Enzymatic technology for low-cost CO_2 capture in oil sands operations

by Jonathan A. Carley

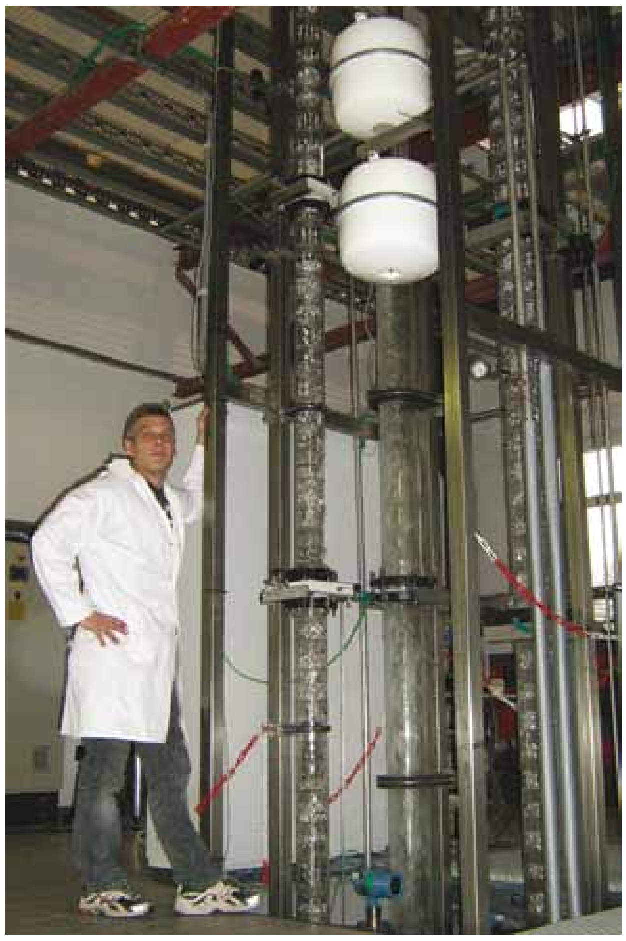
The environmental footprint of unconventional hydrocarbon production from the Alberta oil sands has been a subject of growing interest both in Canada and internationally. Much of this interest and debate has been focused on the industry's higher overall carbon dioxide (CO_2) emissions footprint compared to conventional oil production. This has resulted largely from the combustion of natural gas to produce steam which is injected underground to produce this oil in-situ. With growing public concerns about the effects of global climate change brought about by rising CO_2 emissions industry and government are focused on ways to tackle this challenge, with carbon capture and storage (CCS) being a mitigation option of major interest.

Post-combustion, solvent-based carbon capture is widely accepted as the nearest term technology option as part of an overall CCS solution for large emitters. However, conventional solvents such as monethanolamine (MEA) require significant amounts of heat to release the captured CO_2, creating a highly inefficient process in terms of energy consumption. In this regard, the Alberta oil sands face a significant cost challenge in utilizing conventional CO_2 capture technology. In the case of in-situ production (typically steam-assisted gravity drainage technology, or SAGD), CO_2 generated from gas combustion is contained in flue gas at approximately only 4-10 percent concentration. Due in part to this, associated capture costs are very high. This challenge also exists when natural gas or field gas is combusted for Steam Methane Reforming (SMR) facilities as part the heavy oil upgrading process, and in co-generation plants. The Government of Alberta recently estimated conventional CO_2 capture costs for the industry would range from approximately $68-112 per tonne of CO_2 for SMR operations, up to $100-172 per tonne for SAGD operations, making the technology uneconomical. Compounded by the fact that the oil sands in-situ extraction sector is currently the fastest growing source of CO_2 emissions in Alberta (and Canada), the need for new cost-effective approaches to CO_2 capture for the industry is significant.

Breakthrough brings down cost barrier

CO_2 Solutions Inc. has developed and patented a breakthrough enzymatic platform technology which addresses this cost barrier. The technology is built around the use of the extremely powerful enzyme catalyst which efficiently manages carbon dioxide in living organisms, carbonic anhydrase (CA). When applied in an industrial CO_2 removal system, CA dramatically accelerates energy-efficient, but kinetically limited solvents, which would otherwise be too slow for CO_2 capture from flue gases, such as methyldiethanolamine (MDEA) and sodium carbonate.

Rate-based modelling from lab work by CO_2 Solutions and its process engineering consultant Procede Group BV



has shown that by employing CA with these solvents to commercially capture CO_2 from a large SAGD operation can reduce absorber heights by more than 90 percent, to near the equivalent of an MEA process.

These findings highlight the innovative feature of the enzymatic technology: MDEA and sodium carbonate have significantly weaker binding to CO_2 than MEA (due to the formation of bicarbonate rather than carbamates), and thus require less energy to separate the CO_2 during the solvent regeneration phase. Based on known energies of regeneration and preliminary process simulations, CO_2 Solutions predicts that with appropriate plant energy integration, cost savings of 30-40 percent will result from the use of the technology compared to conventional MEA process.

The technology is also designed to be used with existing packed tower gas scrubbing architecture well understood and accepted by industry.

Also, compared to chemical CO_2 capture accelerants such as piperazine, the use of the enzymatic technology is more economically and environmentally sustainable. With the use of piperazine, the formation of stable carbamates results and therefore solvent regeneration energy is negatively impacted. Piperazine also results in the creation of carcinogenic nitrosamine air emissions when reacting with nitrogen oxides contained in flue gases. Conversely, CA is a pure catalyst that does not lead to carbamate formation or air emissions, achieves equivalent kinetic enhancement without increased regeneration energy requirements, and is less expensive on a mass basis.

CO_2 Solutions utilizes the enzyme either soluble in solution or attached (immobilized) to the surface of very small particles. This has the major advantage of the CA being present in high quantities in the CO_2-solvent reaction interface. This is opposed to other approaches, notably where CA is immobilized to the fixed packing in the absorption column. In this case, the enzyme is generally too far from the reaction interface and the process faces significant operational challenges with the change-out of the packing material when the enzyme needs to be periodically replaced. Most importantly however, not enough CA can be immobilized to this packing material to sufficiently catalyze the reaction. In this regard, the immobilization of a complete monolayer of enzyme to a very high surface area structured packing (700m^2/m^3) will yield a maximum of only 40 mg CA/l solvent whereas approximately 500 to 1000 mg/l of solubilized CA is required to obtain the required process catalysis.

CO_2 Solutions was the first to recognize and patent enzymatically enhanced carbon capture and has the broadest portfolio of patents in Canada and abroad (24 issued and 46 pending) encompassing the use and application of the enzyme in various process configurations and with key low-energy solvents.

Working with major producer

In collaboration with a major oil sands producer, CO_2 Solutions is in the final planning stages of a program to apply its technology to the Alberta oil sands and which would support its parallel scale-up for other large emissions sectors. Building from current work, a first phase (2012-2013) of this program will see the optimization of the technology at bench-scale through work at its Quebec laboratory and that of Procede Group.

This effort will involve selecting the best commercially available solvent to be accelerated by CA for oil sands applications, and the best enzyme management system (i.e. soluble or particle-based). Enzymes for the project will be supplied by CO_2 Solutions' enzyme development and manufacturing partner Codexis, Inc. of California. Since 2009, CO_2 Solutions and Codexis have collaborated on the development of customized CAs which are now stable for scale-up of the carbon capture process. The best selected CA-solvent process will then be tested in an existing large-bench unit to determine energy savings relative to an MEA baseline process. If this testing is successful, the process would then be migrated to a larger field pilot in Alberta to be hosted by the producer partner in the 2013-2015 timeframe.

A successful field pilot test would pave the way for larger demonstration and commercial deployment after 2015 in conjunction with the development of CO_2 pipeline and storage infrastructure in planning in Alberta and expected further carbon regulation. Importantly, CO_2 Solutions believes that by addressing the cost barrier to the CO_2 capture component of CCS, which is about 80 percent of the total cost of CCS, its viability as a carbon mitigation tool could be effectively realized at the large-scale needed for substantive emissions reductions. This in turn would support the Government of Canada's goal of a 17 percent overall reduction in Canada's greenhouse gas emissions by 2020.

In this regard, there is the potential for the enzymatic technology to provide the lowest cost post-combustion CO_2 capture approach using known solvent absorption technology, providing a strong technical pathway to commercial adoption.

Jonathan A. Carley is Vice-President, Business Development with CO_2 Solutions Inc.

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