Carbon Dioxide Compression
DOE – EPRI – NIST
Large CO₂ Compression Workshop

By: Harry Miller
Product Manager – Marketing
March 30, 2009
Safe Harbor Disclosure

Some of the information contained in this document contains "forward-looking statements". In many cases, you can identify forward-looking statements by terminology such as "may," "will," "should," "expects," "plans," "anticipates," "believes," "estimates," "predicts," "potential," or "continue," or the negative of such terms and other comparable terminology. These forward-looking statements are only predictions and as such inherently included risks and uncertainties. Actual events or results may differ materially as a result of risks facing Dresser-Rand Company (D-R) or actual results differing from the assumptions underlying such statements. These forward-looking statements are made only as of the date of this presentation, and D-R undertakes no obligation to update or revise the forward-looking statements, whether as a result of new information, future events or otherwise. All forward-looking statements are expressly qualified in their entirety by the "Risk Factors" and other cautionary statements included in D-R's annual, quarterly and special reports, proxy statements and other public filings with the Securities and Exchange Commission and other factors not known to D-R. Your decision to remain and receive the information about to be presented to you shall constitute your unconditional acceptance to the foregoing.
Any person allowing themselves to directly or indirectly receive the information contained in this presentation (the "Receiver") agrees that this presentation and all information contained herein and/or in any way distributed to the Receiver with respect to the same (verbal or otherwise) is the confidential and proprietary property of Dresser-Rand Company and is being provided to and received by the Receiver in confidence. Receiver agrees not to divulge the contents hereof to any third party without the prior written approval of Dresser-Rand's duly authorized representative. Receiver shall advise any permitted recipient of the confidential information of the nature of the same and obtain their agreement to be bound to these terms before such confidential information is disclosed to them. Receiver on behalf of its principal, representatives, employees and themselves individually to hereby unconditionally agree to the terms hereof and agree to defend, indemnify, and hold Dresser-Rand harmless from and against any and all damages that result from Receiver's failure to strictly comply with these terms. Receiver further agrees that failure to comply with these terms will cause Dresser-Rand to suffer irreparable harm. Your decision to remain and receive the information about to be presented to you shall constitute your unconditional acceptance to the foregoing.
CO₂ Compression Applications

- CO₂ pipeline transmission
- CO₂ production
- CO₂ injection - enhanced oil recovery
- Feedstock for urea & fertilizer plants
- Food & beverage processing
- Refrigerant, propellant, fire extinguishers
- Greenhouse gas sequestration
**CO₂ Miscible Flooding**

- CO₂ Injection for EOR has a four-fold benefit
  - Lowers viscosity of the oil in place
  - Provides a measure of pressure drive
  - Can penetrate more types of rocks better than other enhancing agents
  - Leaves a cleaner well
CO₂ Miscible Flooding

continued…

- CO₂ injection proven to be one of the most efficient EOR methods since its introduction in the early 70’s.
**CO₂ Compression Experience**

- Centrifugal
  - More than 100 units, first shipped in 1948, most recent 2009
  - Max discharge pressure:
    - more than 2,500 psia (175 bar) operating
    - more than 4,400 psia (300 bar) - delivery 200
  - Installed in 16 different countries
  - Max inlet flow greater than 48,000 acfm (82,000 m³/hr)
  - Max power greater than 15,000 bhp (11,000 kW)
  - Total installed power > 400,000 bhp (>300MW)
D20R4S CO₂ Booster Rotor & Internal Flowpath
$\text{CO}_2 \text{ EOR Recycle Unit - Canada}$
Sleipner CO₂ Injection Compressor

- First CO₂ re-injection project for the purpose of mitigating greenhouse emissions
- 9 million tons CO₂ injected

Harald Underbakke
Sleipner CO₂ Injection Compressor

continued…

- Objective: reduce the CO₂ content from 9% to 2.5% (sale spec.)
- Capture the CO₂ by an amin plant
- CO₂ storage in an aquifer
- Start up: Aug 1996
- Injection: ~ 1 mill ton CO₂/yr
- Regularity: 98-99%
CO₂ Compression and Injection Systems

Suction pressure 1 bara

Injection pressure ~ 65 bara

Pressure control by cooling (CO₂ density)

1st stage 4 bar / 170 °C
2nd stage 15 bar / 180 °C
3rd stage 32 bar / 120 °C
4th stage 66 bar / 130 °C
Compressor General Arrangement
Platform and Injection Module
1\textsuperscript{st} and 2\textsuperscript{nd} Stage Compressor
D-R High Pressure CO₂ Application

4472 psia final pressure
CO$_2$ Phase Diagram
CO₂ Sealing Gas Phase Map

- Single Phase Gas Region
- Single Phase Liquid Region
- Two Phase Gas + Liquid Region

Enthalpy Btu/lbmole

Dew Line
Bubble Line
DATUM CO₂ Predicted vs. Actual Performance
**D-R Shaft End Seals - Dry Gas Seals**

- Minimum leakage - approx. 1 scfm
- Requires seal gas supply
  - Normally comes from compressor discharge
  - Alternate supply source is usually required for start-up
- D-R manufactures their own high-quality gas seals
**CO₂ Compression Experience**

- Reciprocating
  - more than 200 units, first shipped in 1928, most recent 2007
  - Max discharge pressure - more than 6000 psig (425 bar)
  - Max inlet flow - more than 4000 acfm (7,000 m³/hr)
  - Max power - greater than 5,000 bhp (4,000 kW)
  - Total installed power > 530,000 bhp (>395MW)
Process Reciprocating Compressor

5,500 HP HHE-VL Process Reciprocating Compressor on Hydrogen Makeup Service in USA Gulf Coast Refinery
Challenges with CO₂ Compression

- The presence of water together with CO₂ creates carbonic acid which is corrosive to carbon steels. The use of stainless steel for any components in contact with wet CO₂ eliminates the problem.
- Similarly, the presence of water with CO creates iron carbonyl upon contact with carbon steel. Again, the use of stainless steels for solves the problem.
- Special O-ring materials required to resist explosive decompression due to entrapped CO₂.
Toxic Effects of $H_2S$

- 1 PPM smell
- 10 PPM 8 hr. TWA
- 100 PPM loss of smell
- 300 PPM loss of consciousness with time (~ 30 min.)
- 1000 PPM immediate respiratory arrest, loss of consciousness, followed by death
**Future Considerations...**

- Increasing the amount of inter-stage cooling will reduce the overall power required for CO\(_2\) compression.
- Advanced inter-stage cooling concepts are being investigated to improve the effectiveness of existing water-cooled stationary diaphragms.
- D-R working with SwRI on DOE-NETL funded project to develop advanced inter-stage cooling for traditional multi-stage inline centrifugal compressors.
- D-R supporting RAMGEN supersonic compression development.
High Capacity and High Power Compressor Experience
DATUM Product Flexibility

- General Refining
  - Wet Gas
  - Alkylation
  - Isomerization
  - Hydrocracking

- Ammonia
  - Syn Gas
  - NH₃ Ref

- Methanol
  - Feed Gas
  - Syn Gas

- Urea
  - CO₂

- Gas Injection
- Gas Lift
- Gas Processing
- LNG
  - MCR
  - Propane
- Ethylene
  - Charge Gas
  - Propylene
  - Ethylene
  - Feed Gas
- GTL

<table>
<thead>
<tr>
<th>Pressure (PSIG)</th>
<th>Flow (CFM)</th>
<th>Flow (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>1,700</td>
<td>1,700</td>
</tr>
<tr>
<td>500</td>
<td>10,000</td>
<td>17,000</td>
</tr>
<tr>
<td>300</td>
<td>100,000</td>
<td>170,000</td>
</tr>
<tr>
<td>200</td>
<td>1,000,000</td>
<td>1,700,000</td>
</tr>
</tbody>
</table>

- Gas Mole Wt 2 - 44+
- Horsepower 500 - 120,000+
- Speed 2,000 - 35,000 RPM
- 14 Frame Sizes
- 5 Imp. Families / Frame
- Impeller Dia 9” - 66”
- Case ID 17” - 123”

Radially Split
Axially Split
Radially & Axially
Supplied
DATUM Product Flexibility

Radially Split & Axially Split Casing Coverage Map

CO₂ Experience To Date

Future Full-Size IGCC, Oxy-Coal, & PC CCS Applications

Flow (CFM)  1,000  10,000  100,000  1,000,000
Flow (m³/hr) 1,700  17,000  170,000  1,700,000

• Gas Mole Wt 2 - 44+
• Horsepower 500 - 120,000+
• Speed 2,000 - 35,000 RPM
• 14 Frame Sizes
• 5 Imp. Families / Frame
• Impeller Dia 9" - 66"
• Case ID 17" - 123"

Radially Split
Axially Split
Radially & Axially
Supplied
LNG Liquefaction Compressors
Large Trains = Large Casings

Over (100) Dresser-Rand compressors are in liquefaction services. Nine (9) of these very large Dresser-Rand vertically split compressors are operating in propane refrigeration service.
DATUM D26R9B
DATUM & RR Trent on Test
52 MW Rating at ISO Conditions
DATUM - Trent Train on Test
52 MW Rating at ISO Conditions
DATUM - Trent Installed at Site
RR Trent Enclosure
DATUM D22R7S + GE LM6000
D-R Compressor Driven by 42MW VFD Motor
110MW McIntosh CAES Installation
D-R CAES Single Train Arrangement
D-R High Power Driver Experience

- GE Frame 7
- GE Frame 6
- GE LM6000
- RR Trent
- ABB Electric Motor
- EM (Converteam) Electric Motor/Generator
- Steam Turbines up to 70,000 bhp
Thank You!

Questions?