How turbocompressors safeguard and drive downstream plant operations

Ulrich Schmitz, Atlas Copco Gas and Process

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The situation we face: Challenge and opportunities

- **Paris Climate Change Conference** in 2015 marked a step into a unified strategy on reduction of greenhouse gases worldwide.
- Ambitious plan to change from fossil fuels in renewable as partly be moved from 2040 to 2050.
- Measures must be taken and possible ways to reduce emissions must be found.
- **IMO 2020**: As of 01 January 2020, ships will have to use marine fuels with a sulphur content of no more than 0.5%S against the current limit of 3.5%S. Emission Control Areas (ECAs) will remain at the 2015 standard of 0.1%S content.

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Emerging markets:
Protecting global climate and human health

Emerging markets: Protecting global climate and human health

Hydrogen – production / transportation / storage / use

Annual worldwide hydrogen production is about 70 MTPA and mainly used for production of ammonia and in refinery for blending fuels. Grey hydrogen is produced from feedstock such as NG or coal. Blue hydrogen is produced if CCS is applied and green hydrogen if electrolysis with renewable energy is used.

LNG as fuel

Technology for production and usage of hydrogen is already available, but transportation and storage of larger quantities of hydrogen remains a challenge. **Hydrogen may gain traction, but currently there is strong demand on LNG as a fuel. When LNG as a fuel is produced from biomethane it has a better CO_2 footprint than methane-based LNG**.

CCUS – Carbon Capture Utilization and Storage

CO_2 capturing from exhaust gases coming from cement & iron making, power plants, natural gas exploration, refineries (H_2 production), ship exhaust just to name a few. In addition to CCUS, CO_2 is also getting popular to apply as working fluid in energy recovery, district heating & cooling.

Emerging markets: Protecting global climate and human health

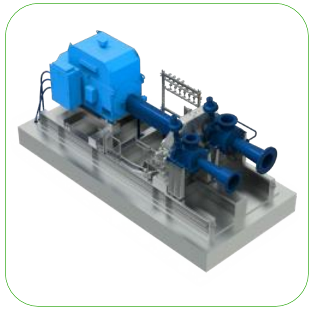
Technologies are required to support **new, emerging** and **sustainable energy sources**

Starting in 1984, Atlas Copco Gas and Process has supported with technology to reduce carbon footprint.

Oxy combustion projects	Geothermal, waste heat to power and pressure let down	Heat pumps and CO_2 compression

CO_2 compressor "Callide", Delivery **2008**

CO_2 compressor "Netpower", Delivery **2016**



Heat pump "Rya", Delivery **1984**, **still in operation**

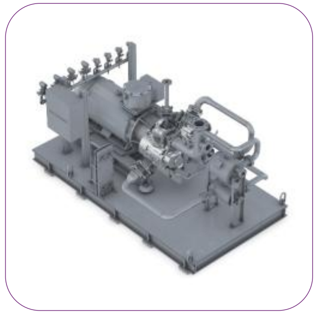
CO_2 compressor "Greenhouse", Delivery **2005**, **still in operation**

Emerging markets: Protecting global climate and human health

Technologies are required to support **new, emerging** and **sustainable energy sources**

Increased amount of **CO_2 & sCO_2, H_2, LNG and energy storage related projects**

Oil-free gas screw compressors for fuel gas supply



Compressor / Expander in sCO_2 cycle / energy recovery

Single-stage compressor for H_2 BOG

Compressors and Expanders for District Heating and Cooling

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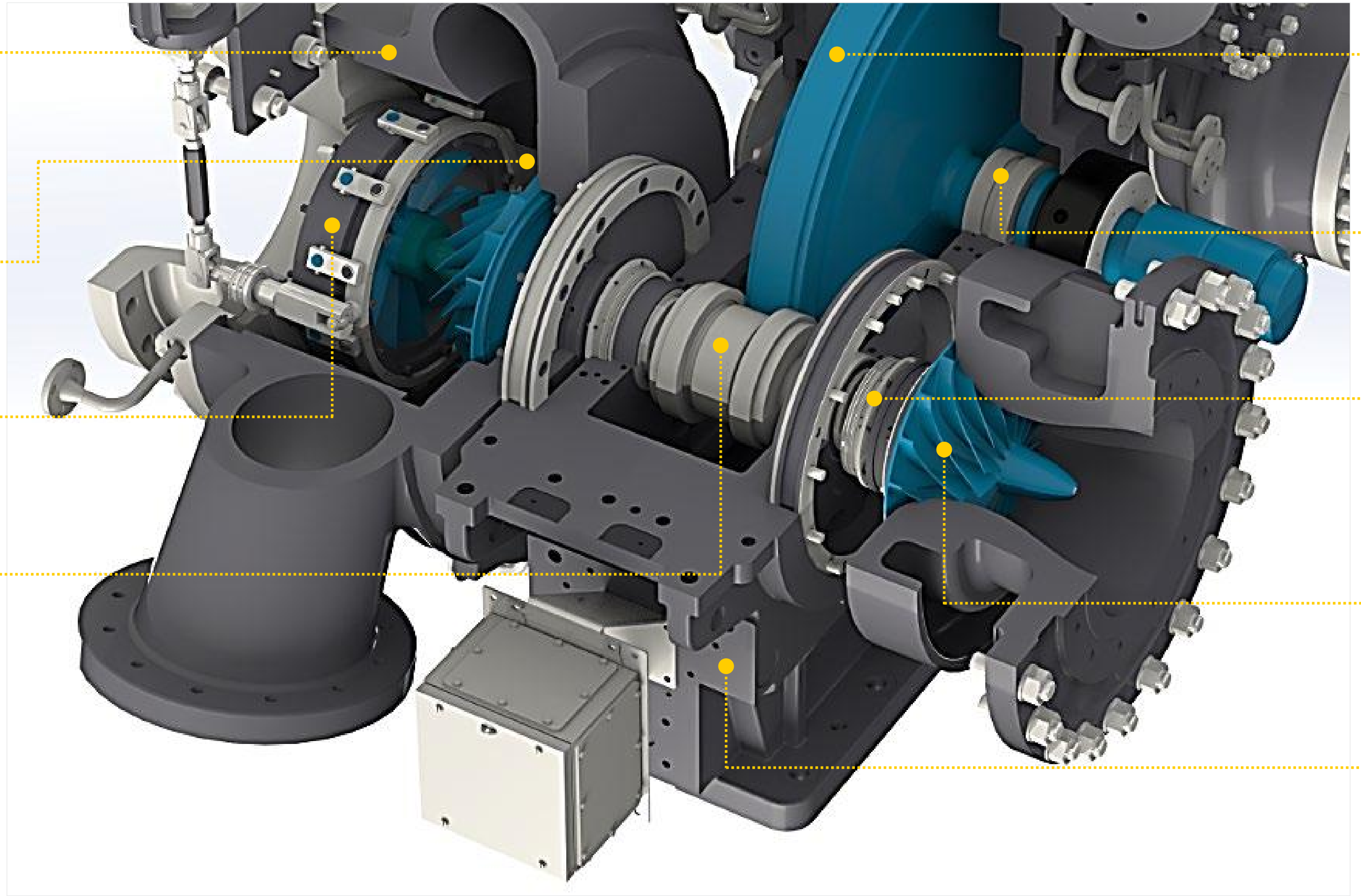
Integral gear technology and API

Core components of integral gear technology



Volute
Cast iron, Cast steel, Stainless steel

Diffuser
(with or w/o guide vanes)

Inlet guide vanes
Cast, Fabricated

Pinion
High-speed (with thrust collar)

Bull gear
Low-speed

Bearing
Tilting-pad

Seal
Carbon ring, Labyrinth, Dry gas seal

Impeller
Open, Shrouded

Gear box casing
Cast steel, Fabricated steel

Integrally-geared compressor technology and API

"Integrally geared" as defined in energy API AMERICAN PETROLEUM INSTITUTE

API standard 617 8th Edition, September 2014

Foreword

- API 617 consists of the following parts, under the general topic "axial and centrifugal compressors and expander- compressors for special purpose applications handling gas or process air":
  - Part 1 – General requirements
  - **Part 2 – Non-integrally geared** centrifugal and axial compressors
  - **Part 3 – Integrally-geared** centrifugal compressors
  - Part 4 – Expander-compressors

IG compressor first defined in **API 617 7th Edition, July 2002**

Integrally-geared compressor technology and API

Short list of **API codes**

API 617	gas compressors
API 672	integrally geared air compressors
API 613	gears
API 614	lube oil systems
API 692	**(new code)** shaft seals
API 671	couplings

Short list of **end-user API 617 amendments**

PETRONAS	PTS 31.29.40.30
	DEP 31.29.40.30
Reliance	10080-1-SS-MR-004
woodside	W1000SM5219235
EIL	6-42-0005
bp	GIS-34-101
QAPCO	QES-M-0023

API-compliant compressor solutions for Floating LNG production

PETRONAS

Regen Gas

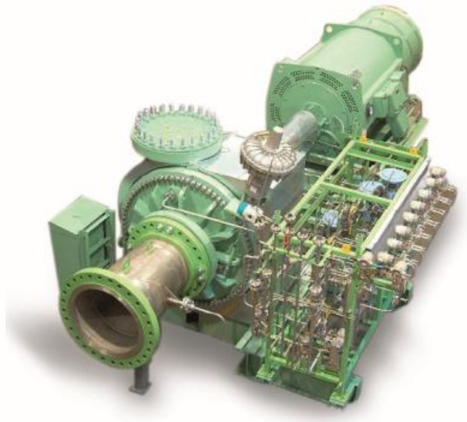
Maintenance Gas

Instrument Air Compressors

API-compliant compressor solutions for Olefins / Polyolefins

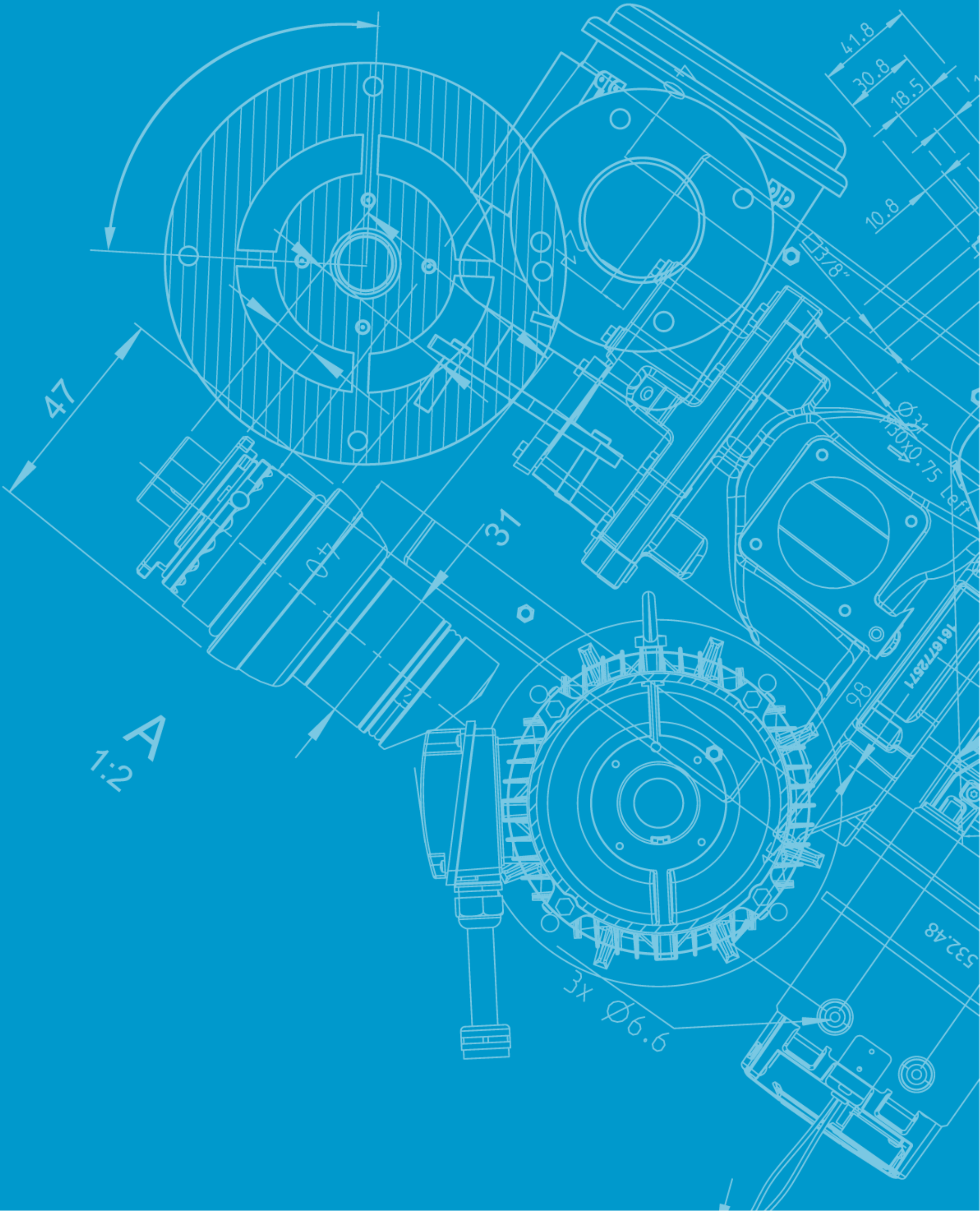
KBR
THE LINDE GROUP
TechnipFMC
CB&I
GRACE
TOYO ENGINEERING
Univation TECHNOLOGIES
Novolen TECHNOLOGY
lyondellbasell

Steam cracker – decoking air



Cycle gas compressor

Radial compressor characteristics



Impeller range in integrally-geared compressors

Smallest impeller build

Diameter: 12 mm

Speed: 350 000 rpm

High pressure CO_2 impeller build

Diameter: 100 mm

Speed: 37 500 rpm

Largest impeller build

Diameter: 1 530 mm

Speed: 5 370 rpm

The principle of impellers

- Velocity triangles:

$$\boxed{\vec{U}} + \vec{W} = \boxed{\vec{C}}$$

$\rightarrow C_2 > C_1$

$\rightarrow U_2 > U_1$, as $r_2 > r_1$

- Euler equation of total head:

$$\Delta H_{total} = \boxed{C_{U2}} \cdot U_2 - C_{U1} \cdot U_1$$

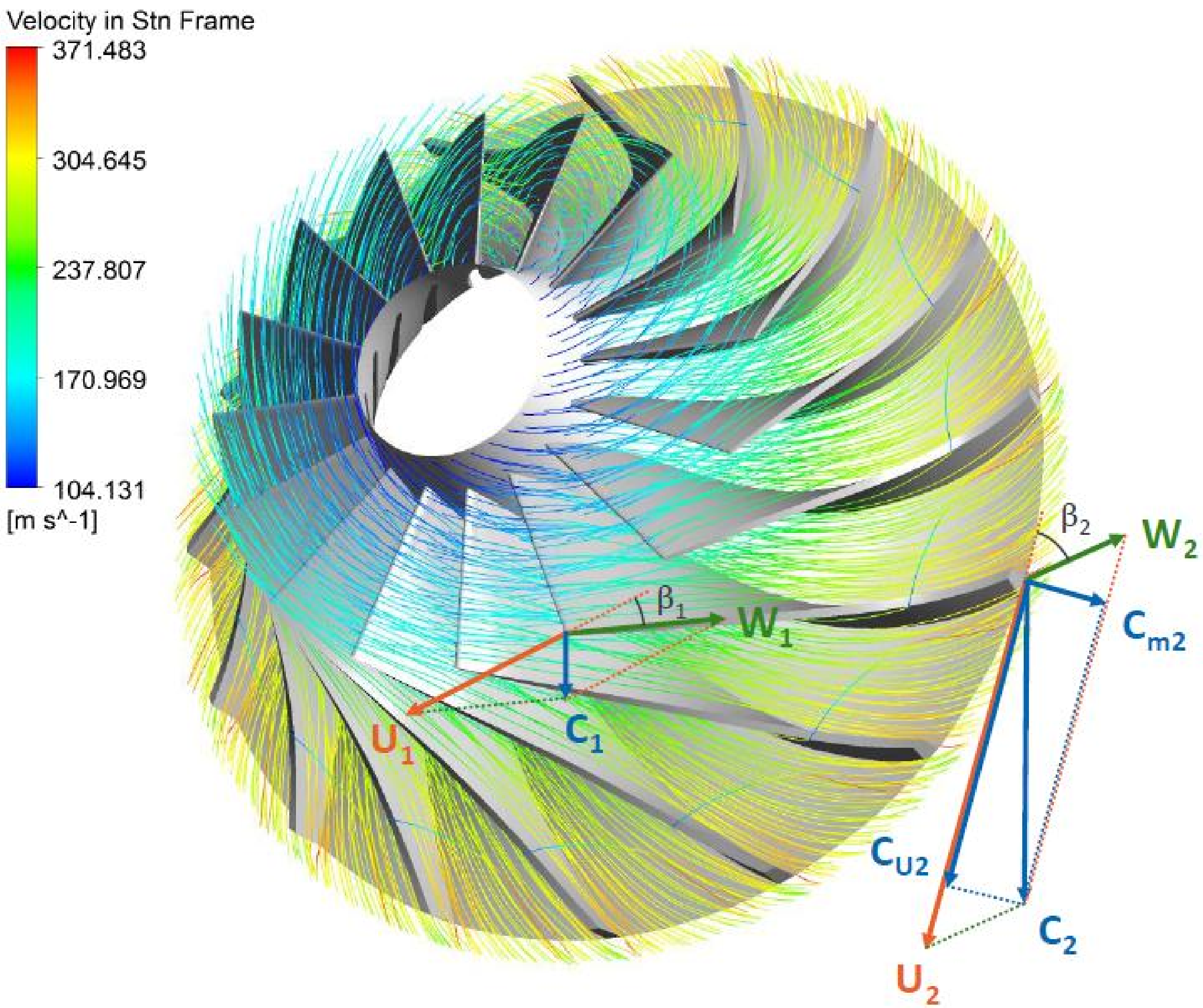
$\rightarrow C_{u2}$ changes with blade angle β_2

where: U = Peripheral velocity; W = Relative velocity;

where: C = Absolute velocity; C_u = Tangential component;

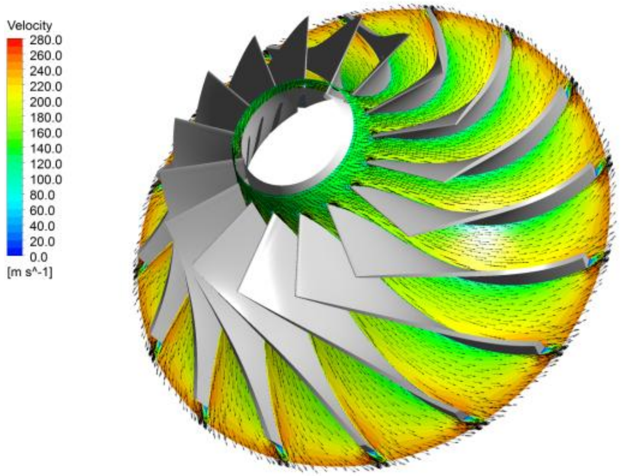
where: β = Blade angle

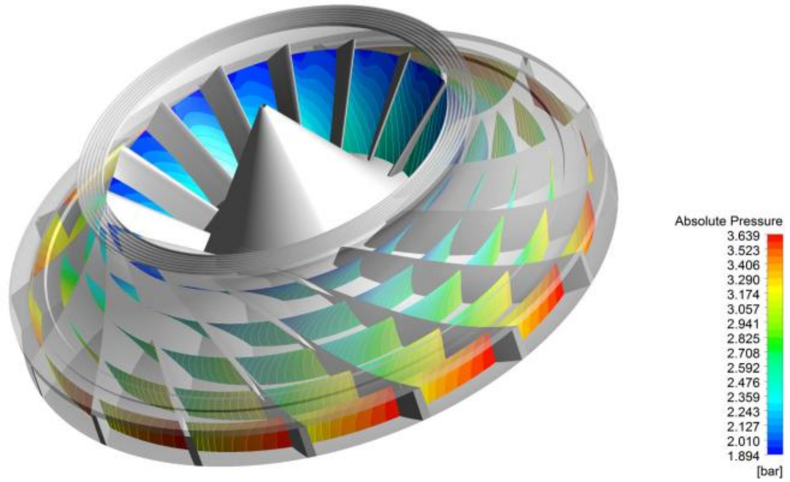
where: 1 = Impeller inlet; 2 = Impeller outlet



Impeller types

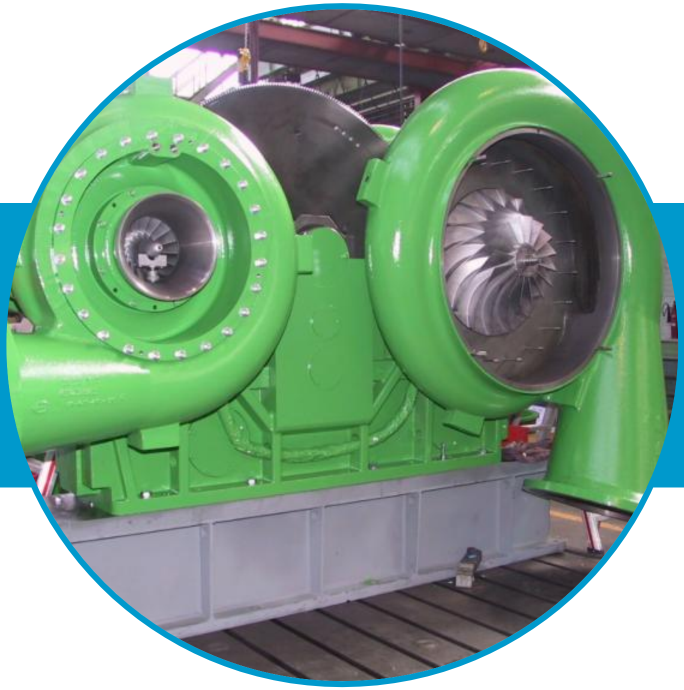
- Open impeller
  - ➕ No strict mechanical limit of tip speed
    → Load ↑ Pressure ratio ↑
  - ➖ Gap between impeller and casing
    → Flow leakage ↑ Impeller efficiency ↓
- Closed impeller
  - ➕ Impeller with cover disk, almost no flow leakage
    → Impeller efficiency ↑
  - ➖ Limited speed of impeller tip
    → Load ↓ Pressure ratio ↓





Casing and volute in integrally-geared compressors

Nodular cast iron (Air, N_2), **cast carbon steel** (high pressure), or **cast stainless steel** (corrosive / cryogenic gas) according to application needs



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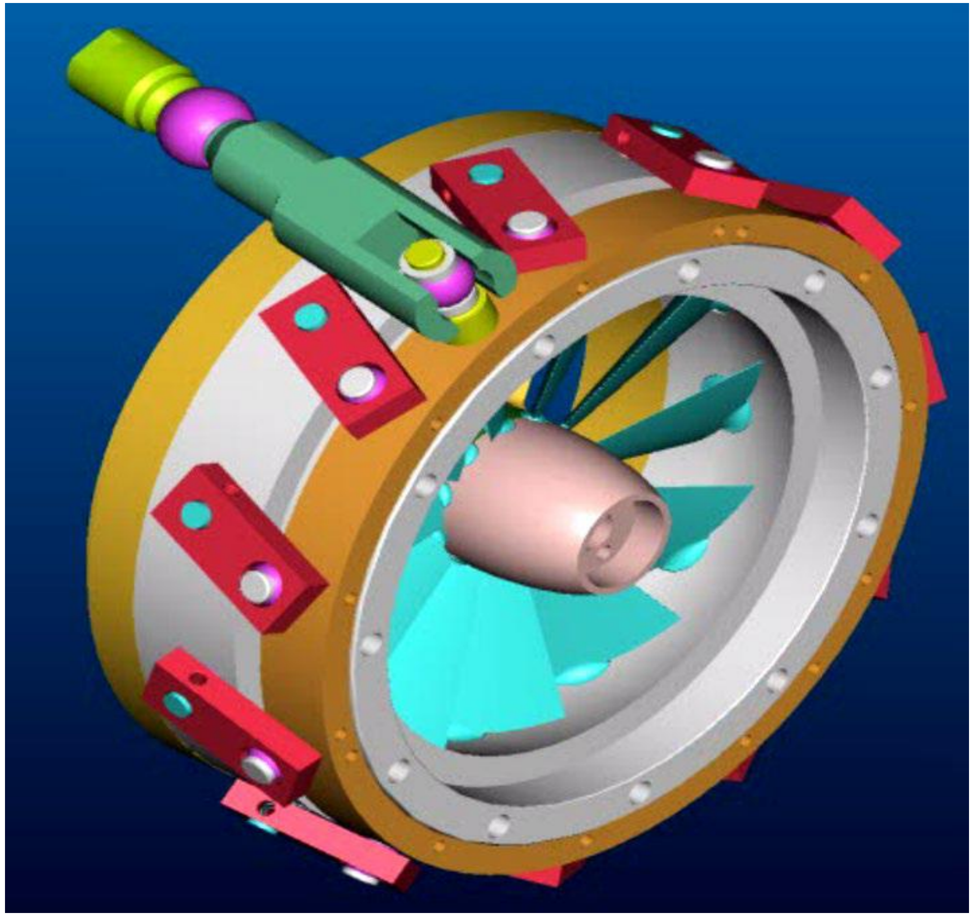
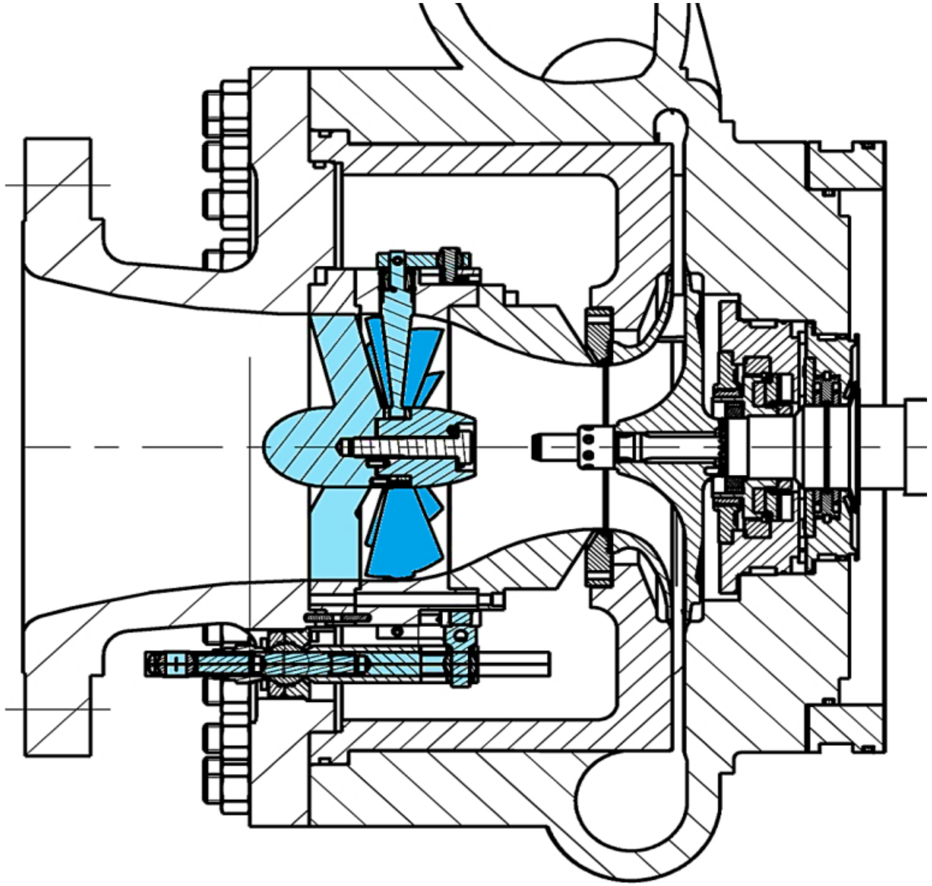
Controls compressor output – Inlet Guide Vanes





The principle of Inlet Guide Vanes

- Flow rate:
  $\dot{V}_m = \boxed{C_{m1}} \times A$
  → IGV↓ C_{m1}↓ V_m↓

- Euler equation of total head:
  $\Delta H_{total} = C_{U2} \cdot U_2 - \boxed{C_{U1}} \cdot U_1$
  → IGV↓ C_{u1}↑ ΔH↓

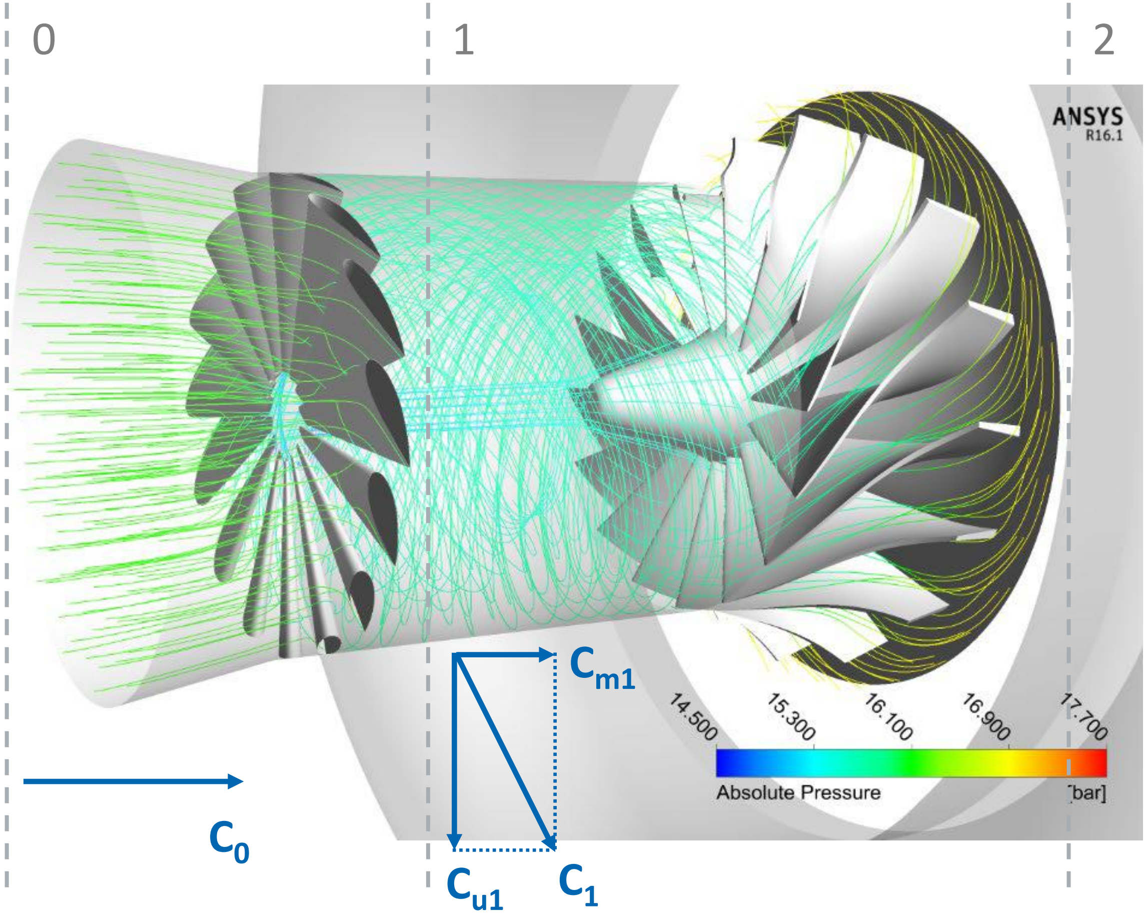
where: C_m = Meridional component of velocity;

where: C_u = Tangential component of velocity;

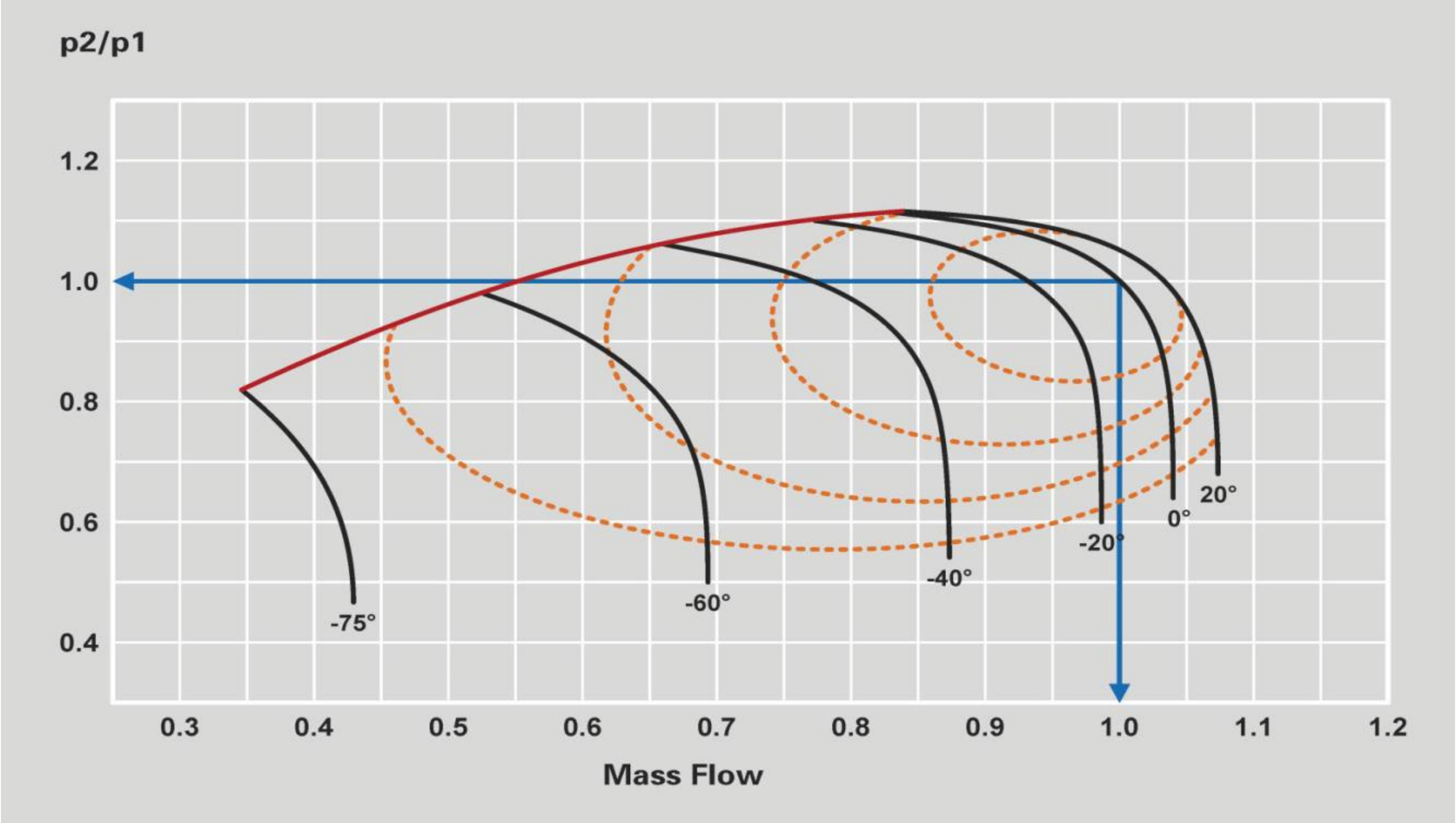
where: 0 = IGV inlet;

where: 1 = IGV outlet = Impeller inlet;

where: 2 = Impeller outlet



Inlet Guide Vanes: Controls for compressor output



Inlet Guide Vanes (IGV)
at 1st stage inlet

Technological experience

Atlas Copco Gas and Process **compressor**, **expander** and **compander experience**

- More than 4 000 turbocompressor packages used in cryogenic, corrosive, hazardous and non-hazardous applications
- More than 4 600 turboexpander systems
- Over 100 Compander systems supplied for various applications

Magnetic bearing supported turboexpanders

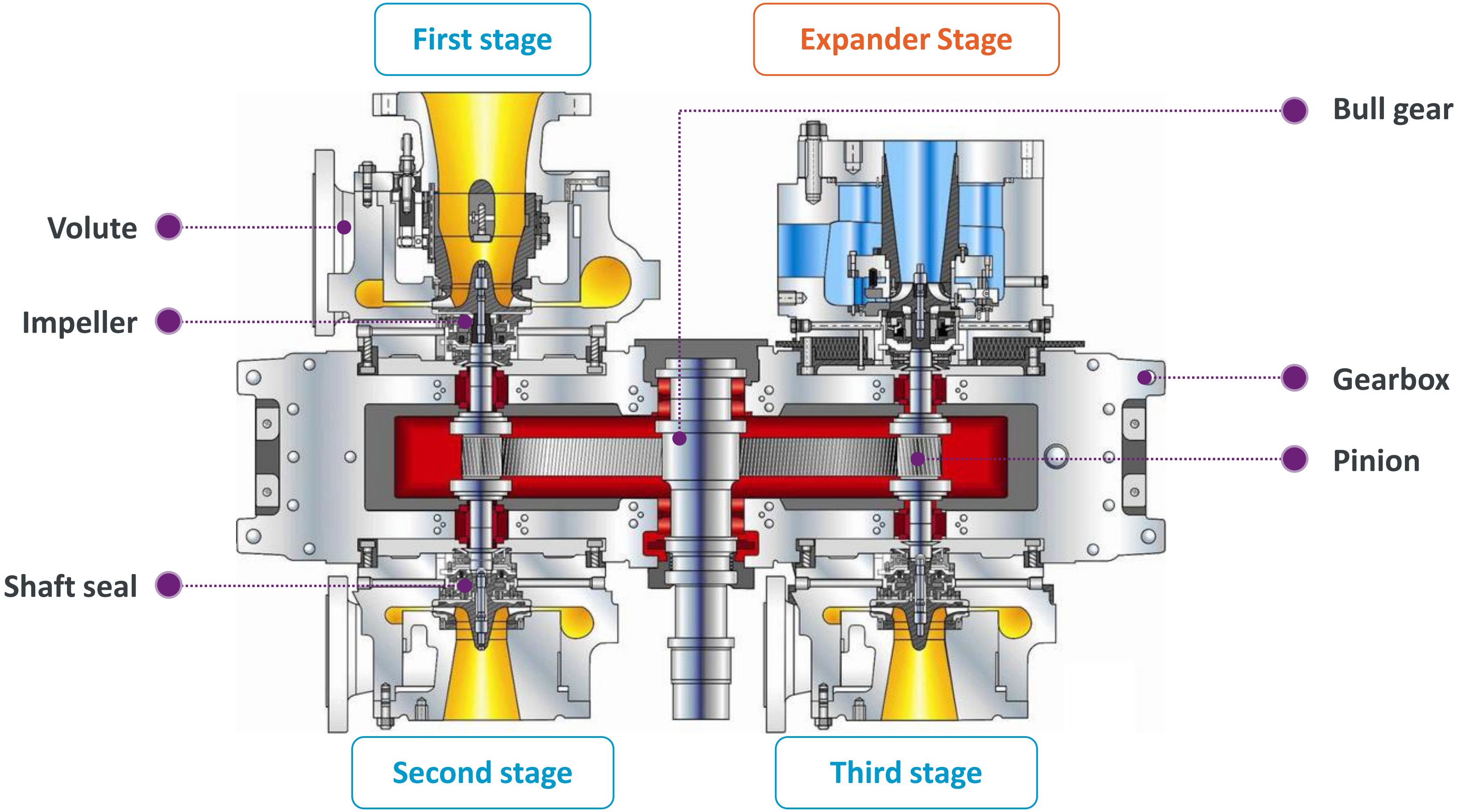
Multi-stage turboexpanders

Compander in Nitric Acid

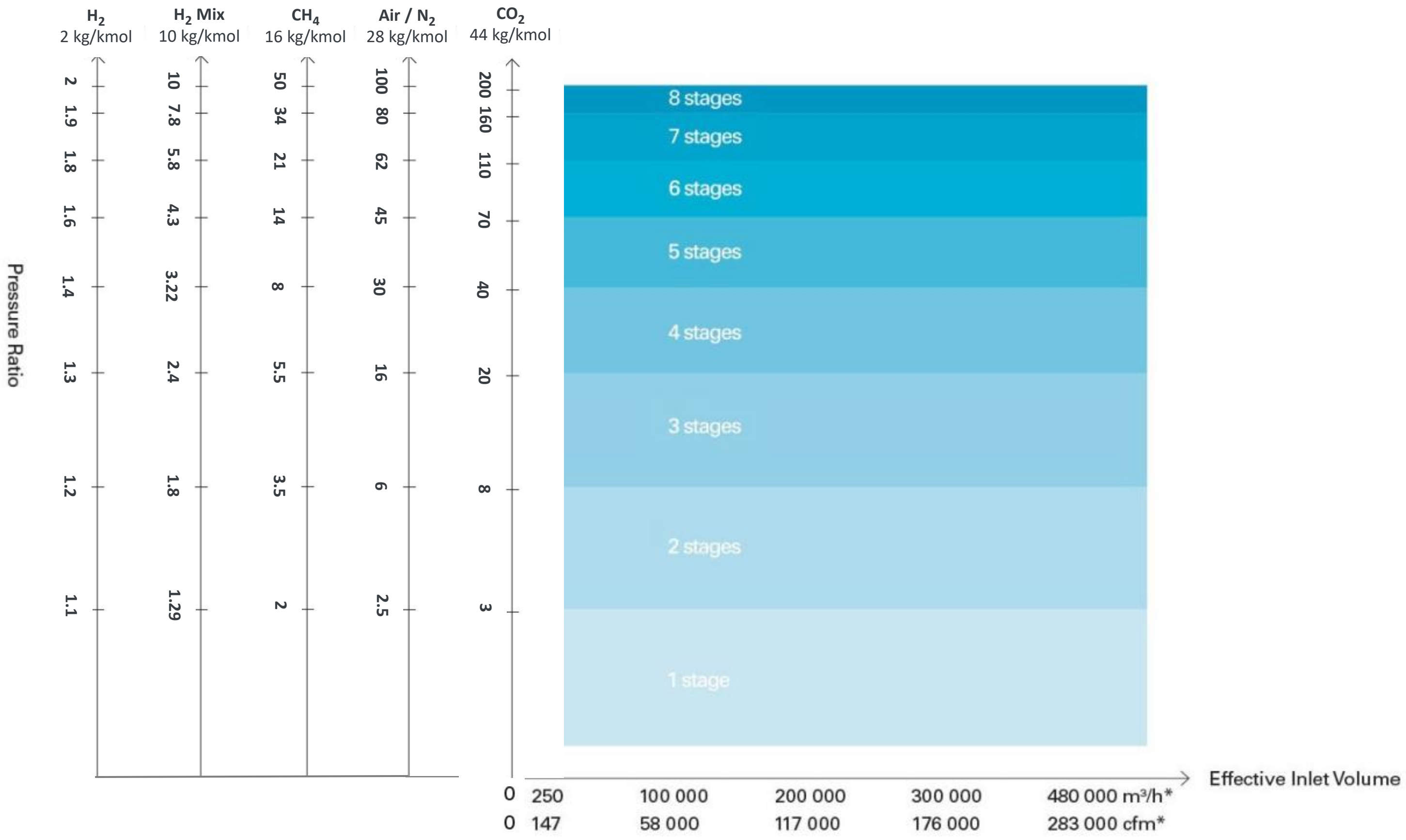
Six-stage compressor for PSA Tail Gas

Eight-stage compressor for Urea

Compander concept and working principle



Performance range of integrally-geared compressor technology

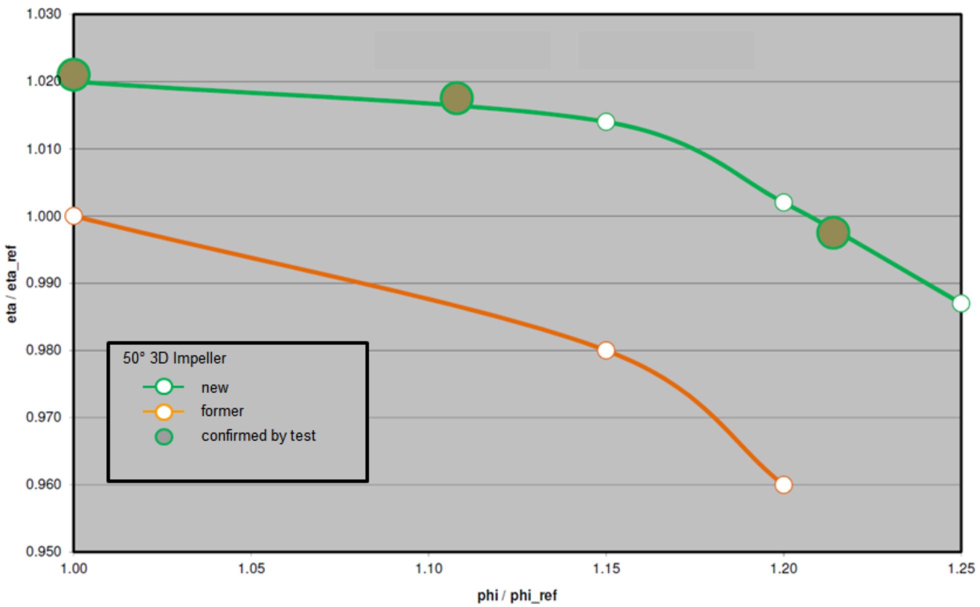


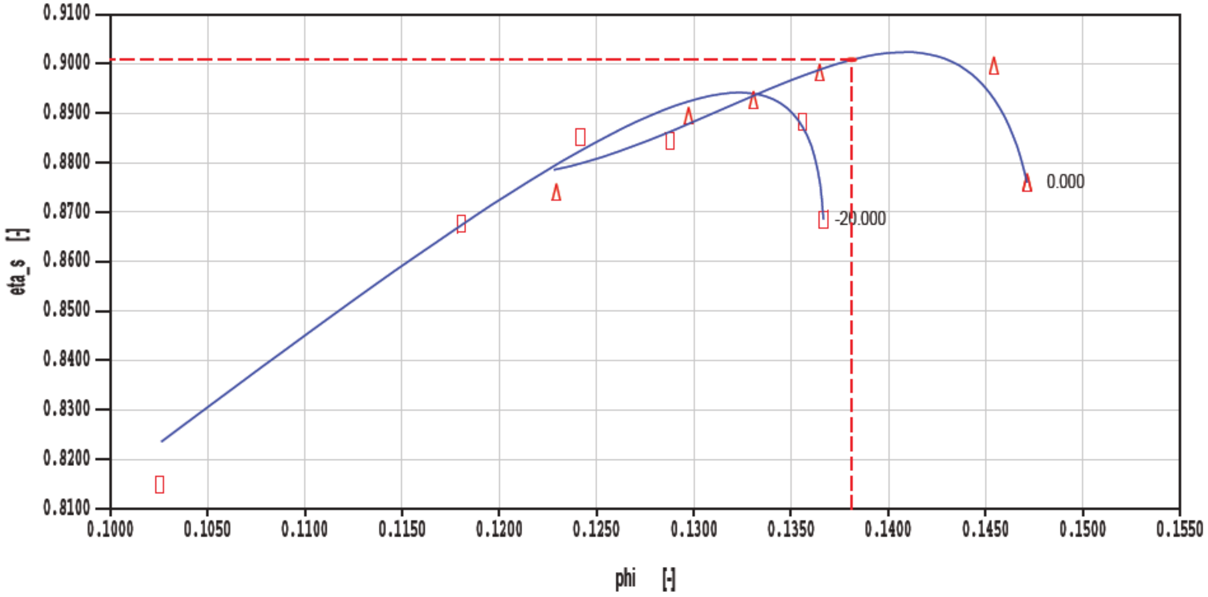
$$Y_S \sim \frac{R_n}{Mw} \cdot \left[\left(\frac{P_2}{P_1}\right)\right]$$

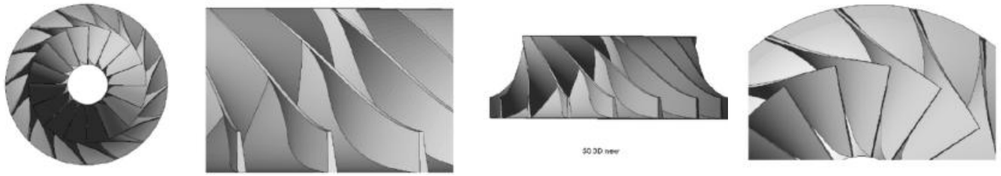
$$Mw \uparrow \qquad \frac{P_2}{P_1} \uparrow$$

Maximizing frame efficiency and superior stage efficiency

Proven in test BED performance test / Significantly improved flow coefficient and proven efficiency



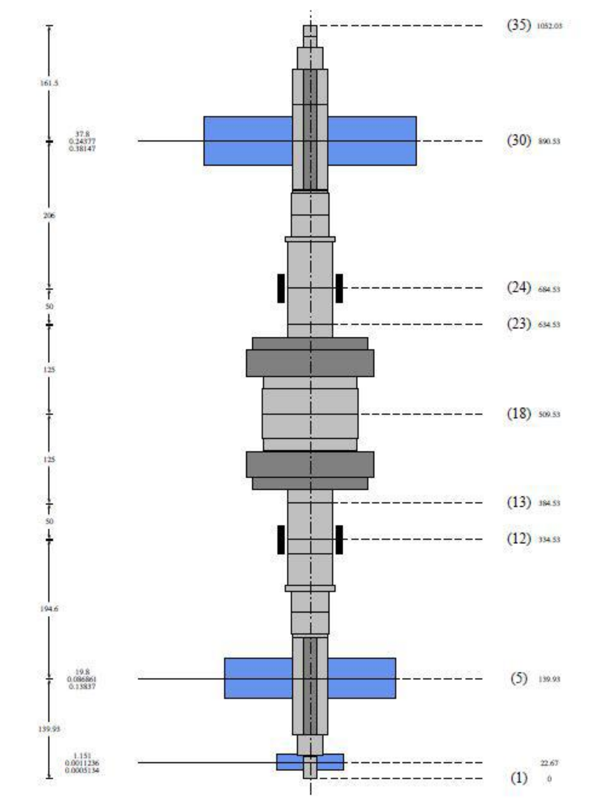




GT137 stage confirmed 90% isotropic efficiency based on PTC10 procedure

How integrally-geared compressor technology ensures reliability

Rotor design



- Rotor model is divided into sections, which are defining mass and stiffness
- Done for every rotor
- Fully API 617 Ch.1 – 2.6 compliant lateral vibration analysis
- The lateral vibrational analysis fulfils the requirements for
  - **Separations Margins (SM)** in regards to its critical speeds,
  - Maximum allowable vibration amplitudes regarding the **minimum design clearances**
  - The requirements of the **stability criteria** according API 617 Ch.1 – 2.6

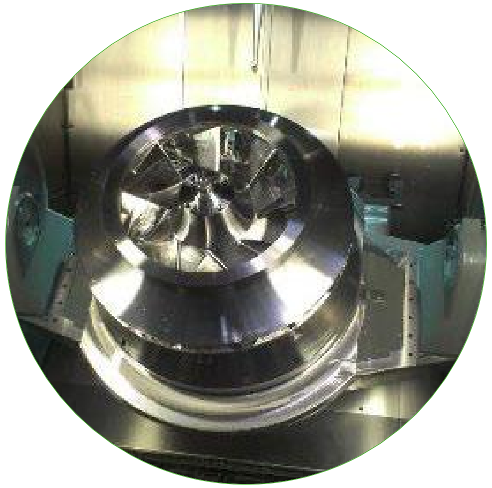
How integrally-geared compressor technology ensures reliability

Bearing design

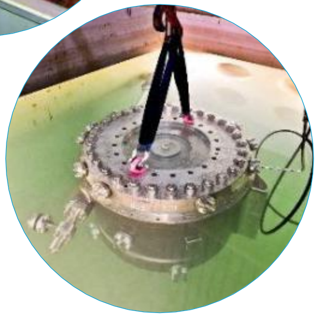
- **Standard bearing temperature limits:**
  - At operating condition: 110 °C
  - Alarm level: 115 °C
  - Trip level: 125 °C
- API requirement of 100 °C can be achieved by appropriate bearing design and power distribution
- Experience shows that higher temps than API recommendations do not affect bearing reliability

How integrally geared compressor technology ensures reliability

Impeller machining



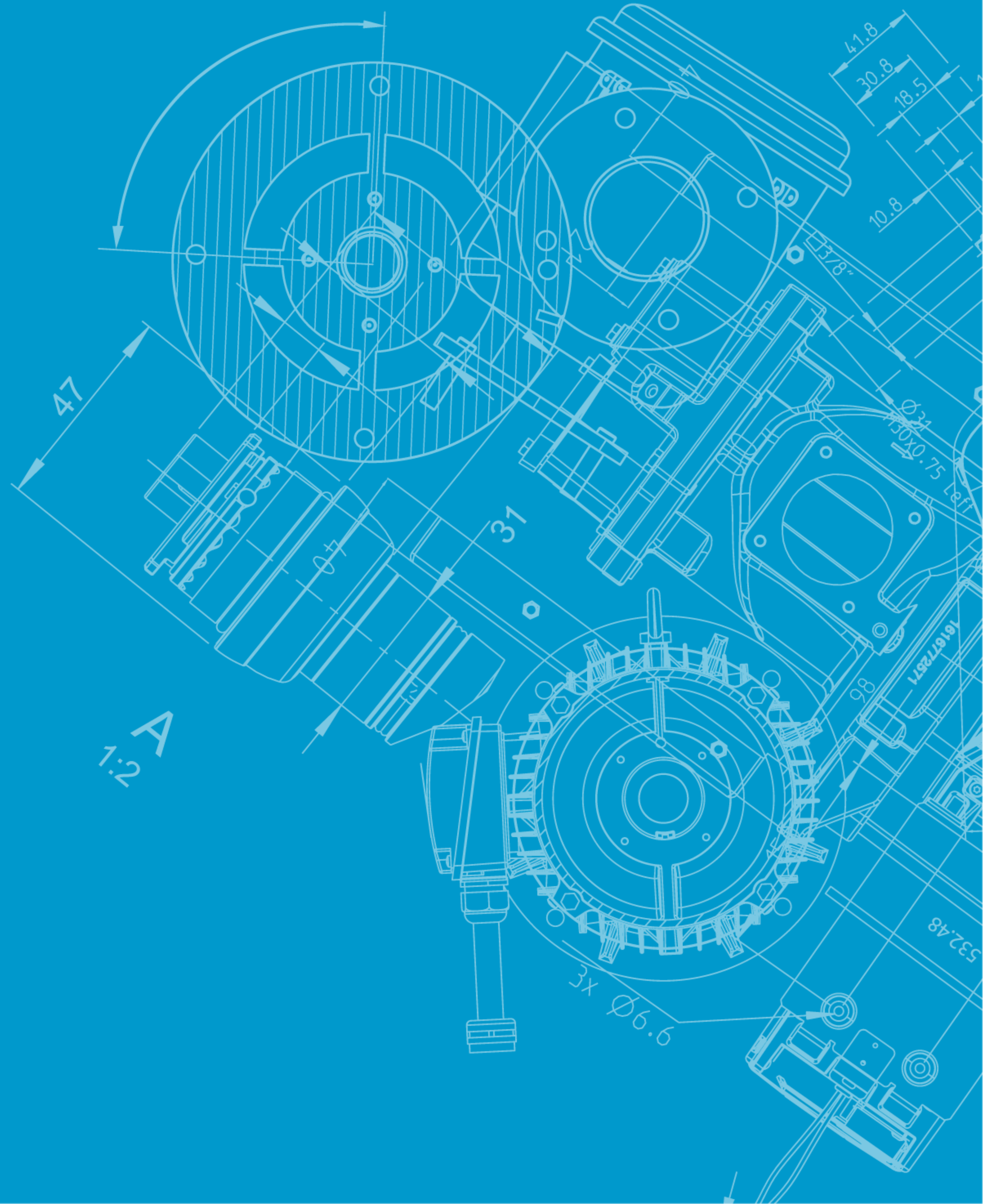
Dye pen and hydro testing



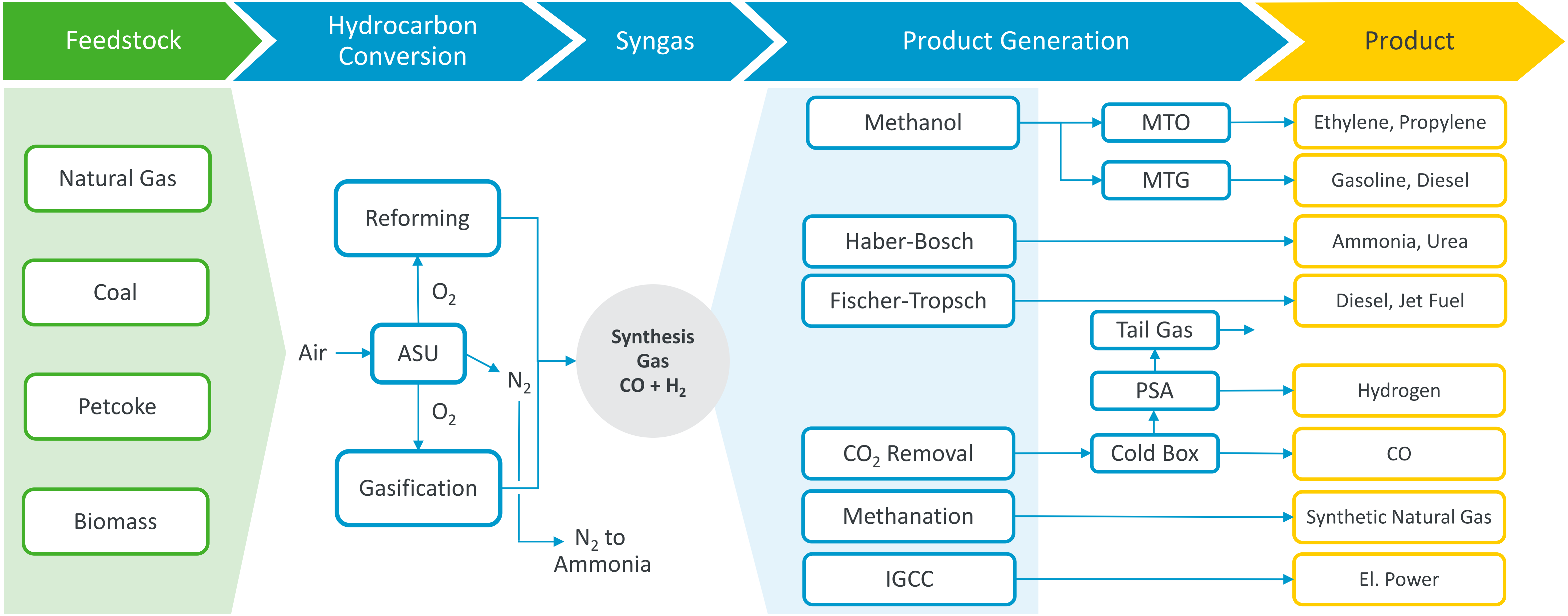
Low and high-speed balancing of rotors

Performance testing

Technological experience in industrial applications



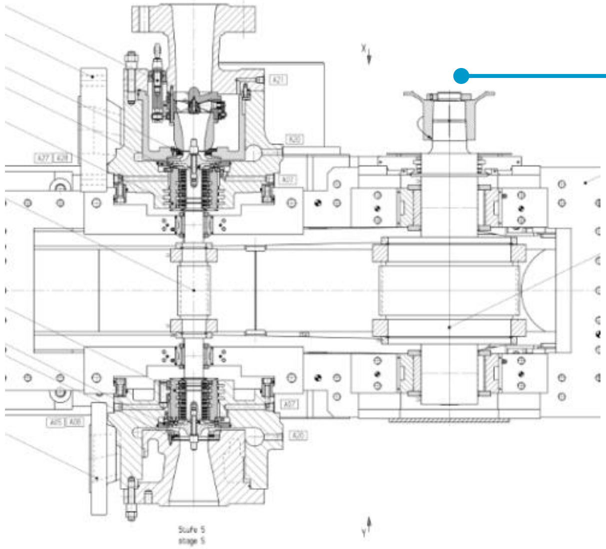
Turbocompressors for syngas: Production of hydrogen and CO

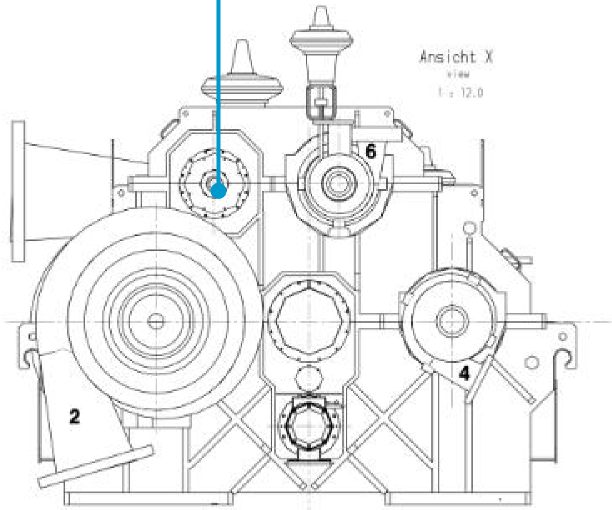


CO_2 compressors in SGP process (coal gasification)

Reference – Datang CO_2

Year Ordered	Code Word	Name of Buyer	Compressor Type	Q'ty	Gas Handled	Volume m^3/h	t1 °C	P1 bar(a)	P2 bar(a)	Speed Rotors rpm	Power kW	Speed Driver rpm	Name of End User	In Country
2008	Datang CO2	CNWR & EPM&E	GT070T5K1/ 021T1K1	3	CO2	43 410 46 548	12 87	1,09 55,43	55,47 82,37	10 364 32 465 28 500	9 300	6 000	Datang International Power	China





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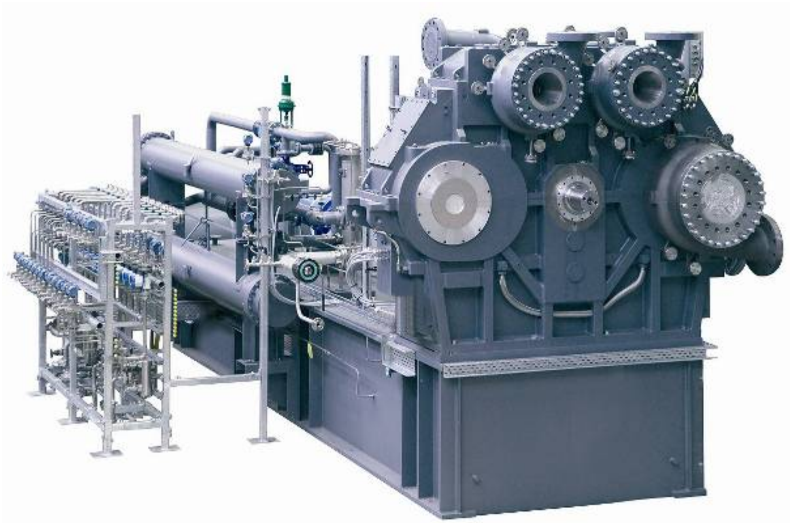
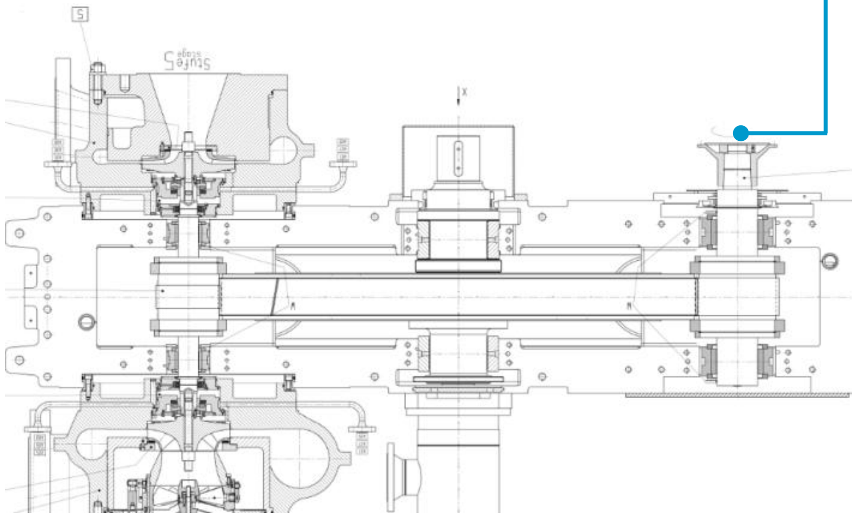
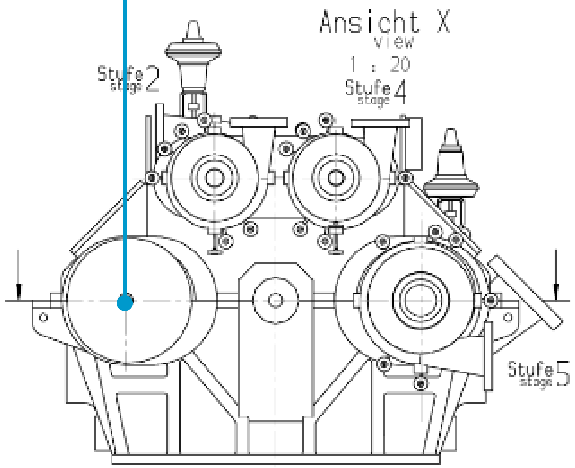
Combined GAS Compressor in Coal-to-Methanol

Reference – Huhot 3

Year Ordered	Code Word	Name of Buyer	Compressor Type	Q'ty	Gas Handled	Volume m^3/h	t1 °C	P1 bar(a)	P2 bar(a)	Speed Rotors rpm	Power kW	Speed Driver rpm	Name of End User	In Country
2005	Huhot 3	CWCEC	GT032T5D0/ 040T1D0	1	H_2, CO, CO_2, CH_4	5 266 9 303	40 55	21 73	73 80	25 646 26 715 13 357	9 600	10 341	CWCEC	China







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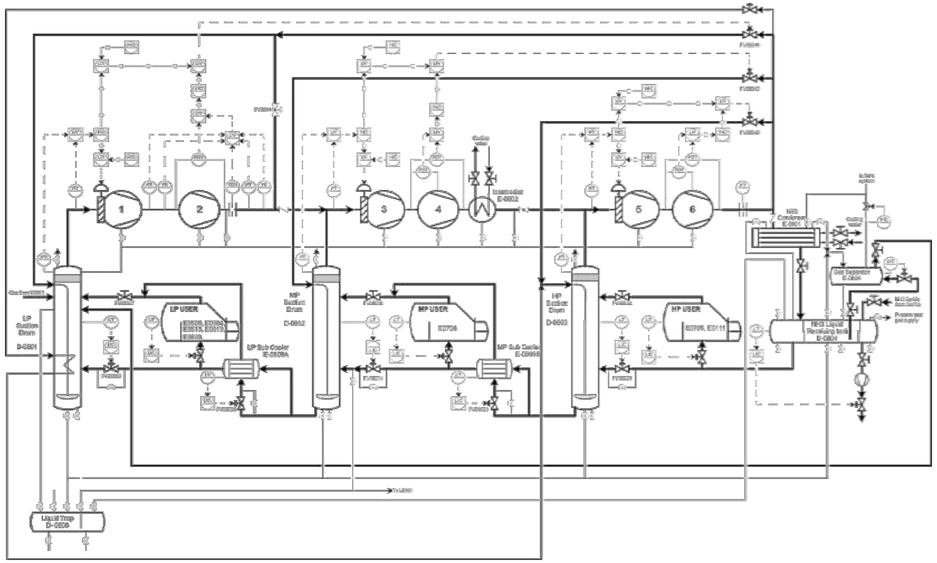
NH_3 refrigeration compressor in ammonia plant

Year Ordered	Code Word	Name of Buyer	Compressor Type	Q'ty	Gas Handled	Volume m³/h	t1 °C	P1 bar(a)	P2 bar(a)	Speed Rotors rpm	Power kW	Speed Driver rpm	Name of End User	In Country
2009	HULUNBEIER NH3	DATANG HULUN-BEIER	GT040T2D1 GT040T2D1 GT040T2D1	1	NH3	12 218 10 793 12 456	-38 20 25	0.77 2.31 4.67	2.34 4.70 15.9	19 023 16 785 23 136	4 590	9 732	DATANG HULUN-BEIER	China



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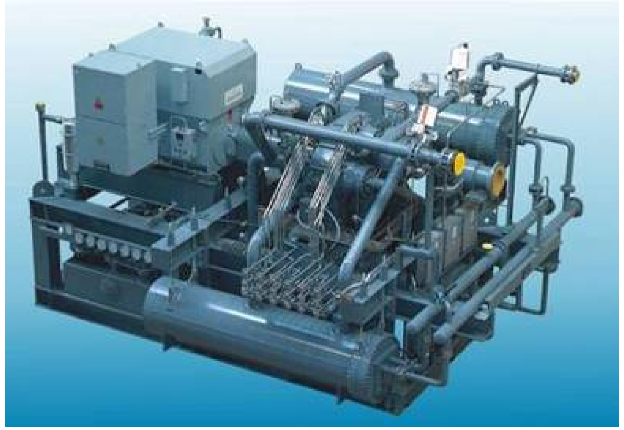
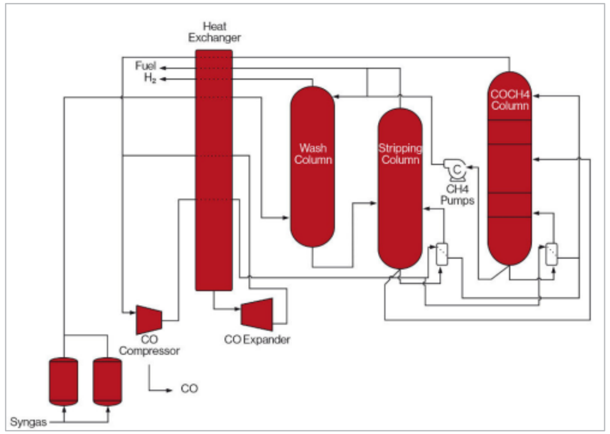
CO production

Rotating machinery around the cold box

- Multi-stage CO compressors
- Turboexpanders





Schematic by Air Liquide

Hydrogen compressors

Single-stage centrifugal compressor for a low mole-weight gas

Reference in operation in China:

Flow	:	12 093 m^3/h
P1	:	49,5 bar (a)
P2	:	53,5 bar (a)
Power	:	2 000 kW
Mol weight	**:**	**15.84 kg/kmol**

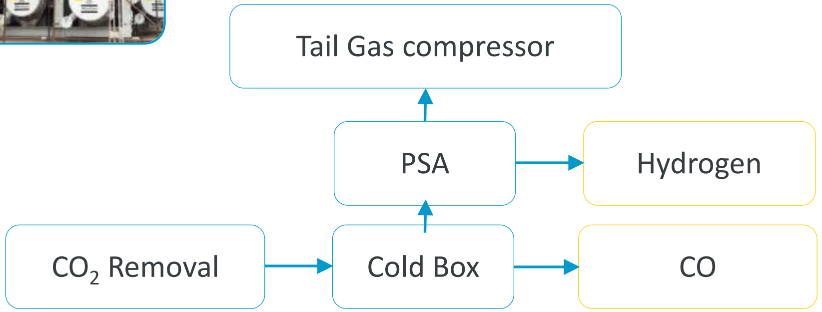
UNIT
Methanation TREMP HTAS

SERVICE
Methanation Recycle Compressor

PSA tail gas compressors

References

Year Ordered	Code Word	Name of Buyer	Compressor Type	Q'ty	Gas Handled	Volume m^3/h	t1 °C	P1 bar(a)	P2 bar(a)	Speed Rotors rpm	Power kW	Speed Driver rpm	Name of End User	In Country
2013	RIL PSA	Reliance	GT063T5D1	1	H2 mix(%) (Mw 5-15)	61 300	22	1,2	5,5	13061 15366 19350	7 000	1 480	Reliance	India



Specific project highlights

- Varying gas mol weight 5 to 15 kg/mol
- H_2(80%) + CO(4%) + CO_2(5%) + CH_4(6%) + N_2(3.7%)
- Double dry gas seals arrangement per API 614 5th ed
- Impeller loads shall be within 75.6 % of the material yield strength of the impeller.
- Bearings metal temperature shall not exceed 90/95°C at most adverse operation with max oil inlet temp of 50°C
- Lube Oil System as per API 614 5th edition

Summary

Summary

- Several different gas services can be handled by one IG compressor → **fewer auxiliaries** and **one driver**
- Maximum reliability with **well-referenced compressor core**, backed by decades of experience in process gas compression and expansion
- **Noticeable energy savings** depending on the application up to 30% versus a single-shaft compressor due to integrally geared technology with possible interstage cooling and individually designed rotor speeds giving highest efficiency
- Reliability and maintainability are assured by meeting **API standards** and requirements for handling process gas
- **Smaller footprint** due to smaller stages and frames and since no intermediate gearbox is required for speed adjustment
- Reduced installation time and cost because the packaged compressors are **delivered "ready for operation"**
- Performance **testing** and worldwide **aftermarket services** available

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