**Lubricant screening for $CO_2$ automotive AC-systems, aspects from a compressor manufacturer point of view**

referent: Dr.-Ing. Jan Hinrichs, LuK-FH

**content:**

**1997 up to 2000** **cooperation with Ruhr-Universität Bochum**

Institut für Thermo- und Fluiddynamik

cooperation partner: AUDI, BMW, DC, VW, LuK-FH, Fuchs-DEA

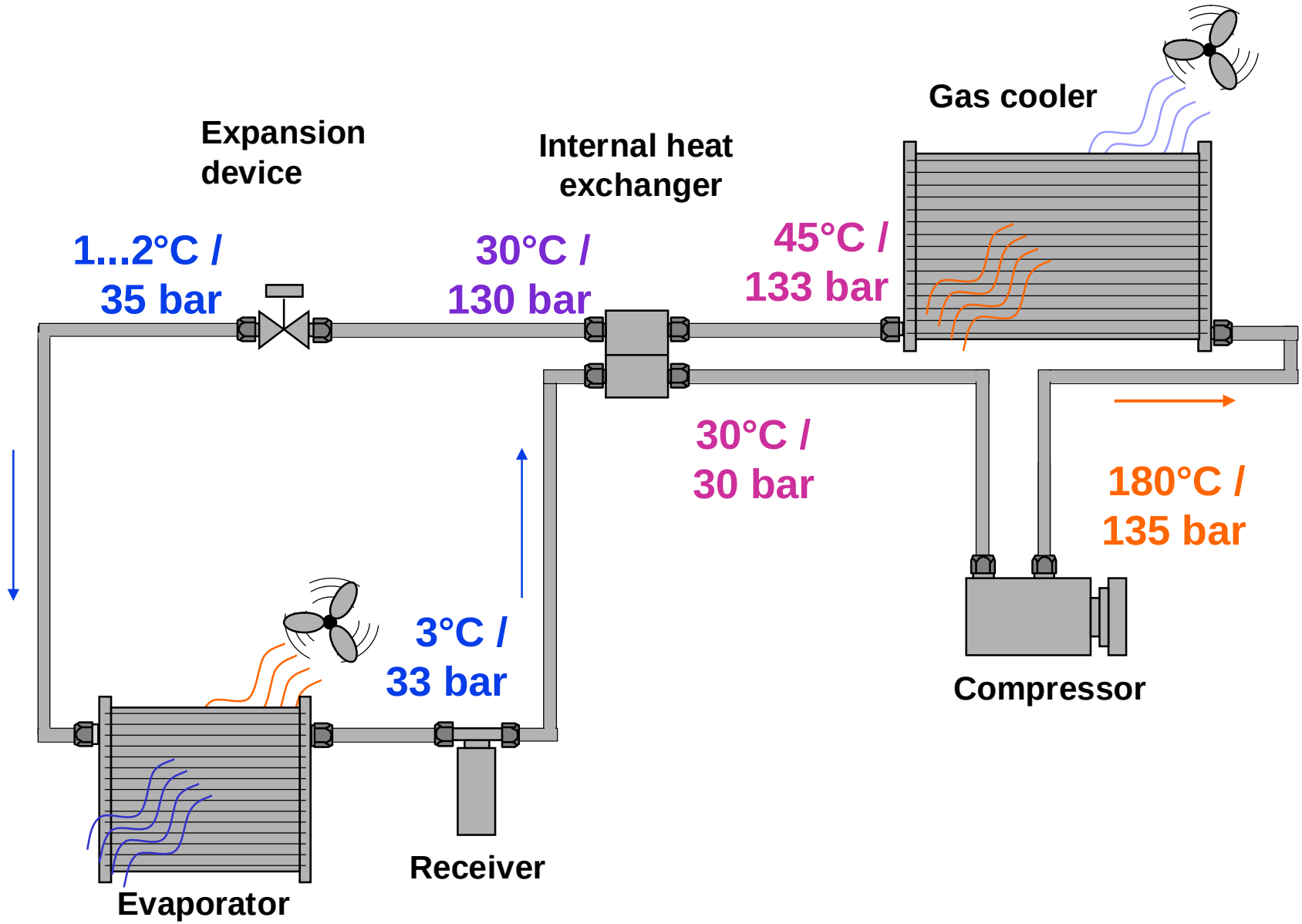
**investigation in thermal- and fluid-dynamic properties of base fluids**

**2000 up to 2003** **cooperation with Ruhr-Universität Bochum**

Institut für Thermo- und Fluiddynamik

cooperation partner: LuK-FH, Sanden, Fuchs

- **detailed investigation in lubrication properties of pre-selected PAG and POE based lubricants**
- **investigation in thermal- and fluid-dynamic properties of pre-selected lubricants**


Expansion device
Internal heat exchanger
Gas cooler
1...2°C / 35 bar
30°C / 130 bar
45°C / 133 bar
30°C / 30 bar
180°C / 135 bar
3°C / 33 bar
Compressor
Receiver
Evaporator

# lubricant - $CO_2$ - system

| | | |
|---|---|---|
| **component**: | **compressor** | **cooling circulation** |
| **functions of lubricant:** | wear reduction<br>sealing gaps<br>heat absorption<br>dirt absorption | no function |
| **requirements:** | **light-duty compressor design**<br>sufficient lubrication under normal conditions<br>lubrication under extreme conditions<br>material compatibility<br>aging stability | **min. influence on system performance**<br>low influence on heat transfer<br>oil return to compressor<br>material compatibility<br>aging stability |

- fundamental investigations in thermal- and fluid-dynamic properties and lubrication properties of

  PAG (Polyalkylenglycol)
  POE (Polyolester)
  PVE (Polyvinylether)
  PME (Polymerester)
  PAO (Polyalphaolefin)

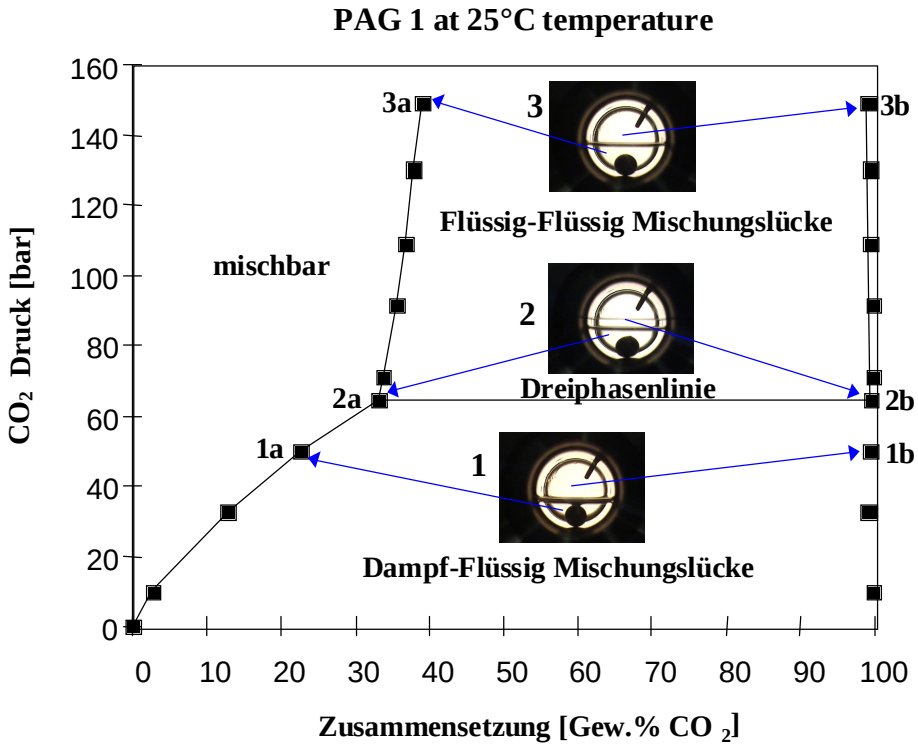
- base fluid with different viscosities

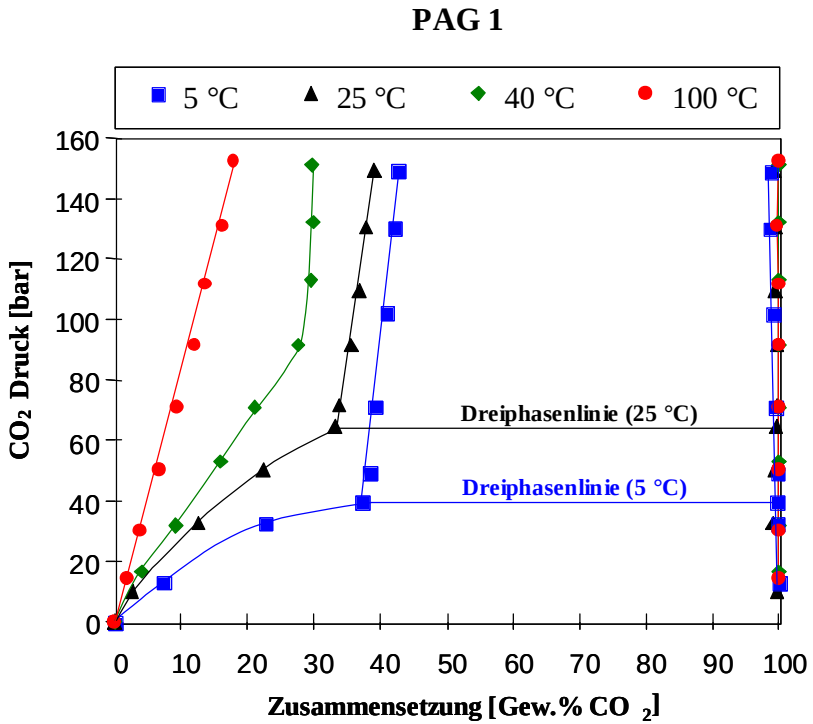
- ND8 and SP10 as reference

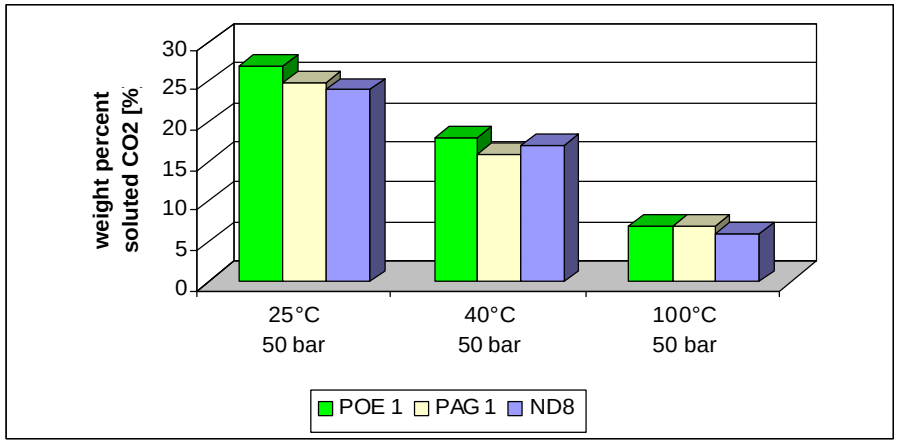
- evaluation of > 40 lubricant samples

- pre-selection of:

| | | |
|---|---|---|
| | ND8 | (ISO VG 46, AW/AO agents) |
| | PAG 1 | (ISO VG 46, AW/AO agents) |
| | PAG 2 | (ISO VG 46, AW/AO agents) |
| | POE 1 | (ISO VG 170, AW agents) |

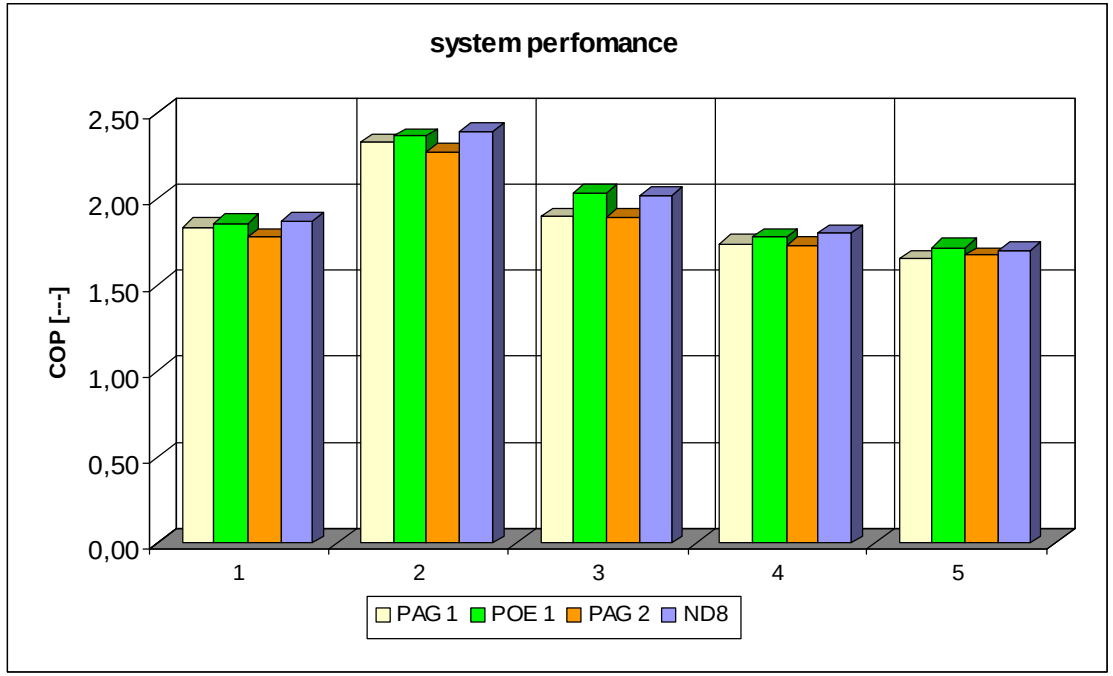





Dr.-Ing. Jan Hinrichs, LuK-FH




| Test condition | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Compressor RPM | rpm | 600 | 600 | 600 | 800 | 1200 |
| Suction Pressure, P1 | bar | 40 | 50 | 40 | 40 | 40 |
| Discharge Pressure, P2 | bar | 140 | 120 | 100 | 120 | 120 |
| Evaporator Face Velocity | m/s | 1,75 | 2,4 | 1,6 | 1,7 | 2,4 |
| Evaporator air inlet temperature | °C | 40 | 40 | 30 | 39 | 43 |
| Gas Cooler Face Velocity | m/s | 0,88 | 0,88 | 0,88 | 0,88 | 1,17 |
| Gas Cooler air inlet temperature | °C | 35 | 35 | 35 | 35 | 36 |
| Compressor ambient temperature | °C | 30 | 30 | 30 | 30 | 30 |



Dr.-Ing. Jan Hinrichs, LuK-FH

Fahrzeug Hydraulik

# system performance (COP)

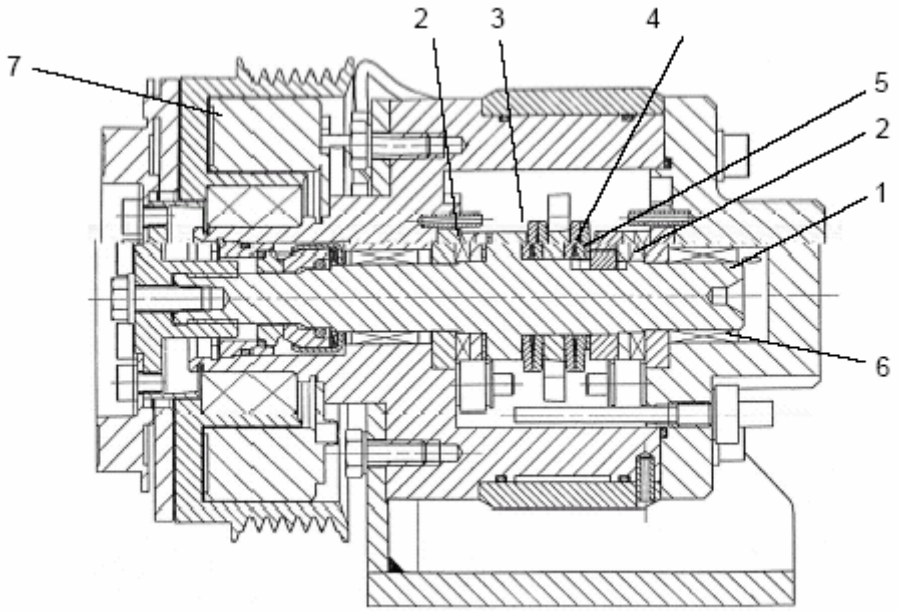
VDA Winter Meeting 18.+19.02.2004, Saalfelden

SANDEN

- COP measurements on a system test rig shows no significant differences between PAG and POE, if OCR *) is low

- PAG and POE have no differences with respect to oil return

***) OCR: oil circulation ratio**



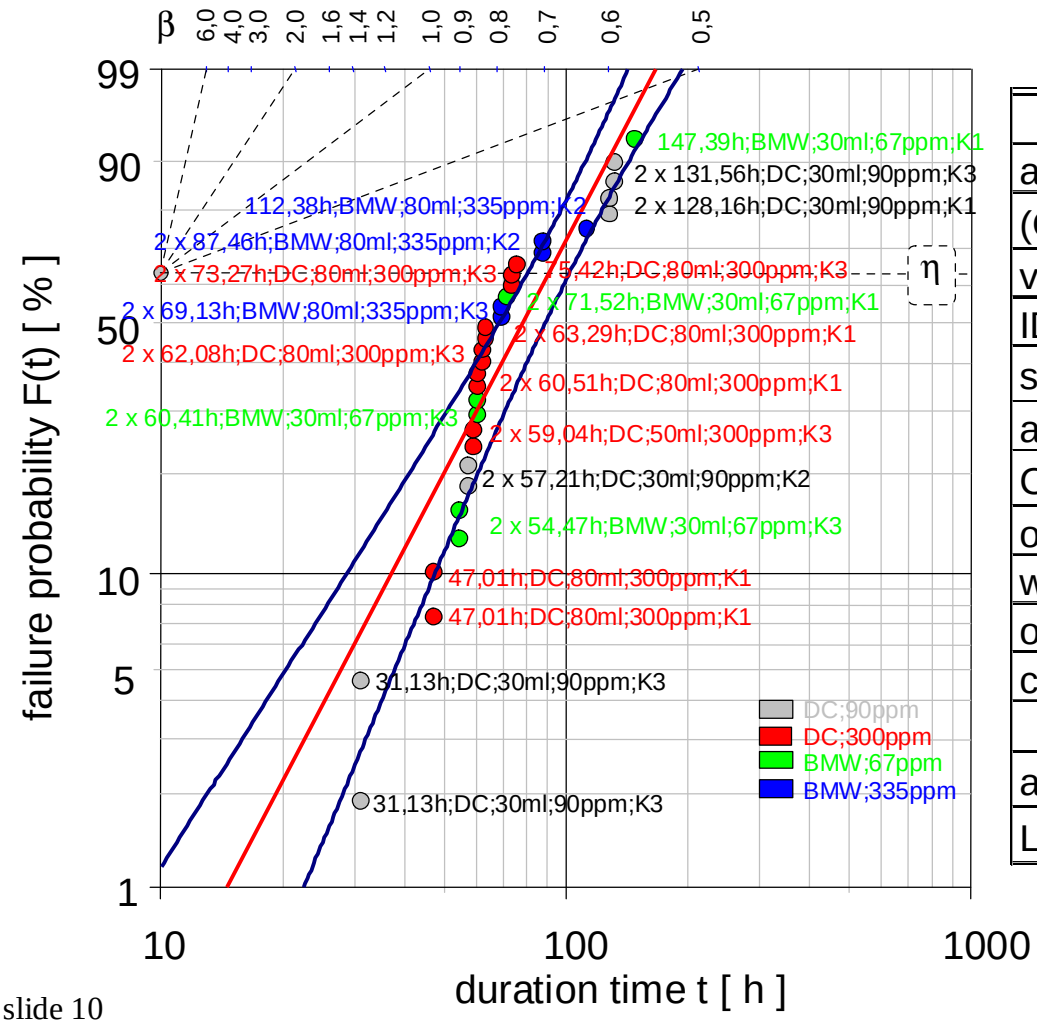

Dr.-Ing. Jan Hinrichs, LuK-FH

Fahrzeug Hydraulik

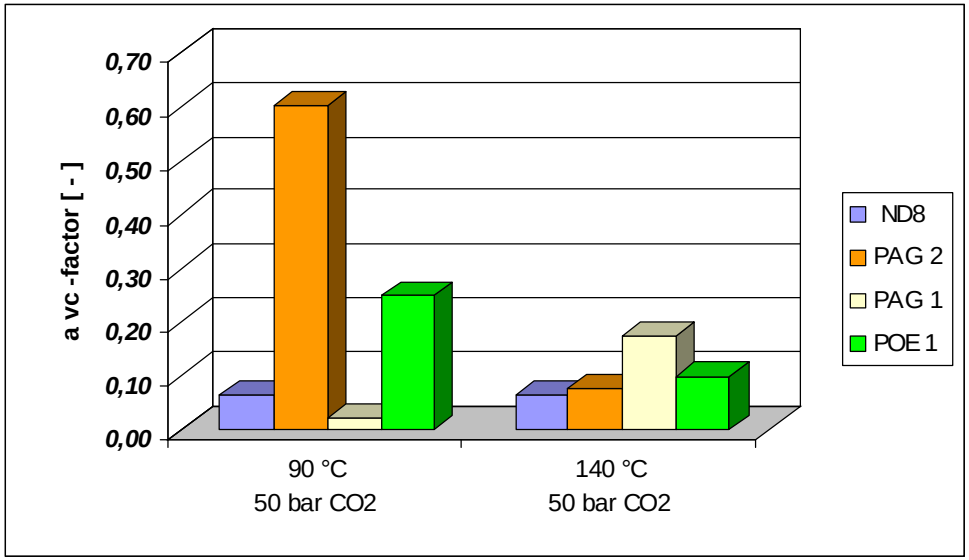
# bearing test rig to evaluate lubrication factor $a_{vc}$

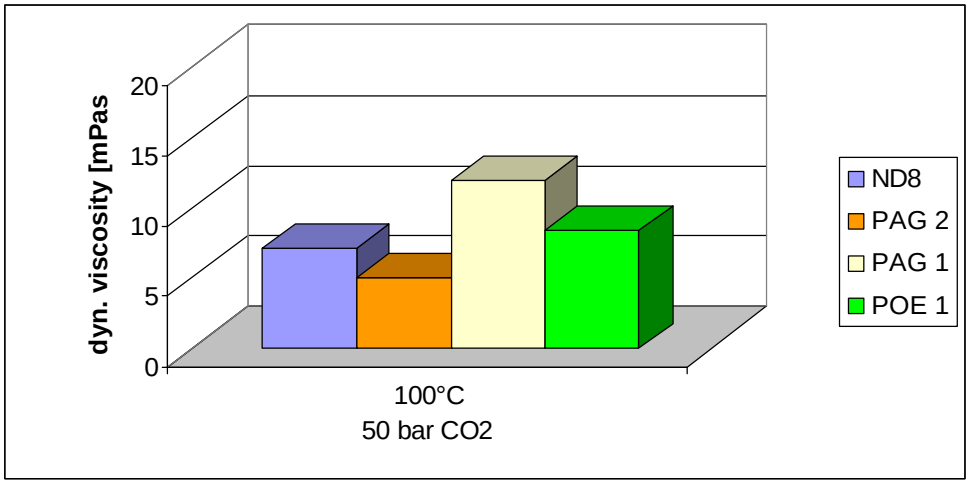
VDA Winter Meeting 18.+19.02.2004, Saalfelden

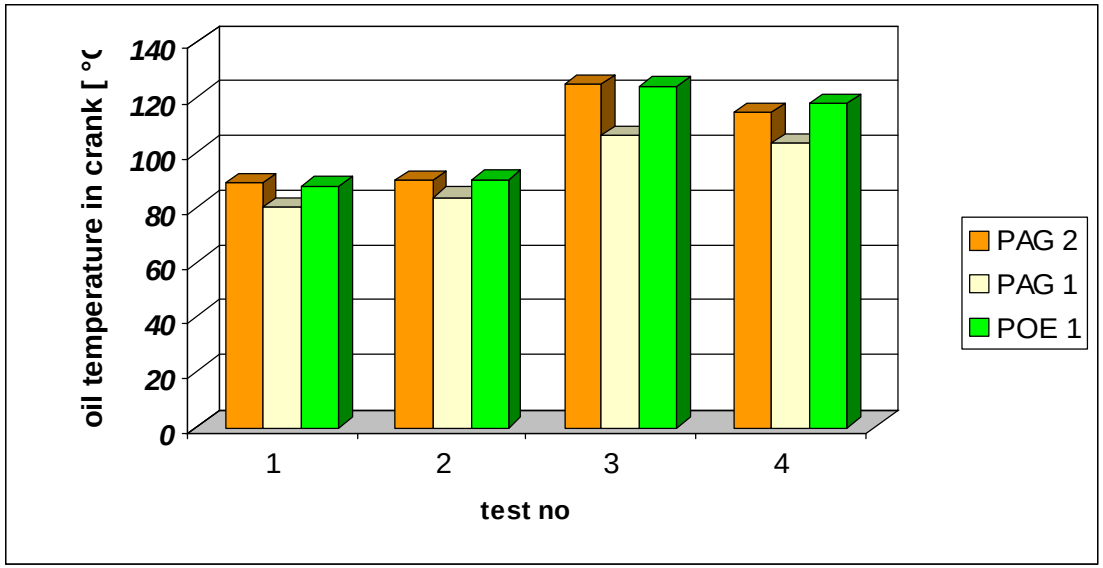
SANDEN



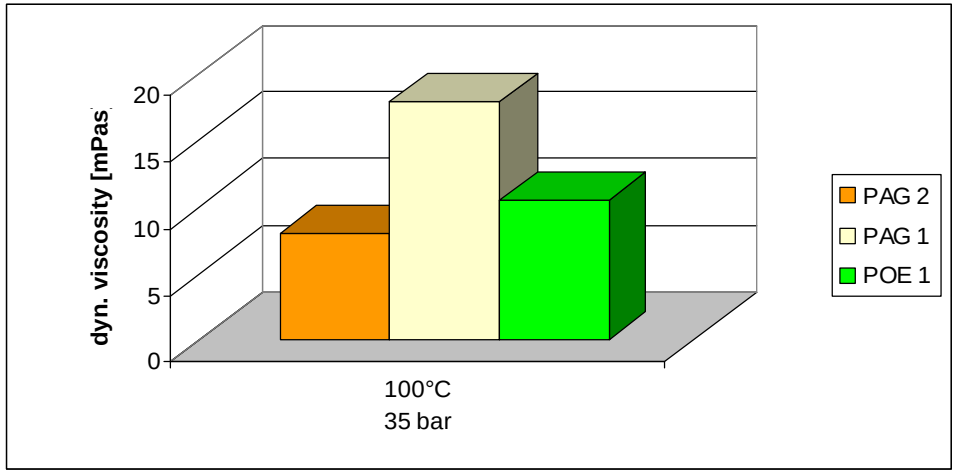

| parameter | | |
|---|---|---|
| axial roller bearing AXK 18x35x4,5 | | |
| (C=21400 N, $C_0$=46500 N, $C_U$=4100 N) | | |
| volume chamber 118 ml | | |
| ID-code bearing | [-] | F-227239.1 |
| speed | [$min^{-1}$] | 800 |
| axial load | [N] | 7900 |
| $CO_2$-pressure | [bar] | 50 |
| oil temperature | [°C] | 90 |
| water content | [ppm] | 67;90;300;335 |
| oil amount in chamber | [ml] | 30;50;80 |
| cal. duration | [h] | 577 |
| results | | |
| $a_{vc}$ | [-] | 0,06 |
| $L_{h10\ v}$ | [h] | 37 |


0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
a vc -factor [ - ]
90 °C
50 bar CO2
140 °C
50 bar CO2
ND8
PAG 2
PAG 1
POE 1


20
15
10
5
0
dyn. viscosity [mPas
100°C
50 bar CO2
ND8
PAG 2
PAG 1
POE 1




| test no | P suc. [bar] | P disch. [bar] | T suc. [ °C] | n [rpm] | m [kg/h] |
|---|---|---|---|---|---|
| 1 | 35 | 90 | 30 | 800 | max |
| 2 | 35 | 90 | 30 | 2000 | max |
| 3 | 35 | 120 | 30 | 800 | max |
| 4 | 35 | 120 | 30 | 2000 | max |

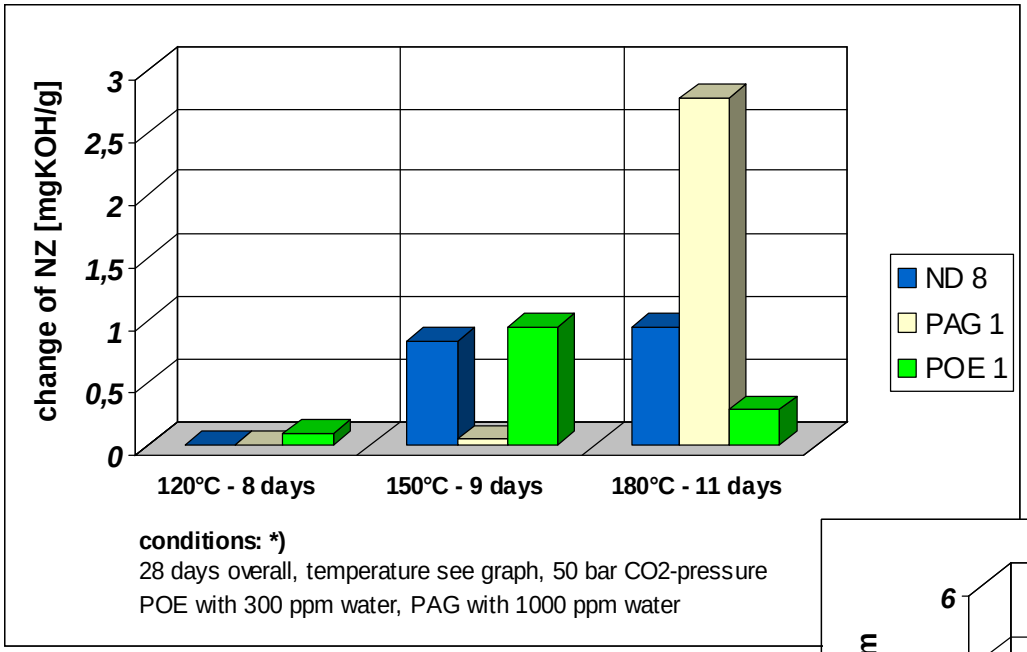


- ND8 has a low lubrication factor in view of bearing design

- PAG 2 has a big decrease of lubrication factor with increasing temperature, compressor parts show not acceptable wear after duration tests

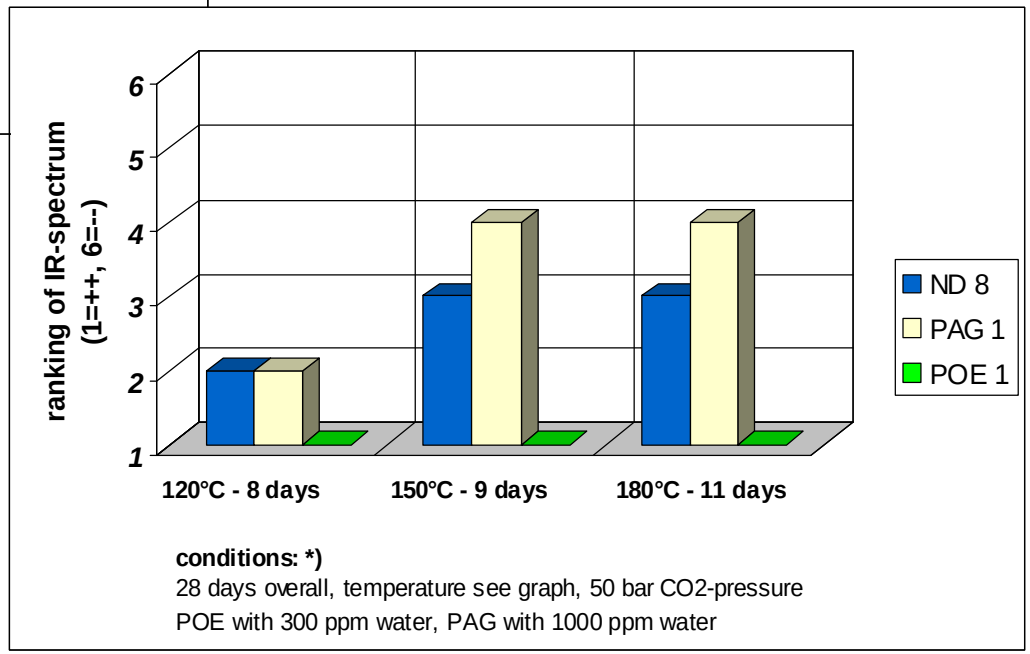
- PAG 1 has a low lubrication factor at low operation temperatures compressor parts show not acceptable wear after duration tests

- POE 1 has acceptable lubrication properties in total




**conditions: *)**
28 days overall, temperature see graph, 50 bar CO2-pressure
POE with 300 ppm water, PAG with 1000 ppm water

*) summary of compressor operation temperatures during 700 hrs VDA duration test




**conditions: *)**
28 days overall, temperature see graph, 50 bar CO2-pressure
POE with 300 ppm water, PAG with 1000 ppm water

**ranking:**
1 and 2: changes of base fluid and agent are acceptable
3: aging of base fluid and agent is recognizable
4: significant aging of base fluid and agent



Fahrzeug Hydraulik

# aging stability, results from laboratory tests

VDA Winter Meeting 18.+19.02.2004, Saalfelden

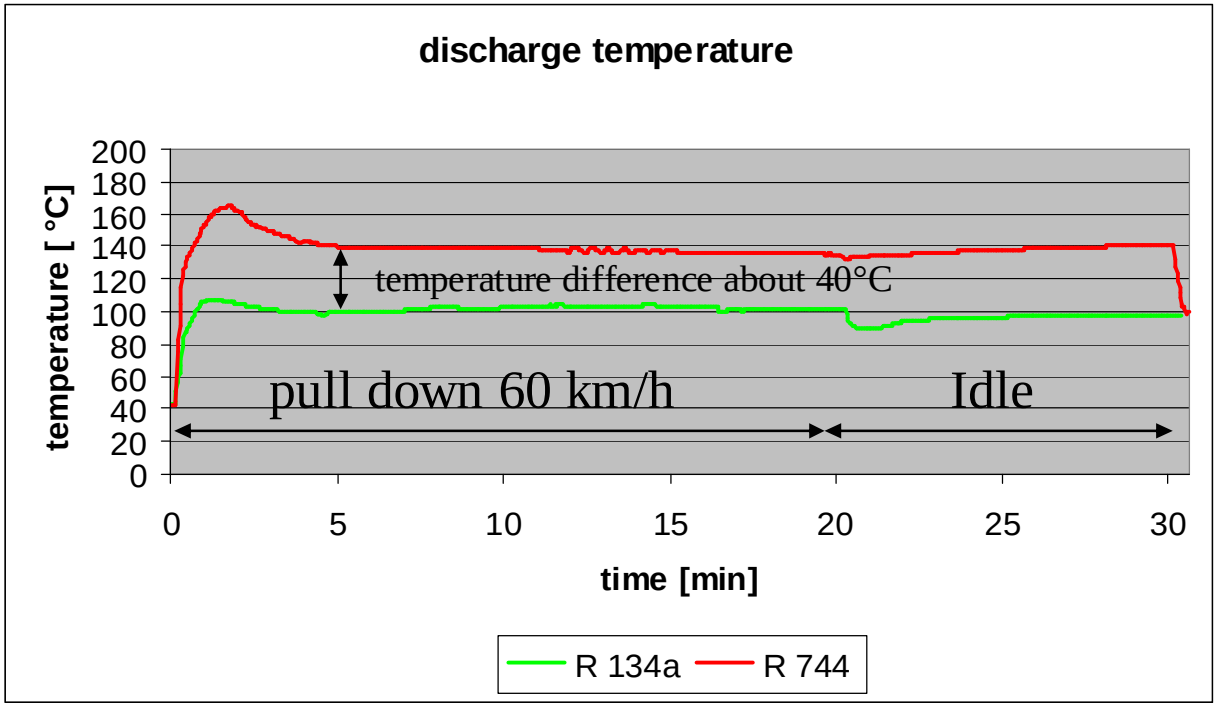
SANDEN

- POE 1 has a good thermal and hydrolytic stability if the water content is about 300 ppm

- ND8 has a minor thermal stability

- PAG 1 has a minor thermal stability

- **internal heat exchanger of $CO_2$ automotive AC-systems**
- **thermo-dynamic properties**
- low charge of system
- operating in heat-pump mode (triangle process)



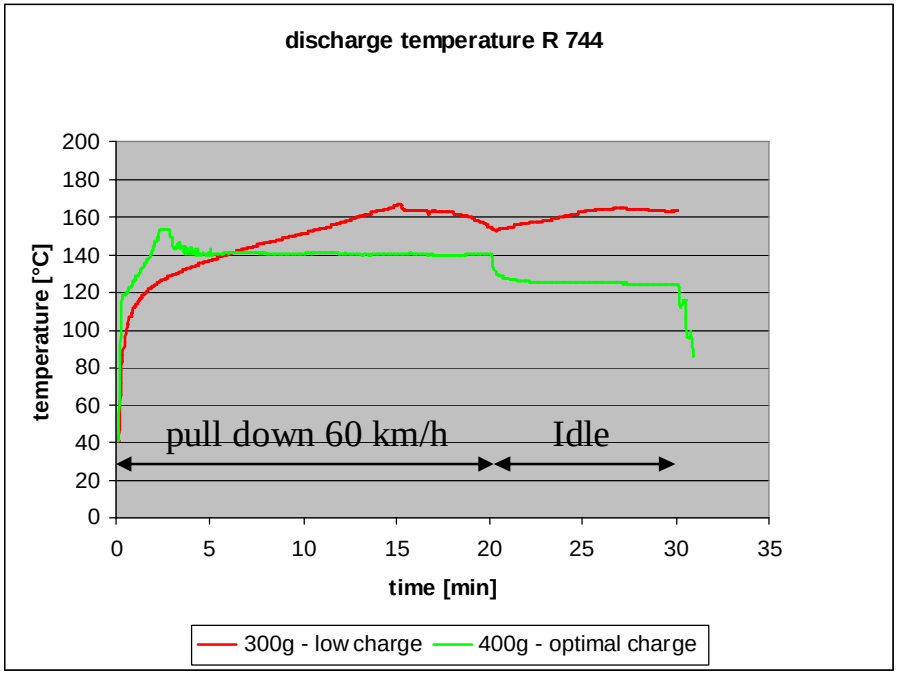

increase of OCR from 1% up to 5....7% cause a temperature reduction about 15°C

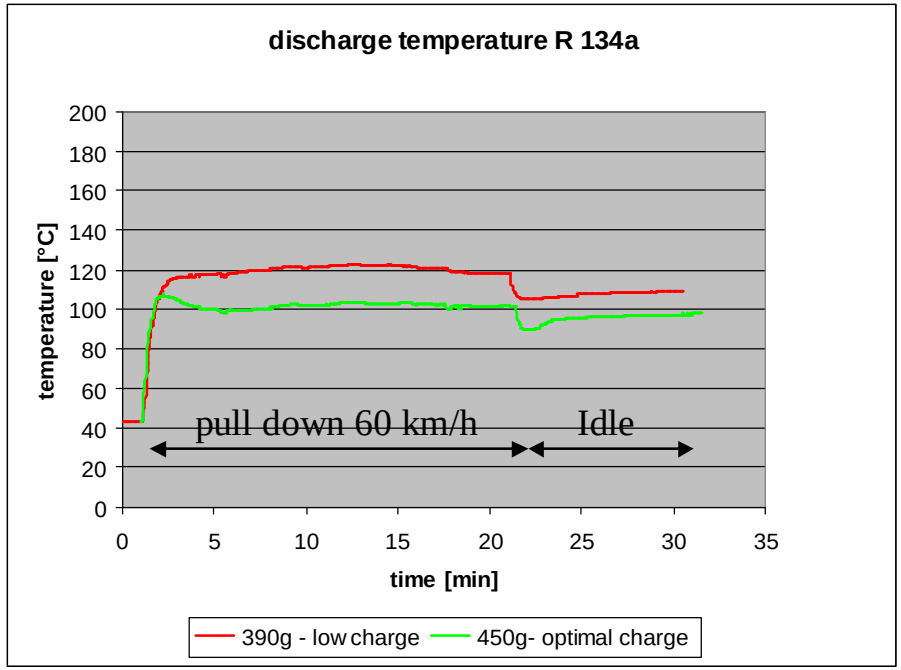
**test conditions:** 2 identical mid class vehicles, 40°C, 30% humidity, 1000 W/m²
1. point :20 min pull down, 60 km/h at 1600 rpm
2. point: 10 min Idle



Dr.-Ing. Jan Hinrichs, LuK-FH

- internal heat exchanger of CO2 automotive AC-systems
- thermo-dynamic properties
- **low charge of system**
- operating in heat-pump mode (triangle process)



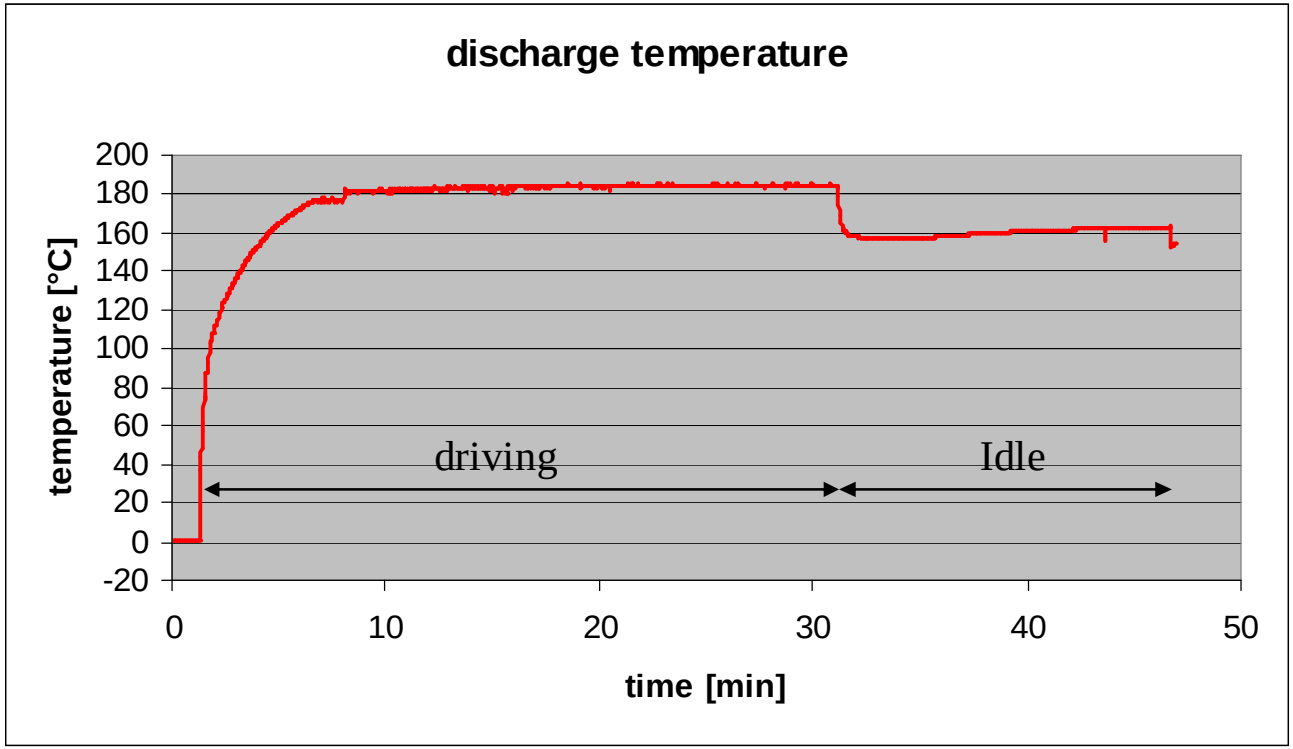



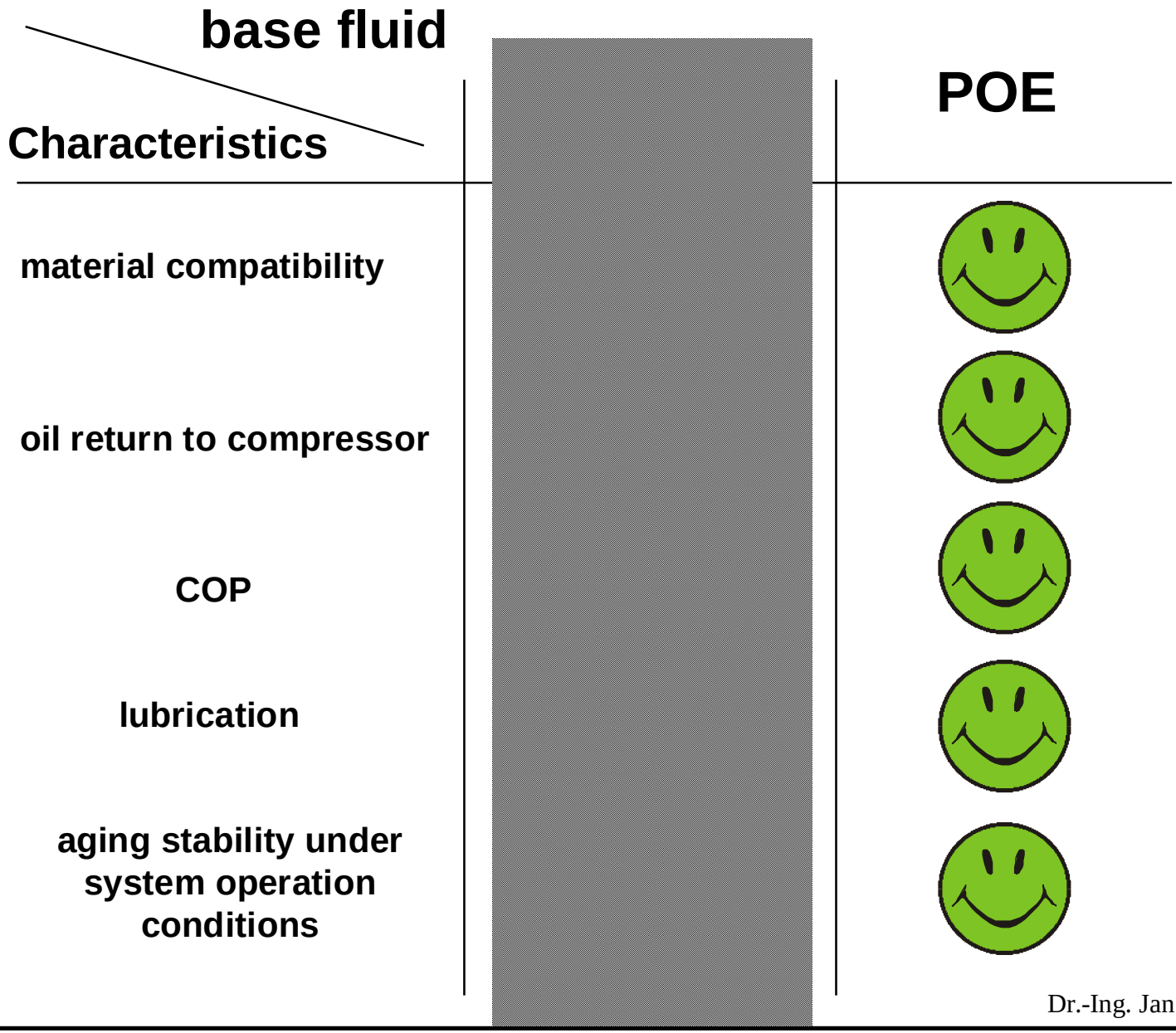

**test conditions:** 2 identical mid class vehicles, 40°C, 30% humidity, 1000 W/m²
1. point :20 min pull down, 60 km/h at 1600 rpm
2. point: 10 min Idle



Dr.-Ing. Jan Hinrichs, LuK-FH

- internal heat exchanger of CO2 automotive AC-systems
- thermo-dynamic properties
- low charge of system
- **operating in heat-pump mode (triangle process)**




base fluid
Characteristics
POE
material compatibility
oil return to compressor
COP
lubrication
aging stability under system operation conditions