POWER-GEN 2011

Recent Development of Hitachi's Advanced Amine-based Post-Combustion CO_2 Capture Technology

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

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

Arthur Heberle
Hitachi Power Europe GmbH
Schifferstraße 80, 47059 Duisburg, Germany

ABSTRACT

Hitachi has been developing an amine-based post-combustion CO_2 capture technology to address the global objectives of reducing CO_2 emissions from coal-fired power plants within the next decade. Key aspects of the technology include 1) development of an advanced solvent with high CO_2 absorption capacity, low solvent regeneration energy, low corrosion potential and low tendency for degradation and amine emissions; 2) design integration of steam cycle and the CO_2 absorber-desorber process; and 3) total plant re-optimization involving the boiler, turbine, air quality control system, and CCS system.

In the early 1990s, bench-scale R&D and the first pilot plant tests were performed to identify a promising solvent from multiple proprietary blends. At the 1 MWth slipstream facility in Yokosuka Power Station built in cooperation with Tokyo Electric Power Company (TEPCO), the best solvent formulation demonstrated an average of 90% capture over 2000 hours of continuous testing under varying load conditions. The latest refinement of Hitachi's proprietary solvent provides the added advantage of reduced amine loss while maintaining regeneration energy of 2800 kJ/kg-CO_2 which is much lower compared with commercial MEA.

Hitachi has built a 5MWth mobile pilot plant that is currently being commissioned at a coal-fired power plant in Northern Europe. In addition to optimization of the absorption-desorption process for CO_2 removal, the goals of the pilot plant include setting design criteria for reducing capital and operating costs, and minimization of environmental impact. Other pilot-scale and larger demonstration programs are being carried out in North America and Europe in cooperation with power companies and academic partners. This paper provides an update of the ongoing pilot and demonstration efforts, and discussions on solvent development including reduced solvent degradation and solvent loss.

INTRODUCTION

In the United States about one half of the electricity is from coal. Worldwide coal contributes to over 40% of the electricity generation today and its share is expected to increase steadily over the coming decades. The continued dominance of coal in global energy structure and the growing concern of climate change necessitate accelerated development and deployment of new technologies for clean and efficient coal utilization. Coal-fired power plants with CO_2 capture and sequestration (CCS) are widely expected to be an important part of a sensible future technology portfolio to achieve overall global CO_2 reductions required for stabilizing atmospheric CO_2 concentration and global warming.

Amine-based CO_2 separation has been implemented 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 CO_2 capture process utilizing conventional amine solvents is very energy intensive and is also susceptible to solvent degradation by oxygen, SOx and NO_2 in coal-fired flue gas, resulting in large operating cost. According to recent DOE/NETL studies, currently available MEA-based CCS will increase the cost of electricity (COE) of a new pulverized coal plant by 80-85% and reduce the net plant efficiency by about 30%.

As a global technology and equipment provider for complete thermal power plants, Hitachi addresses the above challenges of amine-based CCS for coal power with the following approach: 1) development of a flexible CO_2 capture process and the latest advanced amine-based solvent with long service life and low regeneration energy requirement; 2) design integration of steam cycle and CO_2 absorption - desorption process; 3) total plant re-optimization involving the boiler, turbine, air quality control system, and CCS system.

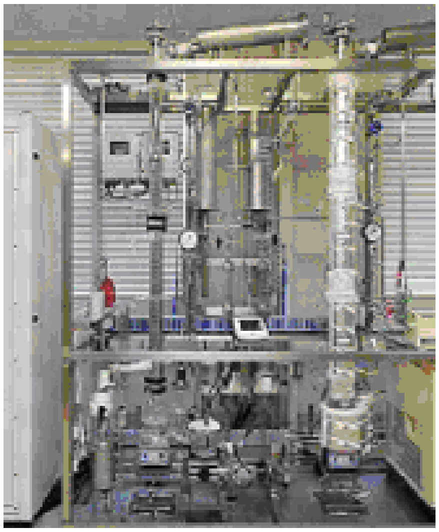
DEVELOPMENT OF HITACHI CO_2 CAPTURE TECHNOLOGY

CO_2 Capture Process and Solvent Development

Hitachi started post-combustion CO_2 capture R&D specifically for coal-fired applications 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 the technology for full-scale power plant applications.

Bench-scale studies (Figure 1) with simulated flue gas have been performed regularly to screen and identify promising absorbents and additives for maximum CO_2 removal efficiencies while keeping solvent degradation and energy consumption low.

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 Corporation (TEPCO) in Japan. The 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.



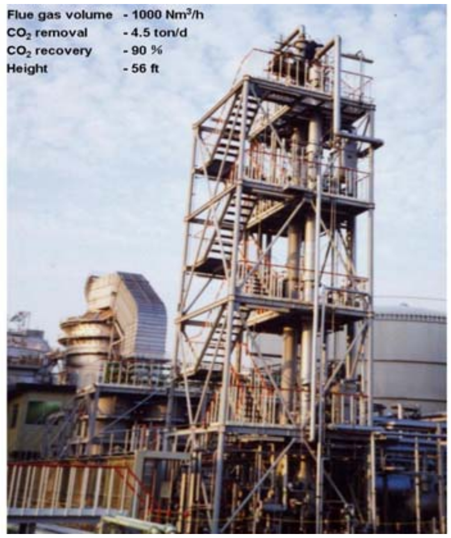


Figure 1: Bench-scale test rig

Figure 2: Pilot plant at Yokosuka

Figure 3 shows that in the 2000 hours of testing under various loads and inlet CO_2 concentrations, H3 consistently achieved greater than 80% CO_2 removal with the average well above 90%. H3 has specific regeneration energy of 2800 kJ/kg CO_2 which is the best among tested solvents and much lower than commercial MEA. It also has high absorption capacity, thus requiring lower liquid-to-gas ratio for 90% capture than that for MEA and resulting in significant operating cost savings. Hitachi continues the refinement of the proprietary solvent blends in its laboratories. New solvent formulations are also being tested and compared with other commercial or near commercial solvents by independent institutions in Japan and USA.

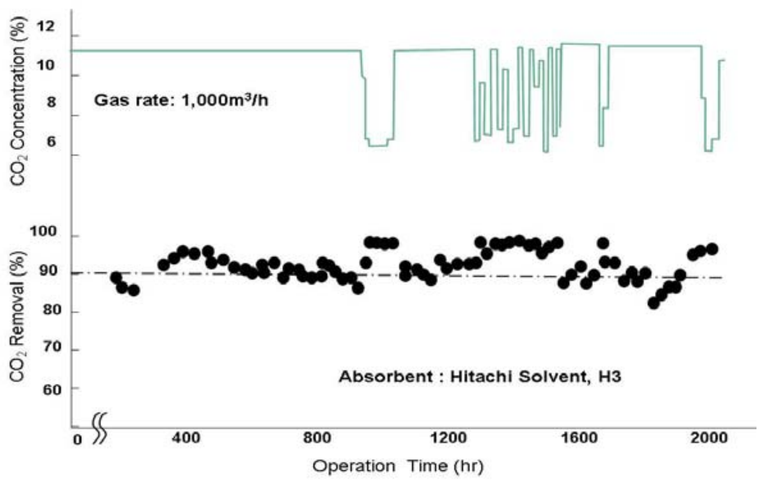


Figure 3: Long-term pilot testing of H3 solvent under various inlet CO_2 concentrations

The latest refinement of the H3 solvent formulation is H3-1, a proprietary blend solvent that has the same advantages of high CO_2 absorption capacity and low regeneration heat as H3, but further reduction in amine loss.

Development of Advanced Solvent, H3-1

With further fine-tuning of the solvent formula based on numerous pilot and bench-scale tests of over 30 combinations of amines and additives, the H3-1 solvent was developed that minimizes amine degradation and loss while maintaining high CO_2 capture performance.

Figures 4 and 5 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.

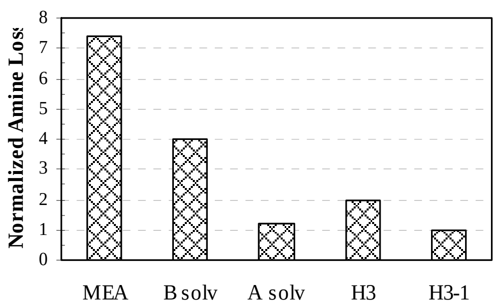


Figure 4: Comparison of Amine Loss from different solvents

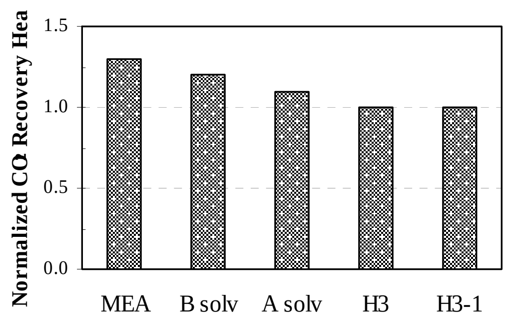


Figure 5: Comparison of CO2 recovery heat from different solvents

RECENT PILOT TEST ACTIVITIES

Independent Pilot Plant Testing

In 2010, the H3-1 solvent was independently tested by the Energy and Environmental Research Center (EERC), University of North Dakota at the 400 Nm^3/h (250 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 6 and 7 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 than that for MEA and the energy required to regenerate the H3-1 solvent is about 30% lower than 30% MEA solution.

[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.

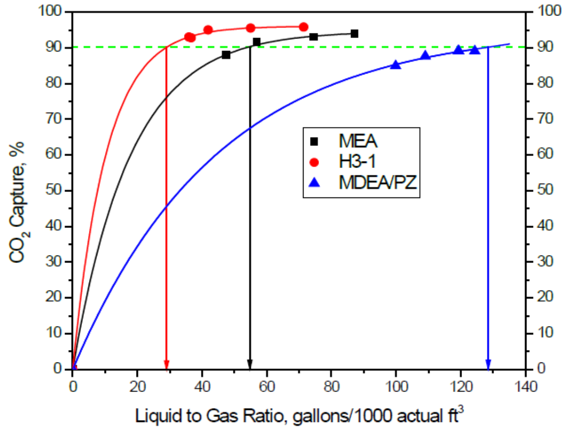


Figure 6: Comparison of the effect of L/G of various solvents

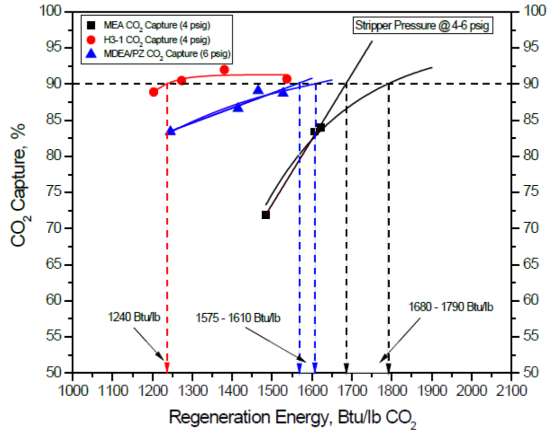


Figure 7: Comparison of Regeneration Energy of Various Solvents

New Pilot Test Facility

In a new 500 Nm^3/h pilot-scale facility in Babcock-Hitachi's Kure Research Laboratory in Japan, the H3-1 solvent is further analyzed under different test conditions. As shown in Figure 8, the process includes a vapor recompression system in order to achieve greater energy efficiency of the CO_2 capture process while using the advanced H3-1 solvent. Structured packing is used in both the absorber and stripper vessels.

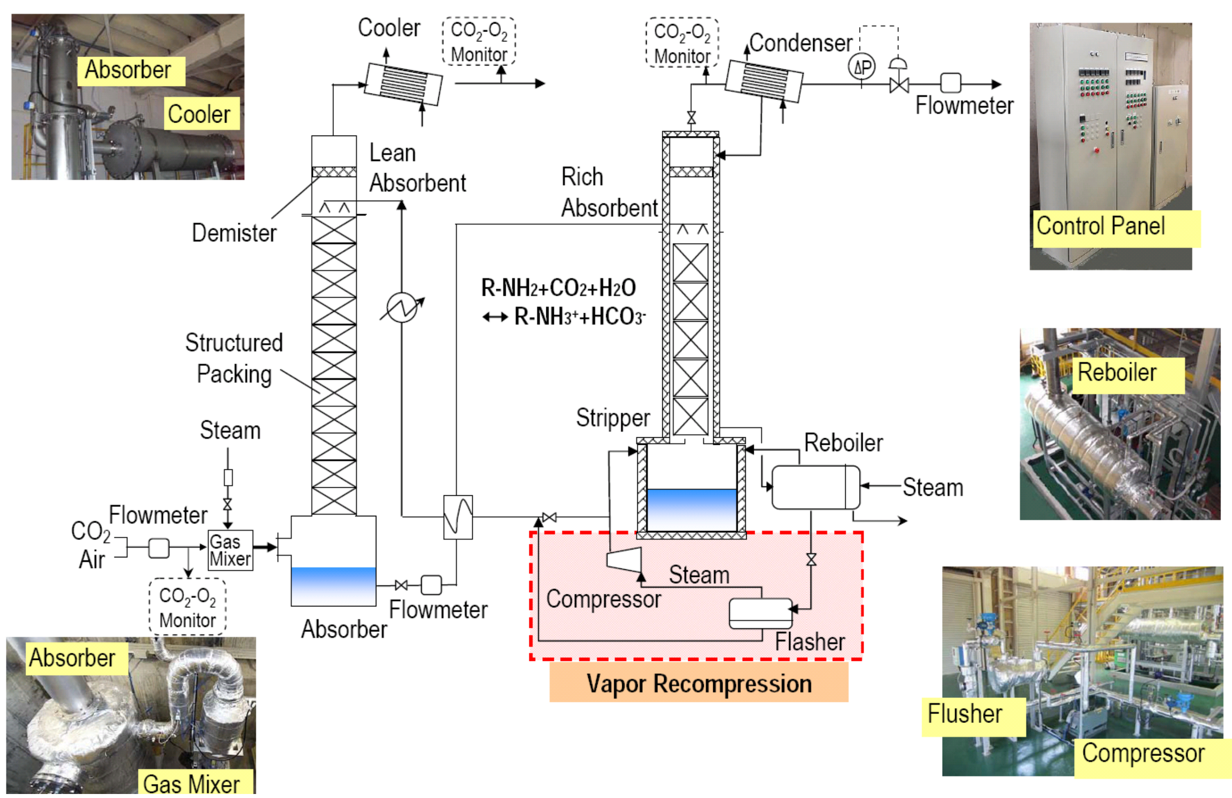


Figure 8: Hitachi's Pilot-scale Facility

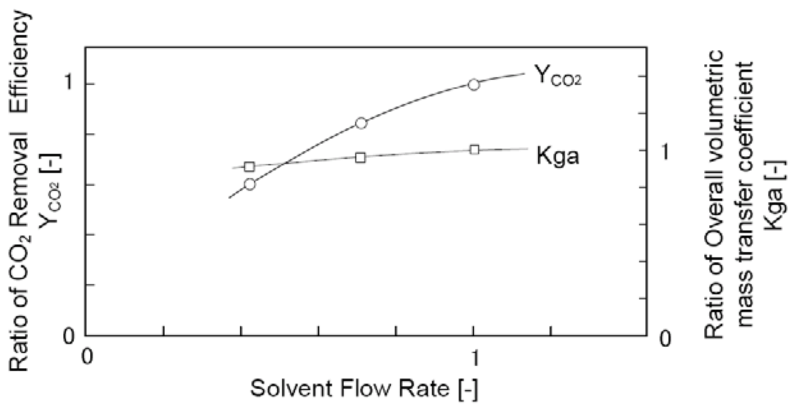


Figure 9: Effect of Solvent Flow Rate on CO_2 Removal Efficiency

Using inlet gas containing 15% CO_2, tests were conducted at various solvent flow rates. Figure 9 shows the effect of solvent flow rates on the CO_2 removal efficiency and overall mass transfer coefficient. System conditions such as pressure drop and flooding point were analyzed in order to provide valuable information for the design of larger demonstration systems.

Large Mobile Pilot Plant

Hitachi Power Europe GmbH, in cooperation with utility partners Electrabel / GDF Suez and E.ON, has built a large mobile pilot plant for the separation of carbon dioxide from coal-fired power plant flue gases. The plant is used to generate data for the development of design concepts for both new power plant integrated with CCS or retrofit of a carbon dioxide separation plant in existing power stations.

Figure 10 shows the general arrangement of the mobile pilot plant. The plant components are built into transportable segments equivalent to overseas containers. These preinstalled segments, shown in Figure 11, are erected at the site of the host power station and connected to a slipstream of flue gas after the plant's FGD unit. The pilot plant is designed to process a flue gas volume flow of approximately 5000 Nm^3/h corresponding to 5 MW_{th}. The auxiliaries and steam needed for the operation are supplied by the host power plant. This modular mobile pilot plant has been erected at a power plant site in Northern Europe.

The pilot plant can be arranged in different configurations (serial and parallel) to offer maximum flexibility. Therefore, the pilot plant will be able to run under a wide range of operating conditions such as process gas flow, residence time, CO_2 removal rate, etc., and produce reliable data for the scale-up to full size plants.

The primary objective of the pilot program is to investigate the lowest energy demand and to determine design criteria for the optimization of capital investment and operating costs. Besides this the design data to minimize the environmental impact of the CO_2 scrubbing system will be of great interest. The pilot plant is fully equipped with an on-line monitoring system to continuously measure trace emissions of solvent as well as some of the degradation products. In addition, periodic campaigns will be conducted for the complete measurement of degradation products and emissions.

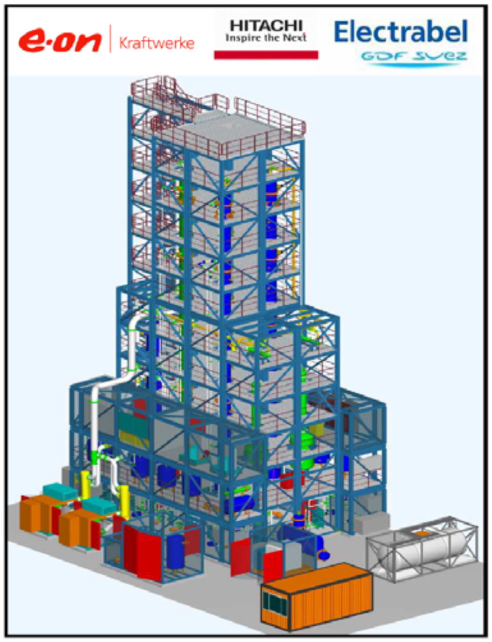


Figure 10. Pilot plant arrangement

Figure 11. Mobile pilot plant segments

SUMMARY

Post-combustion solvent based CO_2 capture technology is a more mature solution presently being developed for CO_2 reduction from coal-fired power plants. However, many technical challenges still remain that need to be addressed to make it cost-effective. Through bench-scale and pilot tests, Hitachi has developed advanced amine-based technologies that can achieve high CO_2 removal efficiencies with minimum solvent degradation and require less energy for solvent regeneration. Hitachi continues to improve its advanced solvents and capture processes through pilot testing programs in Japan, Europe and North America, among other development and demonstration activities that it is pursuing worldwide in order to accelerate commercialization of CCS for coal-fired power plants.