The Engineering Application of CO₂ Capture by Chemical Absorption in China

As concentrations of carbon dioxide (CO₂) in the atmosphere have increased, the climate change issue has become more prominent and has been attributed to a series of climate-related disasters around the world. In China, an important aspect of reducing CO₂ concentrations is to decrease emissions from coal-fired power plants. This article discusses the engineering application of chemical absorption technology to reduce CO₂ emissions from the Beijing Gao Bei-dian and Shanghai Shi Dong-kou power plants.

Climate change is largely the result of the increase of greenhouse gases, such as CO₂. Global CO₂ concentrations increased from a pre-Industrial Revolution level of 280 parts per million (ppm) to 385 ppm in 2010, far higher than the natural variability of the past 65 million years. The main reason for its rapid rise is the extensive use of fossil fuels in energy generation, from which the annual emission of CO₂ is approximately 25.3–27.5 Gt.¹

Climate change has been found to have profound disastrous impacts, such as glaciers melting, species drastically deceasing, severe droughts, and fatal flooding. At present, CO₂ emissions from power plants account for more than 40% of total emissions. This rate will continue to increase if no control measures are taken. There are indications that fossil fuels will continue to be the main source of power in the coming decades and that worldwide electricity demand will increase significantly, especially in developing nations. According to recent forecasts by the U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA), fossil fuel-derived power is likely to account for more than 60% of total world electricity by 2030. IEA also predicts that China will add 1.3 billion kW generation capacity in the coming 20 years, and that coal-fired power generation will account for more than 70% of this generation capacity.²
The development of safe and reliable carbon capture and storage (CCS) technology is one of the key ways to decrease carbon emissions, as proposed by the U.S. Department of Energy in 1999. The biggest obstacle to the application of CCS technology is the high cost of investment and, in particular, the high cost of energy consumption, which accounts for two-thirds of the total cost. Consequently, how to reduce the investment costs has become a noteworthy issue in the recent discussion of CCS technology. However, CO2 capture data from a long-running power plant have been absent—until now. Installed in 2008, the CO2 capture engineering demonstration designed by Xi’an Thermal Power Research Institute and built by Hua Neng Electric Group in China has been running successfully and trapping CO2 from the Beijing Gao Bei-dian and Shanghai Shi Dong-kou power plants for several years and, as a result, a large quantity of reliable data have been obtained and evaluated.

**CO2 Capture at the Beijing Gao Bei-dian Plant**
The Gao Bei-dian thermal power plant is located in the eastern suburb of Beijing and is funded and constructed by Beijing International Power Development & Investment Corporation and Hua Neng International Power Development Corporation. The coal-fired power plant is equipped with a selective catalytic reduction (SCR) system designed to remove nitrogen oxides (NOx) emissions, an electrostatic dust removal system, and a limestone-gypsum wet desulphurization system. The emission of CO2 from a single unit in this power plant is estimated at 1.3 million tons per year. The CCS demonstration system captures only 3,000 tons per year, 0.075% of total CO2 emissions, but nevertheless is the first engineering application in China.

**How It Works**
The decarbonization system is installed following the wet desulfurization system. The CO2 absorption
The system is made up of an absorption tower and a regeneration tower. The absorption and regeneration tower both measure more than 30m in height, and are 1.2m and 1.0m, respectively, in diameter. Flue gas from the fan flows into the absorption tower and contacts with the chemical absorbent of organic amine countercurrent to remove CO2. The flue gas then enters into the washing system. It is discharged from the top of the tower after being washed with water. The nearly saturated CO2 moves through the poor-rich fluid heat exchanger and goes into the boiler, which is connected to the regeneration tower at the bottom. In the boiling device, the fluid that is rich in CO2 is heated to 110°C by low-pressure vapor, it then returns to the regeneration tower. CO2 overflowing from the fluid goes through the condenser and gas-liquid separator. Water and monoethanolamine (MEA) volatilized from the CO2 is condensed and returned to the regeneration tower. At the same time, the extracted dry and pure CO2 is captured. The depleted fluid returns to the absorption tower and continues to work.

The gas absorption system costs approximately US$59,000, the regeneration system costs approximately US$76,000, and all the other equipment costs approximately US$26,000. The proportion of staff costs and system maintenance fees decrease rapidly as the system size increases. But operating costs will not dramatically change as the system increases; it is directly related to the capture performance of the technology. The proportion of operating costs of this system is shown in the graph at left.10

Steam consumption is approximately US$15.3/t CO2, which consumes the largest proportion in operation costs. Another major operation consumption is power. The pump power consumption is approximately 90kW·hr/t CO2, and if we add other power such as controlling and lighting, then the total power consumption is approximately 100kW·hr/t CO2 (or US$4.8/t CO2); the chemical absorbent solution costs approximately US$7.2/t CO2; and the remaining consumption costs approximately US$1.6/t CO2, which increases the overall cost of power by 29%.

CO2 Capture at the Shanghai Shi Dong-kou Plant
The Shanghai Shi Dong-kou power plant is located in the Baoshan District, a northern suburb of Shanghai on the south bank of Yangtze River. Two 600-MW supercritical coal-fired generating units are installed. Flue gas desulfurization and denitrification units are installed. Flue gas desulfurization and denitrification devices went to operation at the end of 2009. The CO2 recovery unit, with the designed capacity of 66,000 standard m³/hr recovering 12.5t of CO2 per hour, was put into operation with the main units simultaneously. The device operates 8,000 hours continuously each year under the rated capacity. This CO2 capture project is the largest of its kind in China, and the CO2 concentration trapped is higher than 99%. After refining, the concentration is greater than 99.9% to meet food grade standard and achieve resource reuse. The technology was developed by the Xi’an Thermal Power Research Institute, and it is especially suitable for the flue gas with low concentration and large flow.

The Basic Process
The basic process for CO2 capture from flue gas consists of three parts (see schematic on page 21): (1) the absorption tower at the center is supported by a cyclone separator, gas and water separator, and pressurization equipment; (2) the regeneration tower and reboiler are supplemented by a cooler, gas separator, and recovering system; and (3) between parts (1) and (2), there is an absorption
solution enriched with CO\textsubscript{2} gas, heat exchanger, and filtration system.

The temperature of the flue gas is approximately 48°C after desulfurization, which is the ideal absorption temperature for MEA. Generally, the flue gas is pressurized by blower into the CO\textsubscript{2} absorption tower directly, after dust removal and the desulfurization process. To avoid solution evaporation and amine loss, some pretreatment, such as cyclone separation or gas and water separation, should be done before the flue gas is carried into the CO\textsubscript{2} recovery system, since the wet flue-gas desulfurization will introduce a large quantity of free and saturated water, which makes it difficult to achieve water balance. In addition, the blowers are mainly used to overcome the pressure drop while gas goes through the separator or absorption tower.

In the absorption tower, the flue gas flows from the bottom while absorbent from the top, which contact by counter-current to remove CO\textsubscript{2}. Purified gas releases from the top. As the MEA has a higher vapor pressure, washing is usually done in the upper absorption tower to cut MEA vapor content in the gas in order to reduce the loss of MEA caused by flue gas emission. Washing water is recycled and supplied with deionized water as needed.

Fluid rich in CO\textsubscript{2} is pumped to the rich-poor solution heat exchanger to recover heat, and then it enters into the regeneration tower. The desorbed CO\textsubscript{2} and steam are then cooled together to remove water, so that CO\textsubscript{2} with a purity greater than 99.5% is captured. Rich liquid of nearly saturated CO\textsubscript{2} enters into the regeneration tower from the top by stripping. After stripping, the semi-lean solution goes into the boil to desorb further. The degassed CO\textsubscript{2} flows out of the regeneration tower from the bottom, then it goes through the rich-poor solution heat exchanger and poor fluid cooler, and the cooled liquid is recycled in the absorption tower.

To keep the solution clean, 10–15% is filtered through the activated carbon. This system sets an amine recovery heater to treat the degradation products. If necessary, part of the lean solution and sodium carbonate will be sent into the heater to recover the amine. The regeneration gas from the trapping zone goes into the refining area for further purification treatment.

The capital investment for this plant was approximately US$256 million. The operating costs of the decarbonization zone are approximately US$62/t CO\textsubscript{2}. In addition, the CO\textsubscript{2} purification costs are US$12/t CO\textsubscript{2}; the power unit costs are US$1.6/t CO\textsubscript{2}; and the human capital costs are US$6.4/t CO\textsubscript{2}. The total operating costs of this decarbonization project are approximately US$82/t CO\textsubscript{2}.

**An Important Role**

Though the scale of the carbon capture demonstration project at the Beijing Gao Bei-dian plant is small, it greatly promotes the development of CO\textsubscript{2} emission reduction efforts in China. The power plant in Shanghai plays an important role in carbon capture in China. In this system, the absorption and regeneration towers are the most expensive equipment, accounting for 50% of the investment. Therefore, it is important to develop new internal structure with more gas-liquid exchange capacity to reduce the size of the tower. At the same time, research on new absorbents with low-corrosion and high-absorption rates will also help reduce costs. In addition, the development of an absorbent with low-regeneration heat and to further recover of the low-grade heat also are the important routes on the path to reducing the costs of CO\textsubscript{2} capture in power plants. em

Further research on new absorbents with low-corrosion and high-absorption rates will help reduce costs.

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**References**

9. Huang, B. CO\textsubscript{2} Capture Technology in Coal-Fired Power Plant [D]; Xi’an Thermal Power Research Institute, 2008; 140-141.