Recent Developments of Hitachi's Advanced Solvent Technology for Post-combustion CO_2 Capture

Sandhya Eswaran, Song Wu
Hitachi Power Systems America, Ltd.
645 Martinsville Road, Basking Ridge, NJ 07920

Hirofumi Kikkawa, Eiji Miyamoto
Babcock-Hitachi K.K. Kure Research Laboratory
6-9 Takara-machi, Kure-shi, Hiroshima, Japan

Frank Morton
Southern Company Services
31800 Highway 25 North, Wilsonville, Alabama 35186

ABSTRACT

Hitachi has been developing amine-based post-combustion CO_2 capture technologies to control CO_2 emissions from coal-fired power plants. Through early bench-scale and pilot-scale tests that started over 20 years ago, different formulations of amines and additives were evaluated to identify solvents with a high CO_2 absorption capacity, low regeneration energy requirement and long service life. Multiple solvent blends along with commercial MEA were tested at Hitachi's first CO_2 capture slipstream pilot plant built at Yokosuka Thermal Power Plant in cooperation with Tokyo Electric Power Company in Japan. The best solvent, H3, showed that in over 2000 hours of continuous operation with coal-fired flue gas an average of greater than 90% CO_2 was removed. The energy requirement for H3 was the lowest among the solvents tested and corrosivity was insignificant. The latest refinement of this proprietary solvent, H3-1, has the same advantages as H3 and further reduced amine loss.

Recent tests conducted in the pilot facilities at the Energy and Environmental Research Center and the National Carbon Capture Center (NCCC) using coal-fired flue gas verified the performance of the H3-1 solvent. Over the 3-month duration of the NCCC test campaign, various parametric tests were conducted and optimal conditions for operation at the facility were determined. An average of 91% of the inlet CO_2 was captured through the duration of testing and regeneration energy of 2.4 GJ/t-CO_2 for H3-1 was achieved. This paper provides an update of the latest developments in Hitachi's solvent technology including preliminary results from the testing at NCCC.

INTRODUCTION AND BACKGROUND

Hitachi's post-combustion CO_2 capture R&D specifically for coal-fired applications began in the early 1990s, when the first bench-scale and pilot test programs were initiated. Since then, the company has been continually improving process design and solvent technologies for full-scale

power plant applications. Bench-scale studies (Figure 1) with simulated flue gas have been performed to screen and identify promising absorbents and additives for maximum CO_2 removal efficiencies. Key factors addressed in the development of the amine solvent technology were low solvent regeneration energy, low corrosion potential and low tendency for degradation and amine emissions while providing high CO_2 absorption capacity.

Figure 2 shows Hitachi's first CO_2 capture pilot plant built at Yokosuka Thermal Power Plant Unit 2 in cooperation with Tokyo Electric Power Company (TEPCO) in Japan. The 1 MWth slipstream test facility treated about 1000 m^3N/h (620 scfm) of flue gas for CO_2 removal during the two-year demonstration period. Five solvent solutions, including a commercial MEA as benchmark and three proprietary solvent formulations were tested. Testing of H3, Hitachi's proprietary solvent formulation and the best performing solution of the five, lasted 2000 hours under various operating conditions and generated a large database of solvent and system behavior.

Figure 1: Bench-scale test rig

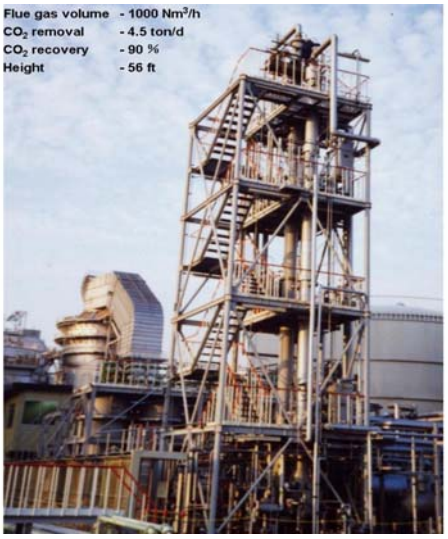

Figure 2: Pilot plant at Yokosuka power plant

The H3 solvent consistently achieved greater than 80% CO_2 removal with the average well above 90%. The regeneration energy for H3 was lowest among tested solvents and much lower than commercial MEA. High absorption capacity of the solvent was demonstrated, thus requiring lower liquid-to-gas ratio for 90% capture compared with MEA and resulting in significant operating cost savings.

DEVELOPMENT OF HITACHI ADVANCED SOLVENT H3-1

With further refinement of the solvent formula based on numerous pilot and bench-scale tests, the H3-1 solvent was developed that minimizes amine degradation and loss while maintaining the advantages of high CO_2 capture absorption capacity and low regeneration energy of H3.

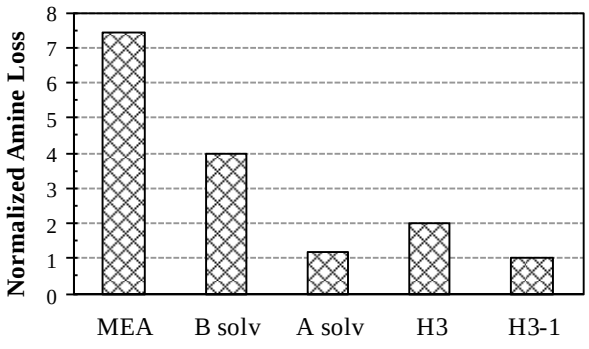

Figure 3: Comparison of Amine Loss from different solvents

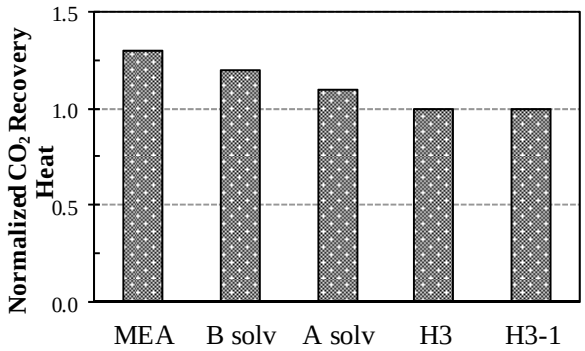

Figure 4: Comparison of CO_2 recovery heat from different solvents

Figures 3 and 4 show comparisons of solvent performance based on third-party independent test data. H3-1 has the lowest regeneration heat compared to 30% MEA solution and two amine solutions by other leading developers. H3-1 also has the lowest amine loss, which is 86% lower than that of the MEA solution. The reduced level of solvent losses and lower heat requirement of H3-1 translate to great savings in utility and operating costs.

RECENT TEST ACTIVITIES

Testing at EERC

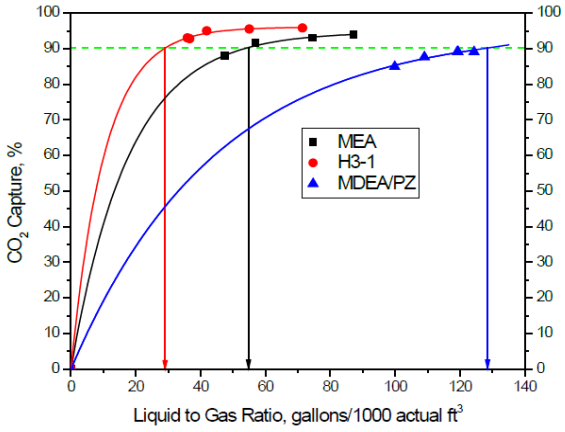

Figure 5: Comparison of the effect of L/G of various solvents

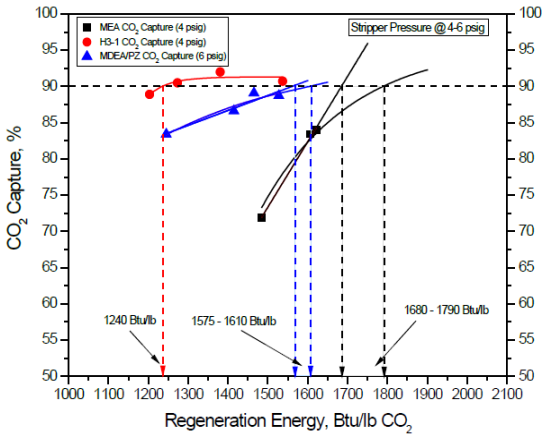

Figure 6: Comparison of Regeneration Energy of Various Solvents

The H3-1 solvent was independently tested by the Energy and Environmental Research Center (EERC), University of North Dakota at the 200 Nm^3/h (130 scfm) CO_2 capture pilot plant. An average of 90% of the CO_2 was removed at steady state even when test parameters were varied during the test period. Figures 5 and 6 show a comparison of the effect of liquid-to-gas ratio and

regeneration energy on CO_2 capture with two other solvents tested under similar conditions[1]. For 90% CO_2 capture, the solvent recirculation rate needed is about 45% lower and the energy required to regenerate the H3-1 solvent is about 30% lower than that for 30% MEA solution.

Pilot Plant Testing at NCCC

In 2012, H3-1 solvent was tested at the National Carbon Capture Center (NCCC) using a slipstream flue gas from Unit 5 of the Alabama Power Plant E. C. Gaston station at the 10 ton/day post-combustion test facility (Figure 7). The test facility consists mainly of a pre-scrubber, absorber (with intercoolers), wash tower, regenerator, heat exchangers and pumps. Additionally, the pilot plant includes a lean solvent storage tank, mechanical filters and a carbon bed in the path of the lean solvent as it flows from the regenerator to the absorber, and an inlet separator in which the rich solvent leaving the absorber is partially flashed before entering the regenerator. A process flow diagram of the roughly 2 MWth post-combustion test facility is shown in Figure 8.

Figure 7: NCCC test facility

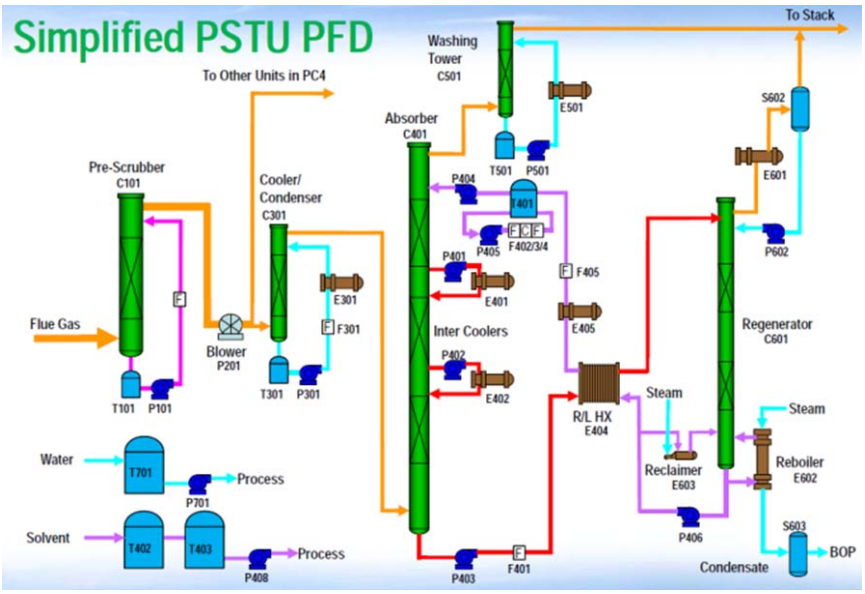

Figure 8: Simplified PFD of the post-combustion test facility

Over the duration of testing, various parametric tests with a wide range of conditions were conducted. The parameters tested include flow rate and temperature of inlet flue gas and solvent, reboiler steam flow rate, pressure in the regenerator, temperature at the outlet of the wash tower, the effect of the intercoolers and the effect of the number of packing beds in the absorber. Table 1 gives a summary of the range of operating parameters. The CO_2 concentration in the inlet flue gas varied between 11% and 13% depending on the boiler load. Inlet NOx concentration was in the range of 20-50 ppm and inlet SO_2, between 1 and 3 ppm. The CO_2 capture performance of the H3-1 solvent for the entire duration of testing at different boiler loads and flue gas conditions is shown in Figure 9. An average of about 91% CO_2 removal was achieved during the test campaign. The sections marked "A" in the figure showing low CO_2 removal indicate parametric

[1] Pavlish, B. *Partnership for CO_2 Capture: Results of the Pilot-Scale Solvent Evaluations*. 2010 NETL CO_2 Capture Technology Meeting. September 13-17, 2010, Pittsburgh, PA.

tests done in order to generate data over a wide range of test conditions rather than to achieve target CO_2 removal. The intervals showing no data points were periods during which flue gas was unavailable to the pilot facility due to main plant outages or maintenance. Excluding these intervals, the total solvent operation time during the roughly three-month test campaign was over 1350 hours.

To determine the optimal solvent circulation rate, parametric tests were conducted at different boiler loads by varying the solvent flow rate in the absorber. Flue gas flow rate was kept constant at about 5000 lb/hr. Steam flow rate to the reboiler was also kept constant for these tests. Figures 10 and 11 show the effects of CO_2 capture performance and regeneration energy at different solvent flow rates at partial boiler load conditions. The inlet CO_2 concentration ranged between 11.5% and 12%. As shown in Figure 10, as the solvent circulation rate increased initially, the CO_2 removal efficiency increased to a value of about 96%. Beyond this value, further increase in solvent flow rate resulted in a reduction in CO_2 capture performance. The reason for this behavior is at very high solvent flow rates and at constant reboiler steam flow rates, the heat provided to release CO_2 from the rich solvent is insufficient. This results in increasing lean loading. At the same time, the rich loading decreases with increasing solvent circulation rate. Therefore, the net working capacity of the solvent is reduced, resulting in lower CO_2 capture.

Table 1: Range of Operating Conditions

Item	H3-1 Typical Range	Unit
Inlet Gas Flow Rate	4000 - 6000	lb/h
Solvent Flow Rate	7000 - 17000	lb/h
Steam Flow Rate	700 - 1100	lb/h
Inlet Gas Temperature	96 - 122	^oF
Inlet Solvent Temperature	96 - 114	^oF
Outlet Gas Temperature (Wash Tower)	107 - 123	^oF
Regenerator Pressure	3 - 22	psig
CO_2 Concentration	11 - 13	% vol dry
Absorber beds	3, 2, 1	
Intercooler	Off, On	

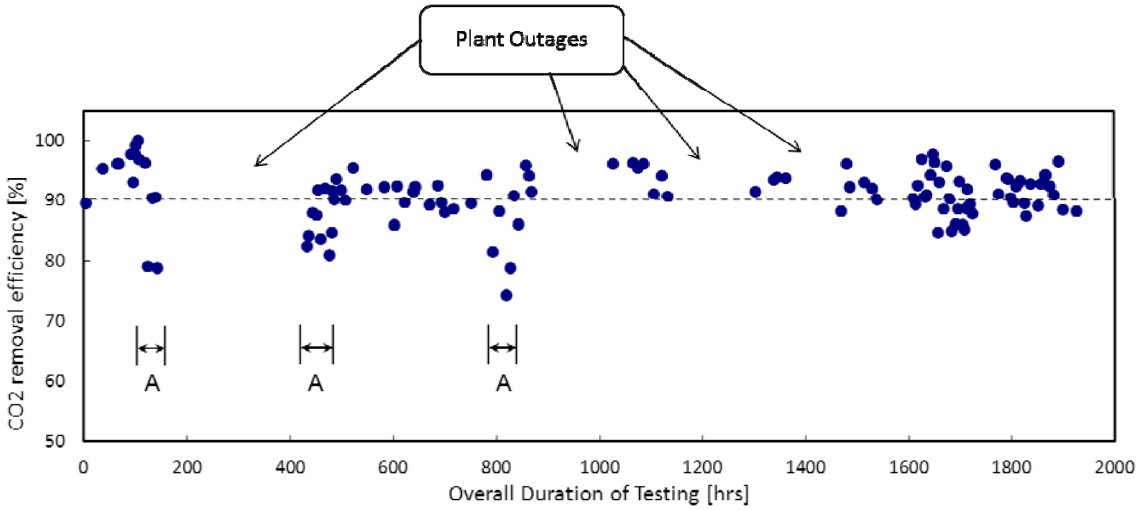

Figure 9: Overall CO_2 capture performance

Regeneration energy is the amount of energy required (which is the reboiler heat duty) to release a unit mass of CO_2. As the amount of CO_2 captured decreases with increasing solvent flow rate beyond the optimal value, the regeneration energy increases (Figure 11). At the optimal solvent flow rate when about 96% CO_2 removal efficiency was achieved, the regeneration energy was lowest at about 2.4 GJ/t-CO_2.

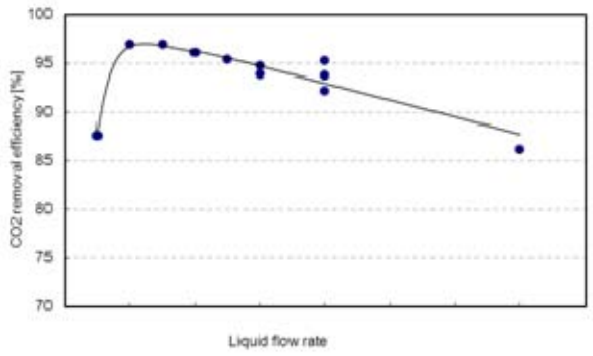

Figure 10: Effect of liquid flow rate on CO_2 removal efficiency

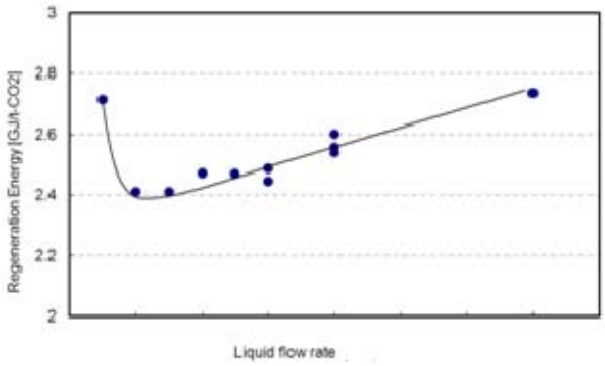

Figure 11: Effect of liquid flow rate on regeneration energy

Similar trends of capture performance and regeneration energy with varying solvent flow rates were observed for tests conducted at full load conditions. In this case, the solvent flow rate required to achieve maximum CO_2 removal and lowest regeneration energy was higher, due to higher inlet flue gas CO_2 concentration which was in the range of 12.6 to 13.1%. Even at full load conditions, regeneration energy of 2.4 GJ/t-CO_2 was observed.

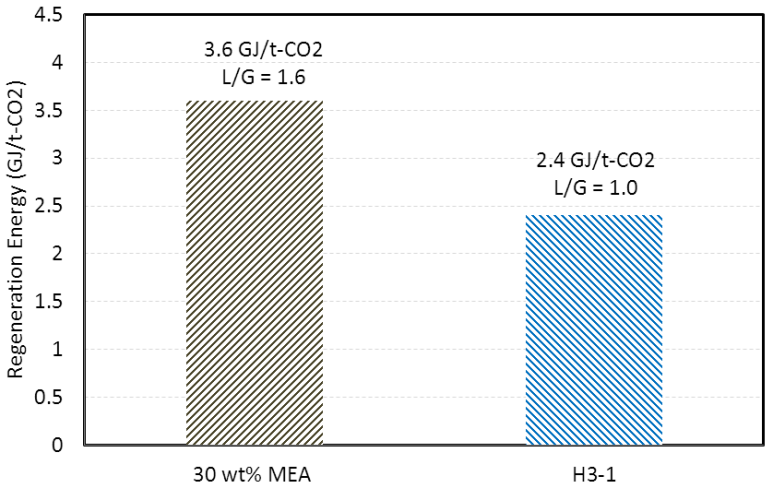

Figure 12: Comparison of regeneration energy and CO_2 capture performance of H3-1 with 30 wt% MEA

Under similar test conditions such as flue gas flow rate and inlet CO_2 concentration, the energy of regeneration for 30 wt% MEA tested at NCCC was found to be 3.6 GJ/t-CO_2 (Figure 12). This value is 1.5 times higher than that for the H3-1 solvent. The CO_2 removal efficiency achieved using H3-1 was slightly higher at 94% than that from the MEA tests (92%). Furthermore, the

solvent circulation rate required for H3-1 was about 37% lower than that for MEA. For a CO_2 capture system, this would translate to savings in capital cost since smaller equipment (absorber, heat exchangers, pumps, etc.) would be sufficient to achieve high removal efficiencies, and also in operating cost since lower amount of solvent would be pumped through the process loop.

20 MWth Test Facility

In collaboration with SaskPower, a utility company in Saskatchewan, Canada, Hitachi has designed a 20 MWth Carbon Capture Test Facility at SaskPower's coal-fired Shand Power Station. The test facility is currently being installed and testing of the H3-1 solvent is scheduled to begin in 2014. The demonstration unit will treat approximately 23,000 Nm^3/h of slipstream flue gas from the coal-fired power plant.

SUMMARY

Hitachi has been developing CO_2 capture and solvent technologies for full-scale power plant applications through research, design, development, field testing, and demonstrations. Through bench- and pilot-scale testing, proprietary amine-based solvent formulations have been evaluated that can achieve high CO_2 absorption capacity while requiring low regeneration energy. Pilot plant tests were conducted recently at the EERC and NCCC to independantly verify the performance of Hitachi's latest advanced solvent, H3-1. In more than 1350 hours of testing at NCCC using slipstream coal-fired flue gas at varying boiler loads and operating conditions, an average of 91% CO_2 capture was achieved. The energy for regeneration of H3-1 was found to be 2.4 GJ/t-CO_2, which is about 33% lower than that for 30 wt% MEA. Hitachi continues to improve its advanced solvent and CO_2 capture process technologies through large pilot tests and demonstration efforts that provide valuable data towards commercial application of post-combustion CO_2 capture for coal-fired power plants.