Novel Absorbents for CO$_2$ Capture
From Gas Stream

Copenhagen, Denmark
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RITE
Research Institute of Innovative Technology for the Earth
Kyoto, Japan  (URL: http://www.rite.or.jp)
Today’s Contents

1. Outline of COCS project

2. Development of new absorbents
   1) Ideas to find new absorbents
   2) Fundamental research
   3) Evaluation of new absorbents
1. Outline of COCS Project

- **COCS Project:** (Cost-Saving CO₂ Capture System)
  - Financial Support by METI
  - Collaboration with 3-Japanese Companies

- **Target of COCS Project**
  
  CO₂ Separation by Chemical Absorption and Storage
  
  - Reduce CO₂ Capture Cost by less than 1/2
Concepts of COCS Project

Steel plant, etc.

Chemical absorption

- High CO\textsubscript{2} conc.
- New absorbents
- Utilization of low-grade waste heat

Reduction of Capture Cost
Objectives of COCS Project

1. Develop new absorbents and absorption system for lower-energy CO$_2$ capture

2. Evaluate new CO$_2$ capture system for steel plant
   1) Utilization of low-grade waste heat
   2) Removal of CO$_2$ from high CO$_2$ concentration discharged gas by bench plant study
### Schedule of COCS Project

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<tr>
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<th>’04</th>
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<td>- New absorbents</td>
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<td>- Utilization of waste heat</td>
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<td>- Bench plant study</td>
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Collaboration with 3 Japanese Companies

(RITE) NSC MHI KEPCO - New absorbents - New absorbents - CO2 capture system - CO2 capture system - Utilization of waste heat

- New absorbents

NSC - CO2 capture system - Utilization of waste heat

MHI - CO2 capture system

KEPCO - New absorbents
Next Topics

Today’s Contents

1. Outline of COCS project

2. Development of new absorbents
   1) Ideas to find new absorbents
   2) Fundamental research
   3) Evaluation of new absorbents
1) Ideas to Find New Absorbents

Desirable characteristics:

- Low energy use for CO$_2$ capture
- High absorption/desorption rate
- High capacity of CO$_2$ capture
- Low volatility and high stability
Keys to Exploring New Absorbents (1)

1. Low energy use for CO$_2$ capture
2. High absorption/desorption rate

(1) Secondary/Tertiary amine  (2) Effect of steric hindrance
Keys to Exploring New Absorbents (2)

1. High capacity of CO$_2$ capture
2. Low volatility and high stability

(1) High density of amino group  (2) Position and number of OH-
2) Fundamental Researches on New Absorbents

(First stage) - Screening
- Vapor-liquid equilibrium
- Heat of absorption

(Second stage) - Corrosion
- Kinetics
- Volatility
etc.
Screening

Gas supply

\[ \text{CO}_2 \text{ 20\%} \]
\[ \text{N}_2 \text{ 80\%} \]
Flow rate
700 ml/min

After 60 min

Absorbent : 50 ml
Absorption time : 60 min

Photo. Screening apparatus with six glass reactors
Results of Screening Tests

Graph showing the CO₂ loading (g·CO₂/L) over time (min) for different solvents:
- 30% MEA
- 30% MDEA
- Solvent A
- Solvent B

The graph displays the CO₂ loading at various time points, indicating the efficiency of each solvent in capturing CO₂.
**Vapor-liquid Equilibrium**

**CO₂/N₂ gas:** 20/80%

**Gas flow rate:** 700 ml/min

**Absorbent:** 700 ml

**Temperature:** 40 - 120 °C

**Pressure:** 0.1 - 1 MPa

**CO₂ conc. in liquid phase:**

TOC (Total Organic Carbon analyzer)
Results of Vapor-liquid Equilibrium test

CO₂ partial pressure (kPa)

CO₂ loading (mol CO₂/mol absorbent)

30% MEA

Solvent A

30% MEA

Solvent B

120 100 40°C
Heat of Absorption

Measurements:

- Differential reaction calorimeter
- Semi-batch process
- 250ml reactor

(SETARAM DRC)
Experimental Results of Heat of Absorption

Heat of absorption [kJ/mol·CO₂]
Theoretical study:

- Analysis of reaction energy of the following reaction as heat of absorption

\[ \text{Amine} + CO_2 + H_2O \rightarrow \text{Protonated Cation} + HCO_3^- \]

- Semi-empirical molecular orbital model, PM3 (Spartan ’04 for Windows)

- Solvation energy
  Cramer/Truhlar SM5.4 model
Results of Heat of Absorption

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Heat of absorption [kJ/mol-CO₂]</th>
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<tbody>
<tr>
<td>MEA</td>
<td>80</td>
</tr>
<tr>
<td>AMP</td>
<td>60</td>
</tr>
<tr>
<td>EAE</td>
<td>40</td>
</tr>
<tr>
<td>DEA</td>
<td>20</td>
</tr>
<tr>
<td>DMAE</td>
<td>0</td>
</tr>
<tr>
<td>MDEA</td>
<td>-20</td>
</tr>
<tr>
<td>TEA</td>
<td>-40</td>
</tr>
<tr>
<td>PZ</td>
<td>-60</td>
</tr>
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</table>

Exp.

Cal.

Solvent A

Solvent B
Direction for Developing New Absorbents

[Graph showing the relationship between heat of absorption (kJ/mol) and absorption rate (g CO₂/min/L) for different solvents.]

- **Target**
- **Absorption rate (g CO₂/min/L)**
- **Heat of absorption (kJ/mol CO₂)**

Legend:
- MEA
- DEA
- MDEA
- Solvent A
- Solvent B
3) Evaluation of Absorbents in the First Stage

(First stage) - Screening
- Vapor-liquid equilibrium
- Heat of absorption

(Extensive research for absorbent evaluation)
- Estimation of CO$_2$ capture energy
Estimation of CO\textsubscript{2} Capture Energy

CO\textsubscript{2} capture energy:

\[ Q = Q_R + Q_H + Q_V \]

Heat consumption in stripper:

1. Reaction heat of stripping CO\textsubscript{2}
   \[ Q_R = f1(m_{top}, m_{bottom}, H_R) \]
2. Sensible heat of absorbent
   \[ Q_H = W_S \cdot C_p (T_{top} - T_{bottom}) \]
3. Latent heat of vapor at stripper top
   \[ Q_V = f2(W_{H_{2}O}, H_{H_{2}O}, T_{top}) \]

\[ m : \text{CO}_2 \text{ loading of absorbent} \]
\[ [\text{mol}_\text{CO}_2/\text{mol}_\text{absorbent}] \]
Calculation under Equilibrium Condition

Fig. Liquid-vapor equilibrium of Solvent A
## Analytical Data

<table>
<thead>
<tr>
<th>Absorbent</th>
<th>Solvent A</th>
<th>MEA30%</th>
</tr>
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<tbody>
<tr>
<td>Heat of absorption ( H_R ) [kJ/mol-CO(_2)]</td>
<td>84</td>
<td>91</td>
</tr>
<tr>
<td>( m_0 ) [mol_CO(_2)/mol_absorbent]</td>
<td>0.64</td>
<td>0.50</td>
</tr>
<tr>
<td>Total gas pressure in stripper ( P_t ) [kPa]</td>
<td>186</td>
<td>186</td>
</tr>
<tr>
<td>Temp. at stripper top ( T_{\text{top}} ) [°C]</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Temp. at stripper bottom ( T_{\text{bottom}} ) [°C]</td>
<td>110</td>
<td>120</td>
</tr>
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</table>
Potential Performance of Absorbents

Minimum CO$_2$ capture energy [MJ/kg CO$_2$]

- MEA: 3.9
- Solvent A: 2.8

Legend:
- Green: Latent heat of Vapor
- Yellow: Sensible heat of absorbent
- Pink: Reaction
Bench Plant (2kg CO₂/h) Study

Bench-scale plant facility with mixed gas (KEPCO)

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<thead>
<tr>
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<th>Diameter (m)</th>
<th>Height (m)</th>
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<tbody>
<tr>
<td>Absorber:</td>
<td>0.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Stripper:</td>
<td>0.1</td>
<td>1.8</td>
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</table>

Experimental condition

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<tr>
<th></th>
<th>Gas volume</th>
<th>L/G</th>
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<tr>
<td>Gas volume</td>
<td>6.5 m³/h</td>
<td>3.0 L/m³</td>
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CO₂ capture energy [MJ/kg CO₂]

<table>
<thead>
<tr>
<th></th>
<th>Solvent A</th>
<th>30% MEA</th>
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<tr>
<td>Experiment</td>
<td>3.0</td>
<td>4.0</td>
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<tr>
<td>Calculation</td>
<td>2.8</td>
<td>3.9</td>
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**Summary**

**Results:**

1) Definition of the target absorbent.
2) Development of the new absorbents with higher-performance than MEA.

**Future Work:**

- Develop higher-performance absorbents.
- Utilize low-grade waste heat.
- Study on process research with bench plant facility.
Acknowledgement

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- Nippon Steel Co.
- Mitsubishi Heavy Industries, Ltd.
- The Kansai Electric Power Co., Inc.