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Project Update of 500 TPD Demonstration Plant for Coal-fired Power Plant

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Abstract

Southern Company and MHI successfully started the world's largest 500 TPD carbon capture plant for a coal-fired power plant in June 2011 at Alabama Power's Plant Barry and achieved full load operation. These operation experience and lessons & learned of the actual plants would help facilitate scale-up CO_2 capture plant for coal fired power plant. This paper gives updated operation results of the demonstration plant along with MHI's R&D activities for the commercial application.

Keywords: Plant Barry; SECARB; KS-1; KM-CDR Process; Amine Emission; Dynamic Simulation

1. INTRODUCTION

It is now widely accepted that anthropogenic CO_2 is a greenhouse gas linked as a cause of global warming. Coal-fired power plants are the largest producer of CO_2 emissions worldwide. Southern Company has taken a leadership position in the utility industry in the area of research and development of

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technologies to reduce CO_2 emissions. The 500 metric TPD CO_2 capture and sequestration demonstration project at Alabama Power's Plant Barry is the world's largest start-to-finish carbon capture and storage (CCS) project on coal fired flue gas. Fig.1 is a block diagram that shows the start-to-finish structure of the demonstration project. The left side of the diagram shows Plant Barry's unit 5 which is the host unit for the capture plant and is a 770 MW supercritical coal-fired boiler (in blue). The CO_2 capture plant receives flue gas from a 25 megawatt equivalent slipstream drawn from the main duct downstream of the existing FGD as shown in Fig. 1. Unit 5 is a flagship coal-fired unit in Southern Company's fleet and is retrofitted with the following environmental controls: a selective catalytic reduction (SCR) for NOx control, an electrostatic precipitator (ESP) for particulate matter control, and a wet flue gas desulfurization (FGD) scrubber for SO_2 control.

The right side of the diagram shows the CCS demonstration project (in pink). The capture plant is shown in the diagram as blocks of CO_2 recovery, CO_2 compression and dehydration, and utilities. The capture plant was predominately self-funded by Southern Company and Mitsubishi Heavy Industries, Ltd. with several smaller third party funders including the Electric Power Research Institute (EPRI).

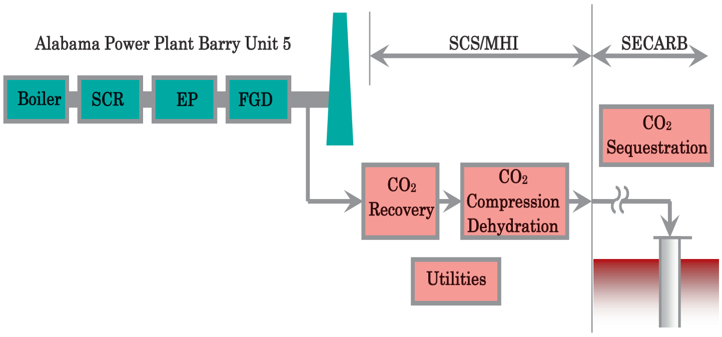

Fig. 1 Block Flow Diagram of the Full Chain CCS Demonstration Project [1]

The capture plant portion of the project was collaboratively executed by Southern Company Services (SCS) and Mitsubishi Heavy Industries America (MHIA). The CO_2 produced from the capture plant is transported via a pipeline and sequestered at the Citronelle oil field. This part of the project was managed by the Southeastern Regional Carbon Sequestration Partnership (SECARB).

Table 1. Outline of 500 TPD CO_2 Capture Plant

Items	**Conditions**
Location	Bucks, Alabama
Ownership	Southern Company (Alabama Power)
Process	KM CDR® Process
Solvent	KS-1™ solvent
Capacity	25MW equivalent
Flue gas flow rate	73,805 SCFM (116,840 Nm^3/hr)
CO_2 removal efficiency	90%
CO_2 capture rate	500 Metric TPD (150,000 tons per year)
CO_2 concentration in flue gas	10.1 mol.%-wet

Table 1 shows the outline of the CO_2 capture plant. The plant is located at Alabama Power's Plant Barry in Bucks, Al which is in the lower southeastern portion of the state near Mobile, Al. The capture plant implemented MHI's KM-CDR® technology which utilizes KS-1™, a proprietary amine solvent. The capacity of the plant is 25 MW_e with a design flue gas flow rate of 73,805 SCFM. The plants design capacity and removal efficiency are 500 metric TPD and 90%, respectively. The plant design incorporated a CO_2 concentration in the flue gas of 10.1 mol% (wet basis).

The capture plant began successful operation June 2, 2011 and achieved a stable full load operation. Fig. 2 below shows an aerial photo of the capture facility during operation. The footprint of the capture plant island shown above is approximately 300 feet long by 150 feet wide.

Fig. 2 Aerial Photo of the Capture Plant

After successful start-up the project team began to conduct research testing campaigns designed to extract the maximum amount of information from this demonstration project.

The CO_2 capture and compression part of the demonstration testing items are as follows:

- Confirmation of base heat and mass balance including:
    - Mass balance on all major constituents and key trace elements
    - Heat balance on all process equipment with comparison of design performance
- Monitoring of emissions and waste streams
- Parametric testing on all process systems for development of simulation tools (for controlling system)
- Performance optimization
- Dynamic response testing for load following
- Long term testing to validate equipment reliability and life
- High impurities loading testing with burning alternative coal

The plant performance was stable at the full load condition with CO_2 capture rate of 500 TPD at 90% CO_2 removal and lower steam consumption than conventional capture processes. The plant has logged over 5000 operational hours since start-up and has captured over 90,000 tons of CO_2 as of September 2012. In the Results and Discussion section, steady state operation results over a 72 hour period will be presented showing CO_2 capture rate, removal efficiency, and steam consumption. Parametric testing has been performed on the capture plant to determine performance optimization and results from a base case, high efficiency case, and a high load case is presented.

2. KM-CDR® PROCESS

The Kansai Mitsubishi Carbon Dioxide Recovery process (KM-CDR® process) is an advanced, commercially available CO_2 recovery process which delivers economic performance for plants of wide ranging capacities. Fig. 3 below illustrates the KM-CDR® process and is representative of the process for the 500 metric TPD CO_2 capture plant at Plant Barry described in this paper. The MHI CO_2 recovery process utilizes the regenerable "KS-1™ solvent", an advanced sterically hindered amine solvent, in conjunction with a line of special proprietary equipment.

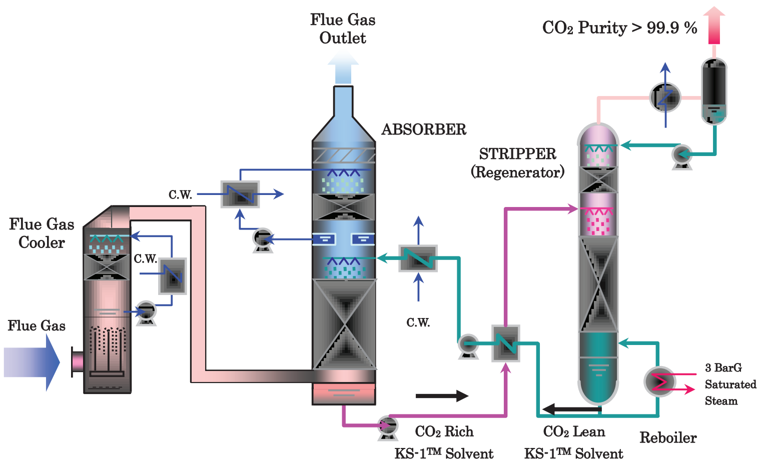

Fig. 3 KM CDR® Process

The technology was developed through cooperation between MHI and Kansai Electric Power Company, Inc., the second largest electric utility in Japan. Users who adopt this economical process will enjoy benefits due to its lower energy consumption, lower solvent degradation and lower corrosion rate. [2]

3. RESULTS AND DISCUSSION

The 500 TPD CO_2 capture plant successfully started up on June 2, 2011 and test campaigns began along with operational data collection for analysis and interpretation. Initially, when the plant started up flue gas flow started at 50% of design and steadily climbed until 100% flow was achieved. Baseline testing followed, then heat and material balances around the process were confirmed. Parametric testing was executed to optimize performance of the capture plant for CO_2 capture rate, removal efficiency, and steam consumption. Also, several emission testing campaigns have been conducted, and the product CO_2 has been analyzed for purity to ensure it meets pipeline standards. Since the capture plant has been operational, the performance has met expectations of both SCS and MHI. This section describes some of the results from test campaigns conducted during the demonstration project.

Steady State Operation Results

To determine the steam consumption for the capture plant process using KS-1™, the capture rate and removal efficiency were set constant to design values of 500 TPD and 90%, respectively. The process was stable over a 72 hour period, and the data was collected and analyzed. Each Fig. 4, 5, and 6 shows an example of operational data over the same 72 hour period. Fig. 4 contains the CO_2 capture rate verses time with an average capture rate of 500 TPD. Fig. 5 shows the CO_2 removal efficiency verses time with an average removal efficiency around 90%. Fig. 6 shows the steam consumption verses time with the average steam consumption of 0.98 ton-steam/ton-CO_2 captured. The steam consumption observed for KS-1™ is much lower than reported values of 30% wt MEA which is around 1.67 ton-steam/ton-CO_2 captured. The plant performance was very stable at full load condition with CO_2 capture rate of over 500 TPD at 90% CO_2 removal. During this stable operating period the steam consumption averaged slightly below 1 ton-steam/ton-CO_2 captured.

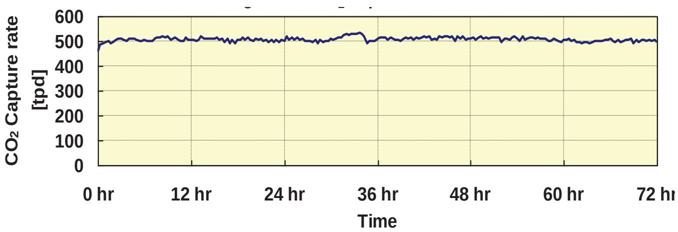

Fig. 4 CO_2 Capture Rate vs. Time

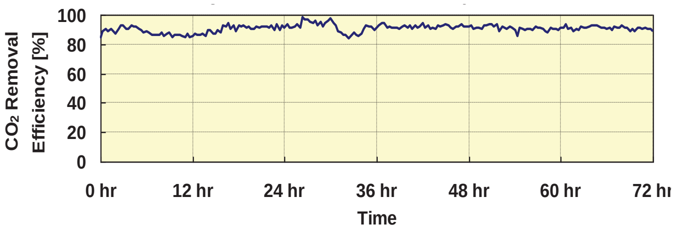

Fig. 5 CO_2 Removal Efficiency vs. Time

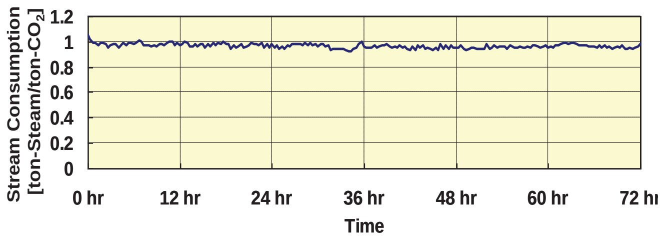

Fig. 6 Steam Consumption vs. Time

Parametric Testing Results

Parametric testing was conducted at the CO_2 capture plant to determine performance optimization for the process. Table 2 shows the representative test results for a parametric testing campaign comparing CO_2 capture rate, removal efficiency, and steam consumption under different test cases. The plant has been operated on the design conditions for the base case except the flue gas flow rate, because the actual CO_2 concentration was higher than the design condition. The design concentration of CO_2 in the flue gas was 10.1 % but we have consistently observed the actual CO_2 concentration higher than design between 10.5-12% during operation. To correct for this the flue gas flow rate for the base case was decreased to account for the higher CO_2 concentration. Both CO_2 capture rate and CO_2 removal efficiency were achieved to the design specifications with low steam consumption of 0.98 ton-steam/ton-CO_2 captured. The steam consumption has been optimized for the high efficiency case as shown in Table 2. In this case, the lowest steam consumption has been achieved at 0.95 ton-steam/ton-CO_2 with the CO_2 capture performance still at the design specifications. For the high load case the plant was operated at the design flue gas flow rate of 116,000 Nm^3/hr and the other operation parameters where varied to achieve a CO_2 removal efficiency of 90%. The steam consumption was 1.02 ton-steam/ton-CO_2 captured which was a little higher than the other cases but the CO_2 capture rate reached 543 TPD which is well over the design rate. This parametric testing confirmed that the KM-CDR® process with KS-1™ solvent achieved very low steam consumption with stable operation even with the flue gas conditions fluctuating due to the host unit boiler load changes.

Table 2. Operation Test Results from Parametric Testing

		Base Case	**High Efficiency Case**	**High Load Case**
Flue gas condition	Flow rate [Nm^3/hr]	109,000	112,000	116,000
	CO_2 concentration at the Quencher Inlet [vol.% (w)]	10.8	10.5	10.8
Operation Results	CO_2 Capture rate [MTPD]	**505**	**509**	**543**
	CO_2 removal efficiency [%]	**91**	**91**	**91**
	Steam Consumption [ton-steam/ton-CO_2]	0.98	0.95	1.02

Amine Emission Results

From pilot scale work done at Georgia Power's Plant Yates using MHI's mobile test unit, it was confirmed that SO_3 in coal fired flue gas accelerates amine emission levels drastically. It has been discovered that SO_3 has the greatest impact on amine emissions from many test campaigns that have addressed this issue.

Deep reduction of amine emission requires not only improvement of the washing system in the absorber but also pre-treatment before the absorber in some cases. Amine emissions are observed as both mist and vapor. Amine vapor emission can be controlled by the washing & absorption sections. Amine mist consists of entrainment or aerosols formed by the reaction between amine vapor and CO_2. Amine liquid entrainment is relatively large so that it can be easily removed, but aerosols are difficult to remove by conventional methods. However, it is possible to remove aerosols utilizing a special designed proprietary demister that MHI has developed. This Proprietary demister has been installed at the capture facility at Plant Barry to improve the reduction of amine emissions.

The amine emission testing for both MEA and KS-1™ solvents was performed to evaluate SO_3 effect at a pilot test plant in Hiroshima R&D center using simulated flue gas with added SO_3, which was generated from SO_2 gas. MHI proprietary demister was also installed to evaluate its performance in the pilot plant. Fig. 7(a) and 7(b) shows emitted amine concentration at the outlet of absorber when increasing levels of SO_3 was added into the flue gas. Solvent amine emission increased with increasing SO_3

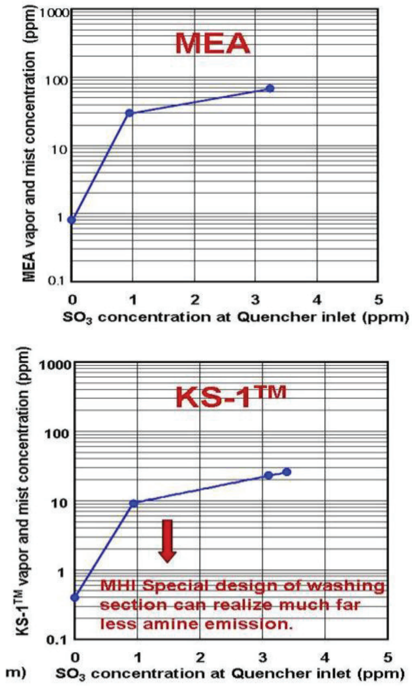

Fig. 7(a),(b) Amine Emission Test Results in Hiroshima R&D center for (a) MEA Solvent and (b) KS-1™

concentration in both MEA and KS-1™. KS-1™ performed better than MEA but amine emissions still increased significantly with increasing levels of SO_3 present in the flue gas entering the system. It was also confirmed that MHIs special design of the washing section along with the proprietary demister can greatly reduce amine emission. This phenomenon is not only for KS-1™ and MEA, but also other amine solvents are susceptible to increasing levels of emissions with increasing levels of SO_3. Also, it should be noted that the emitted MEA concentration was higher than KS-1™ due to the higher vapor pressure. [2]

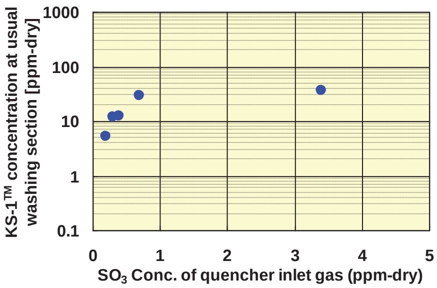

Fig. 8 Amine Emission Test Results at the capture facility at Plant Barry

At the capture facility at Plant Barry the SO_3 concentration was measured at the inlet of the quencher and amine concentration in the treated flue gas leaving the absorber tower during the initial emission testing campaign. Fig. 8 shows the relationship between SO_3 concentration of quencher inlet gas and KS-1™ concentration at the usual washing section outlet at the capture facility at Plant Barry. These results indicate similar levels of emissions compared to the pilot test results in Hiroshima R&D center using a simulated flue gas described above.

Plant Barry normally fires a Columbian coal which is a low sulfur fuel that generates low levels of SO_3. During the project, Plant Barry tested alternative coals from the Illinois Basin and Powder River Basin for a short period of time typically around two weeks during the capture plant's test period.

The capture plant performed consistently with parameters such as capture rate, removal efficiency, and steam consumption for all of the feedstocks, but it was observed that higher levels of SO_3 were present with coals containing a higher sulfur content. Amine aerosol emissions increased with the higher levels of SO_3 observed when increasing coal sulfur content. In response to this issue and the emission results above in Fig. 8, the new MHI multi-stage washing system and proprietary demister as part of an amine emissions reduction system was incorporated into the capture facility at Plant Barry during the fall outage in 2011. The performance of the modification to the system has significantly decreased amine emissions.

Online Amine Analyzer

MHI also developed proprietary online amine analyzer to monitor the process conditions and amine emissions that consists of auto sampling unit and high resolution analyzer with the computational control unit. (Fig. 9) It measures KS-1™ and CO_2 concentration in the solvent on a semi-online basis. It also provides KS-1™ and its degraded amine concentrations in treated flue gas from absorber likewise. These functions greatly contribute to easy operation and constant monitoring of amine emissions. Fig. 10 shows periodic results of CO_2 concentration trends in KS-1™ solvent during actual operation. These data was very useful to verify mass & heat balance on semi-continuous basis for fluctuating operational condition. This system automatically provides the operational status to allow us to optimize operational parameters immediately.


Fig.9 Online Amine Analyzer

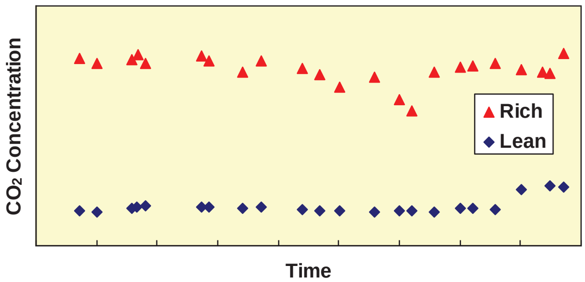

Fig.10 CO_2 Concentration Trend

Load Following Testing

Load following testing was conducted at 500 TPD CO_2 capture demonstration plant. Load change rate for CO_2 capture and compression process was targeted at 5% per minute. Two kinds of load change were tested: CO_2 production load change and flue gas flow load change. Both test results showed that the load control system for KM-CDR® process successfully followed the load change of 5% per minute without any adverse effect (See Fig. 11 and Fig. 12). Furthermore, the CO_2 removal efficiency was controlled within 5% from the target value.

The above system was developed with MHI's dynamic simulator for CO_2 capture and compression process, and each control parameter was tuned up during the testing.

KM CDR® Process is now ready to apply for the load changing power plants by the load control system.

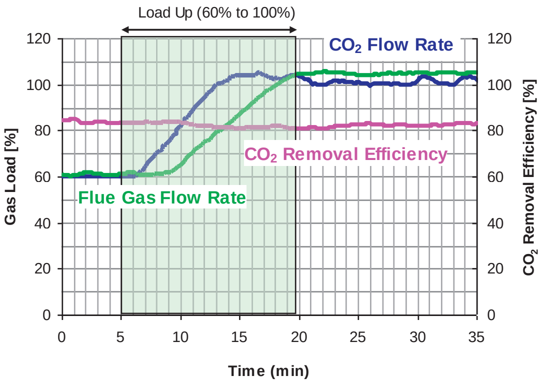

Fig.11 Load Change Results for CO_2 Production

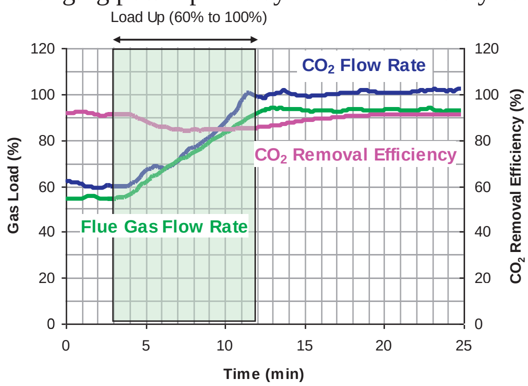

Fig.12 Load Change Results for Flue Gas Flow Rate

4. FUTURE RESEARCH PLANS

The CO_2 capture plant has been operational since June 2011 and research testing campaigns have been ongoing since start-up. Many test items have been performed and demonstrated during the first 18 months of operation, including base heat and mass balance testing, parametric testing on all process systems, performance optimization and monitoring of emissions and waste streams. Not only major constituents but key trace element mass balance has been confirmed. And heat recovery performance of all process equipment has been verified with the design performance. The CO_2 capture plant project will be going to long term operation testing to validate equipment reliability and life, and high impurities loading testing with burning alternative coals.

5. CONCLUSION

This paper presented updates and research plans for the 500 TPD CO_2 carbon capture and storage demonstration project at Alabama Power's Plant Barry. The capture plant utilizing MHI's KM-CDR® process was successfully started up in June 2011 and achieved steady full load operations. The plant performance was stable at full load condition with CO_2 capture rate of 500 TPD at 90% CO_2 removal and lower steam consumption than conventional capture processes. The plant has captured over 90,000 tons of CO_2 as of September 2012. Injection operations began on August 20, 2012 and over 10,000 tons of CO_2 have been injected by the end of September 2012. With the start of CO_2 injection operations, this project became the world's largest start to finish CCS demonstration project on coal fired flue gas. The project will continue to build upon its success striving toward the milestone of injecting over 100,000 tons of CO_2 and conducting research test campaigns to gather important information.

MHI are taking a phased approach to commercialization – there were lessons & learned along the way and there are no short cuts. Building on their experience to date MHI is ready to move forward to a commercial scale CO_2 capture plant.

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