CO2

MAN Turbo
Engineering the future – since 1758.
1. Introduction
2. General presentation of MAN TURBO AG and it’s products
   - MT organisation (also part of MAN)
   - MT product range (with typical operating ranges)
   - some numbers (business)
3. CO2 business
   - applications
   - technical insight (gear box, lubrication, seal construction)
   - specific machine aspects related to CO2
   - onshore compression (stable MW)
   - offshore compression (MW from 20 => 42kg/kmol)
   - references
   - maintenance issues
   - discussion
## CO2 Applications

<table>
<thead>
<tr>
<th>Process</th>
<th>Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASU</td>
<td>air compression (Main Air, Booster, Combi)</td>
</tr>
<tr>
<td></td>
<td>N2 compression</td>
</tr>
<tr>
<td>UREA</td>
<td>high pressure CO2</td>
</tr>
<tr>
<td>EOR</td>
<td>high pressure CO2</td>
</tr>
<tr>
<td>PTA</td>
<td>air compression, residual gas expansion</td>
</tr>
<tr>
<td>Ammonia</td>
<td>air compression</td>
</tr>
<tr>
<td>Nitric Acid</td>
<td>air compression, NOX gas compression, residual gas expansion</td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>flash gas compression, natural gas compression, Methanol</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>fuel gas compression</td>
</tr>
<tr>
<td>Lignite Coal Drying, Destillation</td>
<td>vapor compression</td>
</tr>
</tbody>
</table>
CO2 Applications

EOR – enhanced oil recovery
- CO2
- waste gas
- air
- Acid gas
- ...

CCS - Carbon Capture and Storage
- Power plants
  - post combustion
  - pre combustion
- dry and wet capture processes (Rectisol [dry CO2], Selexol, Amin scrubbing)
- into pipelines to offshore or onshore storages
CO2 Integrally Geared Compressor

- Suction flow rates up to 350,000 m³/h
- Maximum discharge pressure up to 215 bar

- Air separation
- Ammonia
- CO₂ compression
- Fluid Catalytic Cracking (FCC)
- Fuel gas
- Nitric acid
- Oxygen
- Refinery / Petrochemicals
- Terephthalic acid (PTA)
- Urea
CO2
Advantages (I)

High Efficiency
- Integral Gear
- Axial Inflow to each Stage
- Optimum Flow Coefficients (Speed Selection)
- Small Hub/Tip Ratios (low Impeller Eye Mach Number)
- Adjustable Inlet Guide Vanes
- Intercooling possible after each Stage

Low Investment
CO2
Advantages (II)

Wide Application Range
- Multiple Processes on one Gear
- Connects high and low Speed Trains (e.g. Turbine - Generator)
- Easy Adaption of Process Needs (Extractions, Feed Streams …)

Small footprint

RG Package for Methanol
Multiple Processes or Process Stages can be serviced on one Gearbox

Extractions, Feed Streams or other Process Equipment (e.g. H2 Removal Reactor) can be incorporated between two Stages

Process Requirements determine Compressor Sizing

All Process Conditions have to be considered for safe Design

Possible Process Upsets should be considered

Machine Protection is based on all Conditions considered
Shrouded or unshrouded Impellers may be used depending on tip Speed, Pressure, Exit Width, Cost

Large Variety of Impeller Types can be used depending on Process Needs

Impeller Flow Coefficients can be adjusted to optimum Value by selecting different Pinion Speeds

Impellers are fastened to Pinion via Hirth Tooothing and Tension Bolt

- Small Hub diameter leads to small Impeller Eye
- Large Variety of Impeller Diameters can be realized
  (References from 90 mm to 1450 mm)
- Impeller Material can be selected according to Requirements concerning Strength and Density (Weight)
Each Stage requires a Shaft Seal

Labyrinths, Carbon Ring Seals and Dry Gas Seals may be used

Seal selection depends on Process Gas and allowable leakages:

- Labyrinth Seals for low Pressure Air
- Carbon Ring Seals for Air, Nitrogen and CO2
- Dry Gas Seals for toxic or flammable Gases

Buffer Gas may be used with each Seal Type
### CO2 Shaft Seals (II)

<table>
<thead>
<tr>
<th></th>
<th>Labyrinth Seal</th>
<th>Carbon Ring Seal</th>
<th>Dry Gas Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity of Seal</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Complexity of Seal</td>
<td>Low</td>
<td>Low (LP)</td>
<td>High</td>
</tr>
<tr>
<td>System (Piping and Panel)</td>
<td>Low</td>
<td>Medium (HP)</td>
<td>High</td>
</tr>
<tr>
<td>Leakages during Operation</td>
<td>High</td>
<td>Low (LP)</td>
<td>Low</td>
</tr>
<tr>
<td>Leakages during Standstill</td>
<td>High</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>Rotordynamic Impact</td>
<td>None (LP)</td>
<td>None (LP)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Low (HP, Length of Overhung)</td>
<td>High (Length of Overhung and add. Rotor Mass)</td>
<td></td>
</tr>
</tbody>
</table>
Drive may be realised by Motor via Bullgear or by Turbine via Pinion
Compressor Speeds are independent from Driver Speed
Gear links Thermodynamics and Mechanics / Rotordynamics
Gear is sized according to Power and Axial Thrust Requirements

⇒ Compressor and Gear Design go Hand in Hand
1. Introduction
2. General presentation of MAN TURBO AG and it’s products (Mr. Dittmer)
   - MT organisation (also part of MAN)
   - MT product range (with typical operating ranges)
   - some numbers (business)
3. CO2 business (Mr. Dittmer)
   - applications
   - technical insight (gear box, lubrication, seal construction)
   - specific machine aspects related to CO2
   - onshore compression (stable MW)
   - offshore compression (MW from 20 => 42kg/kmol)
   - references
   - maintenance issues
   - discussion
CO2 Traditional CO₂ compression

Three casing centrifugal compressor

Reciprocating compressor
CO2 Gear Type Design (3 pinions)

A direct-driven bull gear

Up to three pinion shafts with different speeds

Two impellers per pinion shaft

Compression of air and nitrogen
CO₂
Gear Type Design (5 pinions)

Patent for the worldwide first geared compressor with double bull gear

First eight-stage compressor for nitrogen, developed, built, and in operation for Hoekloos, Holland

First 10-stage compressor for moist CO₂, developed, built, and in operation for AZOT Nowomoskovsk, Russia
CO2
ASME Class 1 Test on Test Bed

10-stage geared compressor

Urea synthesis

Type RG 53-10

Gas Moist CO₂ mix

Flow rate 23,500 m³/h

Pressure 1 - 200 bar

Power 4,500 kW
CO2 Compression in T, s diagram
CO2
Cooperation with STAMICARBON

8-stage geared compressor

Urea synthesis

Type
RG 40-8

Gas
Moist CO₂ mix

Flow rate
12,800 m³/h

Pressure
1 - 160 bar

Power
4,200 kW
CO2
Enhanced Oil Recovery by CO₂

North Dakota, USA
CO2 Enhanced Oil Recovery by CO₂

C02 injection oil recovery
CO₂ pipeline routing in USA & Canada

.... from Dakota Gasification Company, Beulah, North Dakota, USA to ENCANA, Weyburn Oilfield, Saskatchewan, Canada
CO₂ pipeline routing the USA / Canada

.... from
Dakota Gasification Company, Beulah,
North Dakota, USA
to ENCANA,
Weyburn Oilfield,
Saskatchewan, Canada
CO2
Impeller stages 1 to 8
CO2 Compression in T, s diagram

![Diagram showing CO2 compression in T, s diagram with labels for Druck (p) in bar, Temperatur (T) in °C, Entropie (s) in kcal/°C kg, Zs, Ts, ps,log, n,log, stage no.]}
CO2
Arrangement plan 3D Modell
<table>
<thead>
<tr>
<th><strong>Type</strong></th>
<th>RG 80-8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td>CO2 mix</td>
</tr>
<tr>
<td><strong>Suction pressure</strong></td>
<td>1.15 bar abs</td>
</tr>
<tr>
<td><strong>Discharge pressure</strong></td>
<td>187 bar abs</td>
</tr>
<tr>
<td><strong>Flow rate</strong></td>
<td>62,750 Nm³/h</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>14,700 kW</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>USA, North Dakota</td>
</tr>
</tbody>
</table>
CO2
Project Start Up in September 2000
CO2 Publications

CO₂ Recovery and Sequestration at Dakota Gasification Company

Daren Eliason
Process Engineer
Dakota Gasification Company

October 4, 2004

IPC, Calgary, October 2004

CompressorTech, July / August 2003

11 ELIA, October 2004
1. Introduction
2. General presentation of MAN TURBO AG and it´s products (Mr. Dittmer)
   - MT organisation (also part of MAN)
   - MT product range (with typical operating ranges)
   - some numbers (business)
3. CO2 business (Mr. Dittmer)
   - applications
   - technical insight (gear box, lubrication, seal construction)
   - specific machine aspects related to CO2
   - onshore compression (stable MW)
   - offshore compression (MW from 20 => 42kg/kmol)
   - references
   - maintenance issues
   - discussion
- No references on integrally geared compressors available

- In principle no big issue (taking into account the usual offshore issues)

- Advantages:
  - Compact design
  - Small foot print
# CO2 References

## Selected References for CO₂ Applications

<table>
<thead>
<tr>
<th>Name</th>
<th>Application</th>
<th>Ctry</th>
<th>Order Date</th>
<th>Qty</th>
<th>Type</th>
<th>Frame / Imp.</th>
<th>Gas</th>
<th>Capacity (m³/h)</th>
<th>Pₚ (bar)</th>
<th>Tₛ (°C)</th>
<th>Pₛ (bar)</th>
<th>Tₛ (°C)</th>
<th>Speed (l/min)</th>
<th>Power (kW)</th>
<th>Driver</th>
<th>Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOVAZOT</td>
<td>Urea Synthesis</td>
<td>Russia</td>
<td>1993</td>
<td>1</td>
<td>RG</td>
<td>053/ 10</td>
<td>CO₂-Mix (WET)</td>
<td>23.600</td>
<td>1.04</td>
<td>55</td>
<td>200.00</td>
<td>1.490</td>
<td>4.500</td>
<td>M</td>
<td>CR</td>
<td></td>
</tr>
<tr>
<td>DACOPIPE 1+2</td>
<td>Gas Injection</td>
<td>USA</td>
<td>1998</td>
<td>2</td>
<td>RG</td>
<td>080/ 08</td>
<td>CO₂ (H₂S, NACE, Mercapto)</td>
<td>68.760</td>
<td>1.15</td>
<td>66</td>
<td>187.00</td>
<td>1.800</td>
<td>13.235</td>
<td>M</td>
<td>CR</td>
<td></td>
</tr>
<tr>
<td>SALUR</td>
<td>Urea Synthesis</td>
<td>SVN</td>
<td>2001</td>
<td>1</td>
<td>RG</td>
<td>040/ 08</td>
<td>CO₂ (WET)</td>
<td>12.800</td>
<td>1.00</td>
<td>180.00</td>
<td>1.490</td>
<td>4.200</td>
<td>M</td>
<td>CR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DACOPIPE 3</td>
<td>Gas Injection</td>
<td>USA</td>
<td>2005</td>
<td>1</td>
<td>RG</td>
<td>080/ 08</td>
<td>CO₂ (H₂S, NACE, Mercapto)</td>
<td>68.760</td>
<td>1.15</td>
<td>66</td>
<td>187.00</td>
<td>1.800</td>
<td>13.236</td>
<td>M</td>
<td>CR</td>
<td></td>
</tr>
</tbody>
</table>

**Nomenclature:**

- RG: Gear Type Compressor
- L: Labyrinth Seal
- CR: Carbon Rings Seal
- MS: Oil lubricated Seal

## Selected References for Water Vapour Applications including Coal Particles

<table>
<thead>
<tr>
<th>ORDER- NUMBER</th>
<th>CODEWORD</th>
<th>CUSTOMER / ENGINEERING</th>
<th>Country</th>
<th>Year</th>
<th>Quantity</th>
<th>Compressor type</th>
<th>MEDIUM</th>
<th>PROCESS</th>
<th>Overall stage numbers</th>
<th>Capacity (m³/h)</th>
<th>suction pressure (bar)</th>
<th>suction temperature (°C)</th>
<th>discharge pressure (bar)</th>
<th>Driver</th>
<th>rated driver power (kW)</th>
<th>driver speed [r/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2800943</td>
<td>LURG1</td>
<td>LURGI</td>
<td>Germany</td>
<td>1990</td>
<td>1</td>
<td>RG 53-3</td>
<td>H₂O</td>
<td>Coal Powder Drying</td>
<td>3</td>
<td>38800</td>
<td>1.08</td>
<td>110</td>
<td>4.62</td>
<td>EMDA</td>
<td>1483</td>
<td></td>
</tr>
<tr>
<td>312 190</td>
<td>STEINBRO</td>
<td>STEINMÖLLER</td>
<td>Germany</td>
<td>1998</td>
<td>1</td>
<td>RG 10-3</td>
<td>H₂O</td>
<td>Coal Powder Drying</td>
<td>3</td>
<td>130248</td>
<td>1.63</td>
<td>110</td>
<td>4.62</td>
<td>EMDA</td>
<td>9850</td>
<td>1500</td>
</tr>
</tbody>
</table>
1. Introduction
2. General presentation of MAN TURBO AG and it´s products (Mr. Dittmer)
   - MT organisation (also part of MAN)
   - MT product range (with typical operating ranges)
   - some numbers (business)
3. CO2 business (Mr. Dittmer)
   - applications
   - technical insight (gear box, lubrication, seal construction)
   - specific machine aspects related to CO2
   - onshore compression (stable MW)
   - offshore compression (MW from 20 => 42kg/kmol)
   - references
   - maintenance issues
   - discussion
1. Enhanced Oil Recovery (EOR)
2. Enhanced Coal Bed
   Methane Recovery
3. Depleted oil / gas fields
4. Unmineable coal seams
5. Voids and cavities
6. Deep saline formations

Green House Effect,
Kyoto Protocol,
Future Projects
The MAN TURBO Upstream Business Unit covers all of the upstream compression requirements of the industry.
CO2

Leading Technology

Powered by experience

www.manturbo.com