is used to simulate absorber/stripper conditions. The cycling system uses hot gas FTIR to determine ammonia and other volatile degradation products. A bench-scale absorber/stripper is being commissioned to provide more realistic long-term evaluation of oxidation mechanisms and mitigation.

Nitrosamine formation and decomposition kinetics have been determined in PZ and a number of other amines. NO_x absorption rate and stoichiometry are measured in the wetted wall column and the cyclic oxidation apparatus. It is probable that that NO_2 plays a major role in solvent oxidation. We will be measuring amine oxidation with and without NO_2. We are developing a method of removing NO_2 with sulfite or a tertiary amine in the SO_2 polishing scrubber. This method has been successfully tested at the National Carbon Capture Center in collaboration with Trimeric.

Modeling and experiments to reduce capital cost

Athreya Suresh, Miguel Torres, Ben Drewry, and Jorge Martorell are developing rigorous models of the amine scrubbing process and using them to evaluate solvents and innovative flowsheets and to optimize the process conditions and configuration to minimize energy and total costs. Most of this work is being performed in Aspen Plus® with rigorous models for the piperazine solvent.

System models are being developed to represent and optimize the economics of building and operating PZAS with natural gas-fired combined cycle power plants that function in power grids with a large penetration of renewables. These models will be applied to specific site conditions and other applications.

Corrosion rates of carbon and stainless steel are being measured by electrical resistance (ER) probes at 100–150 ºC in a cyclic flow system with loaded solutions of amine. A batch agitated reactor sparged with air/N_2/CO_2 is being used to study corrosion at 30 to 70 ºC. Dissolved metals are measured in thermal stability samples and in samples from pilot plant testing. ER probes and corrosion coupons are being applied in pilot plant testing of MEA and PZ to determine the bounds of metal protection by $FeCO_3$ and Cr_2O_3.

These validated models will provide support for a FEED study of the PZAS™ process on NGCC in West Texas. The rigorous modeling will provide a reliable heat and material balance and economic optimization for diurnal and seasonal ambient conditions and energy value. Cost data from the FEED will be used to develop optimized designs for other sites and applications.

Pilot plant

Pilot-scale testing at the facilities of the Separations Research Program (SRP) and the National Carbon Capture Center continues to implement ideas developed by the TxCMP and characterize packing at a larger scale. Dr. Fred Closmann manages our role in these pilot plant efforts. The SRP facility is managed by Dr. Frank Seibert. Interpreted pilot plant results are shared with participants of the TxCMP.

A carefully controlled pilot plant facility has been constructed and is being used to provide quantitative screening of contactor alternatives and to demonstrate important process concepts. This facility has been being used with PZAS™ (30 wt % PZ and the advanced stripper). A campaign in Spring 2022 focused on amine oxidation.

Pilot plant testing of mechanisms and mitigation methods for amine oxidation will be performed for more than 6 months at the National Carbon Capture Center in Fall 2022 and Spring 2023.

<u>Participation</u>

Please consider participating in this research program by providing $50,000/yr. If you wish formal participation, you may execute a Memorandum of Agreement. We will provide you with an invoice for payment. This level of support does not provide intellectual property or contracted deliverables. However, we will provide you with quarterly reports, preprints, and publications generated by the research and you will be invited to attend semi-annual research review meetings and to contribute to discussions of future work.