INTERNATIONAL CCS KNOWLEDGE CENTRE

GHGT-15 Abstracts

April 2020

Preface:

GHGT-15 is a biannual premier international technical conference on carbon capture and storage (CCS). Over the 25 years since GHGT began, the conferences have charted considerable progress and growth in the science behind CCS. The conference aims to promote CCS as an essential climate change mitigation strategy. The conference attracts cutting edge researchers from around the world and provides a platform for knowledge sharing and CCS growth.

The International CCS Knowledge Centre submitted eleven abstracts for this conference. All ten were successful; seven were chosen for oral presentations while four were chosen for poster presentations. The abstracts and their presentations formats are summarized below:

Paper Title	Author	Paper Number	Status	Presentation type	Submitted by
A Feasibility Study of Full Scale, Post Combustion, Amine Based, CO2 Capture Retrofit Application in the Cement Manufacturing Sector at the Lehigh Hanson Materials Limited Facility	Wayuta Srisang	565	accepted	ORAL PRESENTATION	Wayuta Srisang
Approaching Negative Greenhouse Gas Emissions via Bioenergy with CO2 Capture and Storage	Wayuta Srisang	566	accepted	POSTER	Wayuta Srisang
Waste Heat Utilization for the Energy Requirements of a Post Combustion CO2 Capture Retrofit Study of the Lehigh Hanson Cement Manufacturing Facility in Edmonton, Canada	Wayuta Srisang	567	accepted	ORAL PRESENTATION	Wayuta Srisang
Derates and Outages Analysis - A Diagnostic Tool for Performance Monitoring of SaskPower's Boundary Dam Unit 3 Carbon Capture Facility	Stavroula Giannaris	136	accepted	ORAL PRESENTATION	Stavroula Giannaris

SaskPower's Boundary Dam Unit 3 Carbon Capture Facility: The Journey to Achieving Reliability	Stavroula Giannaris	135	accepted	ORAL PRESENTATION	Stavroula Giannaris
A novel methodology for online amine solution analysis of the degradation caused by fly ash	Amr Henni	349	accepted	POSTER	Amr Henni

Table of Contents

A Feasibility Study of Full Scale, Post Combustion, Amine Based, CO_2 Capture Retrofit Application in the Cement Manufacturing Sector at the Lehigh Hanson Materials Limited Facility

Wayuta Srisang[a], Brent Jacobs[a], Corwyn Bruce[a]1, Yuewu Feng[a], Stavroula Giannaris[a], Dominika Janowczyk[a]

[a]*The International CCS Knowledge Centre, 198 – 10 Research Drive, Regina, Saskatchewan Canada S4S 7J7*

Abstract

This paper will present the progress of a feasibility study aimed at retrofitting a cement production facility at Lehigh Hanson Materials Limited (Lehigh), (Edmonton, Alberta, Canada) with a full scale, post combustion, amine-based CO_2 Capture. This study is a major breakthrough for CCS as it represents a first in the world for CCS application in the cement industry. Cement is used to make concrete, the second most-consumed material in the world and the most consumed man-made material in the world. With a global annual production of more than 4 billion tonnes, the cement manufacturing industry contributes as much as 8% of global CO_2 emission. With the demand of this material expected to increase between 12-23% by 2050, actions must be taken to reduce the CO_2 emissions profile of these facilities.

The majority of CO_2 emissions produced by cement plants are derived in its kiln system due to the combustion of fuel to heat the kiln, the chemical conversion of limestone. Minor amounts of CO_2 emissions are also produced by the operation of mobile equipment and the cement milling process in some cases. While the energy used to fire the kiln could be switched to alternative or renewable sources, as adopted by the power generation and other industrial sectors, the emissions resulting from the chemical reactions in the cement production process cannot be similarly eliminated. Consequently, the GHG emissions associated with the chemical process continues to be a significant challenge in reducing the global CO_2 footprint of the cement industry.

To achieve the sustainability commitment on CO_2 emission reduction and support Canadian policies on climate change protection, Lehigh Hanson, which is owned by Heidelberg Cement, is leading the development of the application of a large-scale, amine-based, CCUS project at their cement manufacturing facility located in Edmonton Alberta. The facility emits 600,000 - 750,000 tonnes of CO_2 annually while producing 800,000 – 1,000,000 tonnes of clinker. This project will explore:

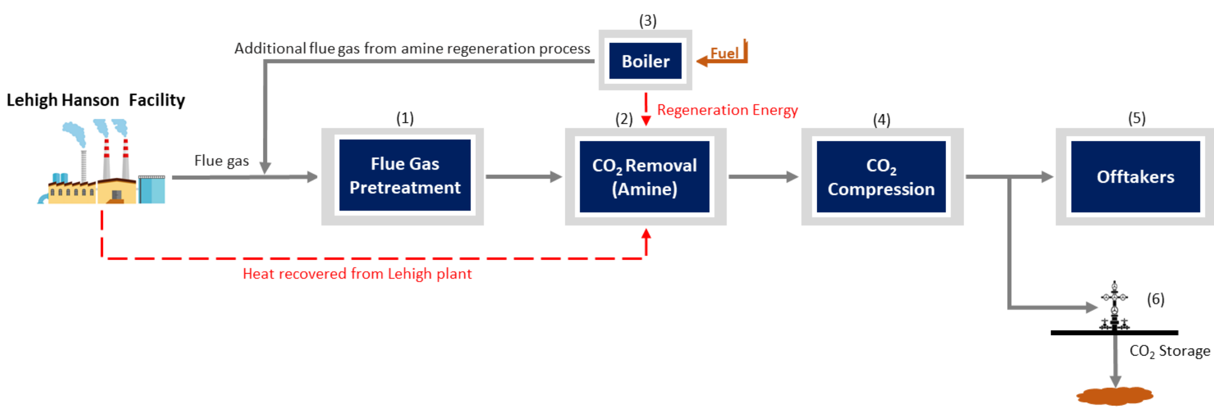
- the economic and technical feasibility of capturing CO_2 produced both by the kiln during the production of clinker and the CO2 produced from the thermal processes required for the regeneration of amine solvents
- the effects of cement plant flue gas contaminants on the CO_2 capture process and develop a mitigation strategy
- the potential of heat recovery from the existing cement plant to fulfill the energy requirement of the CO_2 capture process (specifically amine regeneration)

* Corresponding author. Tel.: *+1 306 565 5668*, *E-mail address:* cbruce@ccsknowledge.com

A schematic diagram of the scope of the project is in Figure 1. Flue gas from the kiln is introduced to the flue gas pre-treatment process. At this stage the flue gas is preconditioned by cooling and removing impurities such as dust, and SOx before being fed to the CO_2 capture process. The CO_2 produced by the capture process is fed to a compression system which simultaneously compresses and dries the CO_2 before delivering it to off-takers for utilization or a CO_2 storage site. Three different CO_2 capture technology vendors will compete and design the flue gas pretreatment, CO_2 capture, and CO_2 compression processes. This is to maintain competitiveness in this project and provide Lehigh with confidence in technology selection for a possible future project. Enhanced Oil Recovery is intended to be the primary end use for the captured CO_2. The Lehigh facility is located about 50 km away from the Alberta Carbon Trunk Line (ACTL) and nearby EOR opportunities. The project will include contingency provisions to establish a direct deep well storage of CO_2 to be utilized during times where demand for captured CO_2 is reduced. Federal Canadian and Alberta Provincial emission regulations justify this initiative as venting excess CO_2 will result in paying carbon tax. The study will be completed through a collaboration between Lehigh, the International CCS Knowledge Centre, HeidelbergCement Technology Centre, three world leading CO_2 capture technology vendors (which have been selected through an evaluation of a Request For Proposal process), and engineering consultants which will design the balance of the plant components.

This feasibility study will be carried out between November 1, 2019 and December 31, 2020 and is projected to cost $2.9M CAD. Funding for this study has been contributed by Lehigh and Emissions Reduction Alberta (ERA). The study will examine both the carbon capture technology and the "balance of plant". Successful completion of this feasibility study will lead to a decision to carry out a Front End Engineering and Design (FEED) study and ultimately to a Final Investment Decision (FID) to implement a commercial scale project. A commercial project is conservatively projected to reduce emissions by 544,159 tonnes of CO_2e per year compared to baseline, a figure which includes potential downstream and over the fence emissions associated with the process. The commercial scale project is conservatively projected to reduce emissions in Alberta by 13.06 Mtonnes over a 25 year lifespan.

Figure 1. A schematic diagram of the scope of the project



Keywords: Cement production; CO_2 capture; Amine; Post combustion; CCS on Cement, CO_2 Emissions; CCS Feasibility Study; CCS Retrofit

Approaching Negative Greenhouse Gas Emissions via Bioenergy with CO_2 Capture and Storage

Wayuta Srisang[a], Corwyn Bruce[a]2, Brent Jacobs[a], Yuewu Feng[a], Stavroula Giannaris[a], Dominika Janowczyk[a]

[a]*The International CCS Knowledge Centre, 198 – 10 Research Drive, Regina, Saskatchewan Canada S4S 7J7*

Abstract

This study performed high level cost analysis of converting a hypothetical 305 MW coal-fired power station located in western Canada to Bioenergy with CO_2 Capture and Storage (BECCS) facility. The Intergovernmental Panel on Climate Change (IPCC) reported that the world will need to take dramatic steps to limit earth's temperature increase to less than 1.5 ˚C above pre-industrial levels. The IPCC report includes an assessment of the role of carbon dioxide (CO_2) removal from air technologies and negative emissions technologies (NETs) such as BECCS. BECCS removes atmospheric CO_2 by pairing post combustion CO2 capture technology with biomass fired electricity generating facilities. Among NET technologies, BECCS is most promising as it takes advantage of existing coal plant infrastructure (therefore decreasing project capital costs) and allows for the continued supply of baseload electricity while reducing CO_2 emissions from fossil-fuel combustion.

This paper utilizes the findings of the Shand CCS Feasibility study, and the Phase IV Biomass Co-firing report from the Canadian Clean Power Coalition to explore the potential advantages which may be realized with a biomass co-firing unit equipped with a 95% CO_2 capture capacity facility. BECCS would allow the power station to take advantage of its existing infrastructure but also provide the benefits of increased fuel flexibility and reductions in SOx and CO_2 emissions. Moreover, reductions in agricultural waste and the creation of local jobs in agricultural production are an added benefit.

Table 1 Summary of the biomass availability and co-firing rate supported within different radii from hypothetical BECCS facility with the considerations of conventional tillage and competing usage for cattle feed and bedding

	Biomass Available (ODt)				Co-firing Rate Supported (%)				Biomass Cost (US$/GJ)			
Straw Type	50 km	100 km	150 km	200 km	50 km	100 km	150 km	200 km	50 km	100 km	150 km	200 km
Wheat	83,0	248,7	524,7	887,0	6%	17%	37%	62%	$2.3	$2.62	$2.94	$3.26

* Corresponding author. Tel.: *+1 306 565 5668*, *E-mail address:* cbruce@ccsknowledge.com

	29	23	40	80					4			
Flaxseed	4,974	20,075	42,548	69,195	-	2%	3%	5%	$2.02	$2.32	$2.59	$2.86
Oats	1,098	7,947	35,345	81,130	-	1%	3%	6%	-	-	-	-
Pellets (BC)	-	-	-	-	100%				$7.03			

Biomass available from agriculture within a 200 km radius of the hypothetical power plant was estimated by the Biomass Inventory Mapping and Analysis Tool (BIMAT). BIMAT, developed by Agriculture and Agri-Food Canada, allows users to view and analyze detailed information about biomass availability within Canada using digital maps and database searches. The summary of the biomass availability and co-firing rate supported within different radii from the hypothetical power plant is shown in Table 1. Due to the hypothetical power plant's proximity to the US Canada boarder additional biomass could also be available from the US.

The conversion of the hypothetical power plant to BECCS with 95% CO_2 capture capacity produces a negative CO_2 emission intensity as shown in Fig. 1 which increases with increased levels of cofiring. With complete conversion of the hypothetical power plant to BECCS, its emission intensity is estimated at negative 1.38 tonnesCO_2/MWh. Main factors influencing the cost of electricity are biomass purchasing and transportation costs. Cases of BECCS with pellets sourced from British Columbia (Canadian province) have significantly higher costs compared to other cases. For co-firing cases, higher levels of co-firing lead to slightly increased cost of electricity due to the requirement for transportation of

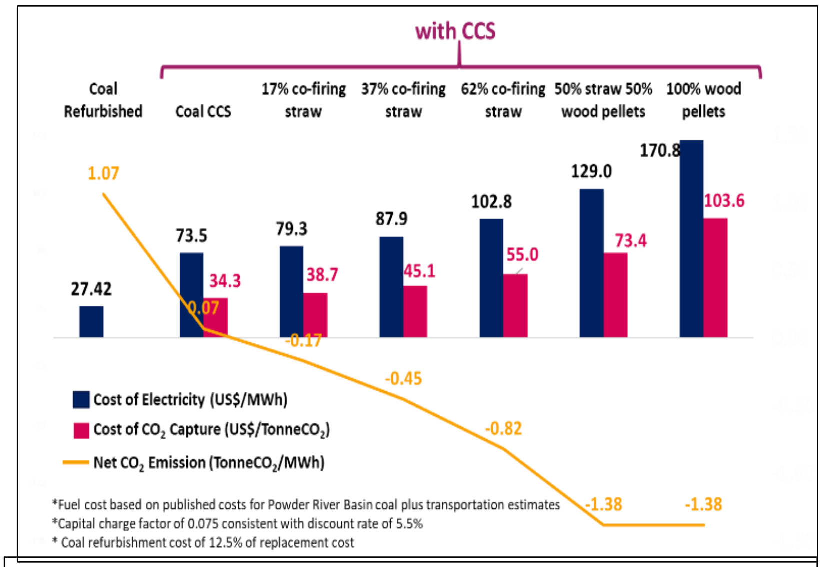


Figure 1. Cost of electricity, cost of CO_2 capture and net CO_2 emission

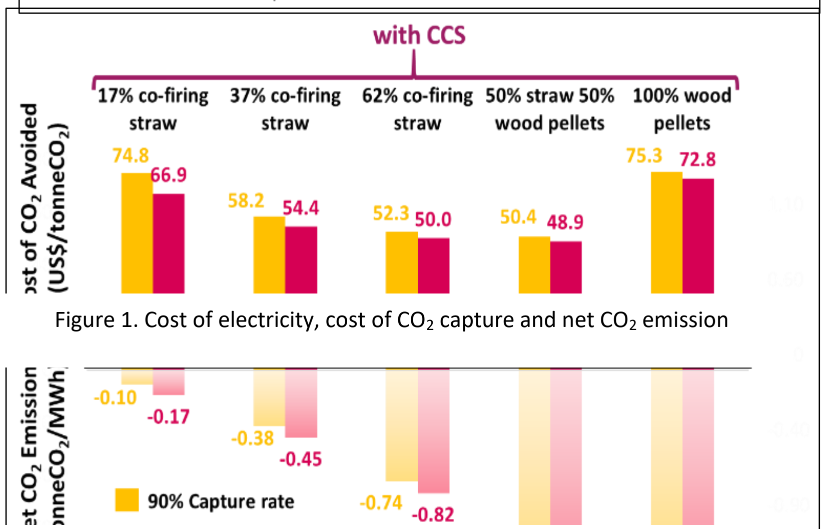


Figure 2. Cost of CO_2 avoided and net CO_2 emission at 90% and 95% CO_2 capture rate

biomass from greater distances. The cost of CO_2 avoided from BECCS varies from 67 to 50 US$/tonne with co-firing and 49 to 73 CAD$/tonne with full conversion (Figure 2). The cost of CO_2 avoided might be lower when the rate of co-firing straw is higher than 60%, however, it will require further study of additional biomass supplies such as forestry, energy crops, and marginal farming operations. For comparison purposes the cost of CO_2 avoided from a commercial scale Direct Air Capture (DAC) facility (published by Carbon Engineering) is evaluated. The levelized cost of CO_2 capture with DAC varies from 94 US$/tonne up to 232 US$/tonne based on financial assumptions and energy costs. By comparison, the costs of CO_2 avoided from BECCS and DAC, including the cost of conversion for the existing thermal power plant to BECCS, is potentially the best approach for realizing global CO_2 emissions reduction target. An effective regulation on policy, carbon pricing, and negative emission credits will be required to incentivize the implementation of BECCS in the power industries' business plans.

Keywords: BECCS; CO_2 capture; biomass; co-firing

Waste Heat Utilization for the Energy Requirements of a Post Combustion CO_2 Capture Retrofit Study of the Lehigh Hanson Cement Manufacturing Facility in Edmonton, Canada

Wayuta Srisang[a], Brent Jacobs[a], Corwyn Bruce[a]3, Yuewu Feng[a], Stavroula Giannaris[a], Dominika Janowczyk[a]

[a]*The International CCS Knowledge Centre, 198 – 10 Research Drive, Regina, Saskatchewan Canada S4S 7J7*

Abstract

The solvent based post combustion CO_2 capture process is the most mature of CO_2 capture technologies. This process utilizes a two-column design and manipulates the reversible nature of the CO_2 – amine solvent bond to capture CO_2 in the first column (absorber) and release it in the second (desorber). Energy (in the form of heat) is required for amine regeneration, or CO_2 release. To date, this technology has been applied to two coal fired power station, Unit 3 at Boundary Dam Power Station (BD3 ICCS) in Saskatchewan Canada and the Petra Nova Project in Texas, USA. Energy, in the form of steam, was sourced from within the turbine for the BD3 ICCS project while an auxiliary heat recovery steam generator was utilized for the Petra Nova Project. As CCS moves into other industrial sectors, novel heat recovery and heat integration methods will be required to meet the energy requirements of CCS. One such industry is the cement manufacturing industry. Cement is used to make concrete, the second most-consumed material in the world next to water and the world's most consumed man-made material. With annual global production of cement is more than 4 billion tones, the CO_2 emitted from cement production accounts for approximately 8 percent of global CO_2 emissions.

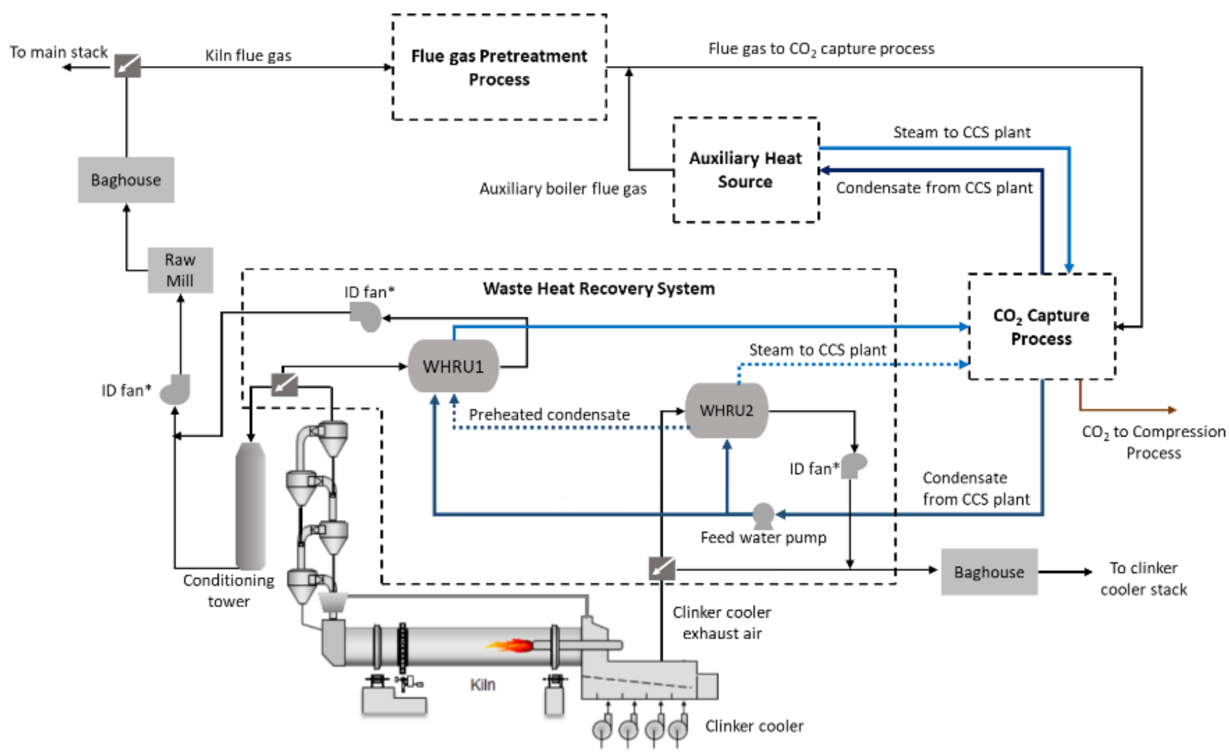
Lehigh Hanson Materials Limited (Lehigh), part of the HeidelbergCement Group, and the International CCS Knowledge Centre (Knowledge Centre) have received funding from Emissions Reduction Alberta (ERA) to assist in conducting a feasibility study for the application of CCS at Lehigh's Edmonton Cement Facility. This feasibility study will be carried out between November 1, 2019 and December 31, 2020 and is projected to cost $2.9M CAD. The Lehigh Edmonton facility emits 600,000 - 750,000 tonnes of Carbon Dioxide (CO_2) annually while producing 800,000 – 1,000,000 tonnes of clinker. Of these emissions, burning of fuels to heat the kiln

* Corresponding author. Tel.: *+1 306 565 5668*, *E-mail address:* cbruce@ccsknowledge.com

accounts for 1/3 of the emissions, while the chemical conversion of limestone (which is the main raw material in cement production) accounts for the remaining 2/3.

Determining an alternative energy source for amine regeneration will be a major deliverable and challenging component of this study as previously utilized methods do not apply in this situation because cement plans do not normally produce steam. Cement manufacturing is an energy intensive process resulting in multiple high temperature exhaust streams. Preliminary thermodynamic investigations have identified the potential for installing Waste Heat Recovery Units (WHRU) at two flue gas streams: (1) kiln flue gas (WHRU1) and (2) clinker cooler fresh air exhaust (WHRU2) (Figure 1.).

Figure 1. Schematic of the cement manufacturing plant highlighting two possible locations (WHRU1 and WHRU2) for heat recovery



(1) Kiln Flue Gas

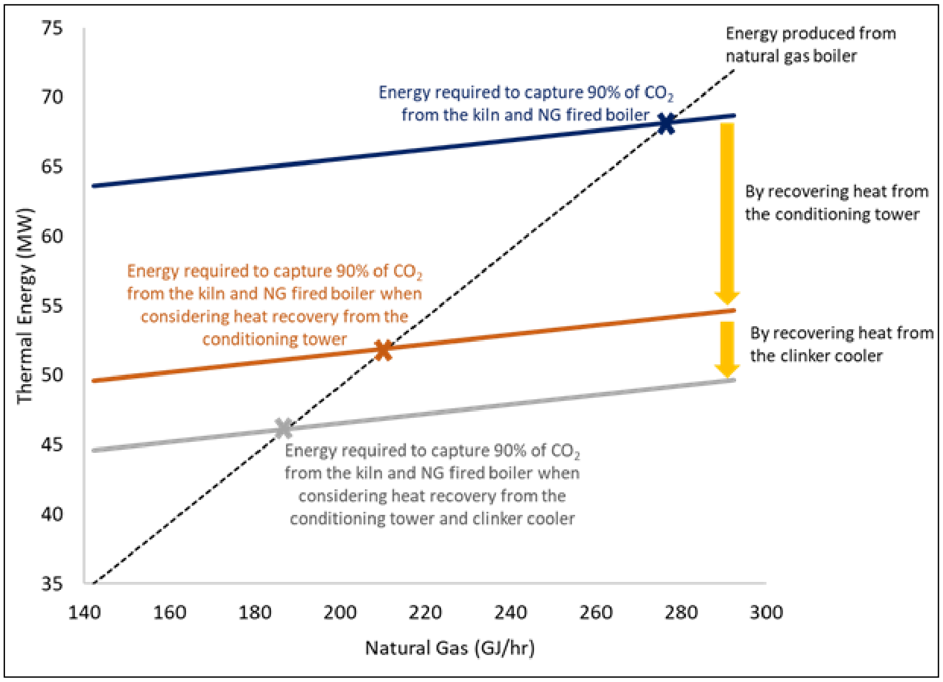
Current process operations involve hot gas (~400°C) from downstream of the kiln preheater tower entering the kiln conditioning tower to be cooled before it is directed to the raw mill or coal mill. The coal mill does not operate when the Lehigh facility uses natural gas as its primary fuel. The hot flue gas enters the top section of this vertical, cylindrical-shaped tower for cooling, to approximately 200 ˚C, by water injection. The gas is drawn through the conditioning tower by the kiln ID fan to feed the gas to the raw mill for drying the raw materials and conveying of ground mill product to storage. The gas and raw mill product are then directed to the baghouse for particulate removal. The proposed waste heat recovery unit (WHRU1), which would recover heat from the flue gas downstream of the preheater tower, is proposed to be installed in parallel to the existing kiln conditioning tower, as depicted in Figure 1.

(2) Clinker Cooler Flue Gas

Clinker is cooled from 1200°C to <100°C in a clinker cooler through heat exchange with ambient air. Some of this heated ambient air is used as combustion air and feed to the kiln and pre calciner. The remaining air, with an approximate temperature of 200-400°C, is directed through a baghouse to the exhaust duct. The clinker exhaust air is cooled to approximate 100°C using a heat exchanger before it enters the baghouse for particulate removal. A heat recovery unit is also proposed to be installed to utilize this heat. The heat recovery unit for clinker cooler exhaust air (WHRU2) will be install in parallel with the clinker cooler exhaust air cooler.

The configuration of the two WHRUs would allow the cement plant the ability to operate independently of the WHRUs as these could be bypassed when not in operation. Based on the information received from various CO_2 capture technology vendors during the pre-feasibility study phase of this project, the thermal energy requirement varies depending on the specific amine and process configuration of each vendor. Based on a 90% capture rate of the CO_2 emitted from the kiln at Lehigh facility, 50-60 MWth will be required by the CO_2 capture process. To meet this requirement an auxiliary heat source will also be required to supplement the recovered waste heat.

Figure 2. Analysis of energy requirements for a CCS retrofit for the Lehigh Edmonton cement manufacturing facility



If fossil fuels are used to supplement the energy requirements, the additional CO_2 emitted will need to be captured resulting in additional energy requirement for the CO_2 capture process. Utilizing available waste heat from the Lehigh facility helps to overcome this challenge. Results from the preliminary investigation into sources for the required regeneration energy are summarized in Figure 2. Specifically, the relationship between the energy required to capture 90% of the CO_2 from the existing Lehigh kiln and the additional CO_2 that will be generated due to the amine regeneration energy supply is highlighted. Results illustrate that the energy requirement will be significantly lower if the waste heat in the existing conditioning tower and clinker cooler is recovered and used in the capture process. This justifies investigating waste heat recovery and integration methods as opposed to sourcing the energy requirement solely from an auxiliary heat source. Such heat recovery units and their installation can add significant costs to a project. An economic impact assessment of this option will be completed. This will quantify required modifications to the existing plant to accommodate this option such as the installation of dampers, waste heat recovery systems, additional ID fans, or upgrading the existing ID fan.

Keywords: Waste heat recovery; cement production; CO_2 capture; CO_2 emission; CCS on cement; amine regeneration energy.

Derates and Outages Analysis - A Diagnostic Tool for Performance Monitoring of SaskPower's Boundary Dam Unit 3 Carbon Capture Facility

Stavroula Giannaris[a], Dominika Janowczyk[a], Brent Jacobs[a], Corwyn Bruce[a]4,

Yuewu Feng[a], Wayuta Srisang[a]

[a]*The International CCS Knowledge Centre, 198 – 10 Research Drive, Regina, Saskatchewan Canada S4S 7J7*

Abstract

Establishing CCS as a viable CO2 emission mitigation strategy for various industries will require identifying and eliminating existing barriers to achieving desired performance. SaskPower's Integrated Carbon Capture Storage Project on Boundary Dam's Unit 3 (BD3 ICCS) began operations in October of 2014. By early November 2019, the facility had captured its 3 millionth metric tonne of CO2. Although no small feat, the cumulative volume of CO2 captured by late 2019 does not reflect the expected cumulative capture volume considering the five-year operational window and the size of the capture facility. As with many "first of a kind" facilities unforeseen barriers hindered the performance of the capture facility. To combat this a rigorous derate and outages analysis was established to evaluate and predict operational performance. Such analyses enable proactive planning and help to better understand the workings of the process works while ensuring to meet the needs of industry.

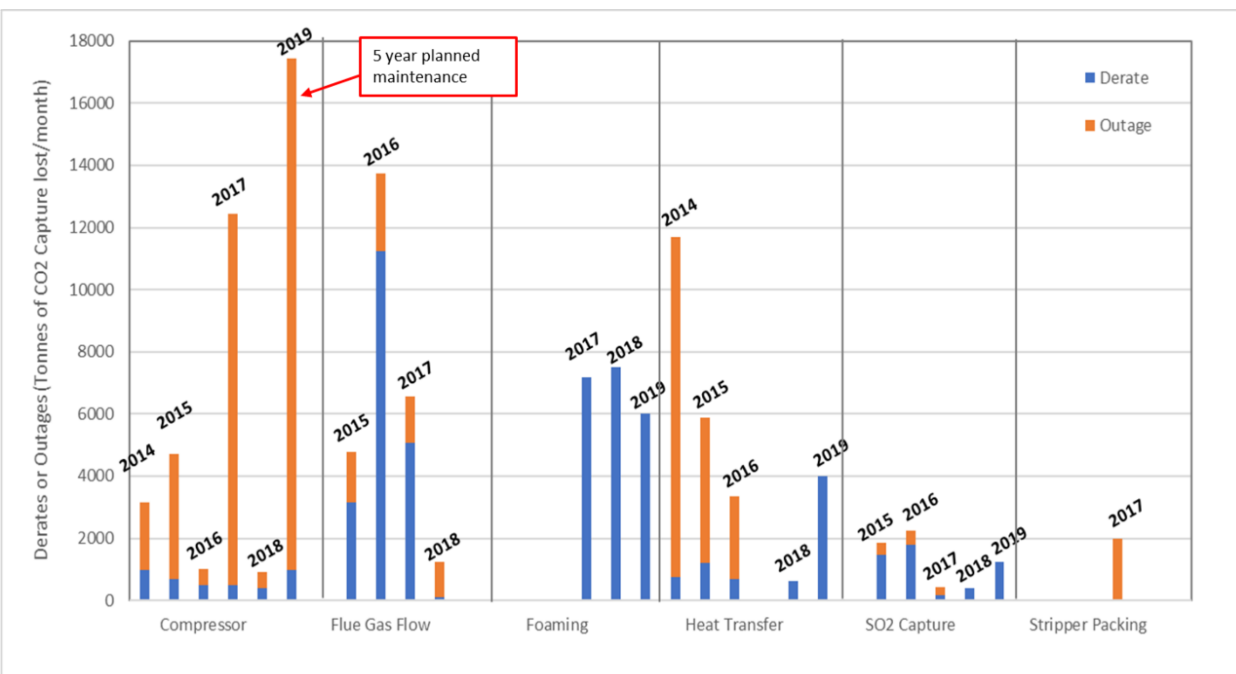
Derate and outage analysis identifies areas of concern and provides a means for reporting performance. Derates imply that the facility performance has been reduced as a result of operational issues with the process or its equipment, that limits the facility's capacity. Derates can affect both the power plant and the capture plant. Outages refer to a full shutdown of the facility. There are two types of outages, planned and unplanned outages. Planned outages enable maintenance activities that are part of scheduled maintenance for equipment and are known years in advance. Unplanned outages, on the other hand reflect unforeseen issues with the process or its equipment. Unplanned outages can be instantaneous, often these are related to the progression of a derate that makes continued plant operation un-sustainable and presents a short planning horizon for the outage. For both outages and derates, the capture facility is dependent on the operation of

* Corresponding author. Tel.: *+1 306 565 5662. E-mail address:* cbruce@ccsknowledge.com

the power plant as a prerequisite for its operation. The capture plant production of CO2 cannot exceed the operating point of the power plant.

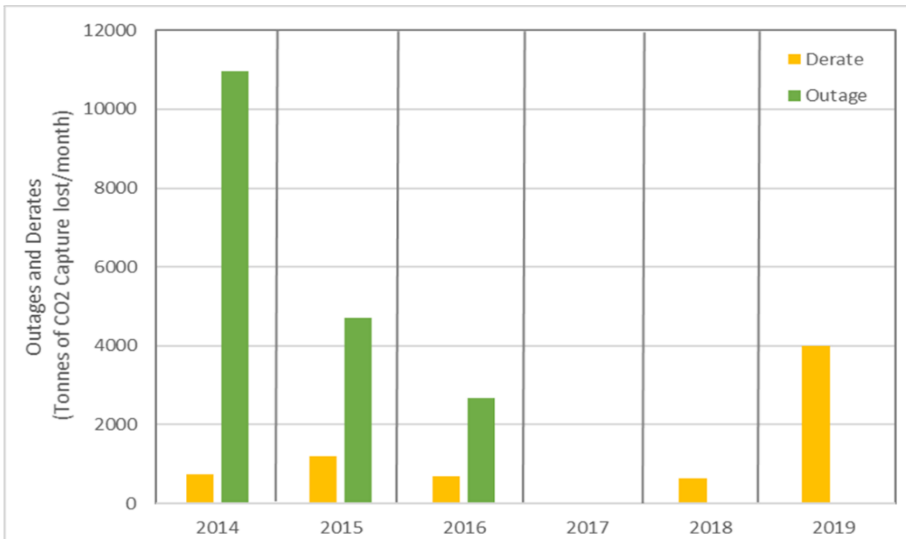
Unplanned outages to address design deficiencies and operational challenges reduced the capture rate particularly in the early years of operation. During the first year and a half of operations availability of the capture facility did not exceed 70% while the average daily capture rate in the first 12 months of operation was only 1238 tonnes/day. SaskPower utilizes OSI PI for operational data logging while PI ProcessBook is used to view the data. The dearate and outages analysis involved sorting daily operational data from PI and attributing operation hours lost to six broader grouping of equipment with in the capture facility (as shown in Figure 1). This method allowed the project team to identify deficiencies in the capture facility and to devise a plan to correct them. A major outage was planned in the summer of 2017. During this outage of redundancy and isolation were added to key pieces of equipment. These corrections improved the availability and reliability of the capture facility as the incidence of outages are more prevalent prior to the 2017 planned overhaul (Figure 1).

Figure 1. Summary of annual derate and outage occurrence



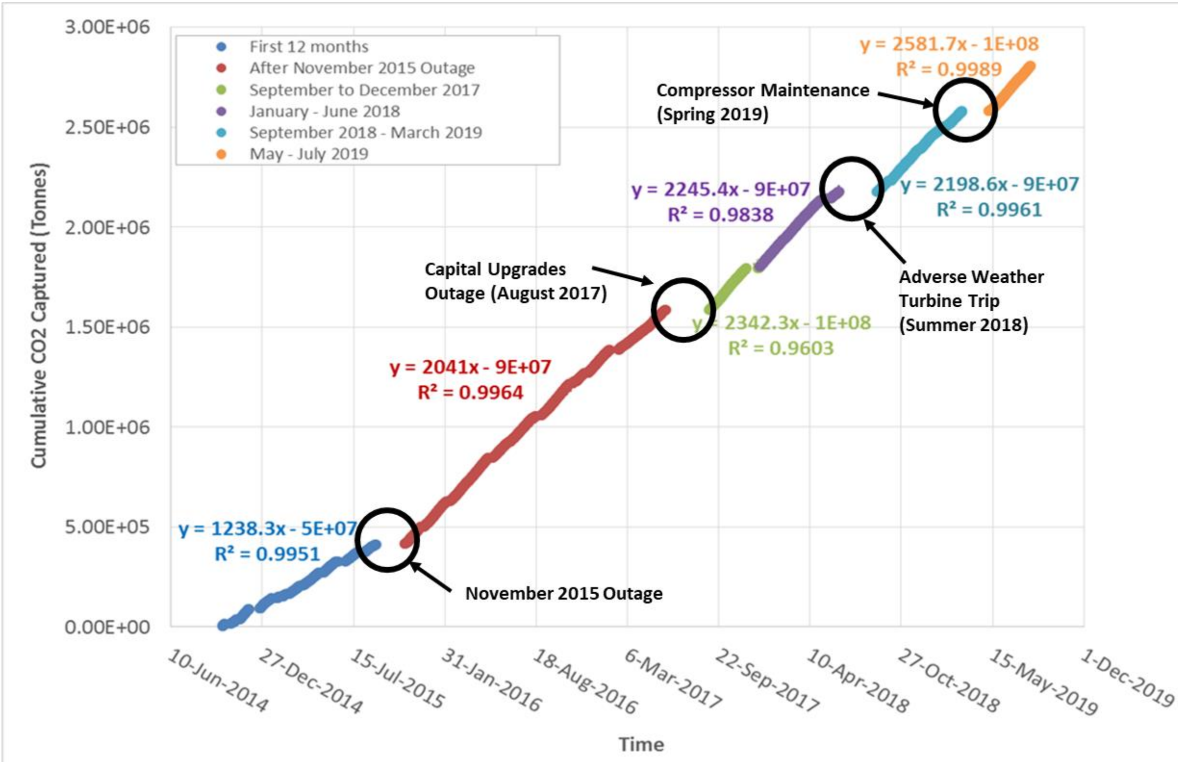
Redundancy and isolations allow for derating of the facility in favour of avoiding outages. This was particularly evident in the case heat exchanger performance. Prior to the 2017 overhaul the fouling of a heat exchanger would result in an outage for maintenance. Installation of redundancy and isolations for online maintenance eliminated the need for outages in favor of derates (Figure 2). Despite the increased incidence of dertaes overall capture performance has improved as the frequency that the capture island is on line for has increased.

Figure 2. Summary of annual heat exchanger induced derates and outages



By the summer of 2019 (May to July) the daily average capture rate was 2582 tonnes/day (Figure 3) while availability in the 2018 to 2019 period had improved to over 90%. The performance of the capture facility continues to be favourable today.

Figure 3. Summary of cumulative and daily CO2 capture performance (October 2014 – July 2019)



Keywords: Derate Analysis; Outages Analysis; Industrial Scale CCS; CCS Retrofit; Coal Fired Power Stations; Process Redundancy; Perfomance Reliability.

SaskPower's Boundary Dam Unit 3 Carbon Capture Facility: The Journey to Achieving Reliability

Stavroula Giannaris[a], Dominika Janowczyk[a], Brent Jacobs[a], Corwyn Bruce[a]5,

Yuewu Feng[a], Wayuta Srisang[a]

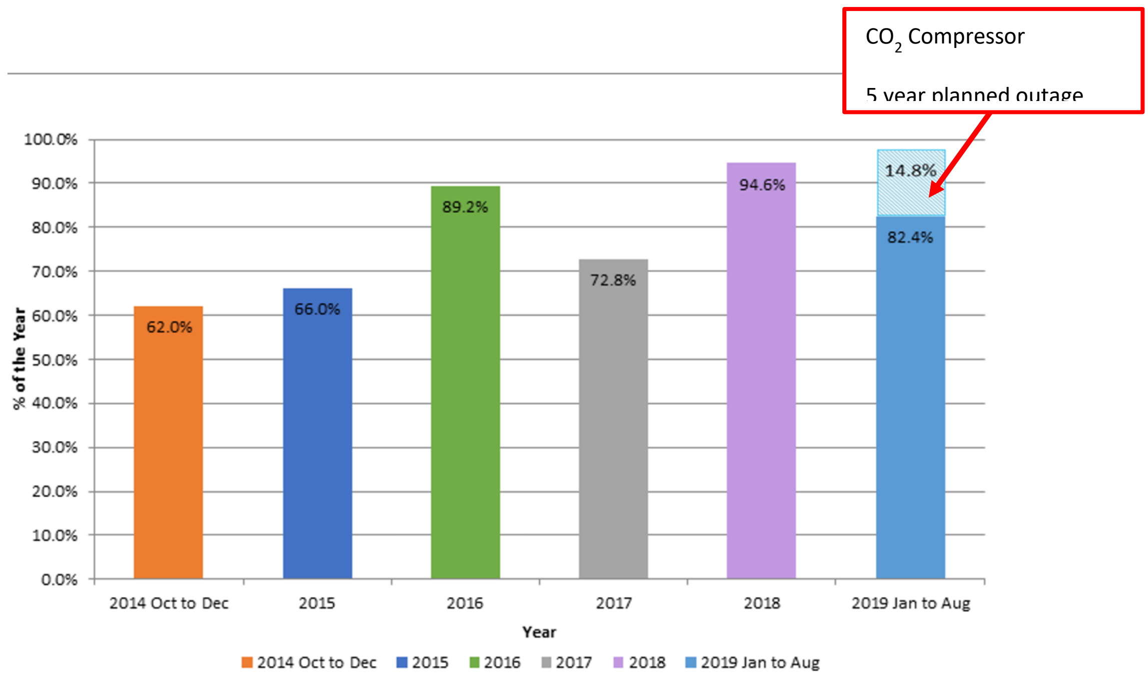
[a]*The International CCS Knowledge Centre, 198 – 10 Research Drive, Regina, Saskatchewan Canada S4S 7J7*

Abstract

SaskPower's Integrated Carbon Capture Storage Project on Boundary Dam's Unit 3 (BD3 ICCS) began operations in October of 2014. By early November 2019, the facility had captured its 3 millionth metric tonne of CO2. The road to 3 million tonnes of CO2 abated was not without difficulties. As a "first of kind" project, the capture facility at BD3 experienced unforeseen operational challenges and design deficiencies which hindered overall performance and significantly reduced reliability and availability of the capture facility in the early days of operation. Availability of the capture facility did not exceed 70% during the first year and a half of operations while the average daily capture rate in the first 12 months of operation was a merely 1238 tonnes/day. Reduced capture performance can be attributed to experiencing difficulties in three broad categories of process flows: limitations in flue gas flow, limitations in amine flow and limitations in heat transfer. Equipment responsible for facilitating these flows was identified. Major issues included fly ash accumulation, fouling of key heat exchangers and amine foaming. Corrections and additions to the capture facility were made to increase reliability and availability of the capture facility. The installation of redundancy and isolation to key pieces of equipment was instrumental in correcting the performance of the capture facility. By the summer of 2019 (May to July) the daily average capture rate was 2582 tonnes/day while availability in the 2018 to 2019 period had improved to over 90%. This paper documents the challenges and measures taken over the first five years of operations to improve the performance of the BD3 ICCS facility.

* Corresponding author. Tel.: Tel.: *+1 306 565 5662. E-mail address:* cbruce@ccsknowledge.com

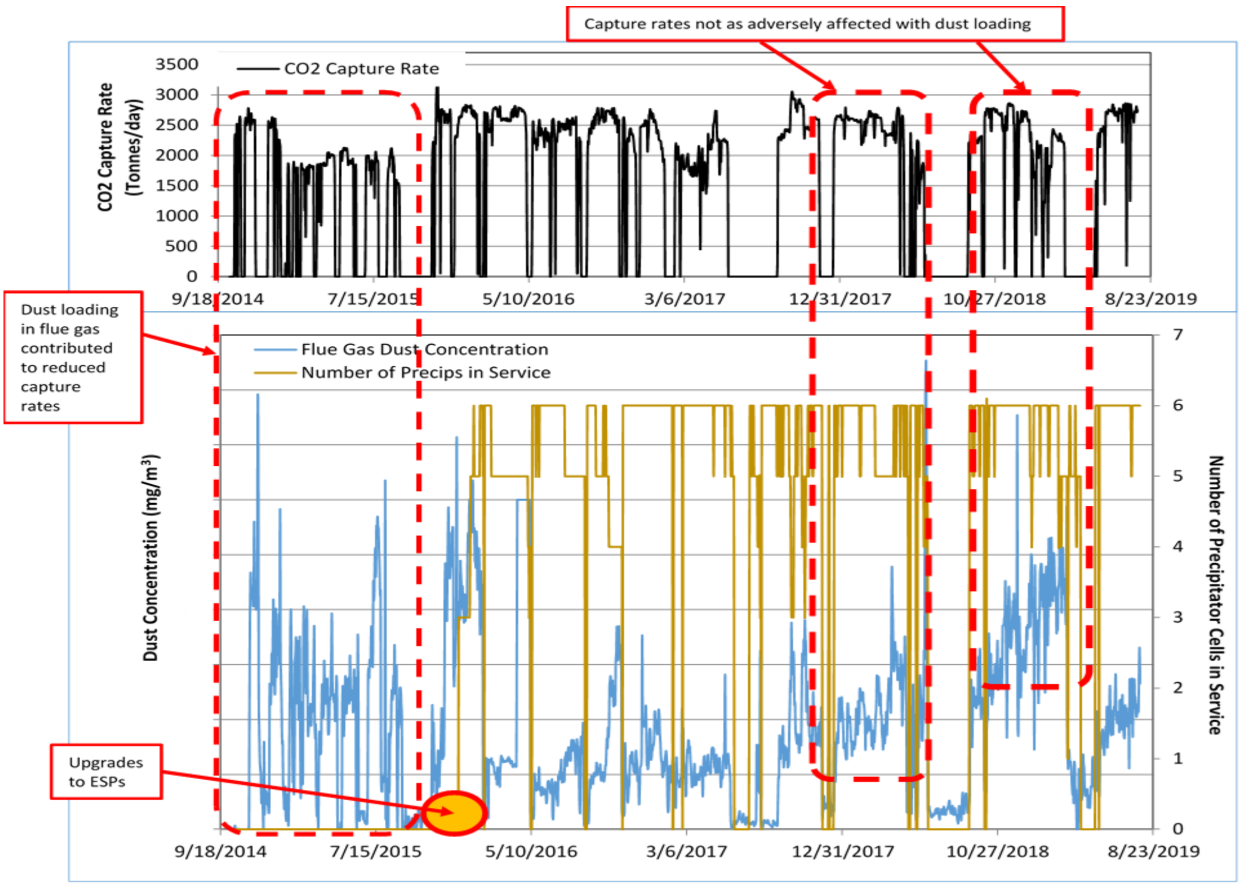
Figure 1. Summary of annual capture facility availability



Addressing fly ash accumulation

Intuitively, limitations impacting flue gas flow impeded CO2 capture rate. The high ash content of the lignite coal used at the BD3 facility produces a fine fly ash that passes through the fly ash mitigating equipment upstream of the capture facility. It was discovered that the buildup of fly ash on certain pieces of equipment, such as the booster fan, was limiting flue gas flow. Measures were taken to combat this issue. Upgrades to the electrostatic precipitators were made and various wash systems were added. Specifically, a throat spray system to the flue gas cooler, curtain sprays to the pre-scrubber entrance, a demister wash system (which included top sprays on the amine, caustic polisher and pre-scrubber sections), and wash systems to the booster fan. These corrections increased the manageability of flue gas dust loading and reduced the incidence of reduced capture rate resulting from fly ash accumulation in the capture facility (Figure 2).

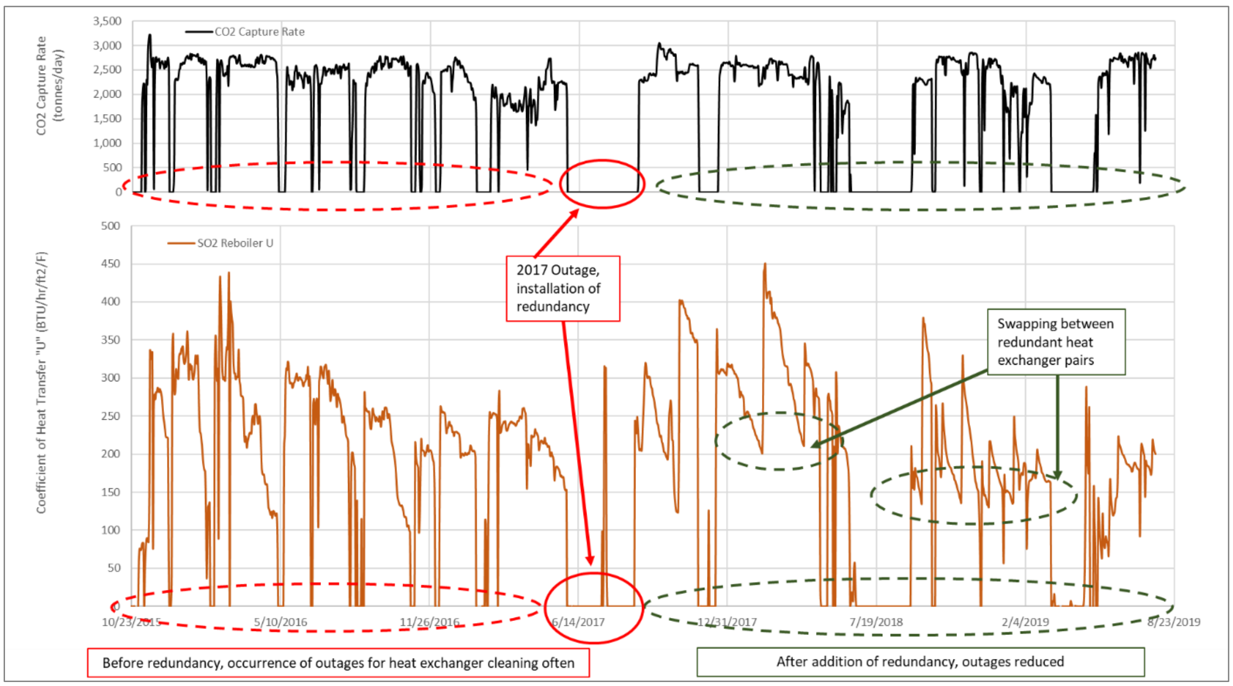
Figure 2. Comparing flue gas dust loading on capture rate



Addressing Reliability of Key Heat Exchangers

The capture facility at BD3 consists of two separate systems arranged in series. The flue gas first passes through an amine based SO2 removal system and then through an amine based CO2 removal system. Each system uses a different amine with specific affinity to the component in removes (SO2 or CO2). Heat is required to reverse the amine-SO2 and amine-CO2 reactions to release and separate the SO2 and CO2 within the stripper columns. Heat exchangers facilitate this transfer of energy. Reduced heat exchanger performance limits heat transfer and consequently capture performance. Three major groups of heat exchangers exhibited fouling in the 2014 to 2015 period: the SO2 reboiler, the SO2 lean rich heat exchanger and the CO2 lean rich heat exchanger. Consequences of fouling included plugging within the heat exchangers which reduced amine flow and restricted capture performance, and pressure drops within the equipment. The original design of the SO2 and CO2 capture systems lacked heat exchanger redundancy which restricted the facility to offline maintenance and cleaning. Outages for heat exchanger maintenance were occurring approximately every 10 weeks in the 2014 to 2015 period. To combat this issue the following solutions were proposed and installed in the major planned outage of 2017: installation of redundant heat exchangers, installation of double block and bleed isolation valves, and installing instrumentation to better monitor equipment fouling. Performance of heat exchangers compared to capture rate improved following the implementation of these changes (Figure 3). The possibility of online maintenance dramatically reduced outages in favor for planned derate of the capture facility.

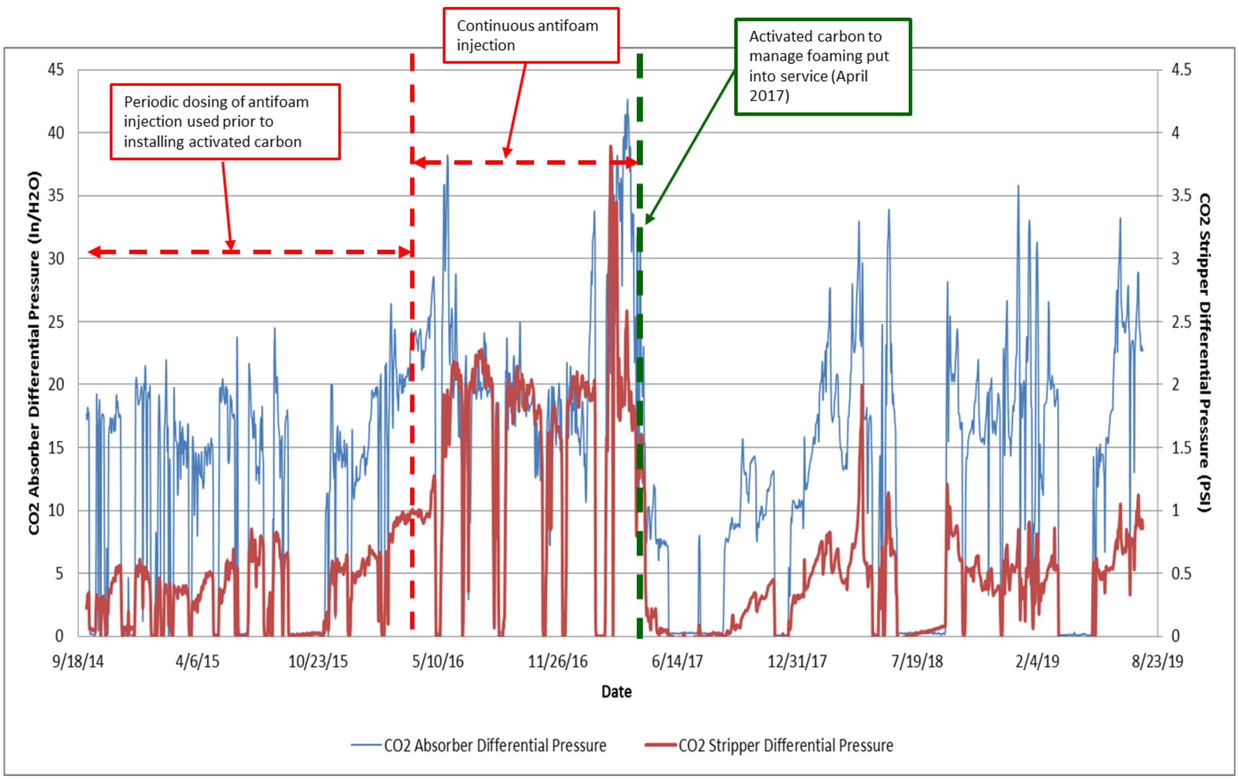
Figure 3. Comparing heat exchanger performance on capture rate



Addressing Amine Foaming

Amine foaming is one of the most common concern of amine solvent based capture systems. For the BD3 capture facility the onset of foaming began late in 2015. Several strategies were used to mitigate foaming which included antifoam injection, increased reclamation, and activated carbon filtration. Periodic antifoam injection was used as the initial means to manage foaming. Continuous antifoam injection began in April of 2016 but also failed to completely mitigate the foaming issue and furthermore caused the capture system to run rather unstable. Amine degradation products can induce foaming. The built-in reclaimer was undersized to sufficiently handle the volume of the amine in the system, a third party was contracted, and reclamation was started in the Fall of 2015; the lessening of foaming was observed as a beneficial side effect. The decision to install an activated carbon filtration system was made; an activated carbon filtration skid was put into service in April of 2017. Some initial success was observed in mitigating foaming although foaming continues to persist. The trend of increased differential pressures observed in the CO2 absorber and stripper columns (indicative of foaming) are depicted in Figure 4.

Figure 4. Trending differential pressures in the CO2 absorber and stripper columns



Keywords: Industrial Scale CCS; CCS Retrofit; Coal Fired Power Stations; Process Redundancy; Perfomance Reliability; Heat Exchanger Performance; Amine Foaming Mitigation;

A Novel Methodology for Online Analysis of Amine Solution Degradation Caused by Fly Ash

Devjyoti Nath[a], Colin Campbell[b], Yuewu Feng[b], Corwyn Bruce[b], Amr Henni[a]*, Wayuta Srisang[b], Brent Jacobs[b], Stavroula Giannaris[b], Dominika Janowczyk[b]
[a] *Faculty of Engineering and Applied Science, University of Regina, Regina, S4S 0A2, Canada*
[b]*The International CCS Knowledge Centre, Regina, S4S 7J7, Canada*

Abstract
Global warming due to the anthropogenic emissions of carbon dioxide (CO_2) is a major worldwide environmental concern. CO_2 capture with an aqueous amine-based solvent is one of the most common and advanced technologies for post-combustion CO_2 capture. Many aqueous amine-based solvents have already been proposed by different researchers to capture CO_2 efficiently from flue gas, however, the technology is still not economical due to high energy requirement for regeneration and operational issues such as solvent degradation. A large number of research studies have been performed investigating oxidative and thermal degradations of amine-based solvent. Although 38% of world energy is derived from coal-fired power plants, research work on the investigation of the impact of fly ash on the amine solvent degradation process in carbon capture plants is still very limited. The accumulation of flue gas contaminants such as NOx, SOx, fly ash, and trace metals in post-combustion CO_2 capture solvents is a major concern, as they contribute to solvent degradation. Fly ash contains various transition metals, depending on the type of coal, and transition metals are known to behave as efficient catalyst for the amine degradation process. The accelerated amine degradation is a serious problem for large-scale applicability, and the potential impact of fly ash is an important consideration for the economic operation of the capture process. The design of modern large-scale plants removing CO_2 from coal-fired power plants must take into consideration the impact on the solvent of fly ash particulate matter entering the absorber. The cost of solvent replacement due to the rapid degradation is a major concern for the feasibility of the whole operation and must be weighed against the costs of flue gas cleanup, including fly ash removal. A very limited number of studies dealing with online analyses of solvents for carbon capture units has been published. The proposed solutions are usually very complex in nature.
This study presents a new online technique to analyse the degradation of aqueous amines (MEA, MDEA and their mixtures) at different concentrations and temperatures. First, the fly ash was fully characterised (Particle size distribution and trace element composition), sieved and then mixed in different amounts with the amine solution at different CO_2 partial pressures. The developed online system included a GC equipped with a liquid sample delivery system. The flow system was equipped with filters to avoid the introduction of large particles into the GC column. A solvent backflush system was used to allow for automated cleaning of the particulate filters. A calibration check sample was run on the GC at least once per day to monitor for calibration drift. In order to study the impacts of fly ash on accelerated degradation, fly ash amounts representing (1 %, 2 %, 10 % and 20) wt.% were used in the experiments. Samples of

the same amine solutions were recirculated for at least a week. The online system was used to asses the degradation of the different amine solutions based on the results obtained before and after contact with different fly ash amounts at different temperatures. Online measurements provided information about CO_2 loading as well as water and amine concentrations which allowed for the estimation of the percentage of amine degraded. The short-term objective is to use the developed online solvent analysis method in our pilot plant before testing it in a commercial size plant. As outlined in the Shand feasibility study, the cost of consumables and OM&A represents 15% of the cost of capturing CO2. Accelerated degradation related to fly ash contamination has been reported to increase the consumables portion of the cost significantly. This materially effects the cost of the CO2 capture. The risk of accelerated degradation has been a barrier to CCS deployment and must be understood. It is believed that the data from these studies will provide valuable information that is necessary for operating cost optimization of the flue gas cleanup, including further particulate removal versus the cost of amine management.

* Corresponding author. Tel.:+1 306 585 4960, *E-mail address:* Amr.Henni@uregina.ca

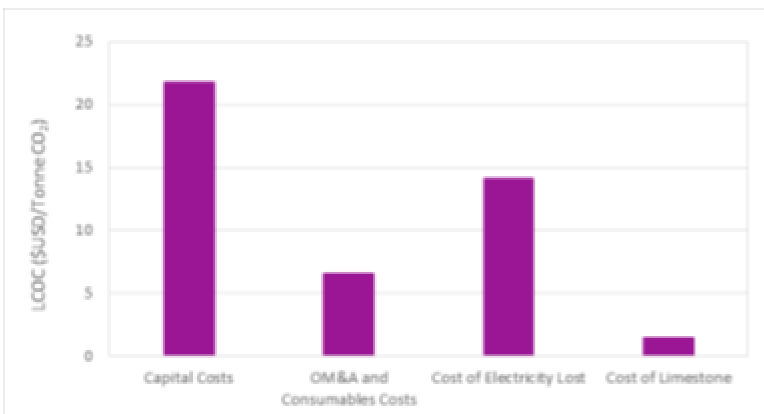


Fig. 1. Break down of Lower levelized Cost of Capture for Shand Plant (The Shand CCS Feasibility Study Public Report, 2018)

Keywords: Carbon capture; Coal-based plant; Flue gases; Amines; Fly ash; Degradation; Online analysis; Gas chromatography.