## *Recent technology development of KS-1 $CO_2$ recovery process*

Takashi Kamijo, Nobuo Imai, Masaki Iijima,
Toru Takashina, Hiroshi Tanaka,

Mitsubishi Heavy Industries, ltd.

**May, 2004**

## Outline

- Background of KS-1 $CO_2$ recovery process
- Highlight operating results from the commercial plant
- Recent technology development
- Low energy regeneration system
- Comparison of improved KS-1 process with conventional technologies
- Summary

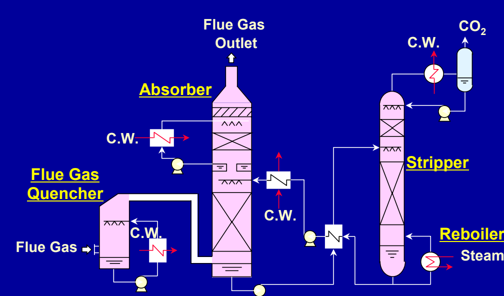
## Background of KS-1 $CO_2$ recovery process

### Features - KS-1 Technology

- Mitsubishi Heavy Industries, ltd (MHI) & Kansai Electric Power Company (KEPCO) 's proprietary Flue gas $CO_2$ capturing technology
- Hindered Amine Solvent "KS-1" with the special proprietary equipment
- Advantages
  - Low Energy Consumption
  - High $CO_2$ Loading
  - Low Corrosion
  - Low Degradation
  - Low Amine Loss

## Background of KS-1 $CO_2$ recovery process

### Typical Process Flow Diagram - KS-1 Technology




## Highlight operating results from the commercial plant (1/2)

- Client : Petronas Fertilizer (Keda) Sdn. Bhd.
- Location : Kedah Darul Aman, Malaysia
- Flue Gas Source : Steam Reformer Flue Gas

| Comp. | vol.% |
|---|---|
| $N_2$ | 67.79 |
| $O_2$ | 0.85 |
| $H_2O$ | 22.28 |
| $CO_2$ | 8.08 |
| Ar | 1.00 |
| SOx | 0.85 ppmv |
| NOx | 160 ppmv |

- Capacity : $CO_2$ Recovery 210 Tons/day Max
- $CO_2$ Recovery % : 90%
- Solvent : KS-1 Solvent
- Use of CO2 : Urea Production
- Start of Operation : October 1999
- Project Scope : Turnkey Lumpsum

## Highlight operating results from the commercial plant (2/2)

### Operating Result

| | | |
|---|---|---|
| $CO_2$ Capturing | : | Max. 210 Metric ton/day |
| $CO_2$ purity | : | 99.95 % vol.dry |
| Utility requirement | : | |
| Steam | | 1.5 ton/ton-$CO_2$ |
| Electricity | | 18 kWh/ton-$CO_2$ |
| Cooling water | | 159 m3/ton-$CO_2$ |
| Chemical requirement | : | |
| Solvent | | 0.4-0.5 kg/ton-$CO_2$ |

## ➢ Recent technology development

- $CO_2$ absorption & regeneration model
- Gas & Liquid flow simulation
- Design consideration for a large single train $CO_2$ recovery plant
- Less utility consumption by improving heat recovery
- Less solvent consumption by refining absorber
- Tower packing optimization for compact absorber
- $CO_2$ recovery from high sulfur coal firing flue gas

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## ■ Rigorous Model for $CO_2$ absorber & Stripper

- VLE : Bench Scale Test result of KS-1 solvent
- Mass & Heat transfer
- Assumption : Steady state
  Bulk Temperature = Interface Temperature
  No axial dispersion

## ■ Simulator

Input : $L_{IN}$, $G_{IN}$, $T_{L,IN}$, $T_{G,IN}$,
G&L Inlet composition

Output : $L_{OUT}$, $G_{OUT}$, $T_{L,OUT}$, $T_{G,OUT}$,
G&L Outlet composition

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## Differential Equation

**- Material Balance**

All components : $-\frac{d}{dz}(\rho_L u_L) = mcMc + mwMw$ $\quad \frac{d}{dz}(\rho_G u_G) = -mc - mw$

CO2 : $-\frac{d}{dz}(\rho_L y_c u_L) = mcMc$ $\quad \frac{d}{dz}(\rho_G x_c u_G) = -mc$

H2O : $-\frac{d}{dz}(\rho_L y_W u_L) = mwMw$ $\quad \frac{d}{dz}(\rho_G x_w u_G) = -mw$

**- Heat Balance**

- Gas Phase $\quad \frac{d}{dz}(\rho_G C_G T_G u_G) = Q_R + Q_W + Q_{GL}$
- Liquid Phase $\quad -\frac{d}{dz}(\rho_L C_L T_L u_L) = -Q_{GL}$

**- Mass Transfer**

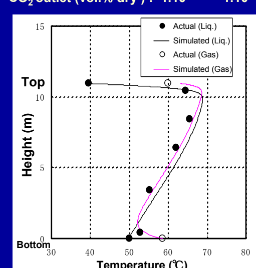
$$m_C = K_{GC} a (p_C - p_C^*)$$

$K_{GC}$: Mass Transfer Coefficient

$p_C^*$: Vapor – Liquid Equilibrium

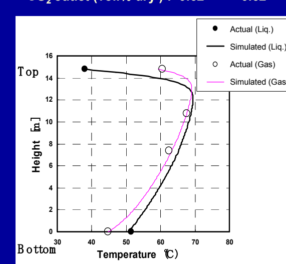
## ■ Simulator results vs. actual operating data

| | Actual | Simulation |
|---|---|---|
| $CO_2$ inlet (vol.% dry) : | 10.2 | (Input) |
| $CO_2$ outlet (vol.% dry) : | 1.10 | 1.10 |




Nanko Pilot Test

| | Actual | Simulation |
|---|---|---|
| $CO_2$ inlet (vol.% dry) : | 9.1 | (Input) |
| $CO_2$ outlet (vol.% dry) : | 0.62 | 0.62 |




Malaysia Commercial Plant

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## ■ Design consideration for a large single train $CO_2$ recovery plant

- CFD Technology
- Distribution Test by 1mx1m Rectangular Tower
- Determine operating condition with effective Gas/Liquid contact

## ■ Result

Large scale $CO_2$ Absorber for 5,000-10,000 Metric ton/day capacity can be realized.

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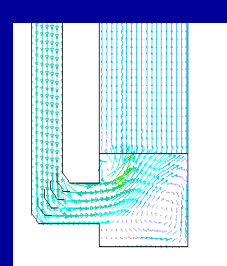
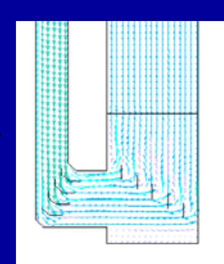
## ■ CFD results for Large scale $CO_2$ Rectangular Absorber



Without Absorber inlet guide vane



With Absorber inlet guide vane

Side View of Absorber

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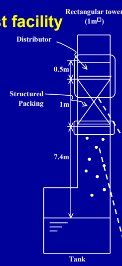
## ■ Rectangular Tower Test in MHI R&D center

Test facility



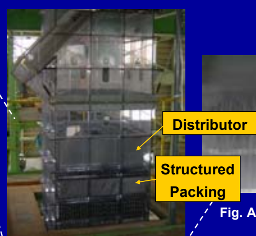




Fig. Outside view

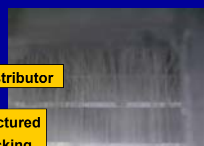


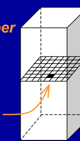
Fig. Appearance of liquid flow below distributor (Liquid flow rate $17 m^3/m^2 \cdot h$)

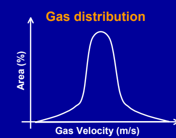
<Test condition>

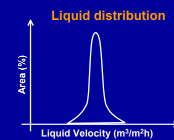
| | |
|---|---|
| Fluid | water |
| Temperature | 30°C |
| Gas velocity | 1.4~5m/s |
| Liquid velocity | $11 \sim 17 m^3/m^2 \cdot h$ |

## ■ Determine operating condition with effective Gas/Liquid contact

$CO_2$ absorption rate $\eta = \int \eta(A)dA$




## ■ Less Utility Consumption

- Less steam and cooling water consumption (15% steam reduction )
- Lower Flue Gas Blower Power by Structured Packing
- Define Optimum Operating Condition by rigorous simulator
  - Lean & Rich loading
  - Packing selection & height
  - Solvent circulation rate
- Integrated heat recovery system with the process of flue gas source or $CO_2$ compression system, etc.

## ■ Less solvent consumption by refining absorber

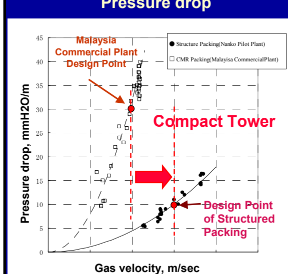
- Installing proprietary device in top of $CO_2$ Absorber to wash and remove amine mist

| | Before | | After |
|---|---|---|---|
| Solvent loss | 0.45 kg/T-$CO_2$ | → | 0.35 kg/T-$CO_2$ |
| Condition | Flue gas<br>$CO_2$ 8 % dry<br>SOx 1.5 ppmv<br>NOx 140 ppmv | | |

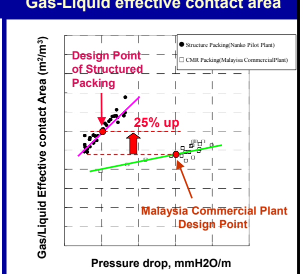
## ■ Tower Packing Optimization

CMR packing vs. Structured packing

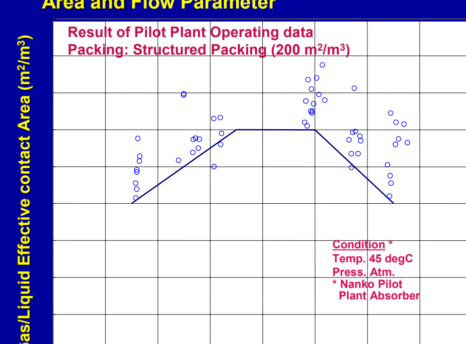
Pressure drop




Gas-Liquid effective contact area




## ■ Relationship between Gas/Liquid Effective contact Area and Flow Parameter




Flow Parameter,
Flooding Approach = L/G*(Density,G/ Density,L)^0.5

## Low energy regeneration system

- Improve heat recovery around $CO_2$ stripper
  - Utilize heat of Lean solvent & Steam Condensate from from Stripper Reboiler
  - Hot Lean Solvent and Steam Condensate heat up intermediary stage of $CO_2$ stripper
  - Addition several Heat exchanger & Pumps compared with base flow scheme.

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## Comparison of improved KS-1 process with conventional technologies

➢ Case study result for 3,000 Metric ton/day $CO_2$ recovery plant

| | Conventional | Advanced |
|---|---|---|
| Solvent | KS-1 | → |
| Process Flow | Base | Improved heat recovery around CO2 stripper |
| Utility consumption | | |
| Steam | Base | Base x 0.86 |
| Electricity | Base | Base x 1.10 |
| Cooling Water | Base | Base x 0.91 |
| Chemical consumption | | |
| Solvent loss | 0.45 kg/T-$CO_2$ | 0.35 kg/T-$CO_2$ |
| Condition | Flue gas, $CO_2$ 8 % dry<br>SOx 1.5 ppmv<br>NOx 140 ppmv | → |

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## ➢ Summary

- KS-1 technology revealing best performance in Malaysia commercial plant among any other amine based flue gas $CO_2$ recovery processes
- MHI's recent technology development results in better performance than conventional KS-1 process
- Large Single train $CO_2$ recovery Plant capacity of 5,000-10,000 Metric ton/day can be realized
- Solvent loss is reduced further by installing proprietary device in top of $CO_2$ Absorber
- Structured Packing enable compact Tower and utility reduction
- Improved heat recovery around $CO_2$ stripper results in 14 % reduction of steam requirements

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