Current Status of MHI CO$_2$ Capture Plant Technology and Commercial Experiences

2014 CO$_2$ Conference Week;
The 12$^{th}$ Annual (2014) EOR Carbon Management Workshop, TX
December 9$^{th}$, 2014

Mitsubishi Heavy Industries, LTD.
Takashi Kamijo
1. Introduction of KM CDR® Process

2. Application of KM CDR® Process to CO₂ EOR

3. Latest MHI CO₂ Capture Project

4. Summary
1. Introduction of KM CDR® Process
MHI CO₂ Capture Process: KM CDR® Process

Proprietary Technology by MHI & Kansai Electric Power Company (KEPCO)

Hindered Amine Solvent “KS-1™” & Proprietary equipment

Advantages

KS-1™ solvent
- High CO₂ Loading
- Negligible Corrosion
- Negligible Solvent Degradation

Process
- Low Utility & Solvent Consumption
- Easy operation & Maintenance
Advanced CO2 Capture Process – MHI’s Own Technology

- 90% of CO2 is recovered from the flue gas by contacting with KS-1™ solvent.
- The flue gas is cooled to a process desired temperature.
- The "CO2-rich solution" is pumped into the upper section of the stripper.
- CO2 is stripped from KS-1™ solvent in the Regenerator.
- The flue gas is fed into the bottom section of the absorber and passed upward through the packing material inside the tower.
MHI is a World leading LARGE-SCALE post combustion CO₂ capture technology licensor, with 11 commercial PCC plants in operation.
Commercial Experiences

1999
210 t/d Malaysia

2005
330 t/d Japan

2006
450 t/d India

CO₂ Recovery (CDR) Plant – IFFCO Phulpur Unit (India)

2006
450 t/d India

CO₂ Recovery (CDR) Plant – IFFCO Aonla Unit (India)

2009
450 t/d India

2009
450 t/d Bahrain

2010
400 t/d UAE

2010
240 t/d Vietnam

2011
340 t/d Pakistan

2012
450 t/d India

2014
500 t/d Qatar

2016
4,776 t/d U.S.A.
What is Amine Emission?

- Amine is contained in treated gas from Absorber and is one of VOC source.

- MHI discovered the first in the World in 2010 that SO$_3$ accelerates amine emission drastically.


- This is common phenomena among all amine CO$_2$ capture processes.
MHI Amine Emission Reduction Technology

Deep understanding of Amine emission phenomena through abundant R&D activities.

Already incorporated operation data and lesson learned from Commercial Plants into current Parish Unit 8 project design.

Proprietary Emission Reduction System (MHI Patent), including Proprietary Demister.
SO\textsubscript{3} in flue gas from power plant significantly increases amine emission from CO2 absorber outlet.

This will cause increase solvent consumption and VOC significantly.

MHI proprietary amine emission reduction system drastically reduce amine emission – VOC figures and solvent consumption

Applied for multiple patents and some were already granted

<table>
<thead>
<tr>
<th>Item</th>
<th>Before Modification</th>
<th>After Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsubscript{3} concentration at Quencher inlet [ppm]</td>
<td>2.1-2.7</td>
<td>2.3-3.6</td>
</tr>
<tr>
<td>Amine (KS-1) emission [ppm]</td>
<td>12 - 35</td>
<td>0.7 - 3</td>
</tr>
<tr>
<td>Solvent consumption</td>
<td>Base</td>
<td>1/4</td>
</tr>
</tbody>
</table>

Before modification

After modification
2. Application of KM CDR® Process to CO$_2$ EOR
CO₂ Purity

CO₂: App 99.95%

Impurity: Others are mostly nitrogen and trace O₂
3. Latest MHI CO₂ Capture Project
Southern Company Plant Barry

- Flue gas demister and outlet
- CO₂ absorber (lower) and Water wash (upper) column
- Solvent regeneration (“CO₂ stripper”) column
- CO₂ compression and dehydration unit
- Flue gas quench column
- Flue gas inlet

World’s First Integrated CCS plant from Coal-fired Power Plant to CO₂ injection
<Project Overview>

- CO₂ Capture and Compression
  - SCS/MHI collaboration with partners
  - KM-CDR® capture technology

- Transportation and Sequestration
  - DOE SECARB Phase III “Anthropogenic Test”
  - 12 mile CO₂ pipeline to Citronelle Dome

- World’s First CCS Project integrated with Amine-based Post Combustion Process and CO₂ Injection

<Operation Status>

- Gas In for CO₂ Capture Plant: June, 2011
- CO₂ injection started on August 20th, 2012
- 100,000 metric tons of CO₂ injection was achieved as of October 29th, 2013

<table>
<thead>
<tr>
<th>Items</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Operation Time *</td>
<td>hrs</td>
</tr>
<tr>
<td>12,400</td>
<td></td>
</tr>
<tr>
<td>Total Amount of Captured CO₂ *</td>
<td>metric tons</td>
</tr>
<tr>
<td>230,100</td>
<td></td>
</tr>
<tr>
<td>Total Amount of Injected CO₂ *</td>
<td>metric tons</td>
</tr>
<tr>
<td>115,500</td>
<td></td>
</tr>
</tbody>
</table>

*As of August 31st, 2014
Operation History

![Graph showing CO₂ captured and transported over time with specific events marked such as boiler off-line and injection begins on 8/20/12.](image-url)
Operation Reliability > 98%

Reliability calculation basis

\[
\text{Reliability} = \frac{\text{Operation hours}}{\text{Operation hours} + \text{Unexpected S/D period}}
\]

Remarks
*1) Operation hours does not contain commissioning period
*2) Unexpected S/D is defined as a period of outage by operation malfunction. Plant outage for test implementation purpose and test originated purpose is excluded
The world's largest CO₂ capture plant from an existing coal-fired power plant

- Project owner: NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation
- Location: NRG WA Parish Power Plant near Houston, TX.
- Flue gas source: 240MWe slipstream from an existing 650MW coal-fired boiler
- CO₂ concentration: 11.5%
- CO₂ capture capacity: 4,776 TPD
- CO₂ recovery ratio: 90%
- CO₂ Use: Enhanced Oil Recovery (EOR)
- Transport: 12 inch diameter pipeline, Approximately 81 miles
- Injection Site: West Ranch oil field in Jackson County, TX
- Operation Start: 4th Quarter, 2016
4. Summary
Summary

MHI can provide cost competitive and reliable CO2 capture plant from flue gas based on our abundant commercial experiences.

Southern Company’s Plant Barry 500 TPD CCS plant has successfully completed its 2nd year of operation.

MHI has started to construct the world largest CO2 capture and compression plant near Houston, Texas for NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation.

CO2 capture from flue gas can contribute to global warming issue and useful for CO2 EOR.
Appendix
Deployment of R&D Facilities for specific CO₂ capture testing.

More than 25 years R&D Experience

(A) R&D laboratories (MHI Technologies and Innovation Headquarters)
(B) 2.0 TPD Nanko Osaka pilot plant from 1991
(C) 1.0 TPD Hiroshima pilot plant
(D) 0.2 TPD mobile test unit
(E) Absorber 1 by 1 scale test plant in Mihara (400 MW equivalent)
(F) 10 TPD Matsushima pilot for testing coal fired flue gas
(G) 500 TPD Barry CCS demonstration plant in Alabama, (25MW equivalent)
### Summary of Coal-Fired Pilot & Demonstration Plants

- MHI conducted R&D at various stages of the test for coal-fired flue gas.
- 500 TPD demonstration plant integrated with coal-fired power plant and CO₂ injection started in June, 2011.
- The demonstration test results verified the high reliability of the KM-CDR® Process

<table>
<thead>
<tr>
<th>Location</th>
<th>Capacity</th>
<th>Client/Host</th>
<th>Flue gas source</th>
<th>Purpose</th>
<th>Start up</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A. SoCo Yates power station</td>
<td>0.2 MT/D</td>
<td>Mobile unit (Southern Company)</td>
<td>Coal fired boiler flue gas</td>
<td>R&amp;D</td>
<td>September 2010</td>
</tr>
<tr>
<td>Japan MHI R&amp;D Center</td>
<td>1 MT/D</td>
<td>-</td>
<td>Coal fired boiler flue gas</td>
<td>R&amp;D</td>
<td>April 1999</td>
</tr>
<tr>
<td>Japan Matsushima power station</td>
<td>10 MT/D</td>
<td>J - Power</td>
<td>Coal fired boiler flue gas</td>
<td>R&amp;D</td>
<td>July 2006</td>
</tr>
<tr>
<td>U.S.A. SoCo Barry power station</td>
<td>500 MT/D</td>
<td>Southern Company</td>
<td>Coal fired boiler flue gas</td>
<td>R&amp;D</td>
<td>June 2011</td>
</tr>
</tbody>
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## CO₂ Capture & Compression Test Items

<table>
<thead>
<tr>
<th>Item</th>
<th>Main Results</th>
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| **Initial Baseline Testing** | • Verified that actual utility and solvent consumption were lower than the design but within the expectation (CO₂ removal efficiency: 90%, CO₂ capture rate: 500MTPD).  
• Proven that KM-CDR® Process can follow the operation condition of CO₂ injection  
• Captured CO₂ quality is within the criteria of the pipeline and CO₂ injection site |
| **Emissions and Waste Stream Monitoring** | • Successfully demonstrated amine emission reduction technologies under the various SO₃ concentration condition (2013)  
• Measured total Volatile Organic Compound (VOC) emissions and verified that the commercial scale CO₂ capture plant using KM-CDR® Process will be acceptable |
| **Process Parametric Test and Performance Optimization** | • Verified operation performance under several controlled operating parameters changes (2011-2012)  
• Achieved 0.95 ton-steam/ton-CO₂ by optimizing steam consumption (2011) |
| **Dynamic Response Evaluation Test** | • Carried out continuous control testing to optimize the operation condition with self-developed dynamic simulator. The system successfully controlled the operation condition (Oct. 2013) |
| **Long Term Impurities Influence Test** | • Achieved 100,000 metric tons of CO₂ injection without any operational issues  
• Verified that the amine emission increased as a result of higher SO₃ loading (Oct. 2011)  
• Verified that the impurities were removed from the solvent by reclaiming operation (2012, 2013) |
Post-Combustion CO₂ capture process using MHI proprietary KS-1™ solvent
MHI developed the KM-CDR® process with Kansai Electric Power Co. since 1990

The flue gas is cooled to a process desired temperature.

90% of CO₂ is recovered from the flue gas by contacting with KS-1™ solvent

CO₂ is stripped from KS-1™ solvent in the Regenerator

MHI Energy Saving System

The flue gas is cooled to a process desired temperature.