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October 2015

Mobil SHC Gargoyle 80 POE Technical Deck

Energy lives here™

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Instructions

- Use arrow keys to scroll into the Power Point presentation. To see a specific item from the Overview Slide (i.e. Lubrication challenges) just click on it.

- Refrigeration outlook

- In some sections by clicking on "More…" you'll be driven to the Back up Data and Slides

- From any slide of the presentation is it possible to go back to the Overview or Main Section by clicking the "Ice Cube"

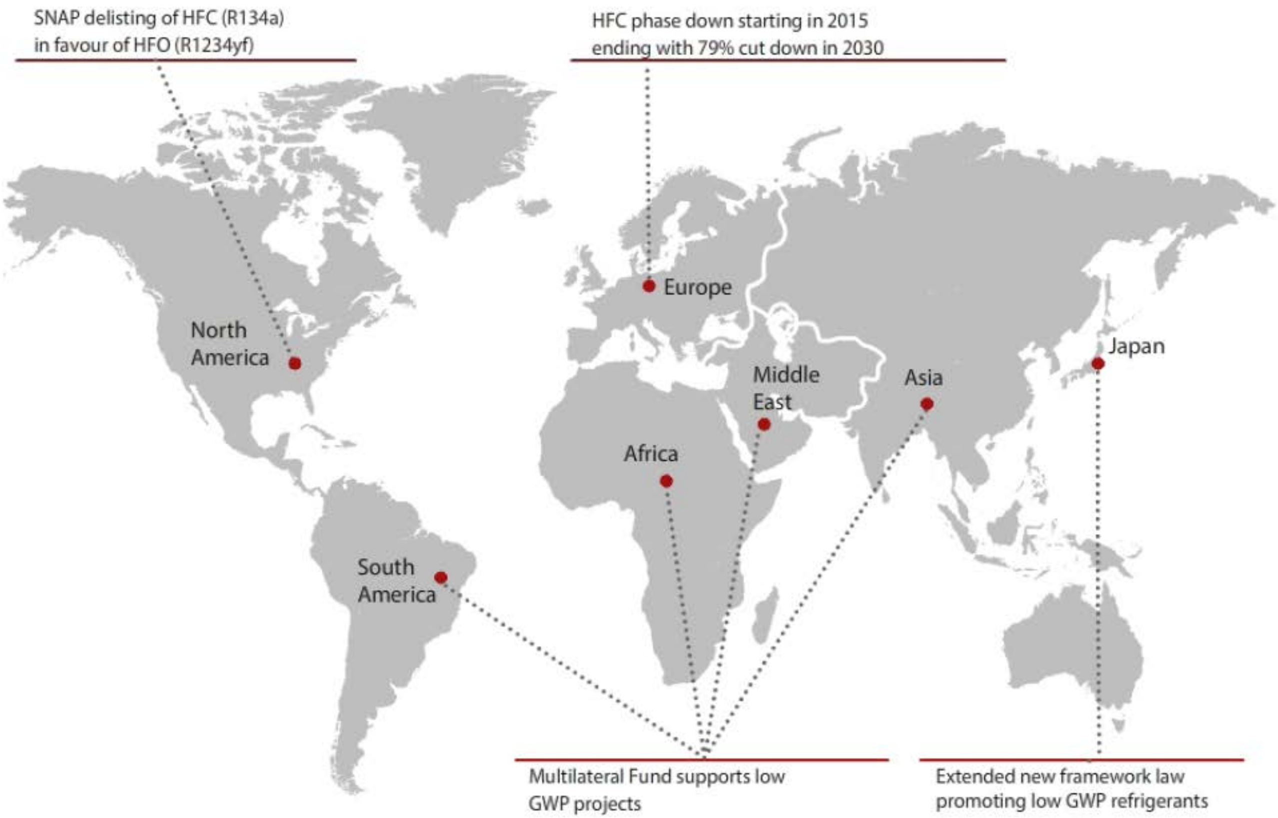
- Glossary of Terms and Acronyms used is accessible by the Overview Slide

Overview

- Refrigeration outlook
- Why CO_2?
- Lubrication challenges
- EM Technology
- Field test results
- Change over procedure
- Daniel Chart, Miscibility, Density
- Glossary
- CO_2 System Safety
- Back Up Slides

Refrigerant Outlook

Global Overview of Refrigerant Regulations



Worldwide:

- Ongoing discussions concerning a global phase down under the Montreal Protocol
- National tax schemes on HFC
- National incentives and subsidies

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**Source Danfoss/Chillventa 2014*

Refrigeration Gases Trends 2014-2020

- **EU** has taken a clear direction towards **phasing down HFCs** and is projected to be the fastest-growing region in the market due to the high rate of **natural refrigerant** adoption by the end users. **Asia-Pacific** is the second-largest market for natural refrigerants.

- **Ammonia refrigerants (R-717)** dominated the market in 2015 and are estimated to experience a steady growth on account of its wide usage in industrial refrigeration and light-commercial refrigeration applications.

- **Carbon dioxide refrigerant (R-744)** is projected to witness the highest growth in the natural refrigerants market till 2020 due to its growing adoption by superstore and food retail chains for refrigeration and air-conditioning applications.

- **Hydrocarbon refrigerants (R-290, R-1270)** are estimated to witness high growth on account of its rising application in domestic refrigeration and light-commercial refrigeration.

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**Source: Refrigeration and Air Conditioning Magazine October 2015*

European Market Trends

Market Segment Future	Current Refrigerant	New Refrigerants
Household Refrigerator	R-134a, R-600a	R-600a (Isobutane)
LT Small Commercial	R-134a, R-404A,	R-290 (Propane) R-744 (CO_2)
Household AC and MT Small Commercial Refrigeration	R-134a, R-410A	R-744 (CO_2) HFC/HFO blend
LT Commercial Refrigeration	R-717, R-134a/R-744	R-717 (Ammonia), R-744 (CO_2), R-1234ze, HFC/HFO blends GWP < 150
Large Commercial/ Industrial Chillers	R-134a	R-1234ze or HFC/HFO blends w/GWP < 150

Why CO_2

Why CO_2

- CO_2 is termed a **Natural Refrigerant** because it exists in the natural environment. Carbon dioxide is a naturally occurring substance – the atmosphere is comprised of approximately 0.04% CO_2 (370 ppm).

- Excellent environmental properties (ODP*=0 and GWP*=1)

- As a refrigerant, it is a manufactured product that conforms to strict purity specifications. Its physical properties require special handling. The system pressures are much higher than in conventional systems, and all the components are designed accordingly.

- Today there is no difficulty in sourcing all the necessary equipment.

- Low cost refrigerant

**See Glossary at the end of presentation*

CO_2 Properties and Application Peculiarities

Criteria	Properties
Cooling capacity	Significantly higher volumetric capacity than conventional refrigerants
Environmental properties	Global Warming Potential (GWP) = 1, significantly lower than for commonly used HFCs
Refrigerant cost	Lower than for HFCs, but system costs are generally higher
Safety	Low toxicity and nonflammable: high-pressures and associated hazards present additional challenges
Availability of appropriate standards	Safety Standards EN378 & ISO 51491 include R744
Composition	Single molecule
Availability of refrigerant	Varies globally but generally available

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CO_2 Properties and Application boundaries

Criteria	Application Peculiarities
Operations	Operating and stand still pressures significantly higher than for all other common retail refrigeration refrigerants
Availability of system components	Many components are different to those used on HFC retail systems, but these are now generally available
Ease of use	High-pressure and low critical point drive the need for more complex systems
Suitability as a retrofit	Refrigerant NOT suitable due to higher pressures

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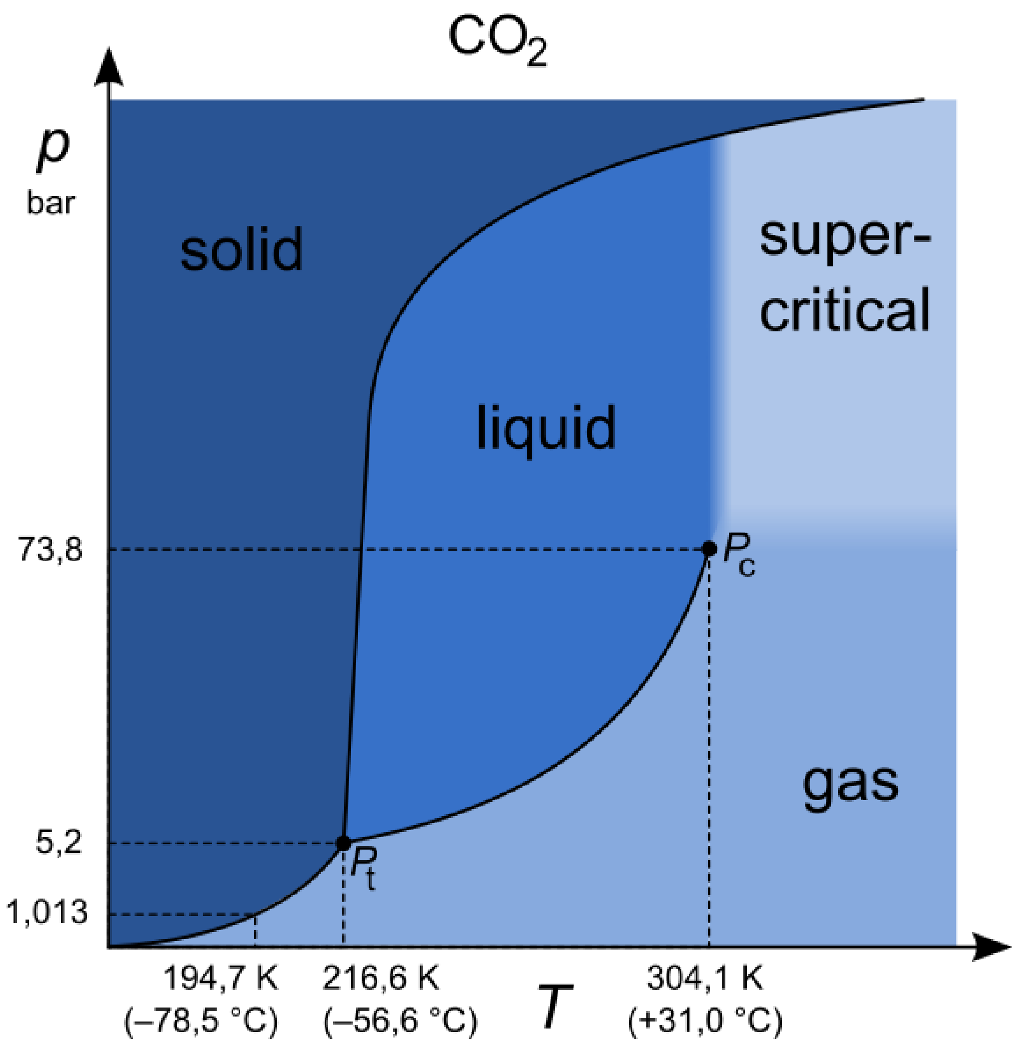
CO_2 Phase Diagram



The **critical point (*Pc*)** is the condition at which the liquid and gas densities are the same. Above this point distinct liquid and gas phases do not exist. There is no phase change when heat is removed from a *transcritical* fluid while it is above the critical pressure and temperature.

The **triple point (*Pt*)** is the condition at which solid, liquid and gas co-exist below this point there is no liquid phase. At atmospheric pressure, solid R744 sublimes directly to a gas. If R744 is at a pressure higher than the triple point and it reduces to a pressure below the triple point (for example to atmospheric pressure), it will deposit directly to solid.

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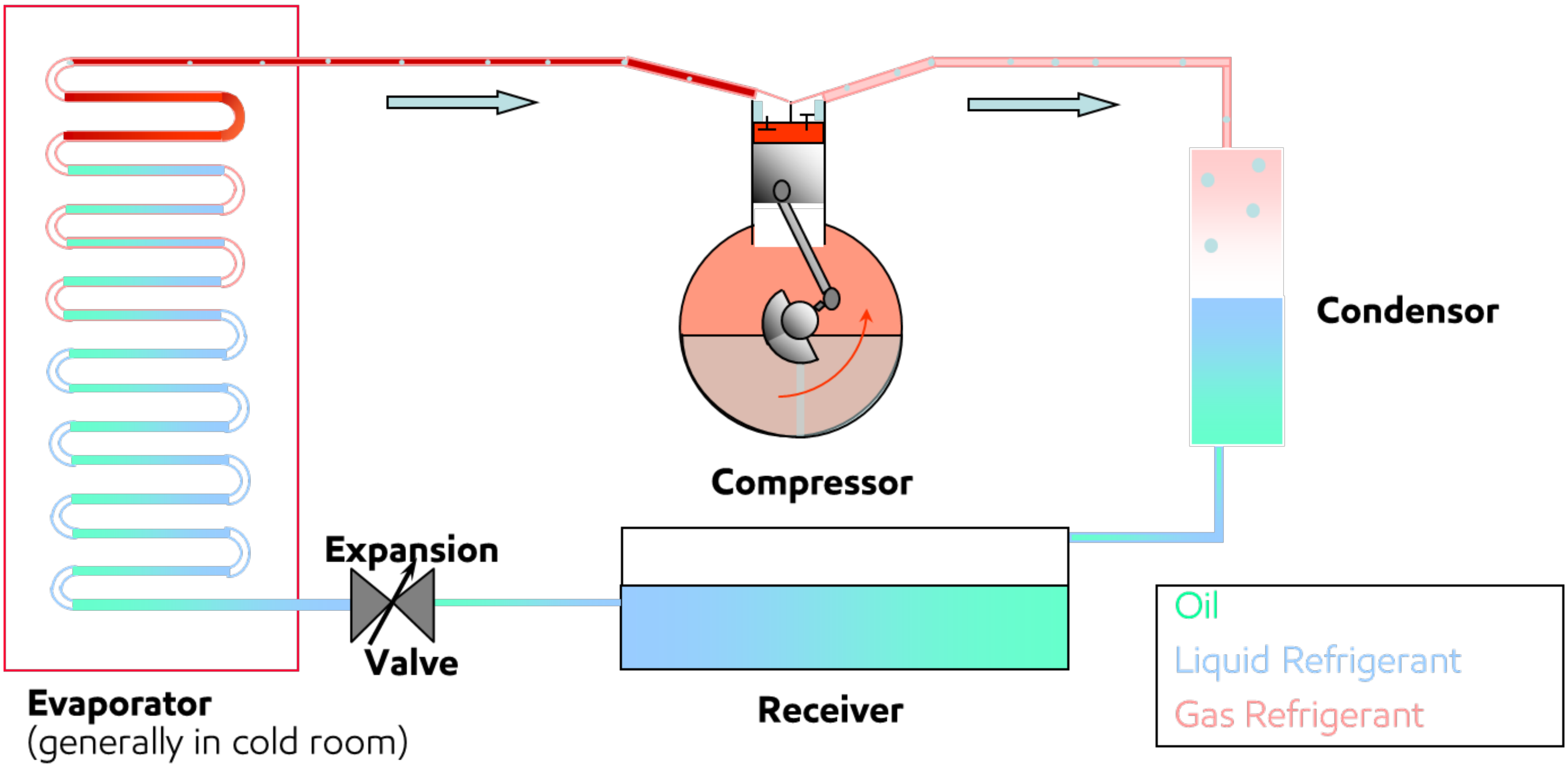
Lubrication Challenges

Lubrication Challenges with CO_2

- Refrigerant changes from **liquid** to **gas** after expansion valve to generate cold
- Compressor is used for gas reliquidfication



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Lubrication Challenges with CO_2

Main Challenges

- High operating pressures (standstill pressure from 50-60 bars up to 130) and temperatures compared to HFCs place higher loads and stress on bearings and other contacting parts in motion.
- High solvency/solubility of CO_2 in some POEs leads to excessive viscosity reduction.
- Outgassing on bearing surfaces may disrupt lubricant films.

Impact on operation

- Insufficient lubrication and increased wear of bearings reduced component lifetime, increased maintenance costs.
- Improper sealing of clearances and loss of compression, reduced compression efficiency, higher operating cost, higher energy consumption.

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EM Technology

Mobil SHC Gargoyle 80 POE: a Miscible Lubricating oil for Subcritical CO_2 System

ExxonMobil has developed Mobil SHC Gargoyle 80 POE, a CO_2 miscible lubricant delivering step-out performance

Features	**Advantage & Potential Benefits**
High oil film thickness in the presence of refrigerant	Improved compressor protection resulting in potential for extended compressor life. Better shaft sealing, reduced bearing fatigue and unscheduled downtime.
Appropriate miscibility and VPT relationships with carbon dioxide	Lower operating oil carter temperature, resulting in higher in-service viscosity ensuring a thicker oil film for better lubricity and wear protection. Reduced compressor wear resulting in lower maintenance costs.
High Viscosity Index	Excellent low temperature fluidity and potential for improved evaporator efficiency.
Low traction coefficient	Potential for improved system efficiency and reduced power consumption.

More...

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Physical Chemical Properties

Product Name		Mobil SHC Gargoyle 80 POE
Kinematic Viscosity at 40 °C, cSt	ASTM D445	78
Kinematic Viscosity at 100 °C, cSt	ASTM D445	11.4
Viscosity Index (typical)	ASTM D2270	142
Total Acid Number, mg KOH/g	ASTM D974	0.02
Flash Point (COC), °C	ASTM D92	285
Pour Point, °C	ASTM D5950	-45
Density at 15.6°C, g/mL	ASTM D4052	1.020
Water, ppm	ASTM D1533	< 30
Brookfield Viscosity, -30°C, cP	ASTM D2983	23,600
Critical Solubility Limit Temperature, 10 wt% Lube in CO_2, °C	Sealed Glass Tube	0
Falex Pin and Vee Block Test, Load at Failure, Direct lbs.	ASTM D3233, Method A	1000

More…

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Performance Summary: Mobil SHC Gargoyle 80 POE

- Excellent lubrication performance
- Improved viscometrics under CO_2 environment
- Extended compressor parts life
- Lower compressor operating temperatures
- Improved process regulation & reliability
- Reduced maintenance and operation costs

Note: Summary based on one customer field trial on 4 CO_2 reciprocating compressors from December 2013 to April 2015

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Field Test Results

Field Test Description

- Site: Slaughterhouse
- Refrigeration System: Cascade System NH_3/CO_2 Subcritical, use of the cold and heat generated
- Units: 4 reciprocating compressors, with variable power
- Previous oil: Conventional POE
- Analysis: Oil sampled from all 4 compressor at regular intervals

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Field Test Implementation Equipment Details

Compressor	Filling date Mobil	Equipment hours at start of test
CP1	19/12/2013	Brand new compressor End of Test : Dec.1st 2014, after 5600 hours
CP2	18/03/2014	7121, 2nd filling Oct. 30th 2014, 8765 hours
CP3	20/02/2014	6974
CP4	06/05/2014	7418

Comments on oil switch:
- Double oil flushing prior to fill the final test oil charge in all compressors
- Oil coalescing cartridges check and maintain upon dimensional integrity
- Study concluded when CP1 reached 5600 hours

End of Test inspection Analysis Results

Cumulative hours oil test inspection summary:

- Viscosity: Stable
- Wear trends: Iron, low regular trend
  Aluminum, very low to no trend
  Copper and Tin, not detectable/low value
- Maximum estimated contamination with previous oil: <2% (Dec. 1st 2014 sample)

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CP1 – End of Test inspection

CP 1 inspection has been carried out on December 2nd 2014:

- Equipment age: 5,600 hours,
- Lubricant: Mobil SHC Gargoyle 80 POE

In presence of:

- Service provider
- Builder
- Customer
- ExxonMobil

CP1 – End of Test inspection – Parts Rating

Compressor part rating	Conditions
Connecting rod:	
Halves bearings	Good condition, limited wear
Bushings	Good condition, very limited wear
Piston Pin:	Good condition, no wear
Piston Rings:	No deposit, move easily & smoothly
Piston:	
Thrust Side	Acceptable, some visible scratches
Anti-Thrust Side	Good conditions no scratches
Cylinder liner/sleeve:	
Thrust Side	Good condition, limited scratch area
Anti-Thrust Side	Excellent condition, honing marks
Discharge Valve:	
Plate	Good condition
Seat	Good condition
Crankshaft:	Good condition
Crankcase:	Clean, no deposits

More…

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CP1 – End of Test inspection – Summary

Mobil SHC Gargoyle 80 POE is exhibiting very good lubricating performance:

- Wear trends through Signum analysis are remaining at low levels after 5,600 hours

- End of Test inspection of Compressor CP1 demonstrated that: most critical and sensitive parts of the compressor are in good condition, Mobil SHC Gargoyle 80 POE is performing better than conventional POE at similar 6,000 hour inspection/overhaul.

Process improvements with Mobil SHC Gargoyle 80 POE

- Crankcase Oil and CO_2 temperatures are lower vs. conventional POE
- Reduced occurrence of peak of required power when using Mobil SHC Gargoyle 80 POE

Compressor #	Oil Type	Suction pressure (Ps), bar	Compressor load, %	Temperature, °C					
				Piston 1	Piston 2	Piston 3	Piston 4	Piston 5	Piston 6
1	Mobil SHC Gargoyle 80 POE	8,5	100%	43,1	42,4	42,6	38,5	41,8	42,8
2	Conventional POE	8,5	66%	54,9	30,1	43,7	45,1	22,5	49,3
4	Conventional POE	8,5	100%	53,2	46,7	51,2	47,9	50,0	52,7

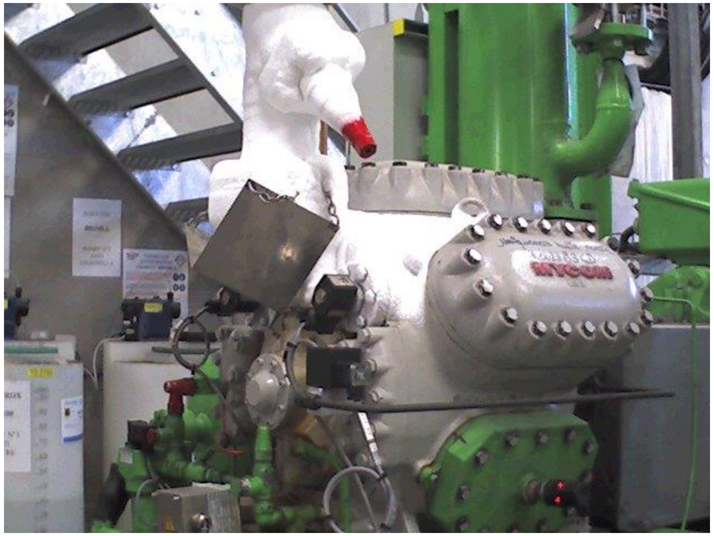
Instant temperatures measured on the head cover plate of the pistons. Measurements were carried out on January 14th 2014

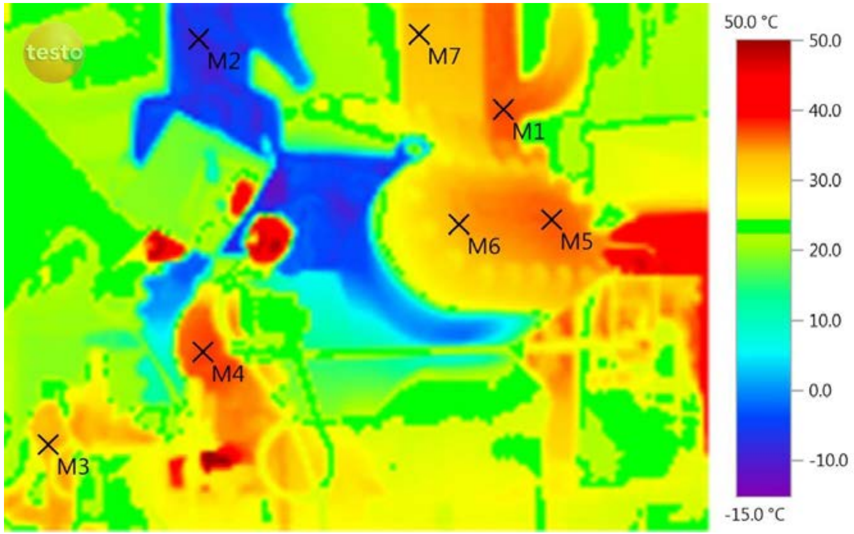
"Compressor 1" lubricated with:	Date	Graph	Motor Speed, rpm	Compressor load, %	Low pressure CO2 receiver, bar		High pressure CO2 receiver, bar		Instant power, kW	
					Average	Max	Average	Max	Average	Max
Conventional POE	October 1st 2014, 2 PM	Graph 5	1500	100	12,0	12,0	29,2	32,0	105,0	123,0
	October 2nd 2014, 2 PM	Graph 6	1500	100	9,8	13,5	28,3	31,5	99,0	128,0
Mobil SHC Gargoyle 80 POE	March 2nd 2015, 2 PM	Graph 7	1500	100	9,3	11,5	26,2	28,0	97,0	100,0
	March 4th 2015, 1 PM	Graph 8	1500	100	9,2	11,5	26,2	27,9	97,0	100,0

Instant powers records on Compressor 1

* *Data Source: Customer in house data logger and temperature probes*

Process improvements with Mobil SHC Gargoyle 80 POE





Temperature mapping through thermal imaging of Compressor 1

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Change Over Procedure

Change over procedure to Mobil SHC Gargoyle 80 POE

1. Start compressor to heat up the oil

2. Drain hot oil as best as possible (to remove potential deposits and as much remaining oil as possible)

3. Estimate compressor cleanliness, change external oil filter and inspect filter(s) Oil coalescing cartridges check and maintain upon dimensional integrity

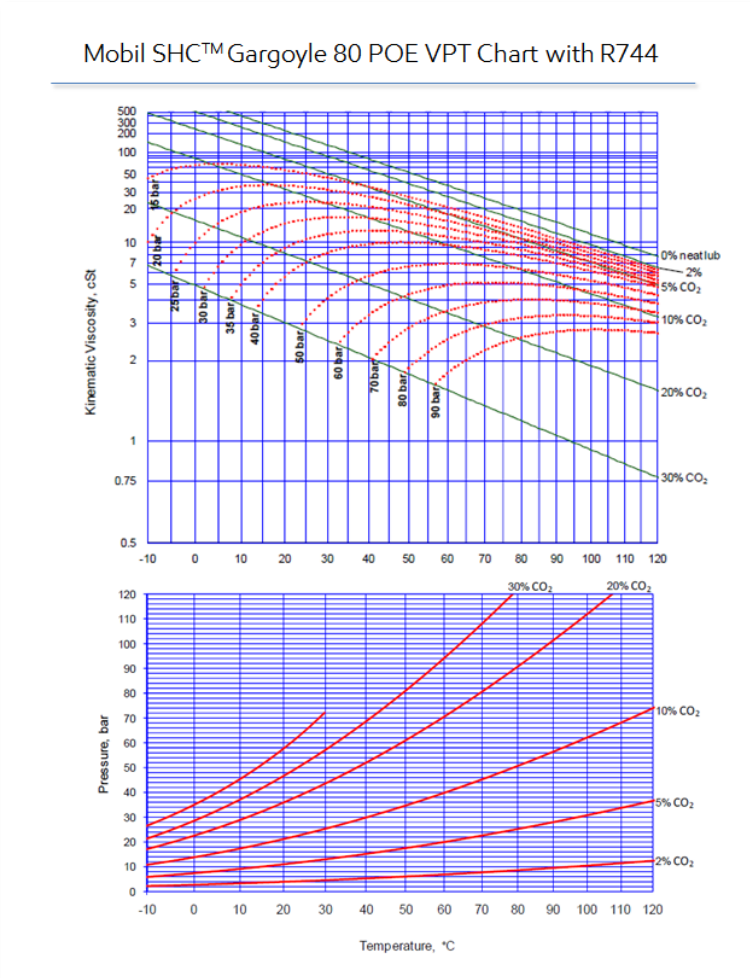
4. Fill in compressor with Mobil SHC Gargoyle 80 POE and start compressor. Control oil pressure and filter(s). Drain after 100 hours.

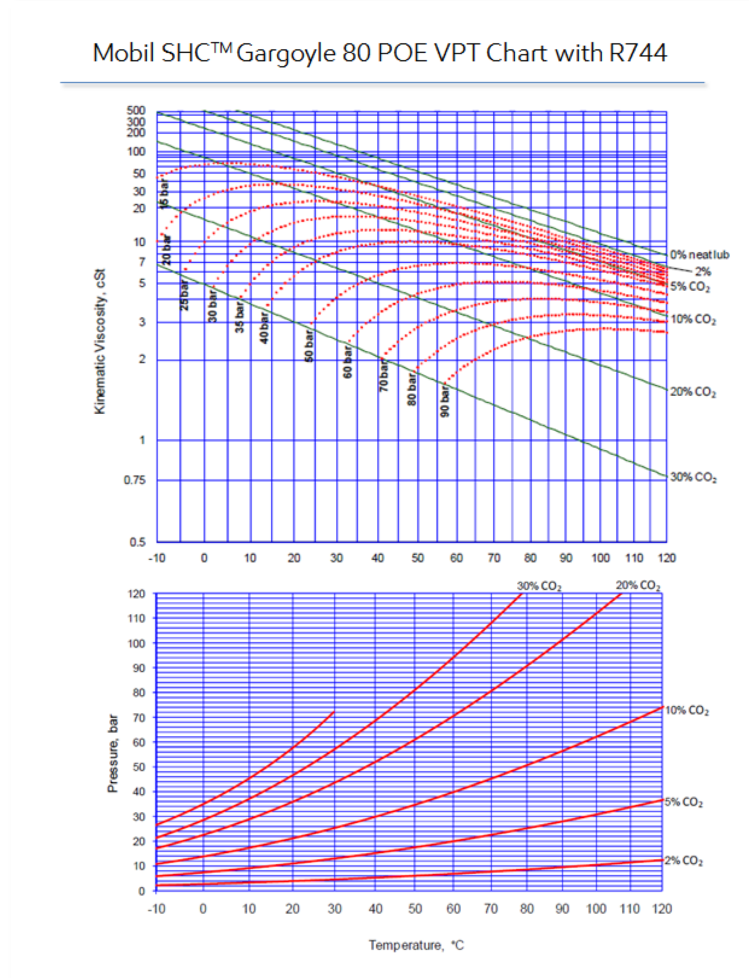
5. Fill in compressor with Mobil SHC Gargoyle 80 POE. Check oil pressure.

Questions & Answers

Daniel Chart, Miscibility, Density

Daniel Chart: Mobil SHC Gargoyle 80 POE with R-744





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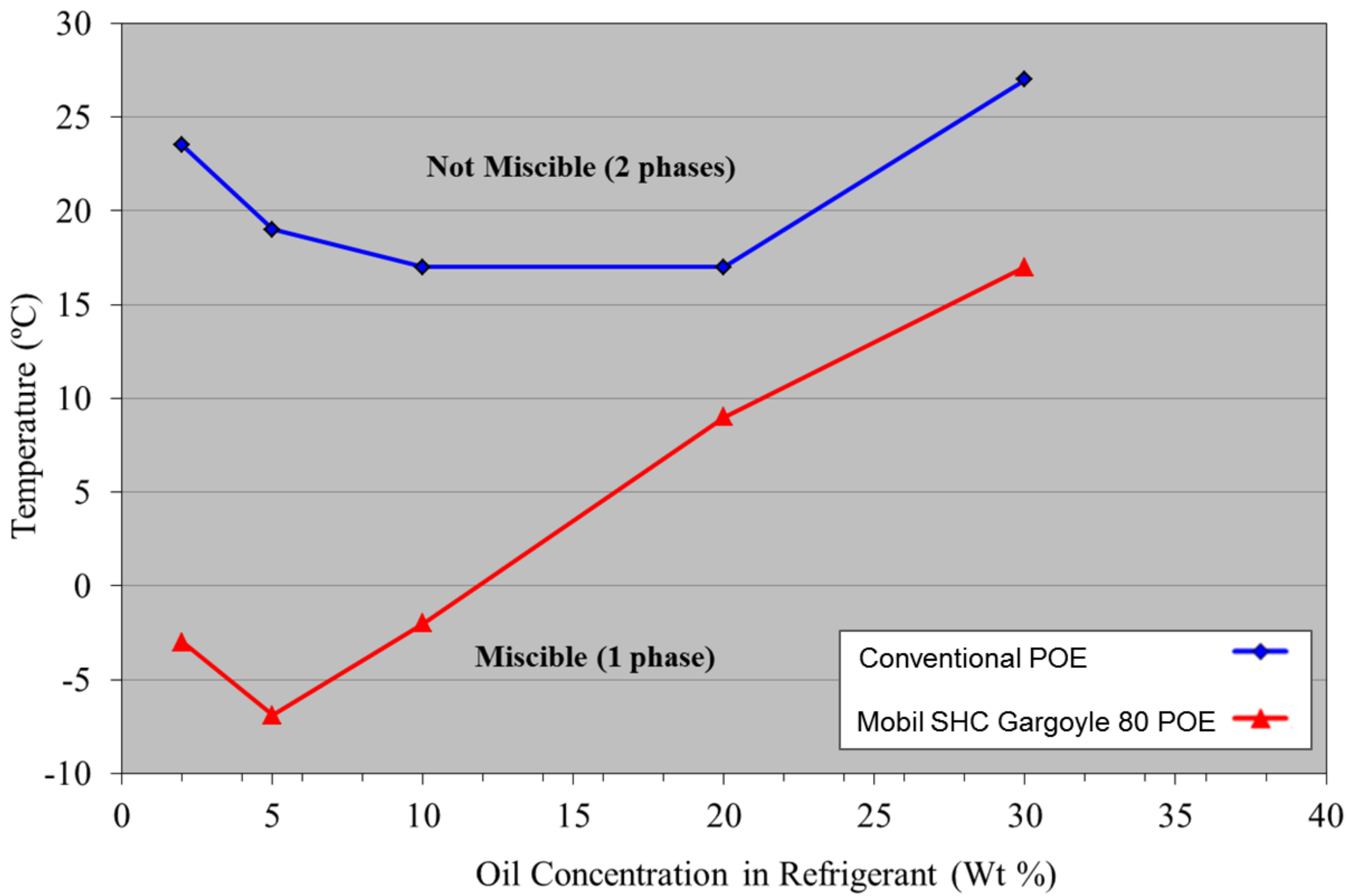
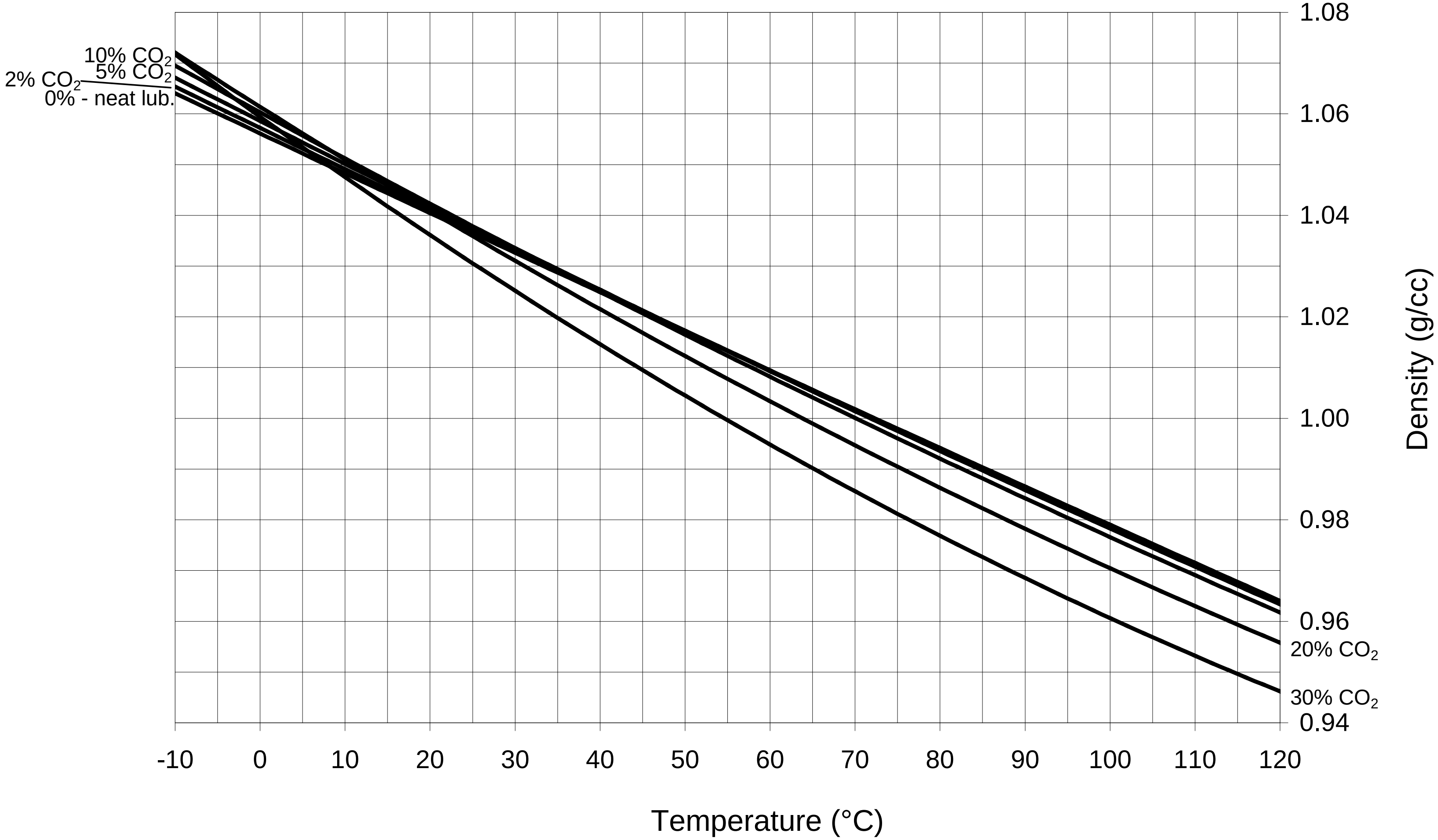
Miscibility Profiles in R-744



Density Chart: Mobil SHC Gargoyle 80 POE with R-744



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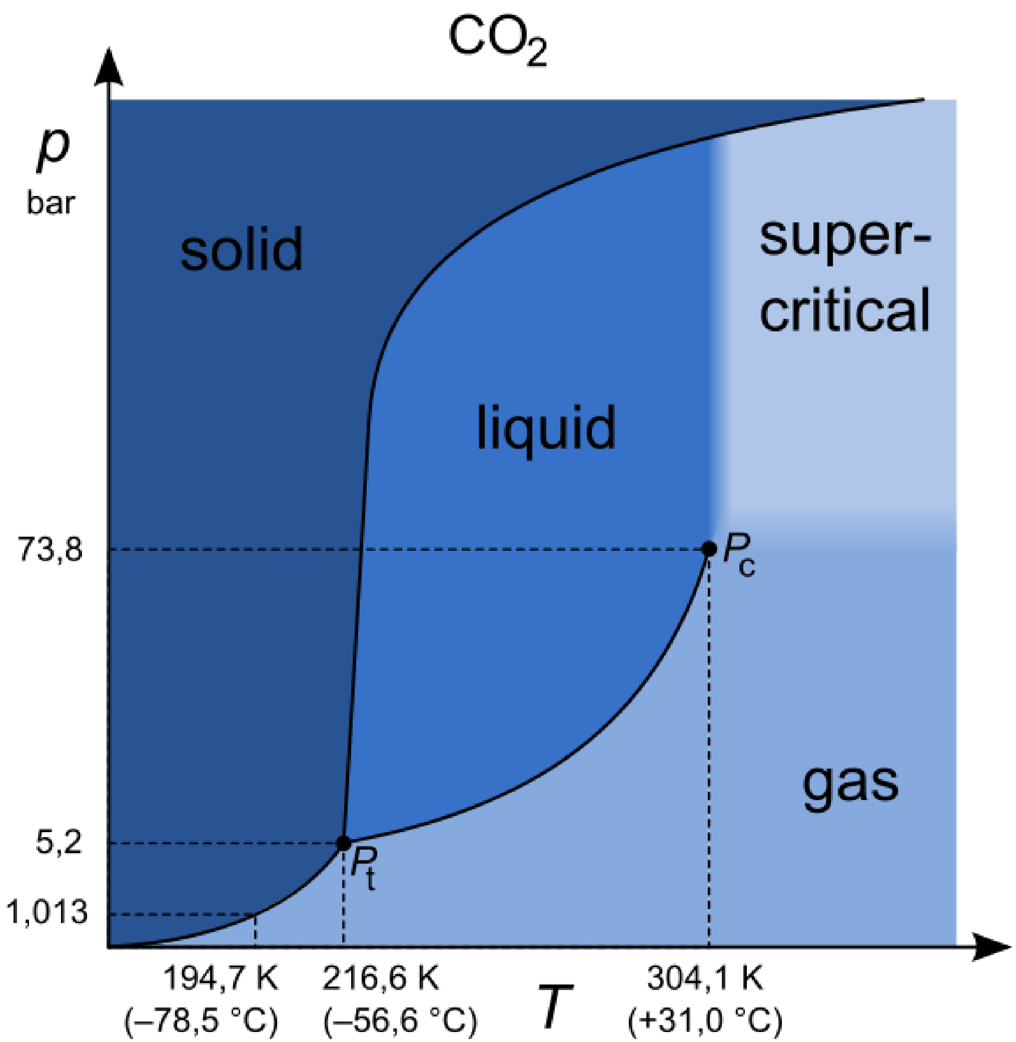
Back Up Slides

CO_2 Systems Safety

CO_2 Phase Diagram



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CO_2 Refrigeration Systems

- **Transcritical systems**: Systems are called transcritical when heat rejection takes place above the critical point of the refrigerant.

- **Subcritical systems**: Systems are called subcritical when heat rejection takes place below the critical point of the refrigerant.

- **Booster systems:** Systems with two temperature levels (e.g., -35°C and -20°C evaporating temperature) and with low-stage and medium stage compressors.

- **Cascade systems:** R744 is the low-stage refrigerant in a cascade system in which the R744 is always subcritical. The heat rejected by the condensing R744 is absorbed by the evaporating high-stage refrigerant. The high-stage system is usually a conventional system using HFC/HC/NH_3. In some systems R744 is used in the high-stage as well as the low-stage. The R744 in the low-stage is always subcritical, but in the high-stage will be transcritical at high ambient conditions.

CO_2 Refrigeration Systems - Safety

- **Asphyxiation**: R744 is odorless, heavier than air and is an asphyxiant. Practical limit of R744, 0.1 kg/m3 (56.000 ppm) according to **EN 378**
- **High-pressures**: System components, pipe work, tools and equipment must be rated for these pressures. It should be noted that the standstill pressure is about 50-60 bars on subcritical systems and up to 130 bars on transcritical systems.
- **Trapped Liquid**: The coefficient of expansion for R744 is significantly higher than for other refrigerants, as a rule of thumb, trapped R744 liquid will increase in pressure by 10 bars for every 1°K temperature increase.
- **Dry Ice**: (solid R744) is formed when R744 pressure and temperature is reduced to below the triple point (4.2 bar g, -56°C). If the dry ice is trapped within the system, it will absorb heat from the surroundings and turn into gas. This will result in a significant pressure increase.
- **Freeze Burns:** Contact with solid or liquid R744 will cause freeze burns.

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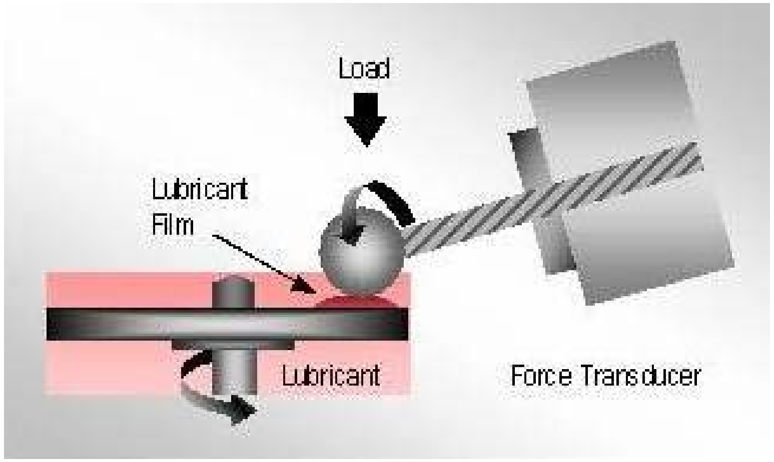
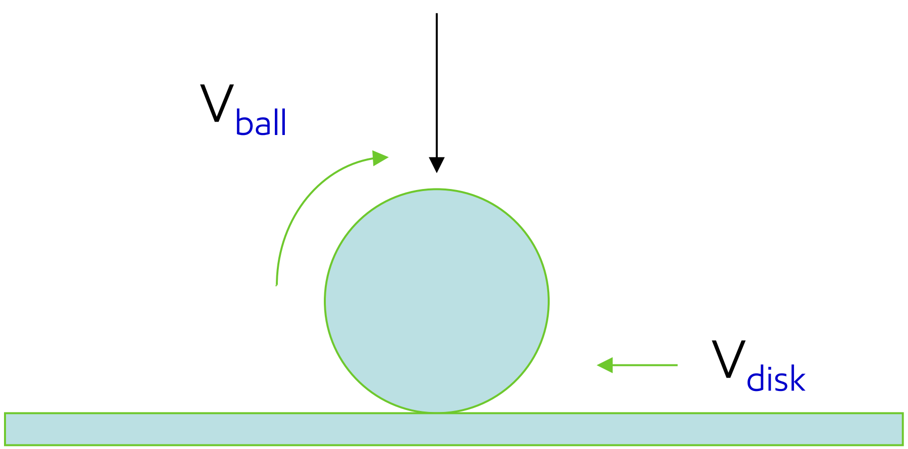
Back Up Slide EM Technology

Measuring the Lubricity Performance of Lubricants with the Mini-Traction Machine





Contact Geometry

$$\text{Mean Entrainment Speed} = \frac{(V_{disk} + V_{ball})}{2}$$

$$\text{Slide Roll Ratio (SRR)} = \frac{2(V_{disk} - V_{ball})}{(V_{disk} + V_{ball})}$$

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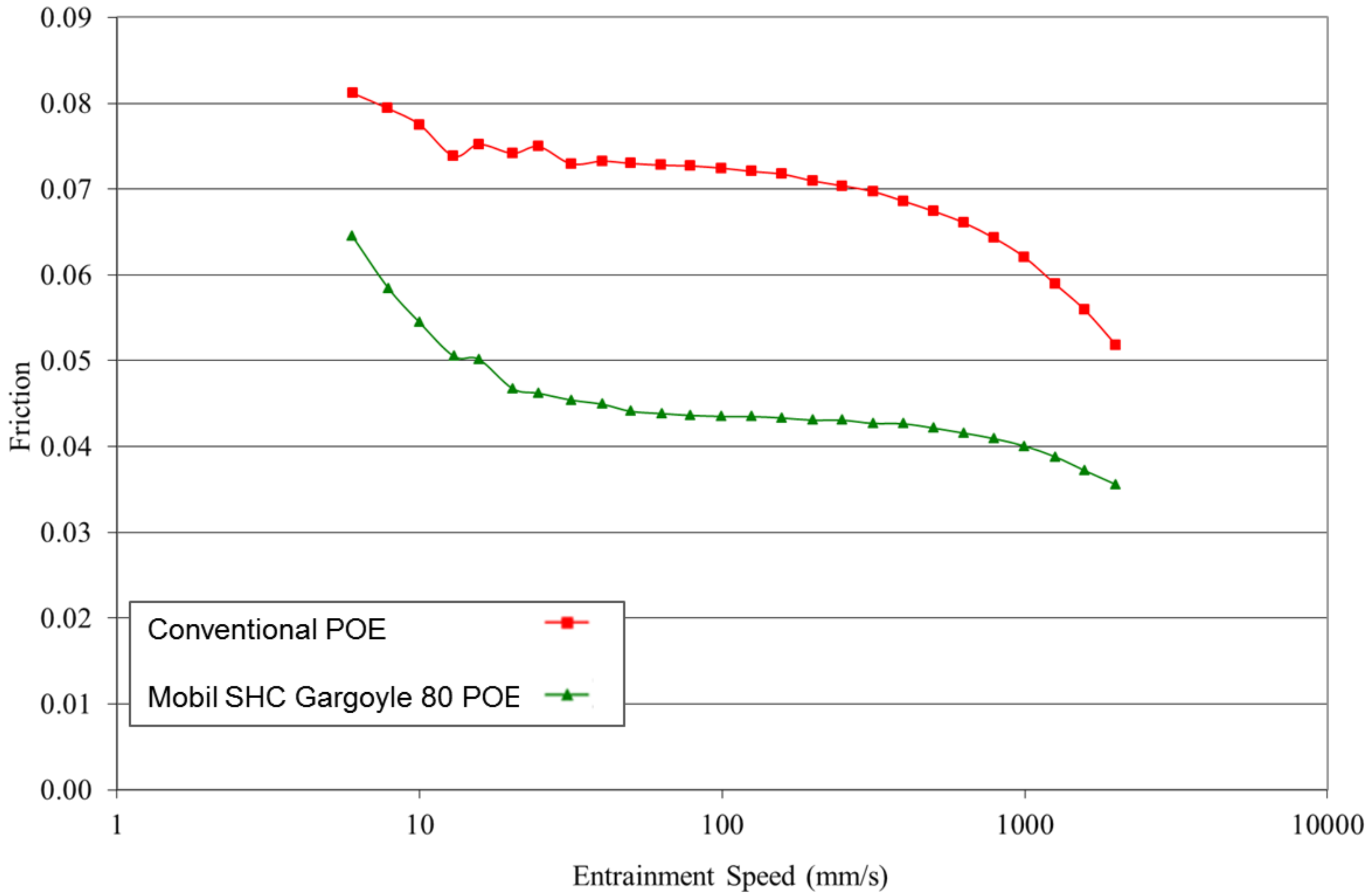
MTM Lubricity Test, Stribeck Curve at 40°C, 30N load and 50% SRR



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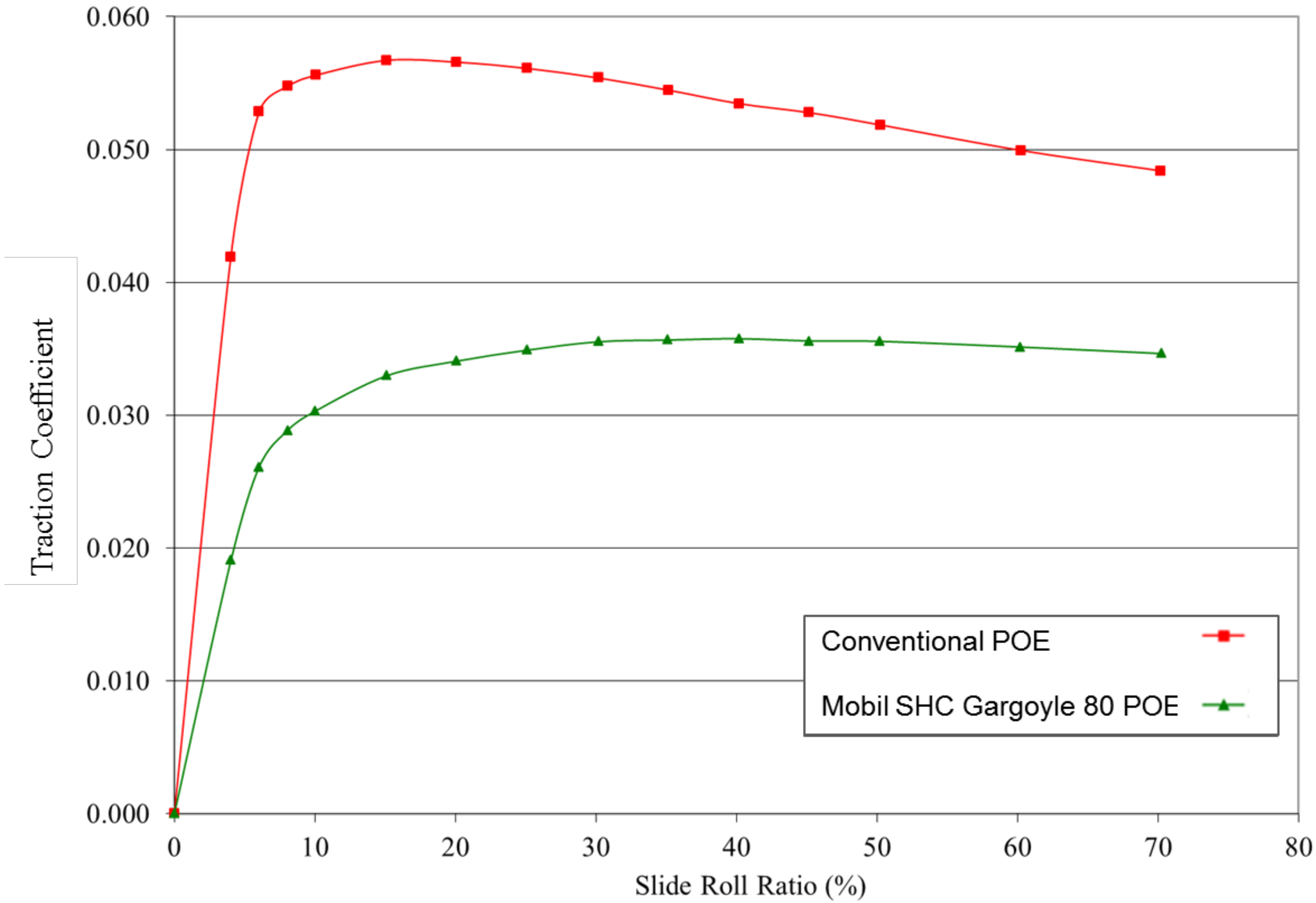
MTM Lubricity Test, Traction Coefficient at 40°C, 30N load and 2 m/s Mean Speed



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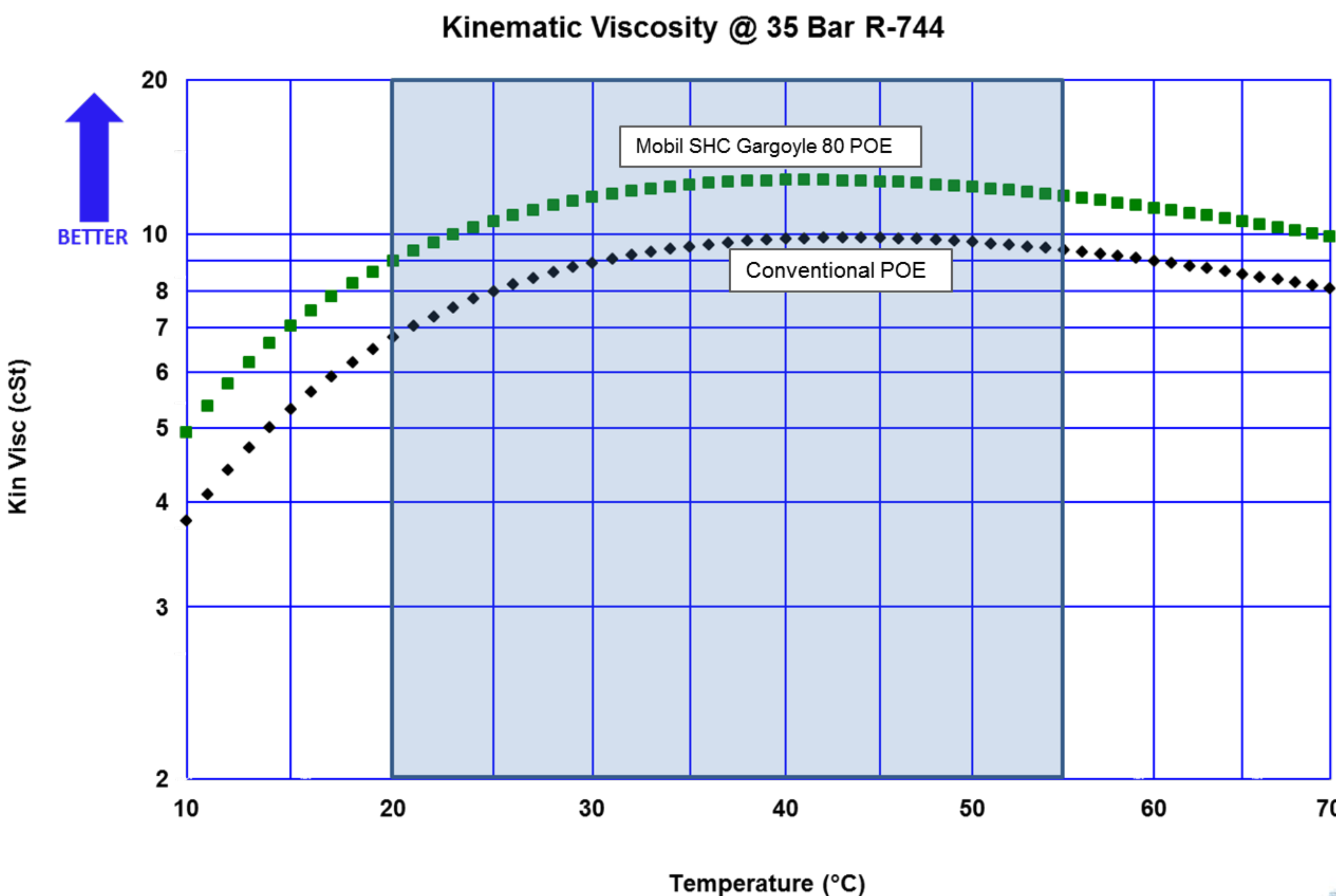
KV comparison with CO_2 @ 35 bar



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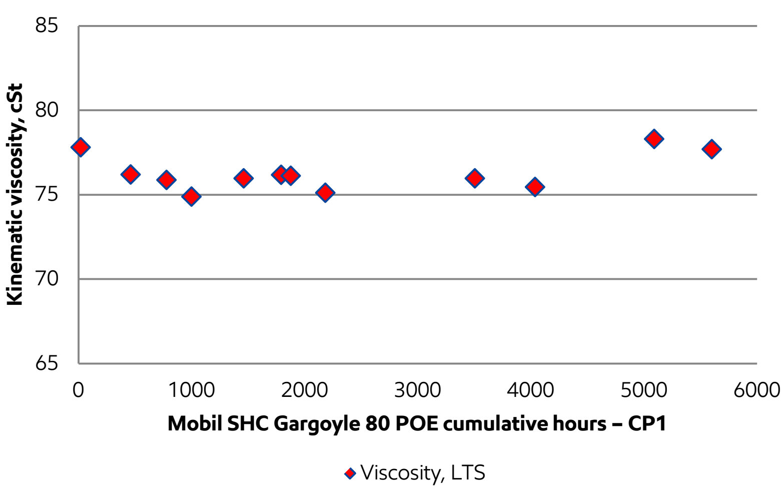
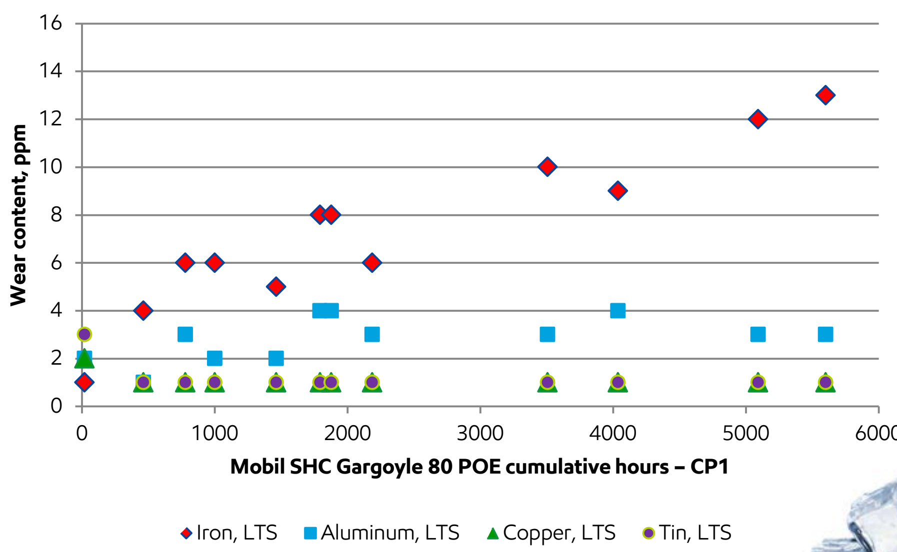
Back up Slides
Field Test Results
Oil Analisys

Analytical results - CP1

Cumulative Mobil SHC Gargoyle 80 POE hours: 5600 hours, End of Test

- Viscosity: Stable
- Wear trends: Iron, low regular trend
  Aluminum, very low to no trend
  Copper and Tin, not detectable/low value
- Estimated contamination with previous oil: <2% (Dec. 1st 2014 sample)



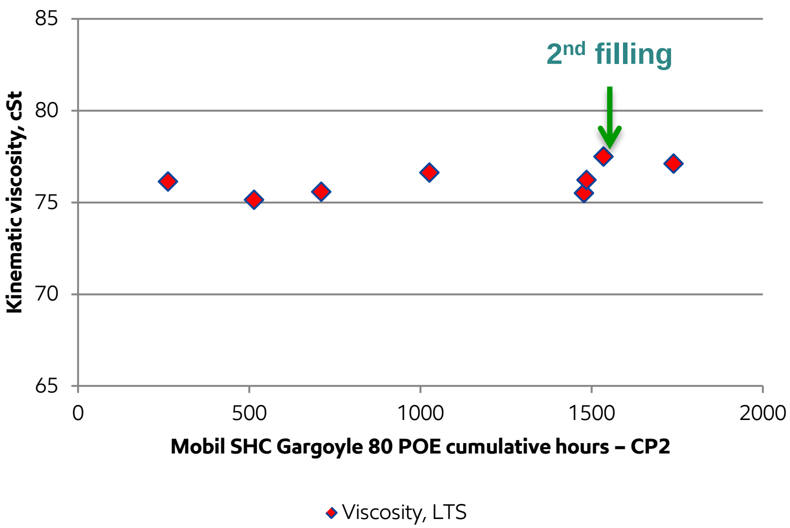


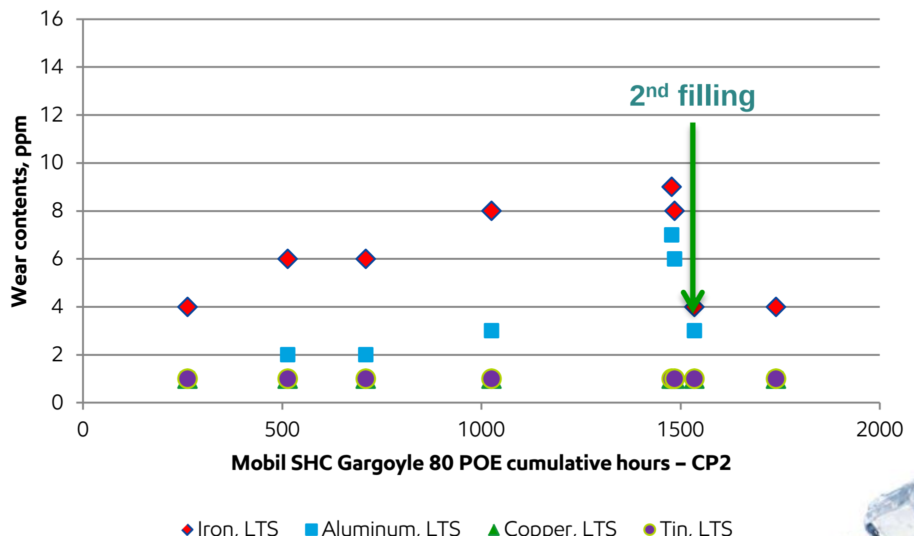
**Data Source: LTS Report 16914*

Analytical results - CP2

Cumulative Mobil SHC Gargoyle 80 POE hours: 205 hours, 2nd new filling, cumulative hours with Mobil oil: 1740 hours

- Viscosity: Stable
- Wear trends: Iron, new charge, low level
  Aluminum, new charge, low level
  Copper and Tin, not detectable/low value
- Estimated contamination with previous oil: <0.5% (Dec. 10th 2014 sample)





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Data Source: LTS Report 16914

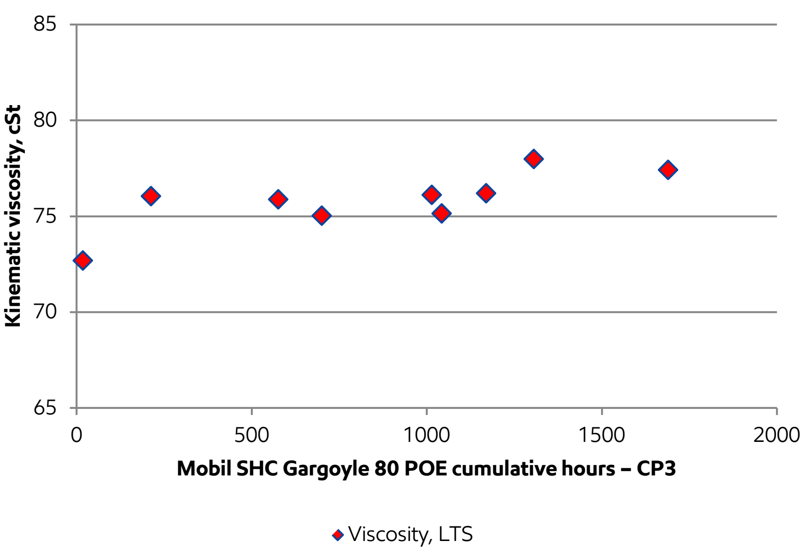
Analytical results - CP3

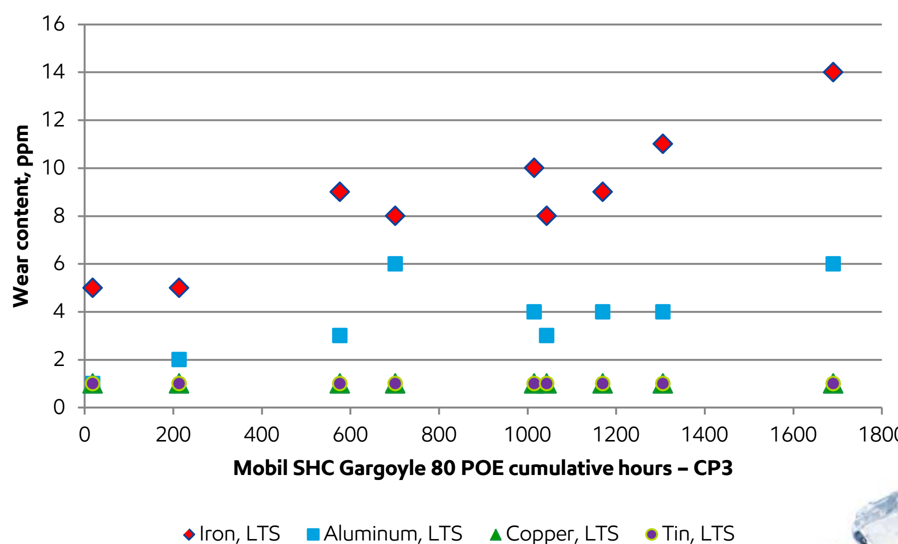
Cumulative Mobil SHC Gargoyle 80 POE hours: 1690 hours

- Viscosity: Stable
- Wear trends: Iron, regular trend

  Aluminum, low trend

  Copper and Tin, not detectable/low value
- Estimated contamination with previous oil: 2% (Dec. 10th 2014 sample)





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**Data Source: LTS Report 16914*

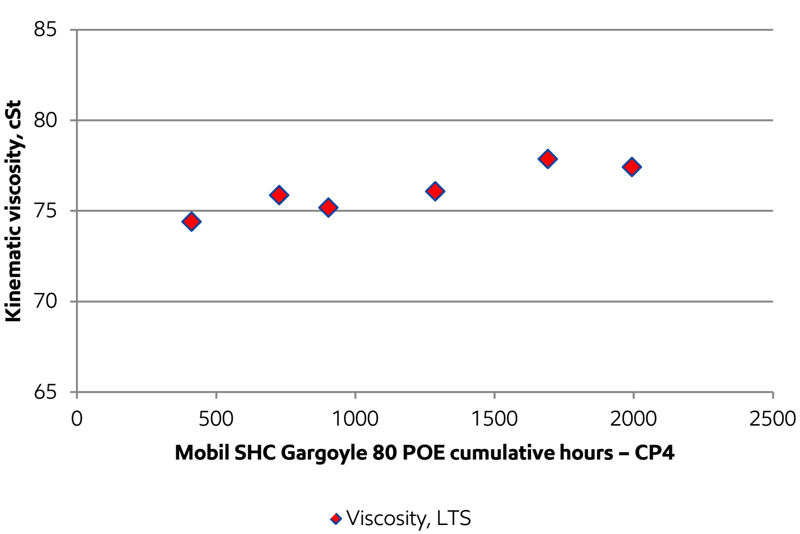
Analytical results - CP4

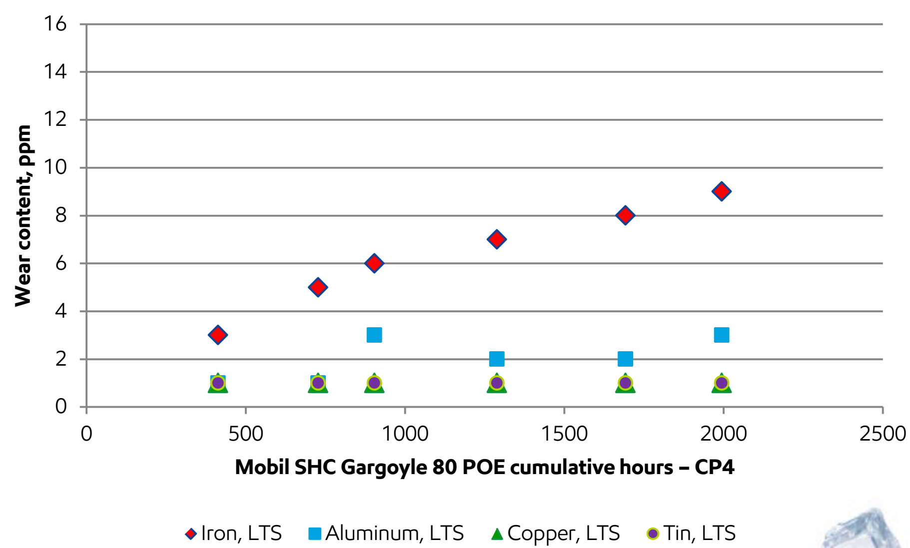
Cumulative Mobil SHC Gargoyle 80 POE hours: 1994 hours

- Viscosity: Stable
- Wear trends: Iron, regular low trend

  Aluminum, very low trend

  Copper and Tin, not detectable/low value)
- Estimated contamination with previous oil: <1% (Dec. 10th 2014 sample)





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Data Source: LTS Report 16914

Back up Slides
Field Test Results
Parts Rating

CP1 – End of Test inspection – Parts Rating & Pictures

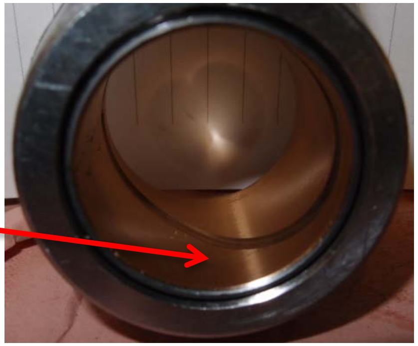
Piston 1 (Piston 1 is facing the most extreme temperature and pressure operating conditions):

- Halves bearings: Good condition, limited wear

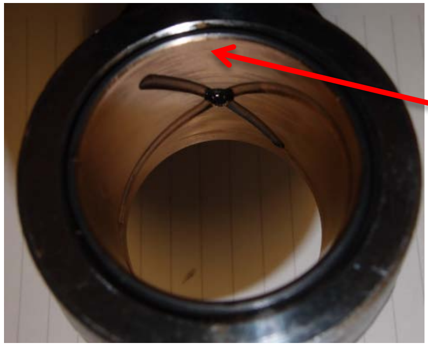
Upper side

Lower side

Bushings: Good condition, very limited wear



Lower side



Upper side

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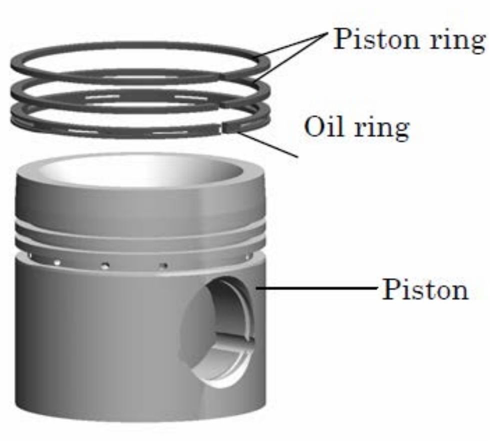
CP1 – End of Test inspection – Parts Rating & Pictures

Piston 1 (Piston 1 is facing the most extreme temperature and pressure operating conditions):

- Piston:

Thrust side
Acceptable aspect
Some marked area

Anti-thrust side
Good condition



- Rings: No deposits, rings can move easily and smoothly

CP1 – End of Test inspection – Parts Rating & Pictures

Piston 1 (Piston 1 is facing the most extreme temperature and pressure operating conditions):

- Cylinder liner/sleeve:

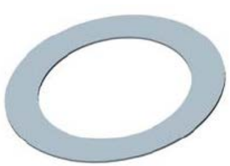
Thrust side
Good condition
Limited scratched area

Anti-thrust side
Good condition

CP1 – End of Test inspection – Parts Rating & Pictures

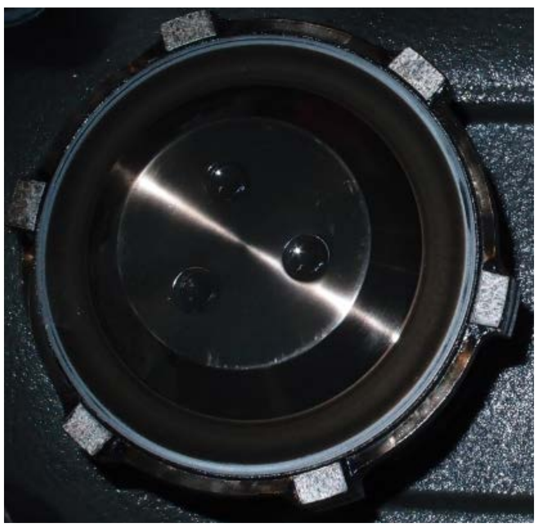
Piston 1 (Piston 1 is facing the most extreme temperature and pressure operating conditions):

- Discharge valve:



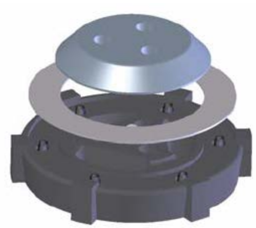
Plate

Good condition



Seat

Good condition

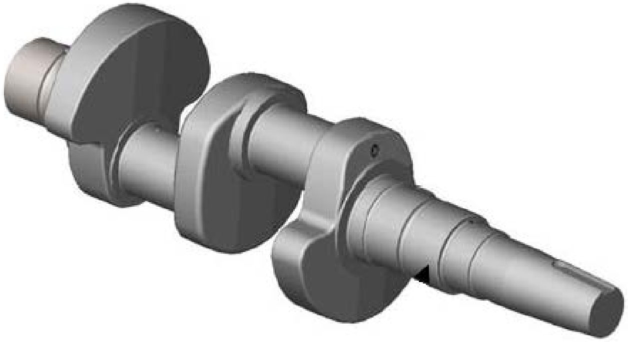


CP1 – End of Test inspection – Parts Rating & Pictures

Piston 1 (Piston 1 is facing the most extreme temperature and pressure operating conditions):

- Crankshaft:

View from Piston 1
Good condition



ExxonMobil

Glossary

Glossary

- **Booster:** A two-stage system where the low-stage compressor(s) discharge into the suction of the high-stage compressor(s).
- **Cascade:** A two-stage system where the heat rejected by the low-stage system is absorbed by the evaporating refrigerant in the high-stage system.
- **Cascade heat exchanger**: The evaporator of the high-stage system and the condenser of the low-stage system in a cascade. The evaporating high-stage refrigerant absorbs the heat rejected by the condensing low-stage refrigerant.
- **Cascade low-stage:** The part of the cascade system that provides the cooling. In retail systems this will run often on R744. The pressure will usually be higher than the high-stage (see below).
- **Cascade high-stage:** The part of the cascade system that absorbs the heat from the condensing low-stage refrigerant and rejects it, usually to ambient air.
- **Critical point:** Condition above which distinct liquid and gas phases do not exist.
- **Deposition:** Process of gas transforming to solid.
- **Dry ice:** Solid form of carbon dioxide.
- **Gas:** State when temperature is above the critical temperature but pressure is below critical pressure.
- **GWP:** Global Warming Potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere.
- **ODP:** Ozone Depletion Potential of a chemical compound is the relative amount of degradation to the ozone layer it can cause.
- **Subcritical system:** A system that operates below the critical point.
- **Sublimation:** Transition from solid to gas without passing through the liquid phase.
- **Transcritical fluid:** State when both the temperature and the pressure are above the critical point. The substance is not a gas, vapor or liquid.
- **Transcritical system:** A system which operates above the critical point. Many transcritical systems are subcritical for a proportion of the year.
- **Triple point:** Condition at which solid, liquid and gas coexist.
- **Vapor State:** where temperature and pressure are below critical conditions.
- **Volatile:** A volatile substance is one that evaporates readily at normal temperatures.