Hitachi's Carbon Dioxide Scrubbing Technology with New Absorbent for Coal-fired Power Plants

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ABSTRACT

Hitachi has been developing a new amine-based scrubbing technology for capturing carbon dioxide in the flue gas of coal-fired power plants. The development program includes testing of commercial and new combinations of absorbents and additives. More than thirty kinds of amines have been evaluated and characterized by both fundamental tests in the laboratory and slipstream pilot plant tests. The pilot plant tests of the CO2 scrubbing system were conducted at a coal-fired power plant in co-operation with Tokyo Electric Power Company. Two thousand hours of continuous operation was achieved with more than 90 % CO2 reduction on average during the entire operation. Energy consumption with the original absorbent blend was much less than that with typical MEA. Since then the CO2 scrubbing system has been further advanced to reduce the energy consumption as well as absorbent degradation drastically by improving the amine-based absorbent in a bench-scale test facility. Pilot tests at Energy and Enviromental Research Center (EERC), University of North Dakota, were conducted in 2010 and the test results indicated high performance of the improved amine-based absorbent, H3-1. This latest advanced solvent is also scheduled to be demonstrated in a large mobile test facility at several coal-fired power plants in Europe starting 2010. In parallel, conceptual designs of the CO2 scrubbing system for commercial plants up to 800 MWe in size are being developed.

INTRODUCTION

Hitachi has been developing new technologies to resolve the global warming issue, including amine-based scrubbing, oxy-fuel combustion, IGCC with CO2 absorption, and 700 C class advanced ultrasupercritical boiler-turbine system.

Amine-based CO2 separation has been utilized since the 1930s for applications such as natural gas purification. It is a leading technology expected to be available commercially within the next decade to enable CCS for coal-fired power stations. However, traditional amine-based CO2 separation process utilizing conventional solvents is very energy intensive when applied to coal-fired power plants and also susceptible to solvent degradation by oxygen, SOx and NO2 in the flue gas, resulting in drastically reduced plant efficiency and output as well as large operating cost. According to recent DOE/NETL studies, MEA-based CCS will increase the cost of electricity (COE) of a new pulverized coal plant by 80-85% and reduce the net plant efficient by about 30%.

To address the above challenges of amine-based CCS for coal power, Babcock Hitachi has been developing a new amine-based scrubbing technology for capturing carbon dioxide in the flue gas of coal-fired power plants. The technology features an advanced Air Quality Control System (AQCS) as a pre-cleaning stage and a low energy-consuming, highly oxygen-resistant amine-based scrubbing system, and a highly efficient steam extraction system. One of key components in the AQCS is Flue Gas Desulfurization (FGD). As demonstrated in various coal-fired plants in the world, the Babcock Hitachi FGD is capable of reducing sulfur oxides to extremely low levels, which makes the downstream CO2 scrubbing system more efficient and compact[1].

The development program includes testing of commercial and new combinations of absorbents and additives. More than thirty kinds of amine have been evaluated and characterized by both fundamental tests in the laboratory and slipstream tests of coal-fired flue gas in a commercial plant. Based on data from these tests a desirable combination of amine and additives was chosen as an appropriate absorbent for coal-fired flue gas to achieve high absorption efficiency and low reagent degradation. In addition, the regenerator adopts a unique design configuration for mixing the solvent and steam, so that it can be operated with a small amount of steam for heating up CO2-loaded amine. These innovations are key to lowering the energy consumption of the CO2 capture system.

Pilot plant tests of the CO2 scrubbing system were conducted at a coal-fired power plant in co-operation with Tokyo Electric Power Company (TEPCO)[2]. Two-thousand-hour continuous operation was achieved with more than 90 % CO2 reduction during the entire operation and energy consumption with the original absorbent blend was (at 2.8 GJ/ton-CO2) much less than that with typical MEA. Since then the CO2 scrubbing system has been further advanced to reduce the energy consumption as well as absorbent degradation drastically by improving the amine-based absorbent in a bench-scale test facility of Babcock Hitachi (Figure 1). The new solvent is scheduled to be demonstrated in a large mobile test facility at several coal-fired power plants in Europe in 2010. In parallel, conceptual design of the CO2 scrubbing system for 800MWe commercial plants has been developed.

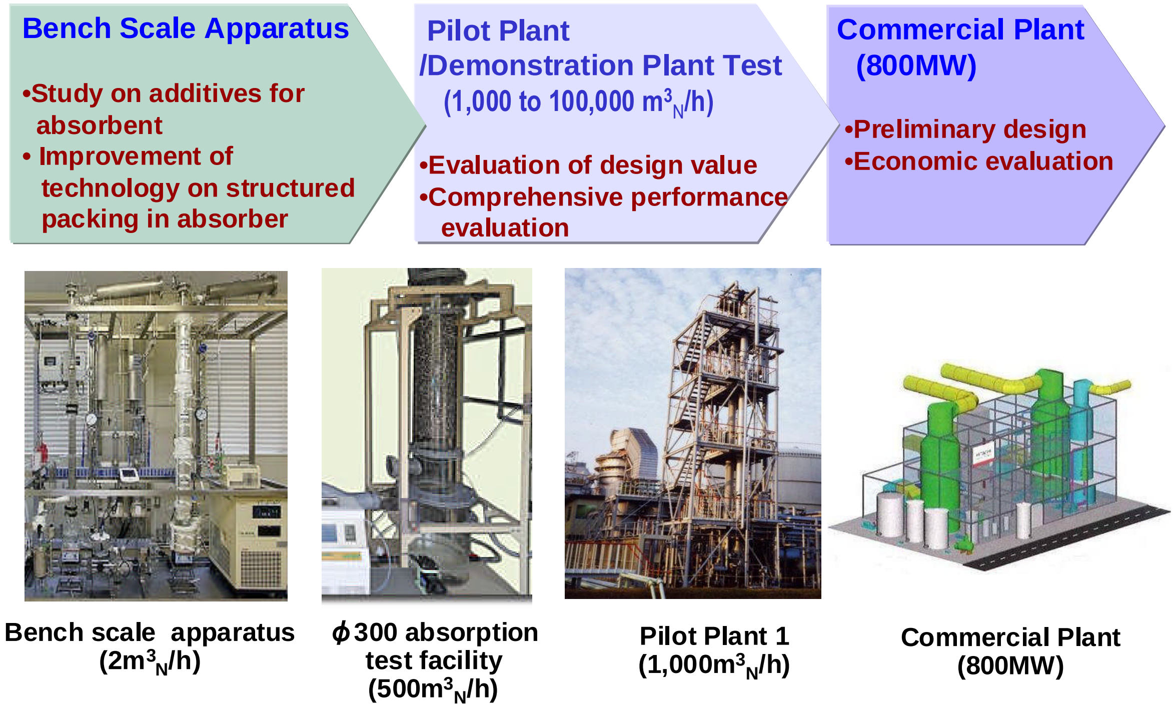

Figure 1 Steps from Bench Scale Apparatus to Commercial Plant

CO2 Capture Process Description

Figure 2 shows a sketch of a post-combustion CO2 capture process. The main system components are a pre-scrubber, an absorber, a desorber and a reboiler. CO2 scrubbing system is arranged downstream of the AQCS system. The gas cooler in AQCS is a unique technology developed by Babcock Hitachi, which controls ESP inlet gas temperature to remove SO3 across the ESP. The energy recovered by the gas cooler can be utilized for the CO2 capture system to reduce overall energy consumption.

Since the SOx in flue gas is removed by ESP, FGD and pre-scrubber, Hitachi can provide a CO2 scrubbing system without a continuous reclaimer.

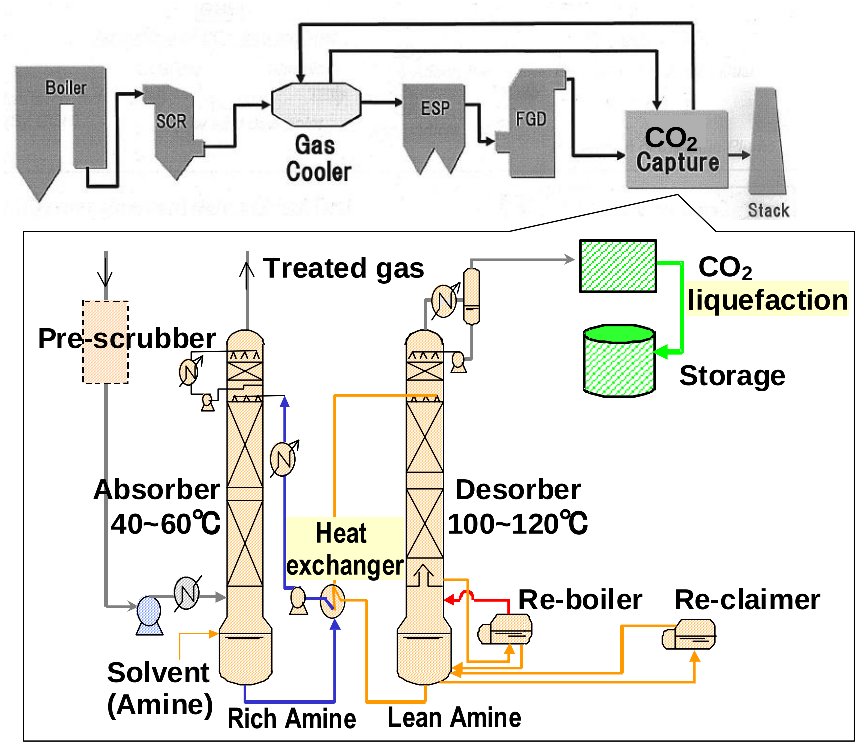

Figure 2 Post-Combustion CO_2 Capture Process

Bench-Scale Tests for Screening Amine Absorbents

High CO2 loading, low corrosivity, low regeneration heat requirement, high oxidative-resistance and low amine loss are necessary characteristics of a good solvent for CO2 scrubbing. By screening more than thirty combinations of amines and additives in a 2 m3N/h bench scale apparatus, shown in Figure 3, Babcock-Hitachi has developed a proprietary amine solution with the above-mentioned characteristics.

Figure 4 shows one set of results of the screening tests. B-1 and B-2 solutions were superior in terms of both high CO2 loading and low corrosivity. Energy required for solvent regeneration was also evaluated and compared with that for MEA solution. As shown in Figure 5, at standard operating conditions, the reaction heat by CO2 absorption of our new solvent, named H3, was less than that required for MEA by 5 to 15% for the range of conditions tested.

Specification

	Item	Value
1	Gas flow rate (m^3N/h)	2.0
2	Solution flow rate (L/h)	1～8
3	Inlet gas temp. (℃)	30～50
4	Dimension of absorber (mm)	ϕ50×1,500

Cooler

Control panel

Absorber

Desorber

Pump

Figure 3 Bench Scale Apparatus

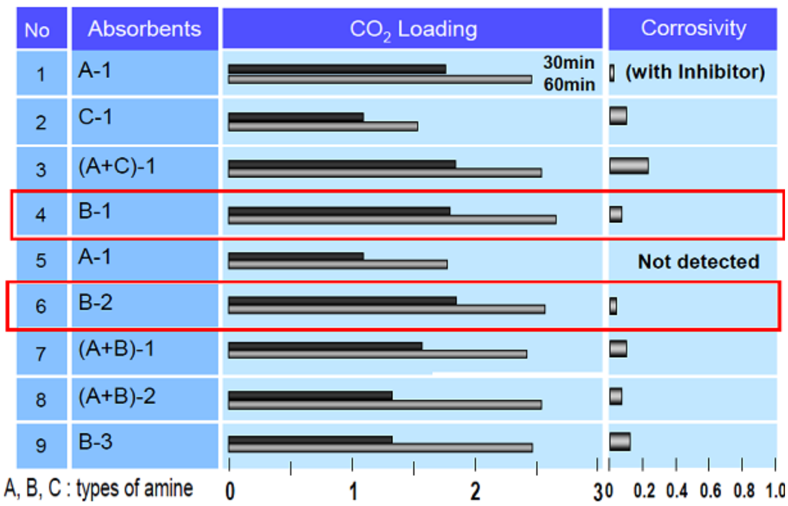

Figure 4 Results of Solvent Screening

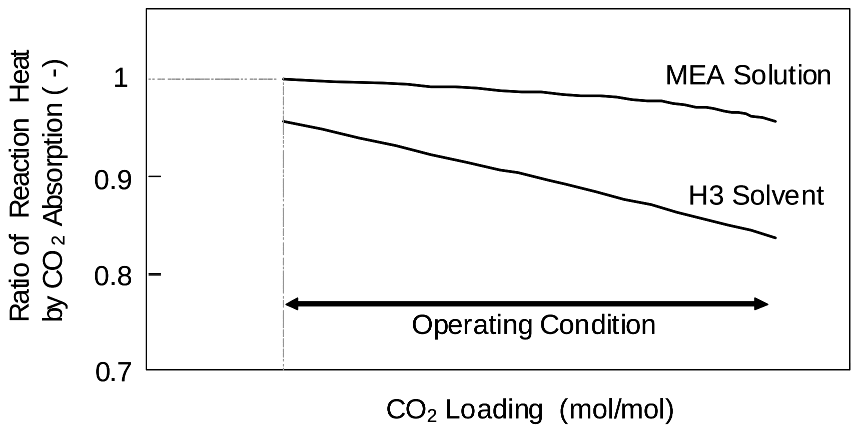

Figure 5 Reaction Heat by CO_2 Absorption of MEA Solution and H3 Solvent

Pilot Plant Tests

Pilot plant tests of amine-based CO2 scrubbing system were conducted at a coal-fired power plant in co-operation with Tokyo Electric Power Company. The overview of the pilot plant and the operating conditions are shown in Figure 6. A slipstream of about 1000 m3N/h of flue gas generated from combustion of a coal – oil mixture (COM) was treated for CO2 removal. In the absorber, the flue gas flow rate was 600 to 1,200 m3N/h and the H3 solvent flow rate was 1500 to 2500 L/h. Random packing was used in the absorber and desorber towers. As shown in Figure 7, in over two thousand hours of continuous operation, an average CO2 removal of more than 90% was achieved using the H3 solvent.

	Flue Gas Composition			
1	CO_2 11 (%)			
2	O_2 5 (%)			
3	SOx 80 (ppm)		NOx	60 (ppm)
4	H_2O 13 (%)		DUST	20 (mg/m^{3}N)

	Parameter	Value
	Absorber	
1	Gas flow rate (m^3/h)	600 - 1200
2	Solvent flow rate (L/h)	1500 - 2500
3	Inlet gas temp. (℃)	40 - 50
4	Gas velocity (m/s)	1.0 - 2.0
5	Liquid to gas ratio (L/m3)	1.5 – 3.0
	Desorber	
6	Temp. of Regenerator (℃)	100 - 120

Figure 6 Pilot Plant Facility and Operating Conditions

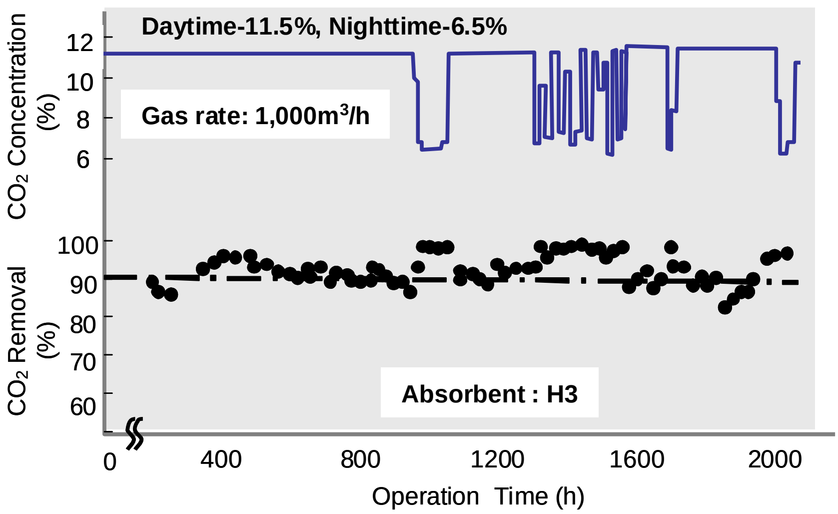

Figure 7 Pilot Plant Test Results

Development of Advanced H3 Solvent

During operation, the capacity of an amine solvent solution for CO2 absorption is reduced by oxidation due to dissolved oxygen, by acid impurities such as SOx or NOx, and due to solvent loss as mist or vapor. This gradual deterioration of absorption capacity results in high solvent usage and large operating costs. Therefore, the H3 solvent was enhanced by treatment with additives to minimize solvent degradation and loss.

A range of additives, antioxidants and a combination of both were screened in the bench-scale set-up. Figure 8 shows some results of the screening tests. Degradation of the H3 absorbent treated with additive-A was over 70% lower than that of the solvent treated with phenolic antioxidant or amino antioxidant, two commercially available additives.

Additionally, the H3 solvent has been improved to reduce amine loss as mist. Microparticles of solvent are generated by the breaking of bubbles on gas-liquid interfaces. A large amount of these microparticles form a mist and get carried away by flue gas, resulting in loss of amine solvent and generation of amine slip. To suppress the formation of such microparticles, the Hitachi solvent has been treated with an additive. Amine loss as mist of the H3 absorbent treated with additive-B was over 70% lower than H3 solvent as shown in Figure 9.

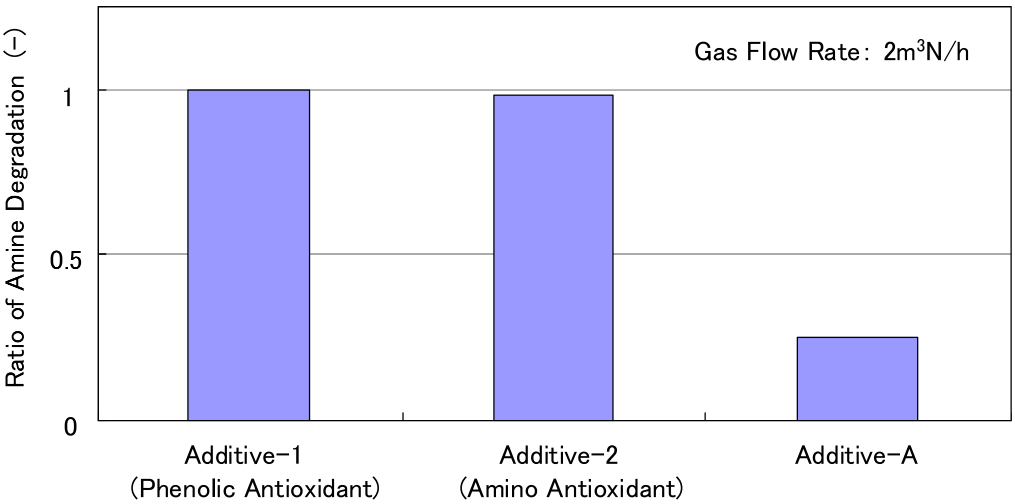

Figure 8 Influence of Additives on Amine Degradation

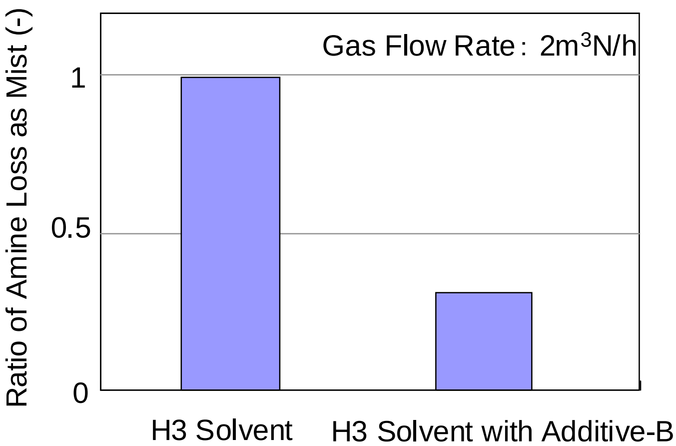

Figure 9 Influence of Additive-B on Amine Loss as Mist

After numerous screening tests an appropriate combination of the base amine and additive-A and additive-B was chosen as an advanced version of the H3 solvent named H3-1. Both additives were chemically well-suited and had little influence on the amine performance of high CO_2 absorption and low regeneration energy requirement. Degradation of the H3-1 solvent was reduced by more than 70% compared to the amine degradation of the H3 solvent, as shown in Figure 10.

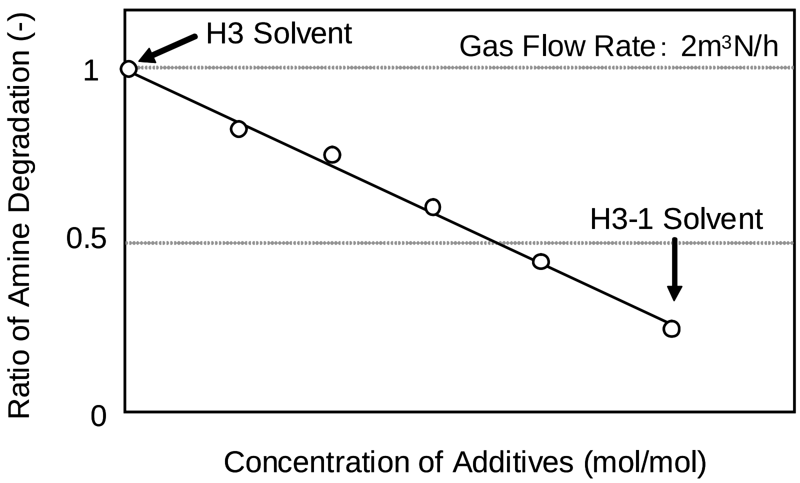

Figure 10: Influence of the Additives on Degradation of H3 Solvent

Figure 11 shows the regeneration heat per unit weight of CO_2 captured for the two Hitachi solvents compared with MEA solution. The heat of regeneration of H3-1 and H3 solvents is about 30% lower than that for MEA solution. Figure 12 shows the amine loss for the three solvents. The amine loss of H3 solvent is about 70% lower than that of MEA solution. The amine loss of H3-1 solvent was about 85% lower than that of MEA solution. Solvent consumption and operating cost of a CO_2 capture process can be reduced further by using the improved H3-1 solvent compared with the H3 solvent.

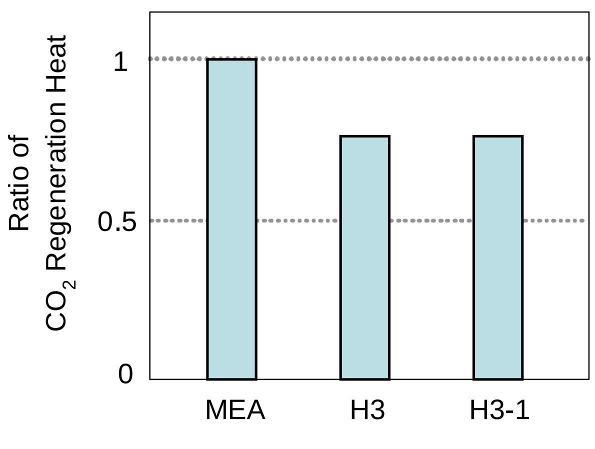

Figure 11 Regeneration Heat of Absorbents

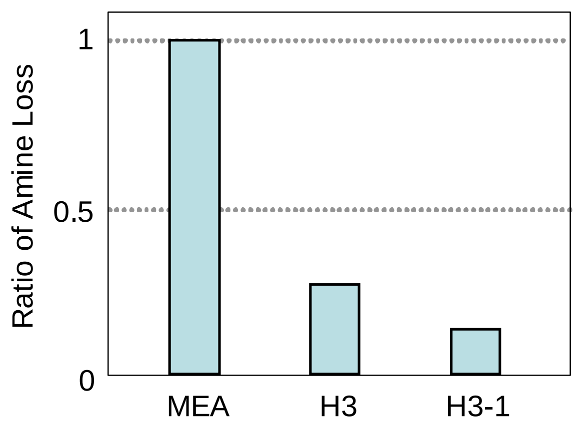

Figure 12 Amine Loss of Absorbents

Pilot Test at EERC

The performance of H3-1 solvent was evaluated by EERC using a pilot scale test facility, equipped with SCR, DESP and WFGD. The flue gas flow rate was 400m3/h. The H3-1 performance was compared with MEA at a given test condition.

Figure 13 shows relationship between solvent flow rate and CO2 removal efficiency. At 90% CO2 removal rate, the required solvent recirculation rate for H3-1 was 35% lower. than that of MEA. Not shown in the figure, the heat requirement of H3-1 was about 25-30 % lower than MEA.

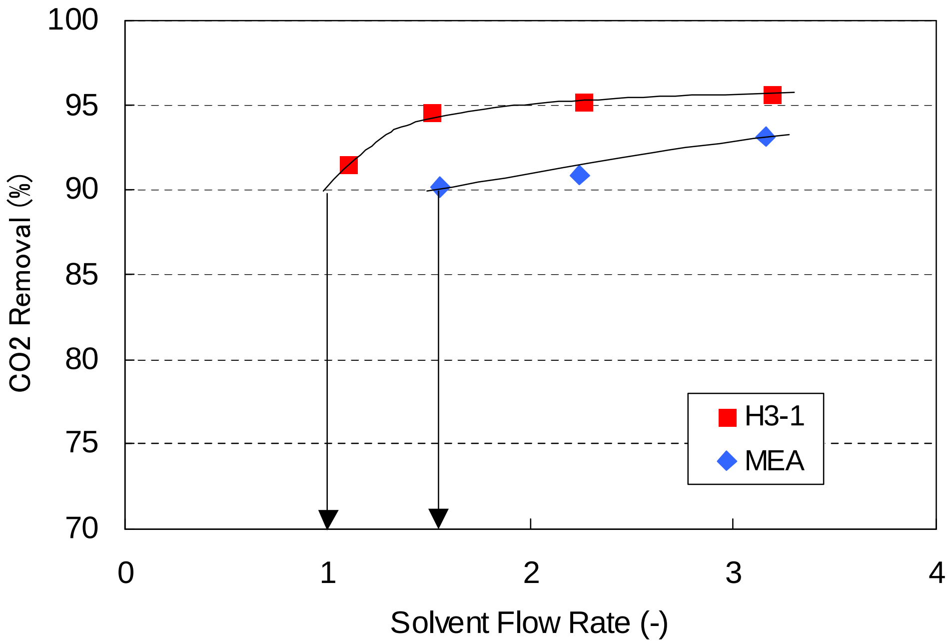

Figure 13 Relationship between solvent flow rate and CO2 removal

Technology Development and Scalability

The advanced solvent will be demonstrated in a larger, 5000 m^3N/h mobile plant to be installed at various power plants in Europe starting this year. As a global supplier of complete power generation product lines, Hitachi can propose the optimum process with the maximum overall energy efficiency by integrating boiler, turbine and generator (BTG), air quality control system (AQCS), and the CO2 capture system, in the areas such as heat recovery from the flue gas, high performance FGD and optimization of steam turbine and condenser system. Figure 14 shows a power station with an integrated post-combustion capture system. The experience in solvent development and scale-up of the CO_2 scrubbing system from bench-scale to small and large pilot-scale units will be applied to the design of larger demonstration and commercial plants.

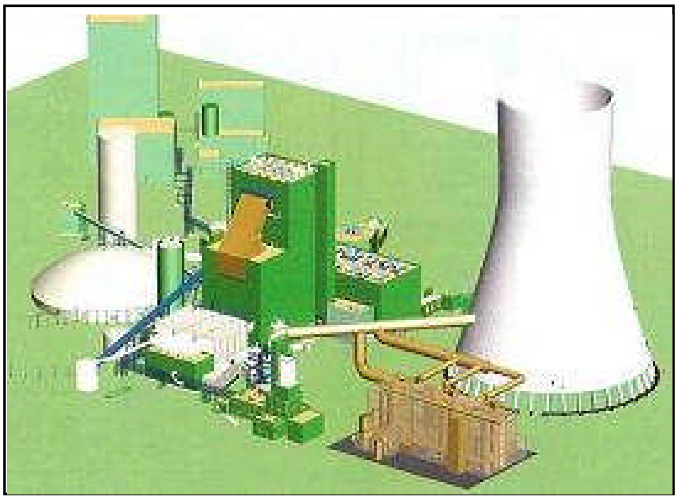

Figure 14: Integration of Post-combustion Capture Plant into a Power Station[3]

SUMMARY

- Babcock Hitachi developed a proprietary amine solvent, H3, by screening more than thirty kinds of amines, additives and combinations of the two.
- Main characteristics of the H3 solvent are the high CO2 absorption capacity, low corrosivity and low energy required for regeneration.
- Over two thousand hours of continuous operation in our pilot test facility demonstrated successful capture of more than 90% CO2 from flue gas using H3 solvent.
- The H3 solvent was further improved to reduce amine loss and solvent degradation due to dissolved oxygen and acid impurities. The advanced H3-1 solvent has an amine degradation rate that is 70% lower than that of the H3 solvent.
- With an advanced amine solvent, an extensive test program, and the expertise in plant integration as a global supplier of power generation equipment, Hitachi has established the technology base to scale-up and design commercial plants.

REFERENCES

1. T.Kawasaki et al, Development of CO2 Scrubbing Technology for Coal-Fired Power Plants, Coal Gen 2009
2. H. Oota et al. CO2 Removal Technology from the Thermal Power Plant Flue Gas、The Fourth Japan-Korea Symposium on Separation Technology 10/1996
3. W.Schreier, G.Boon, V.Kubacz, Post-combustion Capture Plants – Concept and Plant Integration, VGB PowerTech 12/2009