New Energy Efficient Processes and Newly Developed Absorbents for Flue Gas CO$_2$ Capture

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17th-19th May 2011, Yas Hotel, Abu Dhabi, UAE
Outline

- Introduction and Background
- CO₂ recovery pilot plant (Nanko Power Station)
- Process Improvements
- Development of new absorbents
- Commercial CO₂ capture plants
- Summary
Introduction and Background

Kansai Electric Power Company (KEPCO) and Mitsubishi Heavy Industries, Ltd. (MHI) have been working together since 1990 and have developed an advanced CO₂ capture chemical absorption process – KM CDR Process™.
Location: Nanko Power Station, Osaka, Japan

Capacity: 2 metric ton/day

Feed Gas: Natural Gas Boiler

Initial Start-up: April 1991

- Installed at an operating thermal power plant
- Operating for 20 years (longest operation in the world)
- All process are demonstrated

Please come and visit!
**Process Improvement -1**

- **Energy saving process**: Stripper

Utilization of Lean solvent & Steam condensate heat
Addition of several Heat exchangers & Pumps

<table>
<thead>
<tr>
<th>Test Process at Nanko Pilot Plant</th>
<th>Close</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Process</td>
<td>Close</td>
<td>Open</td>
</tr>
<tr>
<td>Improved Process</td>
<td>Open</td>
<td>Close</td>
</tr>
</tbody>
</table>

Diagram description:
- Flue gas cooler
- Flue Gas Blower
- Absorber
- Treated Gas
- CO₂
- Heat Recovery & Solvent Regeneration
- Flue Gas
- Lean Solvent
- Reboiler
- 0.3 MPaG Steam
- Steam Condensate
Process Improvement -2

- **New Energy Efficient Process**: Increased CO$_2$ loading of rich amine -

The Process was confirmed through modification of the Nanko CO$_2$ capture pilot plant in 2009.
- Increased CO$_2$ loading of rich amine by reducing the absorber temperature
- Reduced absorbent heat loss by decreasing absorbent recirculation rate
- Reduced CO$_2$ reflux cooler heat loss by lowering the temperature at the top of the stripper

**Process Optimization**

- **New Energy Efficient Process**: Increased CO$_2$ loading of rich amine -

The Process equipment was further optimized and confirmed at the Nanko CO$_2$ capture pilot plant in 2010.
# Development of new absorbents

- Nanko CO2 capture pilot plant test results of newly developed absorbents

<table>
<thead>
<tr>
<th>Test absorbents</th>
<th>Test condition</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO2 concentration at plant inlet(%)</td>
<td>System configuration</td>
</tr>
<tr>
<td>KS-1™</td>
<td>10</td>
<td>①</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>①②</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>①②③</td>
</tr>
<tr>
<td>New absorbent 1 (yet to be officially named)</td>
<td>10</td>
<td>①</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>①②</td>
</tr>
<tr>
<td></td>
<td></td>
<td>①②③</td>
</tr>
<tr>
<td>New absorbent 2 (yet to be officially named)</td>
<td>10</td>
<td>①</td>
</tr>
<tr>
<td></td>
<td></td>
<td>①②③</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>①②③</td>
</tr>
</tbody>
</table>

Remarks) ① : Process Improvement-1  
② : Process Improvement-2  
③ : Process Optimization

The characteristics of this new absorbent, regarding corrosiveness and volatility, were confirmed through a series of recent laboratory tests.

Best Result in 2009 (=2.44MJ/kg–CO₂)  
Best Result in 2010 (=2.31MJ/kg–CO₂)
Map of MHI commercial CO₂ recovery plant locations

1. 1999 Malaysia (200 t/d)
2. 2005 Japan (330 t/d)
3. 2006 India (Aonla) (450 t/d)
4. 2006 India (Phulpur) (450 t/d)
5. 2009 India (Kakinada) (450 t/d)
6. 2009 Abu Dhabi (400 t/d)
7. 2010 Bahrain (450 t/d)
8. 2011 Pakistan (340 t/d)
9. 2010 Vietnam (240 t/d)
10. 2012 India (Vijaipur) (450 t/d)
Commercial CO₂ capture plants

- Commercial 400 tpd CO₂ recovery plants for FERTIL UAE -

**United Arab Emirates**

*Client*: Ruwais Fertilizer Industries (FERTIL)

CO₂ source: Natural gas boiler & steam reformer

*Start up*: December 2009

*Capacity*: 400 tpd

*Product*: Urea production

*Process*: Improved KM-CDR Process™

*Solvent*: KS-1™

*Status*: Highest Performing commercial CO₂ Capture Plant
1. The Kansai Electric Power (KEPCO) has developed energy efficient chemical absorbents and economical processes which aim to reduce the cost of CO$_2$ capture, in collaboration with Mitsubishi Heavy Industries (MHI).

2. This work has been ongoing since 1990, using several Japan based R&D facilities and a pilot plant, located at Nanko Power Station in Osaka (Japan), to verify improvements.

3. Ten (10) commercial CO$_2$ capture plants (capacity up to 450 tpd), using KS-1™ solvent, have been contracted worldwide (8 operational & 2 under construction).
Summary (2)

4. Process Improvement -1,-2 with process optimization and new solvents were developed and tested at Nanko pilot plant last year. CO₂ recovery and regeneration energy results:

   KS-1 solvent: 563kcal/kg CO₂ (= 2.36MJ/kg CO₂) 
   A ‘new’ solvent: 551kcal/kg CO₂ (= 2.31MJ/kg CO₂)

5. Improvements will be applied to all commercial CO₂ capture plants and for coal fired flue gas applications, designed and delivered by MHI.
Thank you
Any questions?
Non-distributed documents
Development of KS-1™

Reduction of CO₂ recovery energy consumption by 20 to 25%

The energy required for regeneration of the KS-1 was about 20-25% less than MEA, by the conventional MHI process.
Realize the absorber heat optimization with the new energy saving process in the wide range of the commercial operation with KS-1™ absorbent.
Development of new absorbents

- Energy calculation simulation for CO$_2$ recovery -

Laboratory test data

Vapor–liquid equilibrium

Reaction rate

Reaction heat

Related to sensitive heat & latent heat

Absorption

Related to CO$_2$ Recovery rate

Related to reaction heat for CO$_2$

CO$_2$ recovery energy
Future plan
- Application to commercial CO$_2$ capture plant -

1. These technology improvements have been proven through tests at the Nanko CO$_2$ capture pilot plant.

2. These improvements will be applied to future commercial CO$_2$ capture plants, to be designed and delivered by MHI. (For example, Abu Dhabi CO$_2$ capture plant uses Process Improvement-1.)

3. It is expected that coal fired flue gas with higher concentrations of CO$_2$ will lead to a further reductions in CO$_2$ capture and regeneration energy requirements. Therefore, for coal fired flue gas conditions, the steam consumption will be even less then 563 or 551 kcal/kg CO$_2$ (= 2.36 or 2.31 MJ/kg CO$_2$).
Evaluation of vapour-liquid equilibrium (Test Apparatus)
Evaluation of vapour-liquid equilibrium (CO₂ Loading of Absorbent)

<table>
<thead>
<tr>
<th>Liquid component</th>
<th>CO₂ loading</th>
<th>Effective CO₂ loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absorber condition</td>
<td>Stripper condition</td>
</tr>
<tr>
<td>MEA</td>
<td>0.606</td>
<td>0.204</td>
</tr>
<tr>
<td>KS-1</td>
<td>0.801</td>
<td>0.231</td>
</tr>
<tr>
<td>HA</td>
<td>0.755</td>
<td>0.158</td>
</tr>
<tr>
<td>DEA</td>
<td>0.614</td>
<td>0.137</td>
</tr>
</tbody>
</table>

CO₂ loading : (mol CO₂/mol amine)

Absorber condition: Temperature 40°C, CO₂ partial pressure 9.8 kPA
Stripper condition: Temperature 120°C, CO₂ partial pressure 9.8 kPA
Evaluation of kinetics (Test Apparatus)

Gas phase stirrer

Liquid phase stirrer

Dimensions:
- Gas phase stirrer: 85, 60
- Liquid phase stirrer: 50, 20, 115
- Total height: 230
Evaluation of kinetics
(Absorption rate of CO₂ into aqueous solutions)
## Specification of Nanko Pilot Plant

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Flue Gas Source</td>
<td>Natural gas fired boiler</td>
</tr>
<tr>
<td>Flue Gas Flow Rate</td>
<td>555 Nm$^3$/hr</td>
</tr>
<tr>
<td>Flue Gas Composition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N_2$</td>
</tr>
<tr>
<td></td>
<td>$CO_2$</td>
</tr>
<tr>
<td></td>
<td>$O_2$</td>
</tr>
<tr>
<td></td>
<td>$H_2O$</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>80.4 vol.%-Dry</td>
</tr>
<tr>
<td></td>
<td>10.3 vol.%-Dry</td>
</tr>
<tr>
<td></td>
<td>9.3 vol.%-Dry</td>
</tr>
<tr>
<td></td>
<td>5.9 vol.%</td>
</tr>
<tr>
<td></td>
<td>100 vol.%</td>
</tr>
<tr>
<td>CO$_2$ Capacity</td>
<td>2.0 metric ton/day</td>
</tr>
<tr>
<td>CO$_2$ Recovery Rate</td>
<td>90 %</td>
</tr>
</tbody>
</table>
Lower energy regeneration system
- Feature -

- Reduction of steam requirement for Regeneration
  - Improve heat recovery around CO₂ stripper
    - Utilize heat of Lean solvent & Steam Condensate
    - Several additional Heat exchanger & Pumps
  - Lean Solvent Utilization          10%
  - Steam Condensate Utilization 5%
  - Total Steam Reduction               15%