A Novel Vacuum Deaerator for Water using Higee Technology

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Definitions of PI

*Colin Ramshaw’s definition (1983):*  
Process Intensification (PI) is exclusively in term of the reduction in plant or equipment size.

*21st century’s definition:*  
Process Intensification comprises novel equipment, processing techniques and process development methods that compared to conventional ones, offer substantial improvements in chemical manufacturing and processing.
History of Process Intensification (PI)

- Word Intensive originated somewhere in 15 AD;
- In scientific literature term PI started to appear in mid 1960-70;
- While in Chemical Engineering discipline it came in 1983 by Colin Ramshaw.

Existing Research Centers for PI

- DUT with DSM in Holland working on structured reactors;
- DUT investigating in centrifugal adsorption technology;
- France universities are working in compact heat exchanger equipments;
- Germany is researching on micro technology;
- BU in China, working in the area of HIGEE.
Benefits From PI

- **Cheaper Processes**
  - Lower operating costs
  - Reduced material usage

- **Smaller Equipment/Plant**
  - Reduced footprint
  - Increased efficiency

- **Enhancement in Safety**
  - Smaller is safer
  - Less inventories required
  - Better control
  - Less hold-ups

- **Company Image**
  - Sustainable development
  - Safe
  - Environment friendly

- **Lower Costs**
  - Land costs
  - Construction material costs
  - Raw materials costs
  - Utilities costs
  - Waste processing costs
Elements of Process Intensification

Process Intensification

Equipment

- Reactors
  - Spinning Disc reactor
  - Static mixer reactor
  - Monolithic reactor
  - Micro reactor
- Non-reactive Equipments
  - Static mixer
  - Compact heat exchanger
  - Rotating packed bed
  - Centrifugal adsorber
- Multifunctional Reactors
  - Heat integrator
  - Reactive separations
  - Fuel cells
  - Reactive extrusion
- Hybrid Separations
  - Membrane adsorption
  - Membrane distillation
  - Membrane absorption
  - Membrane chromatography
- Alternative Energy sources
  - Centrifugal fields
  - Solar energy
  - Microwaves
  - Plasma technology
- Other Methods
  - Supercritical fluids
  - Process synthesis
Rotating Packed bed (HiGee)

- Ramshaw and Mallinson (1981) developed the rotating packed bed (RPB);
- Counter-current gas-liquid contact is possible in an RPB;
- Centrifugal force in the RPB plays the same role as gravitational force in the conventional packed bed.

**Means of Intensification**

- Enhancement in Throughput;
- Enhancement in Mass Transfer Rate;
- Enhancement in Interfacial Area;
- Reduction in Residence Time.

(a) horizontal axis RPB

(b) vertical axis RPB.
How HiGee Works

Liquid Inlet

Gas inlet

Gas Outlet

Rotor

Rotating Shaft

Liquid Outlet
Type of Rotor Design

- Rotating Packed Bed
  - Single block packing Design
  - Split-packing design
  - Blade-packing design

- Rotating Zigzag Bed
Benefits of RPB

- Smaller size (20-50 times) and low weight of the RPB;
- Plant retrofitting, when the available floor area is limited or restriction on increasing the height of an existing column;
- Off-shore applications;
- On-site applications because unit can be transported easily;
- Reduction in capital cost;
- Short response time of RPB makes process control easier;
- Low liquid holdup in the Higee reduces the inventory requirements.
1. HOCl Production

Reaction:

\[ \text{Cl}_2 (g) + \text{NaOH} (l) = \text{NaCl} (l) + \text{HOCl} (l) \]  
(target product, fast reaction)

\[ 2\text{HOCl} (l) + 2\text{NaOH}(l) = \text{NaClO} (l) + \text{NaCl} + \text{H}_2\text{O} \]  
(side reaction, fast)

Benefit:

- HOCl yield increased by 10%
- Equipment investment saved by 70%
- \text{Cl}_2 \text{ recycle volume reduced by 50%}
2. Deoxygenation of oilfield feeding water

Conventional Technology: Vacuum Packed Tower

<table>
<thead>
<tr>
<th></th>
<th>Vacuum deoxygenation</th>
<th>Higee deoxygenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen in water supply</td>
<td>6~12</td>
<td>6~12</td>
</tr>
<tr>
<td>Oxygen in water after treatment</td>
<td>200<del>800ppb (single tower) 50</del>200ppb (two towers in series)</td>
<td>50ppb</td>
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<tr>
<td>Ground space</td>
<td>1</td>
<td>0.4</td>
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<tr>
<td>Land requirement</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Equipment weight</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Equipment height</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>Investment</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1</td>
<td>&lt;1</td>
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</tbody>
</table>
3. Desulfurization

Design data basis
(Fujiang Petroleum Refinery Co.)

- Gas to be treated:
  feeding rate: 11 t/h, $t = 40^\circ C$, $p = 1.1$ Mpa.
  Composition of dry gas: $H_2S \leq 2.27\% \ CO_2 \leq 3.72\%$

- Absorption solution - recycle deficient amine solution:
  Composition: $H_2S \leq 1.0\% \ CO_2 \leq 0.5\%$
  Amine solution flow rate: 13-16 t/h, $t = 40^\circ C$, $p = 1.1$ Mpa.

- Requirement: Gas after desulfurization:
  $H_2S \leq 20\text{mg/NM}^3$
Other Commercial Applications

- A high pressure Higee operated for selective removal of hydrogen sulfide at the EL PASO Natural Gas Co., New Mexico (Fowler, 1989).
- Chevron and Statoil (Norway) operated Higee for bulk removal of carbon dioxide and dehydration of natural gas at the Chevron plant (Fowler, 1989).

Application to fertilizer plant.

Benefit: absorption solution recycle volume reduced by 50%
Potential Applications

- **Absorption**
  - H$_2$S removal from sour gas by amines;
  - CO$_2$ removal from natural gas, power generation plant, coal gasification, synthesis gas production, oil refineries and hydrogen manufacturing;
  - SO$_2$ removal from flue gases;
  - Deaeration of water;
  - Moisture removal from natural gas.

- **Distillation**
  - Rotating zigzag bed (RZB) can be use for different distillation system;
  - RZB can be use in place of divided wall column for multi-component system;

- **Stripping**
  - RPB can be used as solid catalyzed reactive Higee stripper (SCRHS);
  - RPB can be used as stripper in process industry.

- **Liquid-Liquid Extraction**
A Novel Vacuum Deaerator for Water using Higee Technology
Design basis

- BPCL R&D and EIL R&D has planed to setup a pilot plant of Higee Vacuum Deaerator at BPCL R&D Centre Greater Noida.
- The pilot plant is designed to process 2 ton/hr of water.
- Feed water will have Desorbed oxygen (DO) concentration of 7-8 ppm.
- DO concentration of process water will be 10 -30 ppb.
- Performance of the Higee Vacuum Deaerator will be govern by several parameters such as feed water flow rate, rotor speed, degree of vacuum applied and packing type.
Basic Flow Diagram

Higee Inert Gas Stripping Deaerator

Higee Vacuum Deaerator

Water tank

DO Analyzer

Rotameter

Desorbed $O_2$ + $N_2$

Higee unit

DO Analyzer

Vacuum Pump

$N_2$ (Optional)

Stripped Water

Desorbed $O_2$

Delivering Excellence through People
Rotor Design

Liquid

Gas
<table>
<thead>
<tr>
<th>Throughput (L)</th>
<th>Design Parameter</th>
<th>RPM = 600</th>
<th>RPM = 800</th>
<th>RPM = 1000</th>
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<tbody>
<tr>
<td>2 ton/hr</td>
<td>Inner radius $r_i$ (cm)</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>2 ton/hr</td>
<td>Inner radius $r_o$ (cm)</td>
<td>23.5</td>
<td>25</td>
<td>26.5</td>
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<td>2 ton/hr</td>
<td>Width of rotor $h$ (cm)</td>
<td>3.5</td>
<td>2.2</td>
<td>1.5</td>
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<tr>
<td>2 ton/hr</td>
<td>$r_i - r_o$ (cm)</td>
<td>18.5</td>
<td>20</td>
<td>21.5</td>
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<td>2 ton/hr</td>
<td>Power (kW)</td>
<td>1.4</td>
<td>1.5</td>
<td>1.7</td>
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<tr>
<td>2 ton/hr</td>
<td>Packing Volume (m$^3$)</td>
<td>0.0058</td>
<td>0.0041</td>
<td>0.0032</td>
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<tr>
<td>10 ton/hr</td>
<td>Inner radius $r_i$ (cm)</td>
<td>9</td>
<td>9</td>
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</tr>
<tr>
<td>10 ton/hr</td>
<td>Inner radius $r_o$ (cm)</td>
<td>32.3</td>
<td>34.5</td>
<td>36.3</td>
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<tr>
<td>10 ton/hr</td>
<td>Width of rotor $h$ (cm)</td>
<td>5.8</td>
<td>3.6</td>
<td>2.4</td>
</tr>
<tr>
<td>10 ton/hr</td>
<td>$r_i - r_o$ (cm)</td>
<td>23.3</td>
<td>25.5</td>
<td>27.3</td>
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<tr>
<td>10 ton/hr</td>
<td>Power (kW)</td>
<td>2.5</td>
<td>3.75</td>
<td>5.62</td>
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<tr>
<td>10 ton/hr</td>
<td>Packing Volume (m$^3$)</td>
<td>0.0175</td>
<td>0.0125</td>
<td>0.0093</td>
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</tbody>
</table>
P&ID of Higee Vacuum Deaerator Setup

1. Higee Stripper Unit
   - High specific surface area packing (wire mesh)
   - Electric motor
   - Liquid distributor
   - Casing
   - Rotor

2. Desorbed Oxygen Analyzer
   - At liquid inlet
   - At liquid outlet
   - At water tank

3. Pumps
   - Feed pump
   - Vacuum pump

4. Flow Meter
   - Liquid rotameter
   - Gas rotameter

5. Storage tanks

6. Flow Valves

7. Pressure Gauges

8. Temperature Sensors

9. Level Indicators

10. Electrical Panel
Advantages of Higee Vacuum Deaerator

- Height of vacuum deaeration unit can be reduced to 1 m from 10 m while column diameter can be reduced 1.5 m from 3 m.
- 40-50 times volume reduction can be achieved by the Higee Vacuum deaerator.
- Higee vacuum deaeration result in very light weight equipment compared to the conventional column.
- 10-30 ppb DO concentration can be achieved in single equipment, where as conventionally chemical dosing is required.
- Significant reduction in capital cost can be achieved compared to the conventional towers.
- Easy to transport because of its small size and best available option for offshore applications.
- Safer and easy to operate than convention towers because of very less inventories.
- 20-30% more energy efficient than conventional columns.
Experimental Work Plan

To study and optimize the performance of Higee Vacuum Deaerator unit, following test runs have been planned.

- Performance study by varying water flow rate at constant rotor speed, degree of vacuum and packing type.
- Performance study by varying rotor speed at constant water flow rate, degree of vacuum and packing type.
- Performance study by varying degree of vacuum at constant water flow rate, rotor speed and packing type.
- Performance study by varying degree of vacuum at constant water flow rate, rotor speed and packing type.
- Above test run will be repeated for other packing type.
- System optimization
Mass Transfer capacity in various devices

- Rotating Packed Bed
- Static Mixer
- Static Mixer/Plate Exchanger
- Microreactor
- Pulsed Column
- Spinning Disc Reactor
- Eductor
- Loop Reactor
- Plate Exchanger
- Jacketed Stirred Tank
Conclusions

- Future belongs to intensified processes
- Interest in PI has started picking up
- EIL-BPCL has started development of capability in PI
- Experimental facility is nearing completion, experimentation is to start in a short while.
Thank you