The New SeparALL™ Process and Polybed™ PSA for IGCC and CTL Application

7th International Freiberg Conference
Hohhot, China, June 7th – 11th

Michael Hu
Senior Strategic Marketing Manager
Benefits of UOP’s solutions in gasification

Our technologies and products are designed to deliver superior performance, safety and value when considered for a gasification project:

- Enhanced availability and reliability of processes and products
- Lower capital expenditure and operating costs resulting in lower cost of production
Honeywell’s Businesses

- **$40.3 billion** in revenues in 2014, 50% outside of U.S.
- Nearly **125,000** employees operating in 100 countries
- **19,000** engineers and scientists

**Aerospace**

**Automation & Control Solutions**

**Performance Materials & Technologies**

Morristown, NJ global corporate headquarters
Profile — Significant Technology Position

Business Units:
- Gas Processing and Hydrogen (GP&H)
- Process Technology & Equipment (PT&E)
- Catalysts, Adsorbents & Specialties (CA&S)
- Renewable Energy and Chemicals (RE&C)

Offering:
- Technology, catalyst & services to the refining, petrochemical and gas processing industries
- Supplier of molecular sieve adsorbents to process and manufacturing industries

UOP Facilities — Global Footprint

- Worldwide Headquarters
  Des Plaines, Illinois (suburban Chicago)
  3,500+ Employees

- 20 Offices
- 17 Countries
- 12 Manufacturing Facilities
- 5 Engineering Centers

Sales: Breakdown

- Equipment 45%
- Products 35%
- Services 13%
- Licensing 7%

Sales: Geographic

- North America 32%
- Asia Pacific 19%
- China 12%
- Middle East 9%
- South America 9%
- E&A 9%
- CIS 5%
- India 5%

Global Customers
What is the UOP SeparALL Process?

Next generation solution of UOP Selexol™ process
Selective removal of H₂S, COS, & CO₂ via absorption/ regeneration process
Offered as licensed technology

- Uses a “next generation” physical solvent (SELEXOL™ MAX Solvent) from DOW Chemicals
- Uses a typical solvent-extraction flow-scheme
- Loading directly proportional to partial pressure

Product Quality

- Can be essentially sulfur free
- Project specific CO₂ capture and quality
- Project specific acid gas H₂S concentration

Physical vs Chemical

Typical Gasification Application

High Pressure is advantageous
SELEXOL MAX Solvent Characteristics

- **SELEXOL MAX Solvent:** A physical solvent
  - Chemically similar and completely compatible with SELEXOL Solvent
  - Clear fluid that looks like tinted water

- Regenerated by changing pressure, temperature or applying a stripping gas

- Unique selectivity characteristics desirable for gasification syngas treating

  **Relative Solubility Data**
  - $\text{H}_2 \sim 1$
  - CO $\sim 2.2$
  - CO$_2 \sim 76$
  - COS $\sim 175$
  - $\text{H}_2\text{S} \sim 680$
  - CH$_4 \sim 5$

**SELEXOL MAX Solvent = Selective**
Two Basic Flow-schemes

**Sulfur removal only**
- Typically for power applications
- Can reduce treated gas to any desired sulfur level
- One solvent absorber with solvent regeneration

**Sulfur removal with separate CO$_2$ removal (CCS or chemicals production)**
- Typically for chemicals, SNG or coal to liquids applications
- Involves more stringent product specifications
- Integrated solvent absorbers and solvent regeneration
Process Flow Schemes
SeparALL Process for Sulfur Removal Only

- Power applications typically require sulfur removal to 10 - 20 ppmv. Less than 0.1 ppmv can be achieved.
- Natural Gas MOLSIV™ Regen Gas Applications
- One solvent absorber with solvent regeneration
Treated Gas

CO₂ Absorber

CO₂ Absorber

Feed Gas

Lean Solution Filter

Stripper

Acid Gas

Reflex Accumulator

Makeup Water

Export Water

Reflex Pump

Stripper Reboiler

H₂S Concentrator

Packinox Exchanger

• CO in the CO₂ stream is ~500 ppmv
• CO₂ purity as high as 99.7 mol%
• Sulfur in treated gas to less than 1 ppmv
• CO₂ in treated gas below 1% is achievable
• Sulfur in CO₂ as low as 2 ppmv
• Adjustable acid gas composition
UOP SeparALL Process Advantages

- Mild chilling
- Simple flow schemes with few pieces of equipment
- Low solvent losses
- Absorbs NH$_3$, HCN and other trace contaminants, without the need for additional equipment
- Removes metal carbonyls
  - Metal carbonyls in treated syngas decompose at gas turbine burners and potentially plate-out on the gas turbine blades
  - Metal carbonyl can also act as catalyst poisons for chemical applications
Improvements in Next Gen SeparALL Process

Enhancements include:

- New SELEXOL MAX solvent
- Use of static mixers
- Nitrogen stripping (when appropriate)
- Low pressure reabsorber column
- High efficiency equipment
  - Packinox heat exchangers
  - Raschig column internals/packing

Complex optimization includes:

- Detailed study on the impact of acid gas H₂S% on the SeparALL unit and SRU unit
- CO shift location
- Use of hot syngas as heating media for SeparALL Process reboiler
- SRU/ PSA tail gas recycle streams
SeparALL Competitiveness – Perceptions/Reality

**OPEX**
- Solvent has high $\text{CO}_2$ absorption capacity resulting in increased gas processing capacity
- Substantial process optimization to reduce both CAPEX and OPEX
  - Utilization of hot syngas in regenerator reboiler
  - Colder lean solvent temperature to maximize solvent acid gas capacity
  - Colder semi-lean solvent temperature to maximize solvent acid gas capacity
  - Non-thermal solvent regeneration at higher pressure reduces recycle compression power
  - Internal heat integration reduces refrigeration demand

**Solvents**
- SeparALL CAPEX (including solvent cost) is lower than alternatives
- Solvent payback is < 4 years when accounted against OPEX savings
- Low solvent losses (<5%), result in lower inventory costs
- DOW solvent supply guarantee

**Sensitivity of SeparALL ELC, $M**

- **Capex**
  - Downside
  - Upside

- **Opex**
  - Downside
  - Upside

**Initial Solvent**

**AGR more sensitive to CAPEX than OPEX**
UOP: The PSA Innovation Leader

UOP invented & patented the 5-STEP PSA cycle

more than 1,000 PSA units designed & commissioned into commercial operation worldwide

KIRKPATRICK AWARD 1979
Presented to UOP for the development of Polybed PSA

UOP invented the synthetic molecular sieve adsorbents required to obtain the 99.99+% H₂ purity required for H₂ applications

- PSA technology and performance leader for 50 years
- The first PSA in the world was commissioned in commercial service in 1966
- Experience with all sizes of PSA including
  - The largest single train PSA in the world, which measures 20-beds, and was started in January 2014
  - The second largest unit produces more than 241 kNm³/h from 370 kNm³/h of SMR feed gas and will be started in 2015 using a 16-bed system
UOP Understands Hydrogen Purification

• Targeted hydrogen recovery

• Enhanced product purity levels and reliable operations

• Flexible designs to help deliver the customers’ needed hydrogen recovery

• Local manufacturing and service available for the life of each unit

• Most extensive experience list, with more than 1,000 Polybed PSA units in every geography including China; This includes the largest single train PSA in the world

UOP is the world leader in PSA technology and continues to improve the value we add
Why is H₂ Management Important?

Hydrocracker Operating Costs

- **Hydrogen**: 84%
- **Utilities**: 15%
- **Catalyst**: 1%

**Recovery**
- H₂ feedstock costs are expensive

**Purity**
- Increases hydroprocessing unit capacities
- Increases hydrocracker conversion

**Reliability**
- Downstream unit shutdowns are costly

*Good H₂ management leads to increased profits*
H₂ Purification — Polybed PSA Systems

**Feed Gas**

- **H₂ + Impurities**
- High Pressure

**Product**

- **H₂ @ High Purity**
- High Pressure

**Tail Gas**

- **Impurities (H₂)**
- Low Pressure

**Specifications**

- **H₂ Purity**
  - 99.9 – 99.999 %

- **H₂ Recovery**
  - 80 – 95 %

- **H₂ Feed pressure**
  - 6 – 40 bar g

- **H₂ Product pressure**
  - 5 – 39 bar g
Components of a PSA Unit

1. Control System
2. Valve Skid
3. Vessels and Adsorbents
4. UOP Services and Support
Capabilities

• Targeted state-of-the art PSA pilot plant facilities enable simulation and testing of adsorbents with:
  – Actual process conditions
  – Actual process gas composition
  – Precise measure of performance

• Adsorbent scale-up-facility enables fast and reliable commercialization of new materials

Results

• Next generation adsorbents
  – Higher capacity for existing units
  – Lower capital cost for new designs

• Cycle innovation
  – Same high performance with lower capital costs due to smaller and fewer vessels

UOP continuously innovates to improve customer value
UOP Adsorbent Experience

High Performance Adsorbents

- Enhanced hydrogen recovery
- Enhanced product capacity
- UOP adsorbents can last for life of the unit
- Improved impurity removal – CO/N₂

UOP high-performance adsorbents lead to lower capital costs for new units or higher capacity for revamps.
UOP Superior Control Valves

UOP certified valves = enhanced reliability

- Operate fast and frequently with a high CV value (capacity)
- Fast cycle time for switching 1.5-3 seconds
- Valves certified for PSA service are subject to >1,000,000 cycles
- Utilize trademark materials to provide superior quarter turn performance and exceed Class VI requirements
- UOP guarantees performance when using our valves
A 12-bed SMR feed gas system has shown no performance decrease after 6 years of continuous operation at full capacity and maintained its >90% recovery and product purity.

A 10-bed SMR feed gas system has been in operation since 1983 without visible decrease in performance.

The world’s 1st 10-bed PSA ran 30 years on its original adsorbent charge until the unit was decommissioned.

UOP adsorbents can last for the life of the unit.
Polybed™ PSA Innovations

Single Train PSA Capacity Meeting Refinery Demands

- High Purity H₂
- Increased H₂ Demands
- Methanator Replacement
- Optimized Cycles
- Optimized Adsorbents

Year

Product Capacity (1000 Nm³/h)


4-bed 47,000
10-bed 71,000
12-bed 113,000
14-bed 100,000
First 16-bed 223,000
New Adsorbent 14-bed 253,000

Fast cycle 12-bed
123,000
UOP PSA Applications

14%
Ethylene Off-Gas
No. of Units: 142
Feed Pressure: 0.03 – 44 bar
Feed Flow: 89 – 188,385 Nm³/hr

42%
Steam Reformers
No. of Units: 426
Feed Pressure: 1.0 – 64 bar
Feed Flow: 134 – 383,650 Nm³/hr

20%
Specialty Applications
Ammonia Plants
Coke Oven Gas
Gasification
Methanol Off-Gas
Styrene Off-Gas

24%
Refinery Streams
No. of Units: 238
Feed Pressure: 1.4 – 46 bar
Feed Flow: 53 – 226,179 Nm³/hr

UOP has the most PSAs with the widest applications
UOP Polybed PSA Solution

Reliability
99.95% on-stream
• Designed for reliable PSA operations and more stable downstream operations
• Each day without hydrogen from a 100,000 Nm³/h PSA unit can cost a refinery $500,000
• 99.95% vs 90% on-stream » 90 MM USD in 5 years

Enhanced Purity
99.99+% pure H₂
• Increases downstream unit asset value
  – Higher Conversion
  – Higher Capacity

Enhanced Recovery
• Every 1% of additional hydrogen recovery can be worth more than $1 million annually

High Pressure
• PSA solutions up to 67 bar g

UOP meets or exceed customer needs, the first time, guaranteed
UOP System Features

**Back-up Operating Mode**
- Auto remove of affected vessels
- Processing 100% feed rate

**Auto Purity Control**
- Feed forward control
- Key impurity concentration detection

**Automatic Off-Gas Flow Adjustment**

**Option for PLC Control System**
- Fast scan multi connection to control center

**Control Valves Specifically Designed for PSA’s**
- High pressure cyclic service
- Fast stroke speed & tight shutoff
- Switching in only a few seconds

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*UOP continually invests in operational design improvements to provide an optimal user experience*
UOP PSA User Feedback

Based on Historical PSA Data:

- Seven years operating data from dozens of UOP PSA units
- Average switchovers of less than 1 per year due to PSA issues
- Less than 1 shutdown every 3 years due to PSA issues
- Unexpected switchovers are rare and unusual compared to units provided by our competition.

99.95% on-stream factor

Reliability data collected on a worldwide basis
UOP has been a leader in providing refining and petrochemical technologies in China for more than 40 years

UOP has 18 PSA units in China

Recent startups:

- GXPC started up in July 2014 in Quinzhou
- Sinochem’s 2 units in Quanzhou started up in July and August 2014
- Wanhua will come online in July 2015
UOP Revamps

Some examples of what a UOP revamp can accomplish:

- New Product Specifications
- Change in Feed Composition
- Increase H₂ Product Recovery
- Increase H₂ Product Capacity
- Upgrade Control System
- Increased Reliability for older units
**SELEXOL™ solvent applications and experience**

**Syngas applications**
- Power (IGCC)
- Hydrogen
- Chemicals (Urea, Ammonia)
- SNG
- Synfuels

**Natural gas applications**
- Sulfur - MOLSIV Regeneration Gas Treaters
- Hydrocarbon Dew Point Control
- CO₂ Removal - EOR
- CO₂ Removal - LNG Peak Shaving
- Landfill Gas
- Biogas

**SELEXOL™ solvent applied in over 115 operating plants world-wide**
## Commercial Experience in Gasification

<table>
<thead>
<tr>
<th>Plant</th>
<th>Start-up</th>
<th>Application</th>
<th>Production</th>
<th>Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarlux IGCC Italy</td>
<td>2000</td>
<td>Power</td>
<td>550 MW net</td>
<td>Visbreaker Residue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H2 Production</td>
<td>40000 Nm³/h</td>
<td></td>
</tr>
<tr>
<td>API IGCC Italy</td>
<td>1999</td>
<td>Power</td>
<td>250 MW net</td>
<td>Visbreaker Residue</td>
</tr>
<tr>
<td>Coffeyville Resources</td>
<td>2000</td>
<td>Ammonia</td>
<td>21 T/h</td>
<td>Petcoke</td>
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<tr>
<td>USA</td>
<td></td>
<td>Urea</td>
<td>62 T/h</td>
<td></td>
</tr>
<tr>
<td>OPTI Canada Canada</td>
<td>2008</td>
<td>H2 Production</td>
<td>337,000 Nm³/h syngas</td>
<td>Asphaltene Residue</td>
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<tr>
<td></td>
<td></td>
<td>&amp; Fuel Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duke Energy IGCC</td>
<td>2012</td>
<td>Power</td>
<td>~600MW net</td>
<td>Coal</td>
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</table>
Commercial Experience in Gasification (Some highlights)

- ITALY: Sarlux IGCC
- ITALY: API Energia IGCC
- U.S.: Coffeyville Resources
### Sarlux IGCC Complex Plant

<table>
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<tr>
<th>Start-Up</th>
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<tbody>
<tr>
<td>Application</td>
<td>Power H₂ Production</td>
</tr>
<tr>
<td>Production</td>
<td>550 MW net / 40000 Nm³/h</td>
</tr>
<tr>
<td>AGRU Duty</td>
<td>Sulfur</td>
</tr>
<tr>
<td>Syngas Flow</td>
<td>404 MMSCFD @420 psia</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Visbreaker Residue</td>
</tr>
</tbody>
</table>

Sarrox, Sardinia, Italy
Block Flow Diagram | Sarlux IGCC

- **Air Separation Unit**
- **Combined Cycle Power Plant**
- **Polybed™ PSA**
- **Polysept™ Membrane**
- **SELEXOL**
- **Claus Plant**

**Processes:**
- **Air**
- **O₂**
- **Gasifier w/ Quench & Scrubbing**
- **Gas Cooling & COS Hydrolysis**
- **Purified Syngas**
- **Visbroken Residue**
- **Tail Gas**
- **High Purity Hydrogen to Hydrocracker**
- **Electric Power**
- **Steam for Export**
- **Raw Hydrogen**
- **Elemental Sulfur**
### API Energía IGCC Complex Plant

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-Up</td>
<td>1999</td>
</tr>
<tr>
<td>Application</td>
<td>Power</td>
</tr>
<tr>
<td>Production</td>
<td>250 MW net</td>
</tr>
<tr>
<td>AGRU Duty</td>
<td>Sulfur</td>
</tr>
<tr>
<td>Syngas Flow</td>
<td>169 MMSCFD @744 psia</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Visbreaker Residue</td>
</tr>
</tbody>
</table>

Falconara, Italy
Coffeyville Resources Plant

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<tr>
<th>Start-Up</th>
<th>2000</th>
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<tbody>
<tr>
<td>Application</td>
<td>Ammonia Urea</td>
</tr>
<tr>
<td>Production</td>
<td>21 T/h</td>
</tr>
<tr>
<td>AGRU Duty</td>
<td>Sulfur &amp; CO₂</td>
</tr>
<tr>
<td>Syngas Flow</td>
<td>151 MMSCFD @535 psia</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Petcoke</td>
</tr>
</tbody>
</table>
Air Separation Unit → Ammonia Synthesis → UAN Plant → UAN Product

Air → NH₃ Product

Air → N₂

O₂ → Polybed PSA

Polybed PSA → High Purity H₂

Polybed PSA → Raw H₂

Polybed PSA → Tail Gas

Quench Gasification → Syngas Scrubbing → CO Shift & Gas Cooling

Polybed PSA → Raw CO₂

Purified CO₂ → SELEXOL 2-Stage

SELEXOL 2-Stage → Claus Plant

CO₂ → Vent

CO₂ → Raw CO₂

Acid Gas
Commercial Experience in Gasification

Coffeyville Resources
Gasification Ammonia Complex

SELEXOL Unit*

POLYBED PSA Unit

* Currently uses 50/50 SELEXOL and SELEXOL MAX solvent
Case Study
Revamps Can Increase Hydrogen Supply

Normandy
Expanded from 14 to 16 beds to achieve 100% production on the 1st switchover and increase H₂ production +20%

USA
Increased H₂ production +20% with same number of beds

Korea
Switched from SMR feed to blended, production increased +20% with a configuration revamp
Case Study
Revamps Can Increase Hydrogen Recovery Percentage Points

Taiwan
H₂ increased 1% point by utilizing optimized adsorbents and improved design configuration to meet downstream needs.

Richmond
Increased recovery by +5% points through a full revamp including adsorbents, controls, and switchover configuration
### Sweden
12 bed SMR upgrade, reformer feed changed to NG. New adsorbents enabled them to maintain H₂ recovery while meeting the new N₂ spec.

### Poland
Improved N₂ spec in product from 3000 ppm to 250 ppm while maintaining H₂ recovery by upgrading adsorbents.

### KSA
UOP partnered with Honeywell to eliminate all single point failures by upgrading the control system, adding a new interface for the DCS, and adding new control valves.