ADVANCED AMINE PROCESS: UPDATE ON TECHNOLOGY AND PILOT PLANT OPERATION

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Abstract

The development of CO_2 capture technologies is being pursued by US, European, Japanese and other suppliers in collaboration with utility companies, universities and Governments in the USA, Europe, Canada and Australia. Among the more promising post-combustion solutions is the Advanced Amine Process (AAP), jointly developed by Alstom and Dow.

This paper describes the AAP pilot plant located at a Dow Chemical manufacturing site in South Charleston, West Virginia USA. It provides an update on how the experience from the pilot plant is used to improve the design and predicted performance of large-scale demonstration plants. It will summarize the results and show the progress of the technology development.

The pilot is processing flue gas from a bituminous coal-fired boiler with UCARSOL™ FGC solvent, an advanced amine solvent specifically developed by Dow for flue gas applications. The pilot plant has a CO_2 removal capacity of ~5 tonne CO_2/day and can capture in excess of 90% of inlet CO_2.

A test program with a wide range of operating conditions provides information on capture performance, including solvent and operational stability. A state-of-the-art laboratory measures solvent composition, CO_2 loading, solvent contamination and degradation species. Long term solvent composition is controlled by a combination of flue gas pre-treatment and solvent reclamation.

These results are being used to develop large-scale demonstration plants (above 250 MWe) under the EU Flagship program in Europe and the DOE Industrial Program in the United States.

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Introduction

The Advanced Amine Process (AAP) for CO_2 capture from combustion gas has been jointly developed by Alstom Power (Alstom) and The Dow Chemical Company (Dow). The AAP relies on an advanced amine solvent, UCARSOL™ FGC, developed by Dow specifically for CO_2 capture from combustion gas with an emphasis on reducing the energy consumption associated with CO_2 capture. The development program is focused on three stages of development. The initial stage focused on identifying the most promising amine solvent suitable for flue gas service and on obtaining the laboratory scale measurements necessary for design. The second stage is focused on understanding the performance of the AAP system and demonstrating the viability of the amine solvent when applied to a coal-fired flue gas application using pilot scale equipment. The third stage will focus on commercial scale operation, including amine solvent management over time.

The initial phase of the AAP program work primarily relied on laboratory scale facilities using synthetic flue gas and was completed two years ago. This work has been discussed in earlier reports (see Vitse et al. "An Advanced Amine Process For CO_2 Capture From Flue Gas", Power-Gen Intl. 2009). The second stage of the program is still in progress. The final stage of the program will be centered on a 1.8 million tonne CO_2/year, 260 MW sized plant treating flue gas from a commercial utility boiler that fires lignite coal. The AAP plant will be located at the PGE Elektrownia Belchatow S.A. in Belchatow, Poland and is part of the EU Flagship program in Europe. The entire CCS facility includes CO_2 capture (by Alstom), transmission and sequestration (by others) and is planned to be in operation by 2015.

This paper reviews the achievements recognized to date during the second stage of the program based on the work performed at the Alstom-Dow pilot plant, which treats coal-derived flue gas at a Dow owned facility in South Charleston, West Virginia USA.

The AAP South Charleston Pilot Plant

Alstom and Dow have obtained operating experience treating coal-derived flue gas using a pilot plant located in South Charleston, WV USA. The primary objective of this facility is to gain operating experience in flue gas service with UCARSOL™ FGC solvent. Key performance measures such as energy efficiency, amine solvent degradation and amine reclamation requirements have also been studied. Since commissioning in 2009, the facility has been running a conventional flow scheme, as shown in Figure 1 and key elements of certain advanced flow schemes. The test program at this pilot plant facility is anticipated to continue into 2011.

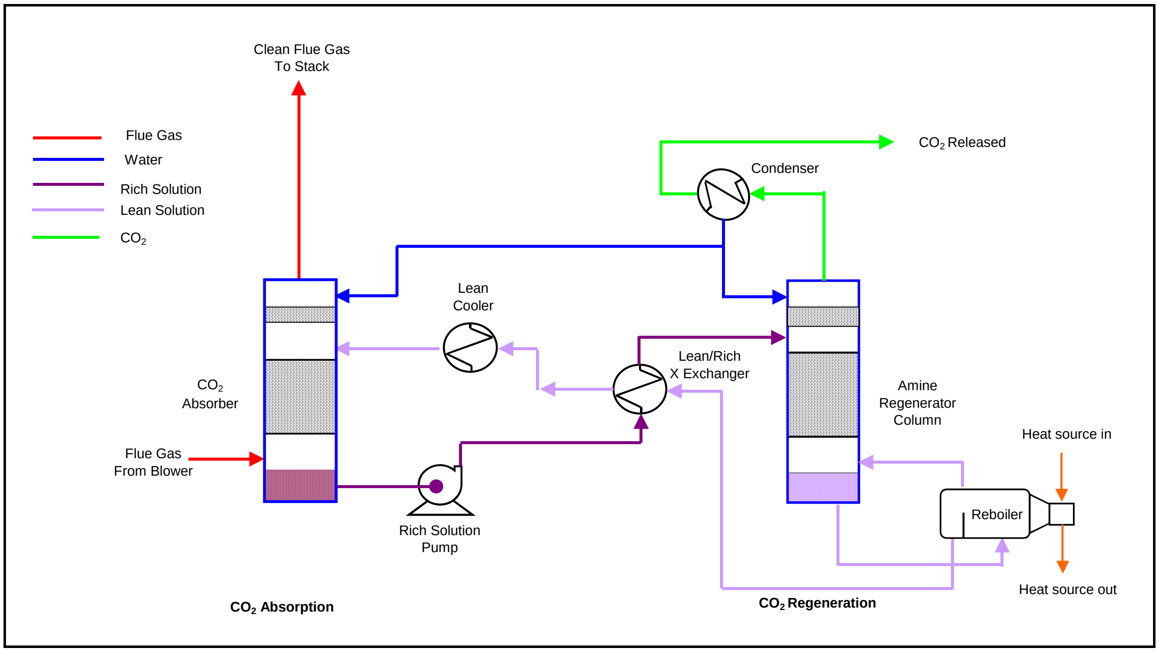

Figure 1 South Charleston Pilot Plant in Conventional Flow Scheme Mode

Site description

The bituminous coal fired boiler that supplies steam and flue gas to the AAP pilot plant unit is equipped with an electrostatic precipitator (ESP) for particulate emission control but no other post-combustion air pollution control equipment. The exhaust gas stream produced by the boiler is nominally 350 °F and contains approximately 9 mole % CO_2 and 200 ppm NO_x. Details regarding the boiler and flue gas are listed in Table 1.

Table 1. South Charleston Boiler 25 Information

Parameter	Value
Boiler Steam Rating	150,000 lb/hr
Unit AQCS	ESP
Coal Type	Appalachian Bituminous
Coal Heating Value	13,300 BTU/lb
Coal Ash Content	7 wt%
Coal Water Content	5 wt%
Coal Sulfur Content	0.8 wt%
Flue Gas Flow Rate	4,200,000 scfh
Flue Gas Temperature	350° F
Flue Gas CO_2 Content	9 mole %
Flue Gas NOx Content	200 ppm

Pilot Plant description

The pilot plant draws a 1200 cfm slip stream. The slip stream is treated for particulate and SOx with a fabric filter and a wet scrubber desulfurization unit. The flue gas SOx content is generally maintained below 20 ppmv and the gas temperature is controlled before entering the AAP system CO_2 absorber. The flue gas is driven through the pilot plant with a blower that is located between the SOx scrubber and the absorber column. The balance of the pilot plant is skid mounted and modular in nature.

In the conventional flow scheme configuration, the absorber is equipped with a water wash section to enable quantification of amine vaporization losses over a wide range of operating conditions. The absorber is typically operated to remove 90% of the incoming CO_2 from the inlet flue gas using UCARSOL^{TM} FGC solvent but other removal rates are possible. The conventional flow scheme also includes a regeneration column containing structured packing, a steam driven reboiler and a water-cooled condenser to dry the regenerated CO_2 stream. The CO_2 depleted flue gas is discharged to the atmosphere. Plate-and-frame heat exchangers are used to exchange heat between the rich and lean amine streams and to cool the lean amine entering the absorber. The pilot plant also features a variety of mechanical filters, an activated carbon filter and an electrodialysis reclaimer unit to manage particulates and heat stable salts. The pilot plant capabilities in the conventional flow scheme configuration are summarized in Tables 2 and 3.

Table 2. South Charleston Advanced Amine Pilot Capabilities (Conventional Configuration)

Flue Gas Flow Rate	300 – 1200 cfm
Flue Gas Temperature	90 - 140° F
Flue Gas SO_x Content	20 ppm max.
Amine Solvent Flow Rate	10 – 40 gpm
Steam Supply Pressure	75 psig max.
CO_2 Removal Efficiency Target	90%
CO_2 Production Rate	1800 metric tonnes/year

Table 3. South Charleston Advanced Amine Pilot Equipment (Conventional Configuration)

Wet Flue Gas DeSulfurization Unit	96% SO_2 Reduction Efficiency
Flue Gas Cooler Unit	90° F minimum
CO_2 Absorber, Water Wash Column	57 ft x 28 inch OD
Amine Regeneration Column	34 ft x 16 inch OD
Reboiler Rating	1.3 MMBTU/hr
Cross Heat Exchanger	1.3 MMBTU/hr
Lean Amine Cooler	0.5 MMBTU/hr

The pilot plant is equipped with a laboratory equipped with a wide range of analytical instruments for evaluating solvent characteristics and process performance. This equipment includes titration for solvent, water and acid gas concentration, gas chromatography and ion chromatography for amine composition and a collection of equipment for physical and chemical properties measurement. In addition, the gas streams are continuously monitored using both NDIR and FTIR. The pilot plant control system is well instrumented and fully automated to support continuous operation, data acquisition and logging.

Operation Results from the AAP South Charleston Pilot Plant

The pilot plant has achieved over 6000 hours of operation since startup. During this time we have made the following observations:

- Procedures have been established for routine plant operation and maintenance, for changes in plant load operation, for a variety of start-up and shut-down situations and for solvent sampling and monitoring.
- Maintaining water neutrality can be accomplished through careful monitoring and equipment operation even during plant wide transients.
- Minimal operation oversight is required when the plant control system is well-tuned, including steam control for the regeneration system.
- Plant instrumentation must be carefully selected to perform well in this service.
- Improved control strategies have been applied to the regenerator condenser temperature, condenser reflux drum level and column sump levels.

Process performance consistency

As stated earlier, one of the major objectives at the South Charleston pilot plant is to measure the viability of the solvent in flue gas service over an extended period of time. This has been achieved by tracking key solvent characteristics and process parameters over time. The main process parameter is the energy consumption required to operate the pilot plant. Key solvent characteristics include concentration of amine, quantity of CO_2 absorbed and individual heat stable salt concentrations. Measurements of these parameters taken during the first four months of plant operation are shown in Figure 2. During this time the plant maintained a 90% CO_2 capture rate despite variable CO_2 concentrations in the flue gas supply. Consistent operation with regards to energy consumption, including reboiler steam, was also demonstrated during the test program. Both amine content and CO_2 loading in the solvent have remained consistent through a combination of solvent management, process control and operating disciplines. The influx of heat stable salts formed from trace level acid gases present in the flue gas supply is adequately managed with the on-site amine reclamation system. Late in this test program the reclamation system was stopped to increase the level of heat stable salts to quantify the impact on solvent and process performance. As shown, there were no detrimental effects observed even with an elevated heat stable salt content.

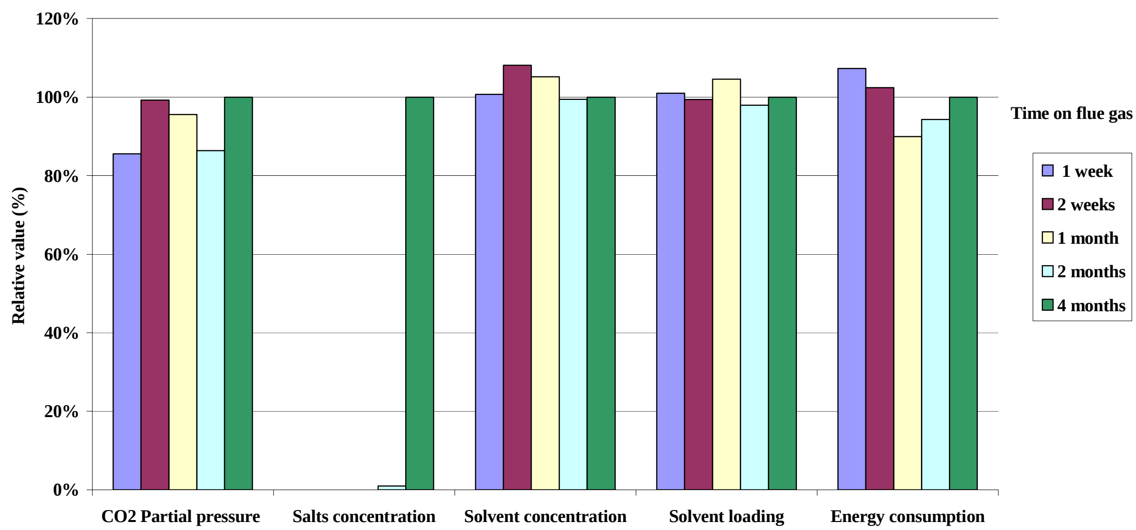

Figure 2. Impact of heat stable salt concentration and CO_2 partial pressure on energy consumption

Solvent viability and management

One of the key objectives with an amine management program is to address the issue of heat stable salts (HSAS) in the amine solvent. While some level of salts may affect system performance, an excessive level of salt can result in decreased CO_2 capture efficiencies, higher energy consumption rates, corrosion problems etc. There are two major sources of heat stable salts: from acid gases in the flue gas and from degradation of the solvent. Management of heat stable salts in the amine solvent is shown in Figure 3. As shown, the principle salts are from SOx and NOx absorbed from the flue gas. Other salts, formed by either oxidative or thermal degradation of the solvent, accumulated relatively slowly. This demonstrates UCARSOL™ FGC solvent has appreciable resistance to thermal and oxidative degradation.

The increase and peak in heat stable salt levels was a result of an intentional shut down of the reclamation system and SOx scrubber to determine the impact of high salt levels on performance. The heat stable salt concentration was quickly restored to previous levels when the reclamation system was returned to service. This demonstrates the amine management strategy is able to withstand outages with the salt management equipment.

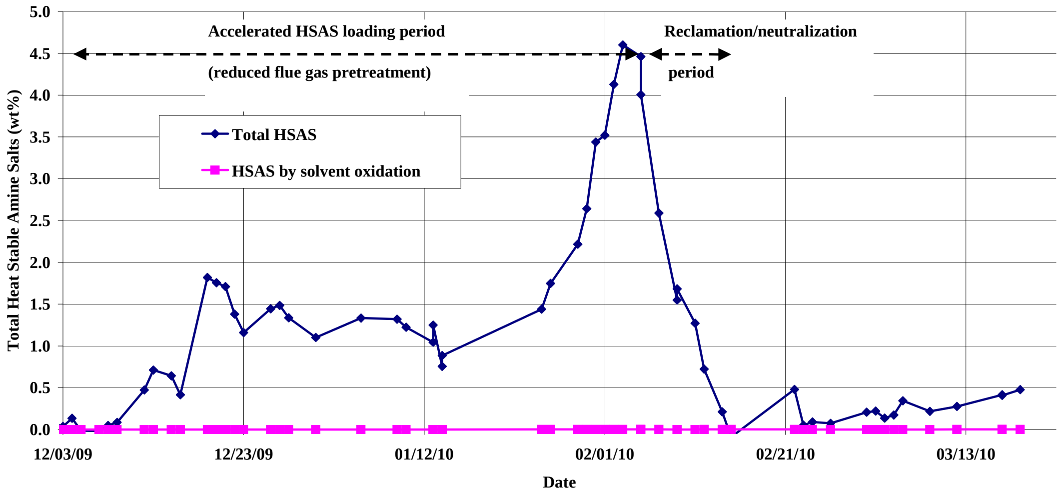

Figure 3. Comparison of heat stable salts from solvent oxidation with total heat stables salts present

Simulation design model validation

One invaluable component of any system development program is the use of models or design tools for defining new systems for a specific application or for predicting the performance of a given system. These tools are validated against measured data as a means to increase confidence and improve their predictive nature. The observed and simulated performance of the AAP system pilot plant is shown in Figure 4. As shown below, there is good agreement between the simulation tool used to design the pilot plant and the observed performance of the pilot plant.

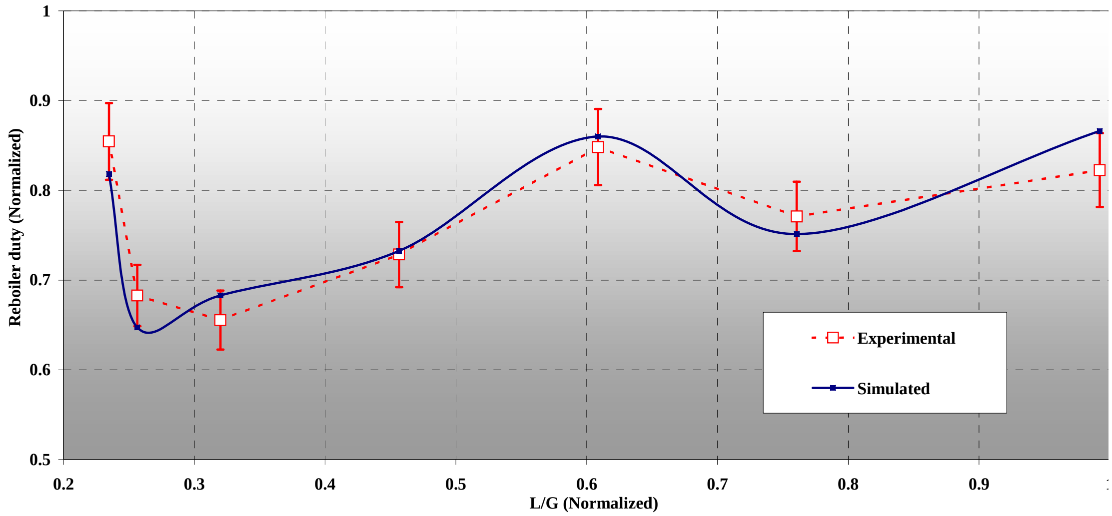

Figure 4. AAP process performance and simulator validation

Advanced process schemes

The pilot plant was designed to allow operation over a wide range of conditions and to allow flexibility for evaluating improved process schemes beyond the conventional scheme described earlier. A number of alternative flow schemes that offer reduced energy consumption have been developed and are under construction at the South Charleston facility. These modifications will allow testing and quantification of novel energy reduction strategies. These results will be discussed in future papers.

Conclusions

For four years Alstom and Dow have been actively involved in the development of the Advanced Amine Process. Since the start of operations in fall 2009, the AAP pilot plant in South Charleston has demonstrated operation and maintenance strategies of the AAP process when treating flue gas from a coal-fired boiler. The information obtained has been used to determine optimal process conditions for minimal energy consumption levels and to validate the simulation tool used to engineer the pilot plant facility.

Solvent management practices have been developed and demonstrated on this flue gas application. This includes maintenance of solvent integrity and overall system performance. Strategies for water and heat stable salt management have also been demonstrated.

The flexible and robust nature of the pilot plant offers the opportunity for investigation of alternative flow schemes. These schemes offer improved energy efficiencies, which is critical for larger AAP facilities.

The demonstration plant will utilize the operating practices and process performance findings from this pilot plant facility. The commercial scale demonstration plant will validate the performance of the most promising advanced flow scheme and corresponding optimized process conditions as tested at the pilot plant scale

Alstom is currently designing its first large-scale Advanced Amine Process demonstration plant for PGE Elektrownia Belchatow S.A. in Poland with an estimated start-up in 2015.