evaluation of various compressor lubricants for CO_2 - refrigeration system

VDA Winter Meeting

18 February 2004

Idemitsu Kosan Co., Ltd.

Company Profile

IDEMITSU KOSAN Co.,Ltd.

- **Business Activities**

  Oil Refining and Marketing, LPG Marketing, Coal Marketing, Petrochemical Products Manufacturing and Marketing, Crude Oil and Oil Products Transportation, Oil Development, Alternative Energy such as Uranium and Geothermal

- **Lubricants Sales Volume** *(including oversea sales)*

  830,000kl(2002) ⇒ No.1 in Japanese Company

Company Profile

IDEMITSU KOSAN Co.,Ltd.

- **Full Range of Lubricants Products**
  - Automotive Lubricants
  - Marine Lubricants
  - Industrial Lubricants
  - Metal Working Fluids
  - Greases

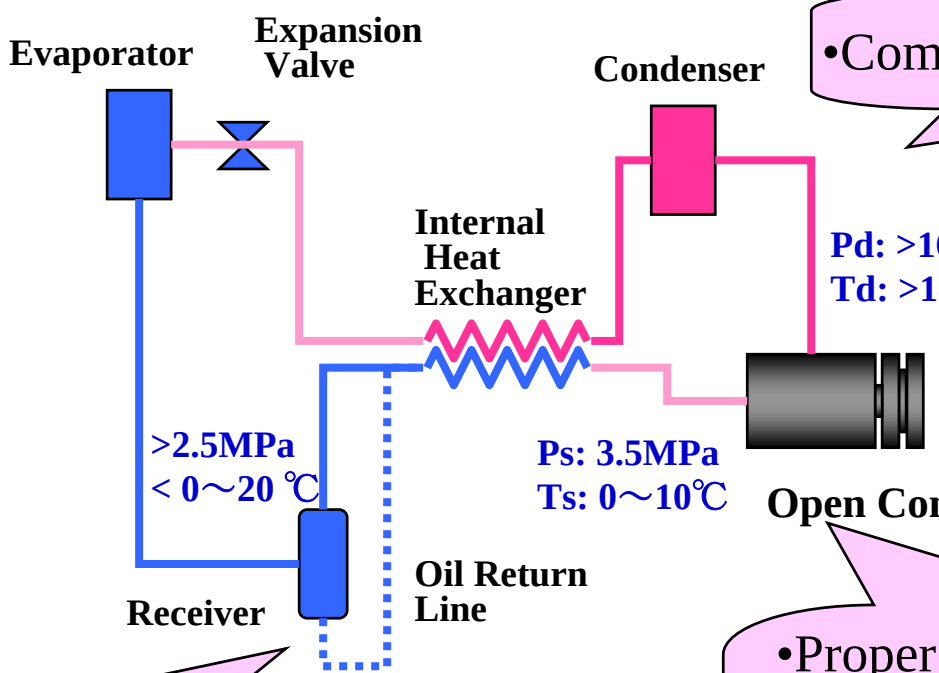
Refrigeration Oil

- Mineral Oil
- AB(Alkyl Benzene)
- PAG(Polyalkylenglycol)
- POE(Polyolester)
- PVE(Polyvinylether)

Market Share of PAG Oil for Automotive A/C

Worldwide : More than 80%

CO_2 Automotive A/C System and Refrigerating Oil Requirement



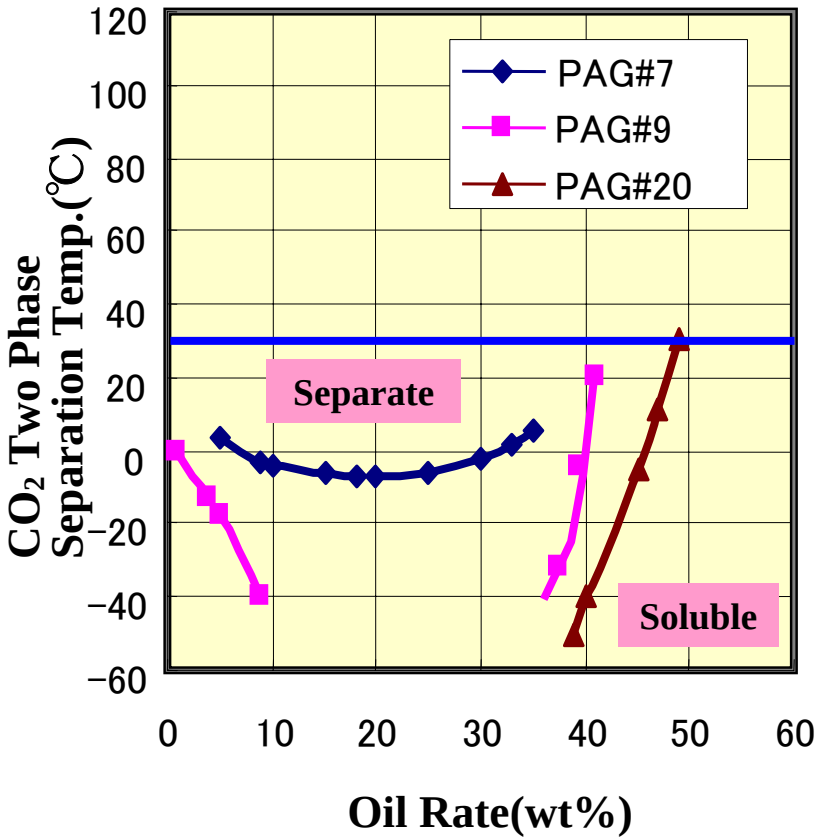
•Compatibility with various material

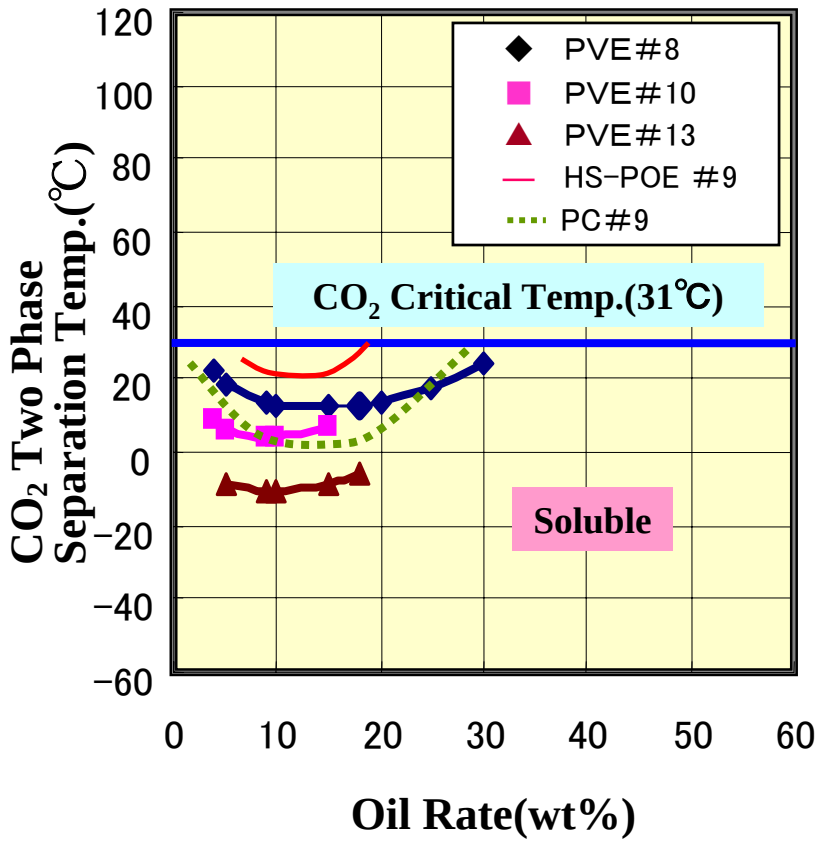
•Miscibility with CO_2

•Proper mixture viscosity
•Lubricity under extreme-pressure
•Stability under supercritical condition
•Stability under high temperature

⇒ *What kind of base oil is the best ?*

Miscibility with CO_2





MO, AB : Immiscible in All Area

Miscibility with CO_2

Miscible Type :

POE $\geqq$ PVE, PC $>$ PAG

(These oils contain oxygen.)

→ This trend is similar to HFC.

Immiscible Type :

Mineral Oil, Alkyl Benzene

→ Complete oil separation is required.

Diluted Viscosity of Testing Oils with CO_2

(mm^2/s)

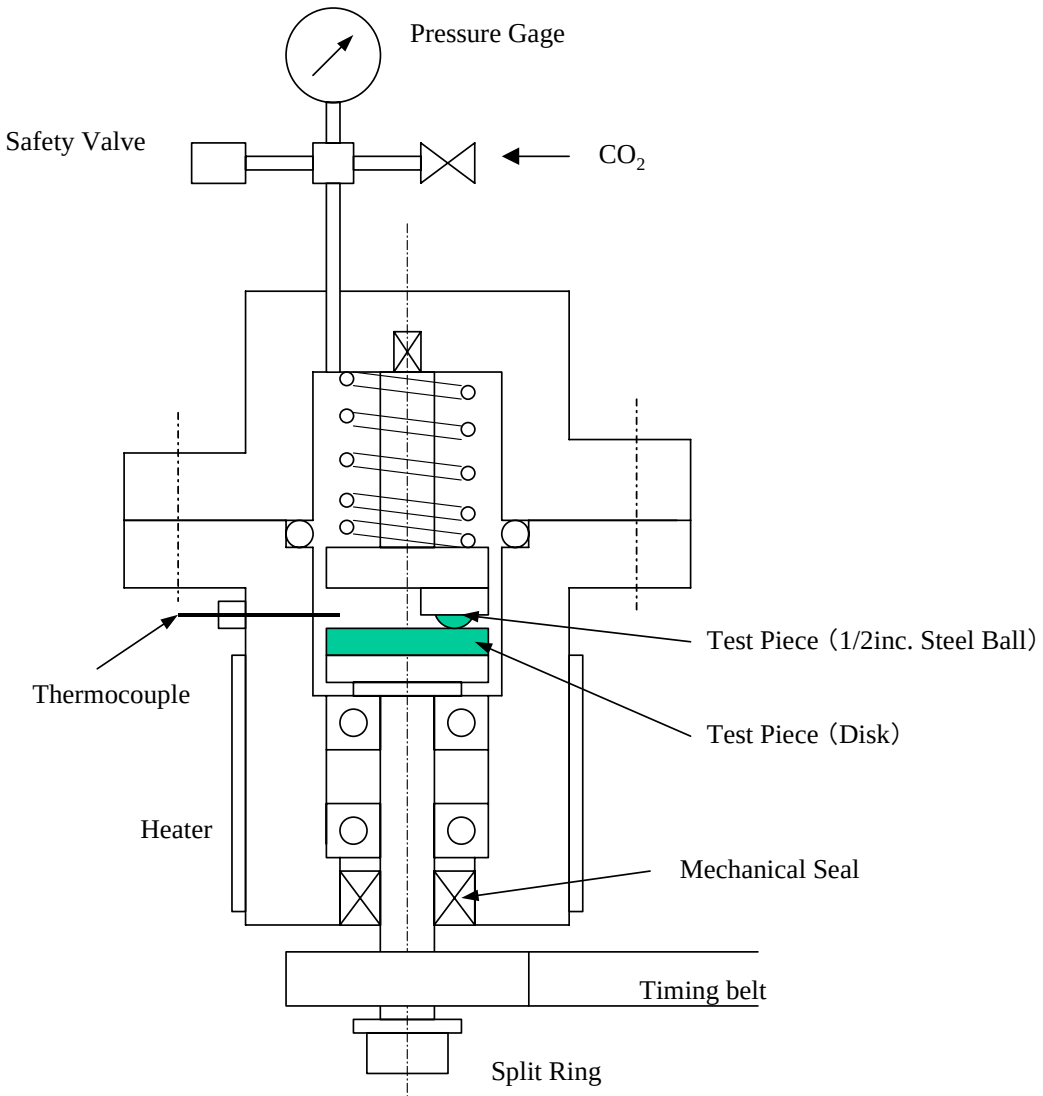
	50℃, CO_2 : 9.0 MPa (Supercritical)		−10℃, CO_2／Oil = 60 : 40(wt%) (Soluble Region)
	Solubility	Diluted Viscocity	Diluted Viscocity
PAG	10wt%	8.2mm^2/s	2.9mm^2/s
PVE	18wt%	3.4mm^2/s	2.8mm^2/s
POE	18wt%	3.2mm^2/s	2.6mm^2/s
PC	20wt%	2.7mm^2/s	2.5mm^2/s

Specification of Oils

	PAG (Base Oil)	PVE100 (Base Oil)	POE100 (Base Oil)	PC100 (Base Oil)
Vis. @40℃ mm^2/s	44.43	104.2	88.93	64.59
Vis. @100℃ mm^2/s	9.511	10.51	9.610	9.453
VI	206	81	82	126
Density g/cm^3	0.9955	0.9462	0.9619	0.999

PC : Polycarbonate

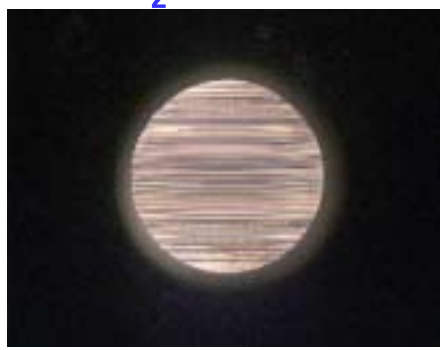
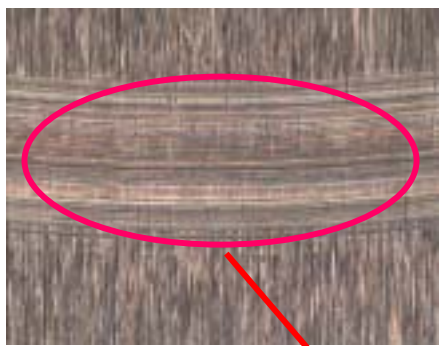
CO_2 High Pressure Ball on Disk Test Apparatus



Test Condition

- Oil Temperature ： 100℃
- CO_2 Pressure ： 0.7, 8.5MPa
- Revolution ： 200rpm
- Load ： 10kgf
- Test Time ： 60min.
- Ball ： SUJ2
- Disk ： SUJ2、A390

Surface of Sliding Parts after Test

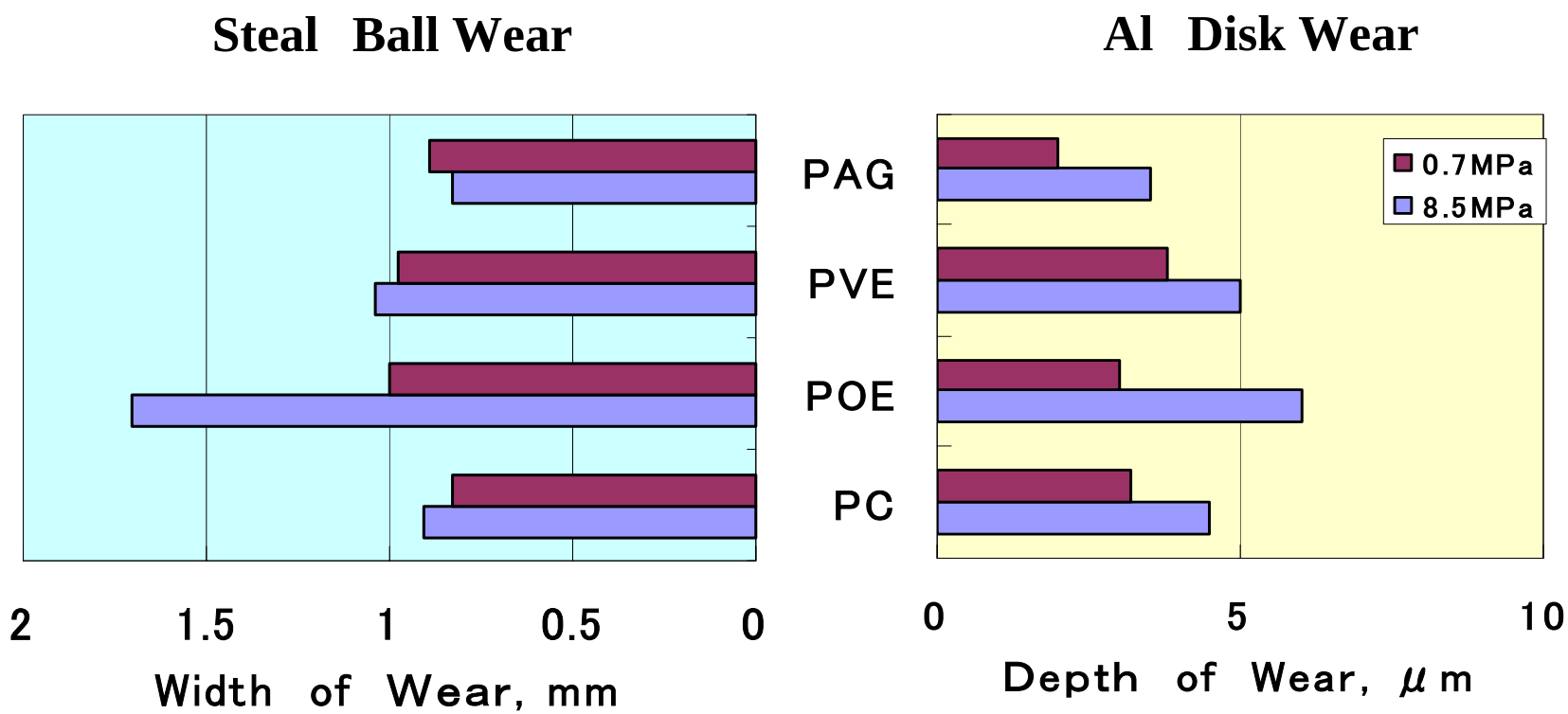
	PAG-Base (SUJ2) CO_2 : 8.5MPa	PVE-Base (SUJ2) CO_2 : 8.5MPa	POE-Base (SUJ2) CO_2 : 8.5MPa	PC-Base (SUJ2) CO_2 : 8.5MPa
Ball				
Disk				

Initial Grinding Scars Remain

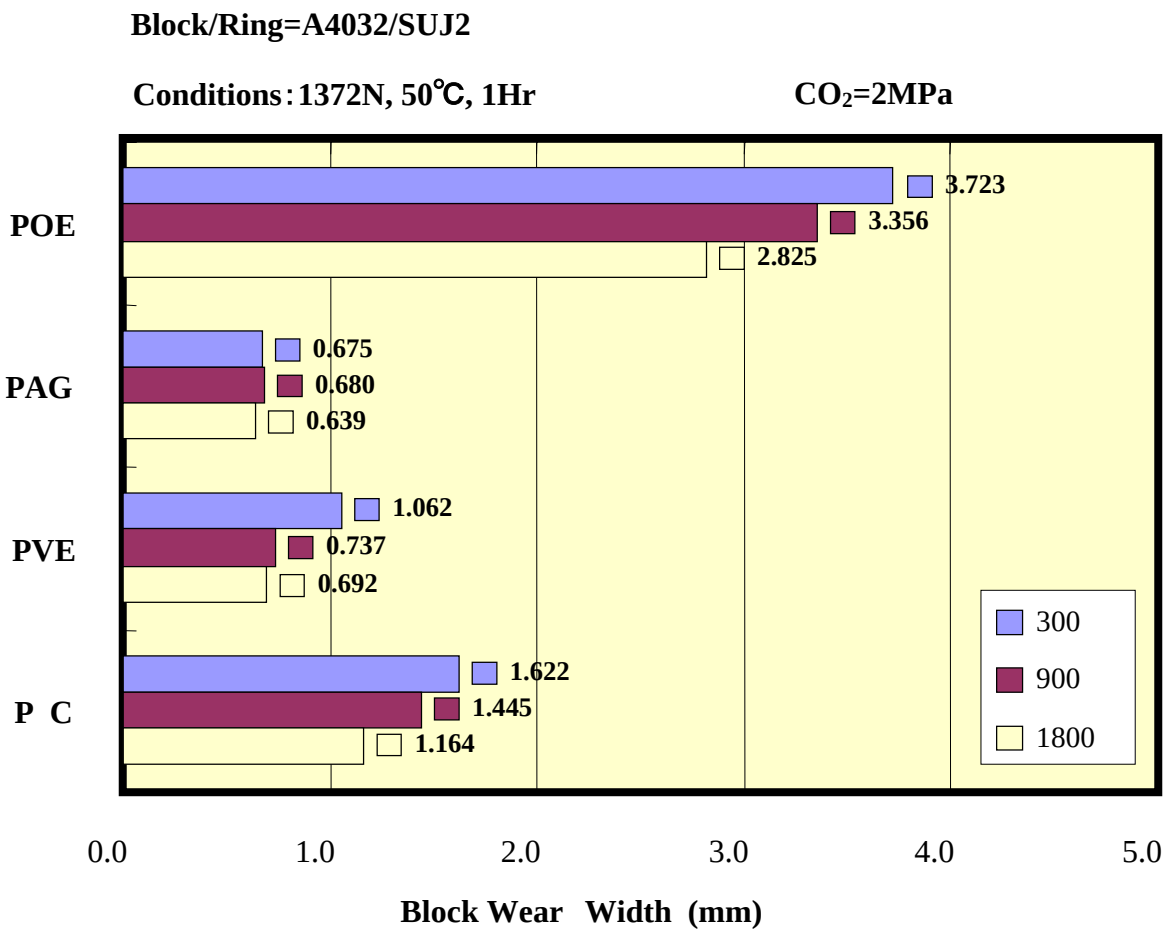
No Initial Grinding Scars

Effect to CO_2 Pressure for Wear

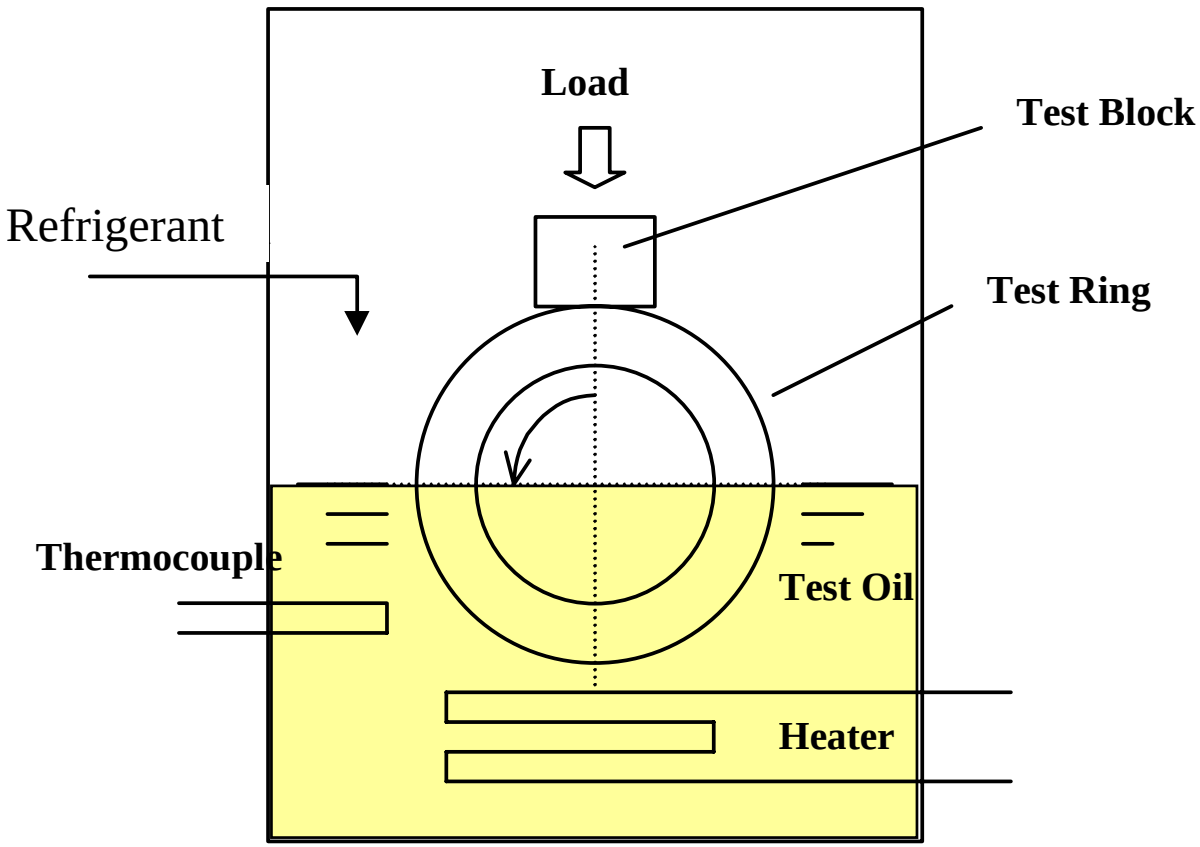
- **Disk/Ball : A390/SUJ2**



Lubricity under CO_2 - Atmosphere

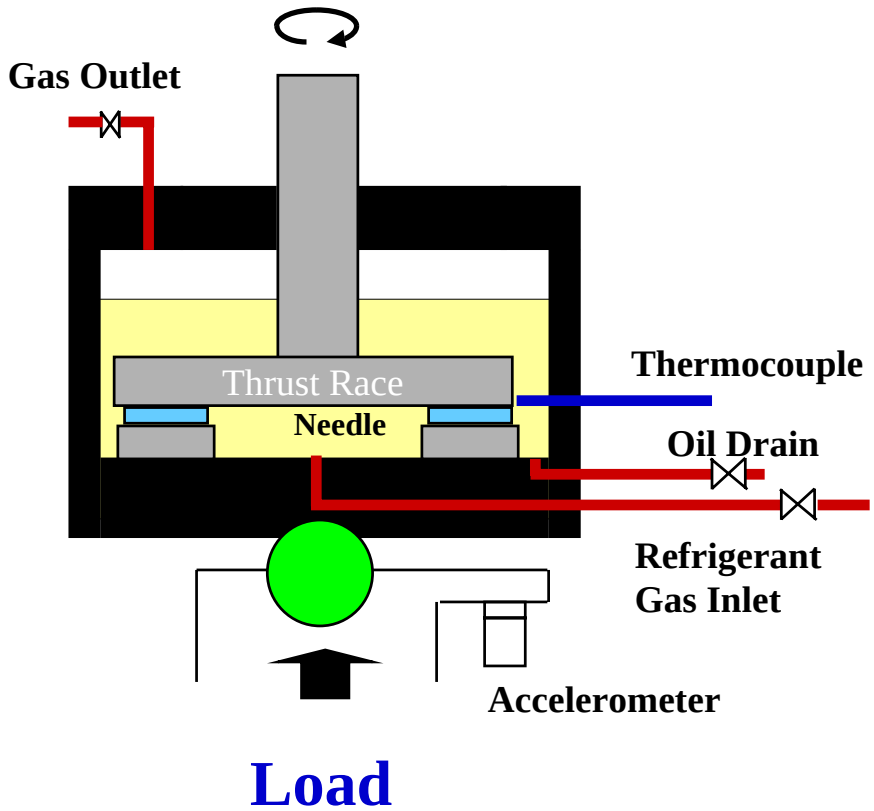


Schematic of an Hermetic Type LFW-1 Test Apparatus

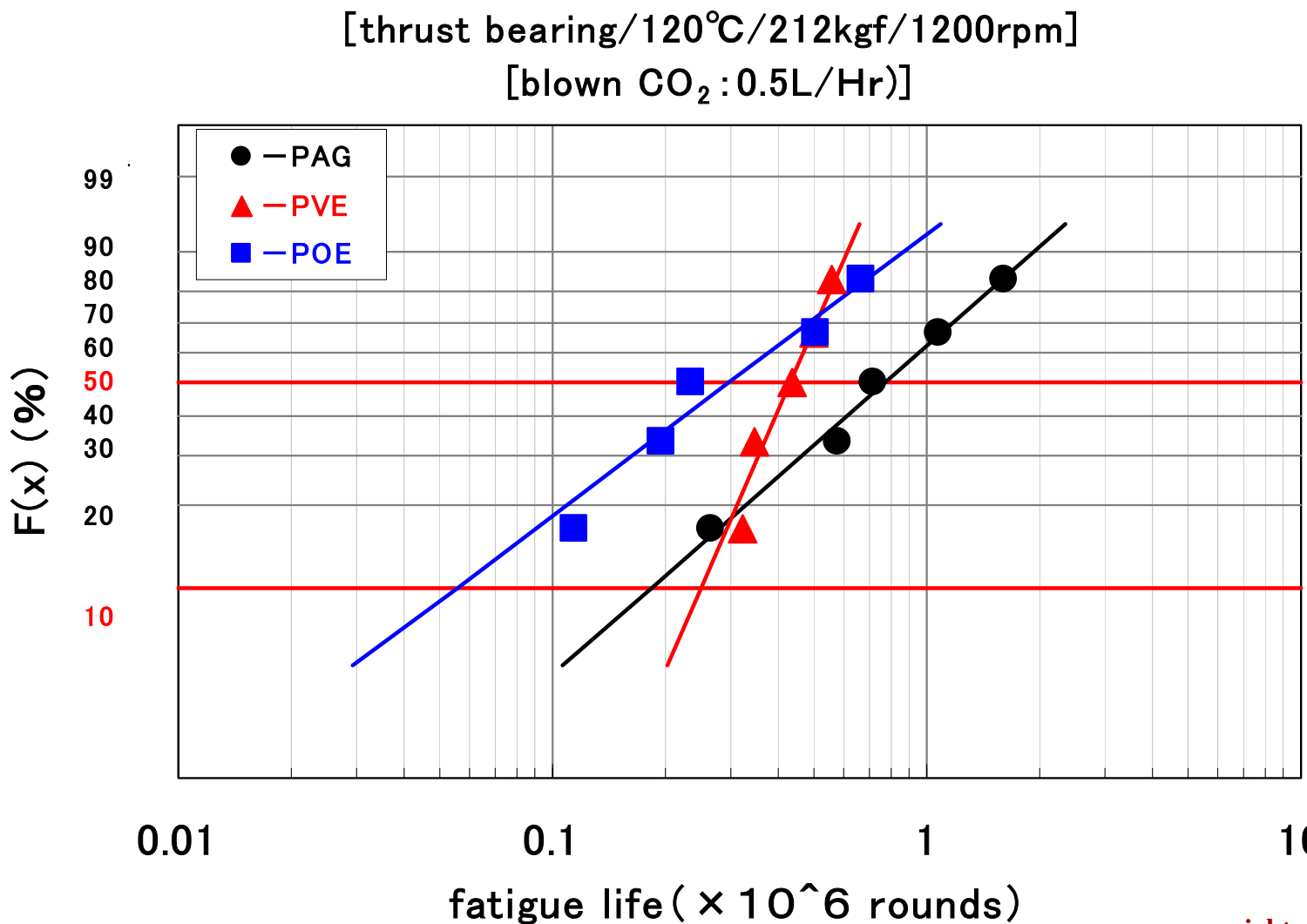


Fatigue Life Tester and Test Condition

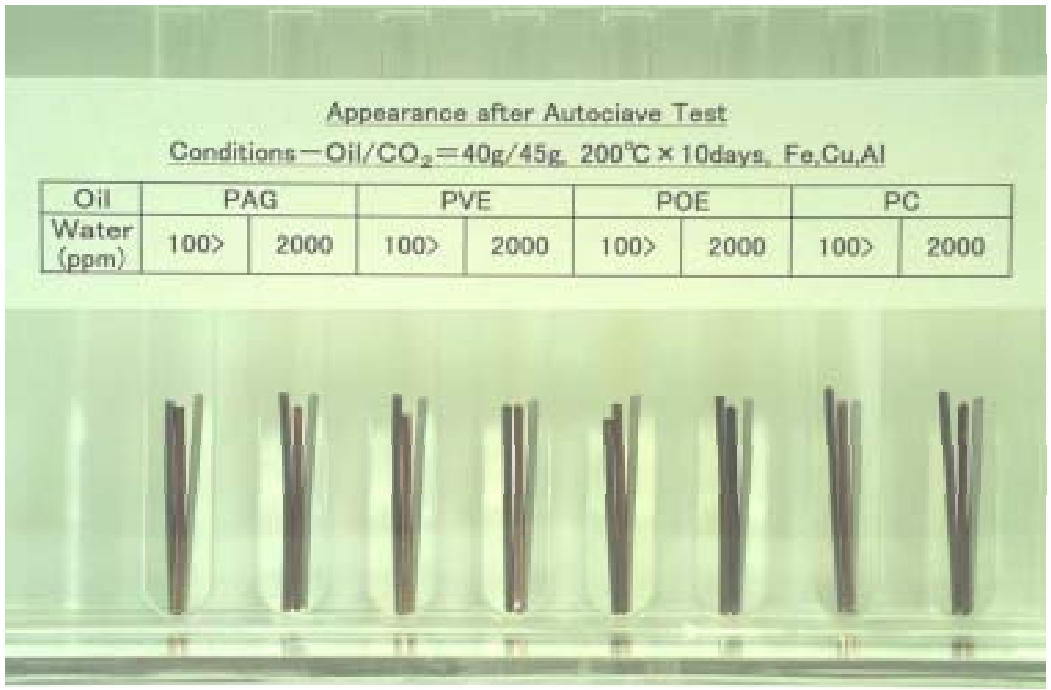
- Needle — SUJ2
  ϕ 1.8X5.55mm
  (3 needle used)
- Load — 212Kgf
- Pmax — 2.23Gpa
- Frequency of Contact — 1200Rev./Min.
- Temperature — 120 ℃
- Oil Feed Amount — 150 cc
- CO_2 — 0.5 L/hrs.



Comparison of Fatigue Life



Stability Under CO_2 Supercritical Condition

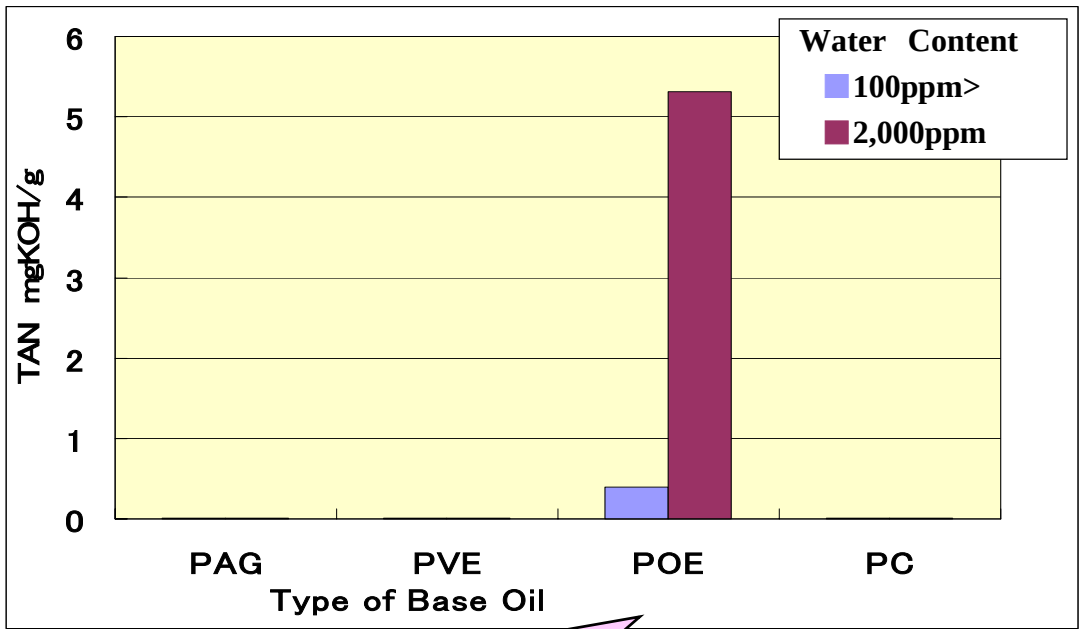


- **Autoclave Test Condition**
  - **Oil/CO_2=40g/45g**
  - **200℃×10days**
  - **Catalyst: Fe, Cu, Al**
  - **Water:100>, 2000(ppm)**

	Water (ppm)	PAG	PVE	POE	PC
Oil	100>	Good	Good	Good	Good
	2000	Good	Good	Good	Good
Catalyst	100>	Cu:light brown	Good	Cu:light brown	Cu:light brown
	2000	Cu:light brown	Good	Cu:light brown	Cu:brown

Stability Under CO_2 Supercritical Condition

- **Autoclave Test Condition**
  - ・200℃×10days ・Oil/CO_2=40g/45g ・Catalyst：Fe, Cu, Al



$$R^1COOR^2 + H_2O \rightarrow R^1COOH + R^2OH$$

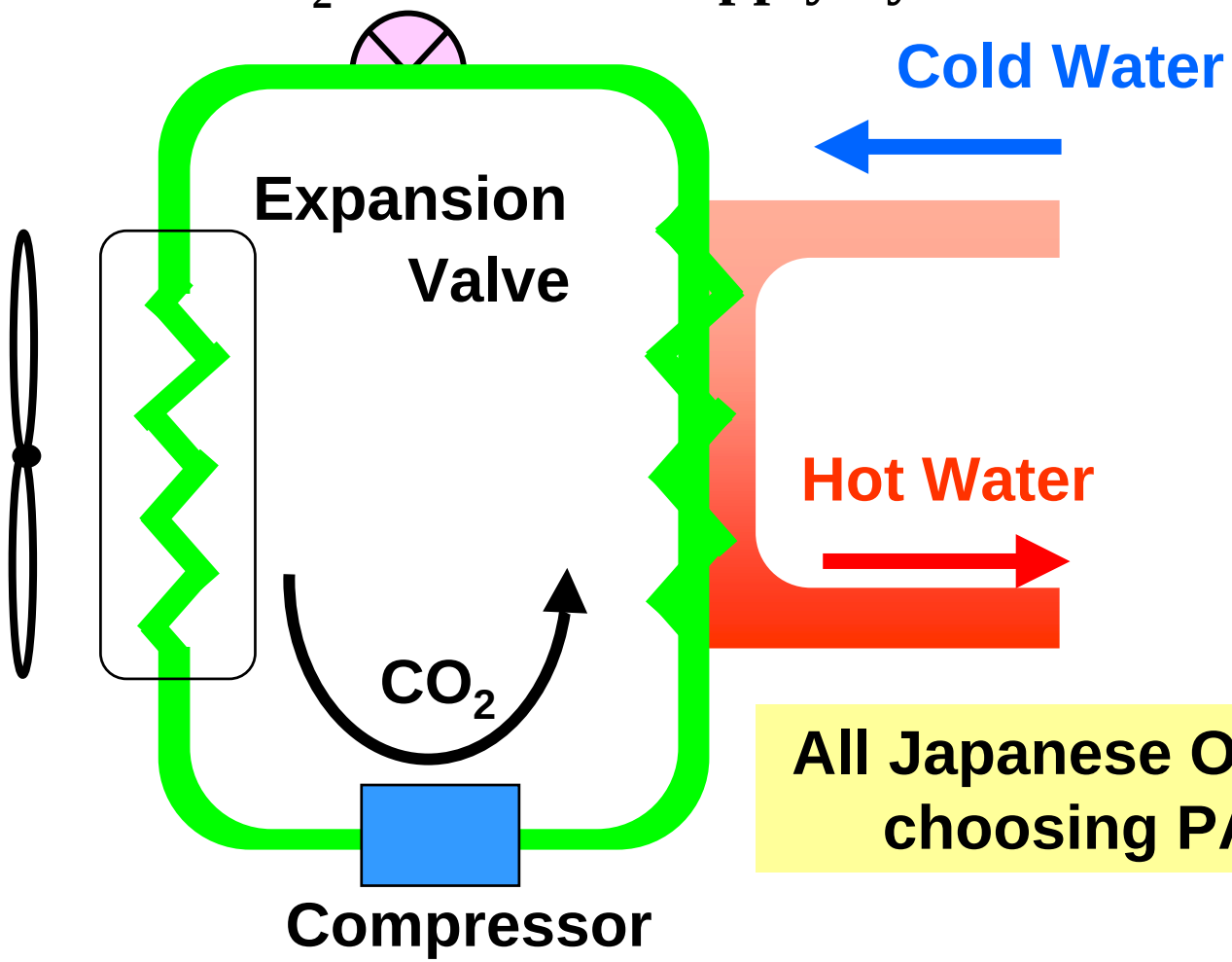
Candidates Performance Comparison

	PAG	PVE	POE	PC
Micsibility with CO_2	＋	＋＋	＋＋	＋＋
Mixture Viscosity (50℃)	＋	－	－	－
Mixture Viscosity (-10℃)	＋	＋	＋	＋
Lubricity	＋＋	＋	－－	－
Fatigue Life	＋	＋	－	
Stability under Supercritical Condition	＋	＋	－－	＋

＋＋: good ＋: neutral －: worse －－bad

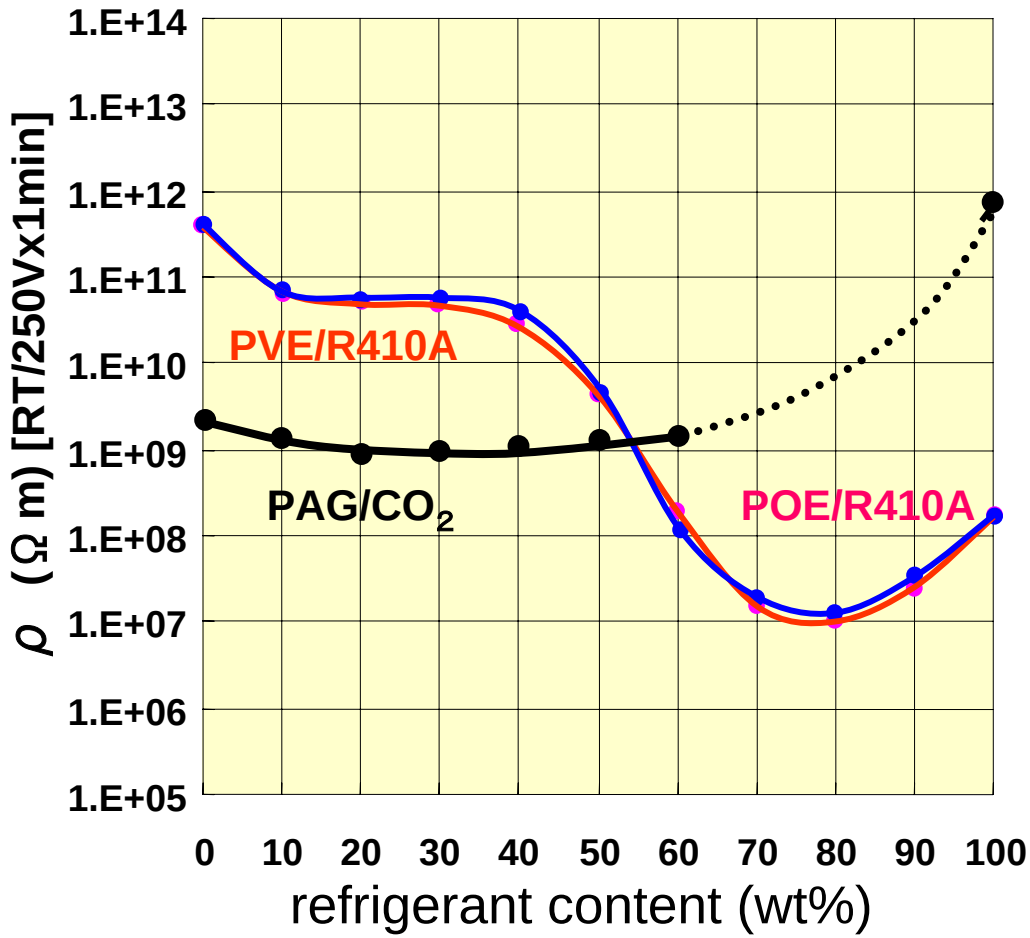
Approval of PAG Oil for CO_2 - Systems

Scheme of CO_2 Hot Water Supply System



All Japanese OEM's are choosing PAG oil

Volumetric Resistivity with Refrigerant



Conclusion

PAG is the best choice for CO_2 Refrigerating Oil for Automotive A/C .

Because…

- **Partially Miscible with CO_2**
- **Excellent Lubricity in Boundary Lubrication and CO_2 Supercritical Condition**
- **Long fatigue life**
- **Good Stability under CO_2 Supercritical Condition**

The Performance of PAG as a refrigeration oil for R152a (Miscibility/ Lubricity study)

Introduction

1. *R152a* is considered as one of the candidates for alternative automotive A/C refrigerants

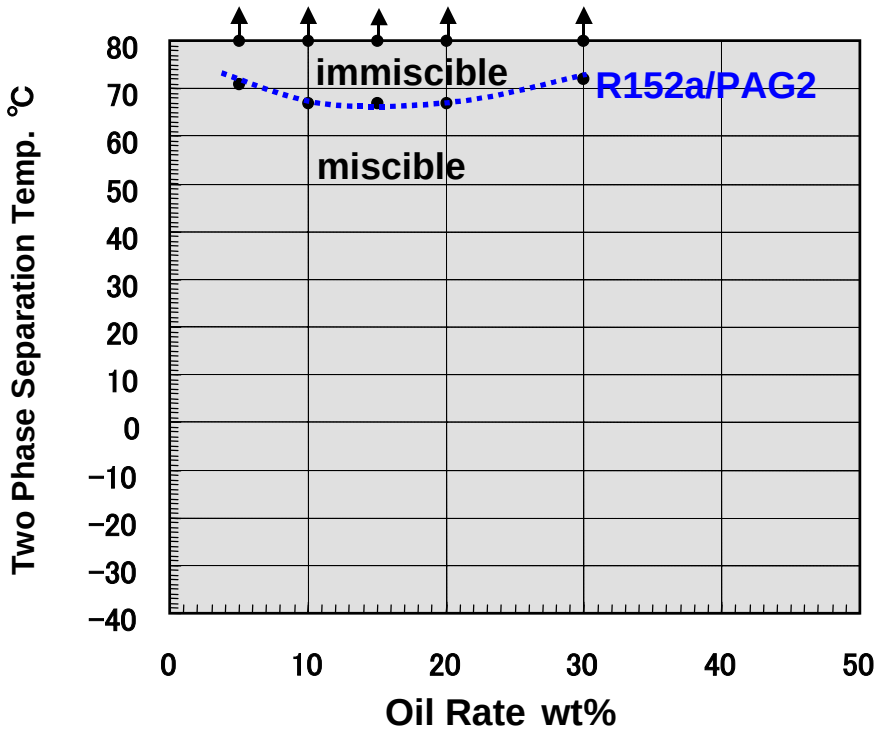
2. Evaluation of PAG as a refrigeration lubricant for *R152a* (miscibility, solubility and lubricity study)

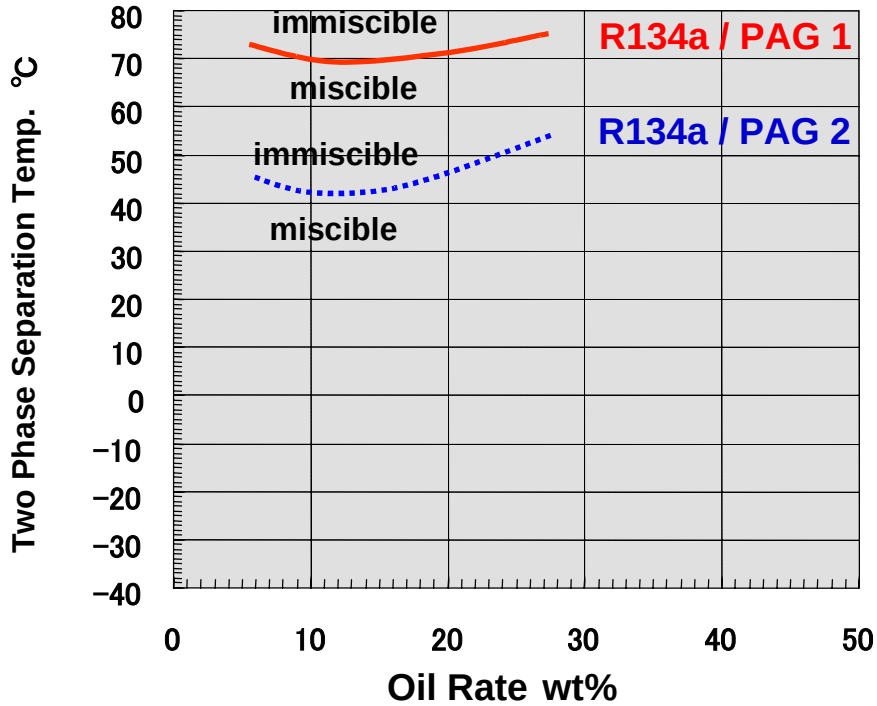
3. Indication of impact to lubricity under a minimal volume lubricant condition
   < oil dipping FALEX seizure test >

4. Performance between SINGLE- and DOUBLE-end capped PAG

Miscibility between PAG and R152a

R152a/PAG1 : miscible in all areas





PAG 1: 10mm²/s PAG 2: 20mm²/s

PAG/R152a has a larger miscible range than PAG/R134a

Solubility and Mixed Viscosity

Refrigerant	PAG 1		PAG 2	
	Solubility Wt%	Diluted Vis. mm^2/s	Solubility Wt%	Diluted Vis. mm^2/s
R134a	31	4.5	30	8.9
R152a	21	4.0	21	6.0

Condition : 90℃, 1.6 MPa

- ✓ R152a shows less solubility with PAG than R134a under same temperature and pressure condition.
- ✓ R152a causes more viscosity decline than R134a, means diluted viscosity with R152a is lower than diluted viscosity with R134a under the same conditions.

Sample Property

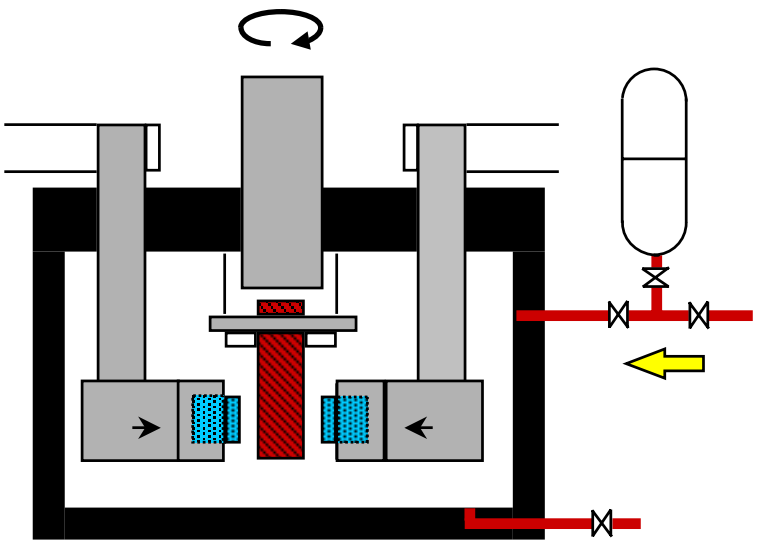
	Double End	Single End (1)	Single End (2)
Kinetic Viscosity@40℃ (mm^2/s)	45.66	56.89	62.52
Kinetic Viscosity@100℃ (mm^2/s)	9.992	10.68	11.62
Viscosity Index	214	181	184
Density @15℃ (g/cm^3)	1.0067	0.9984	1.0032
Total Acid Number(mgKOH/g)	0.05	0.05	0.00

Double End : PAG1

Single End (1) : Single End PAG/with PAG1 additive spec.

Single End (2) : Single End PAG/with different additive formula

Hermetic Type FALEX Apparatus/Condition



Pin

V Block

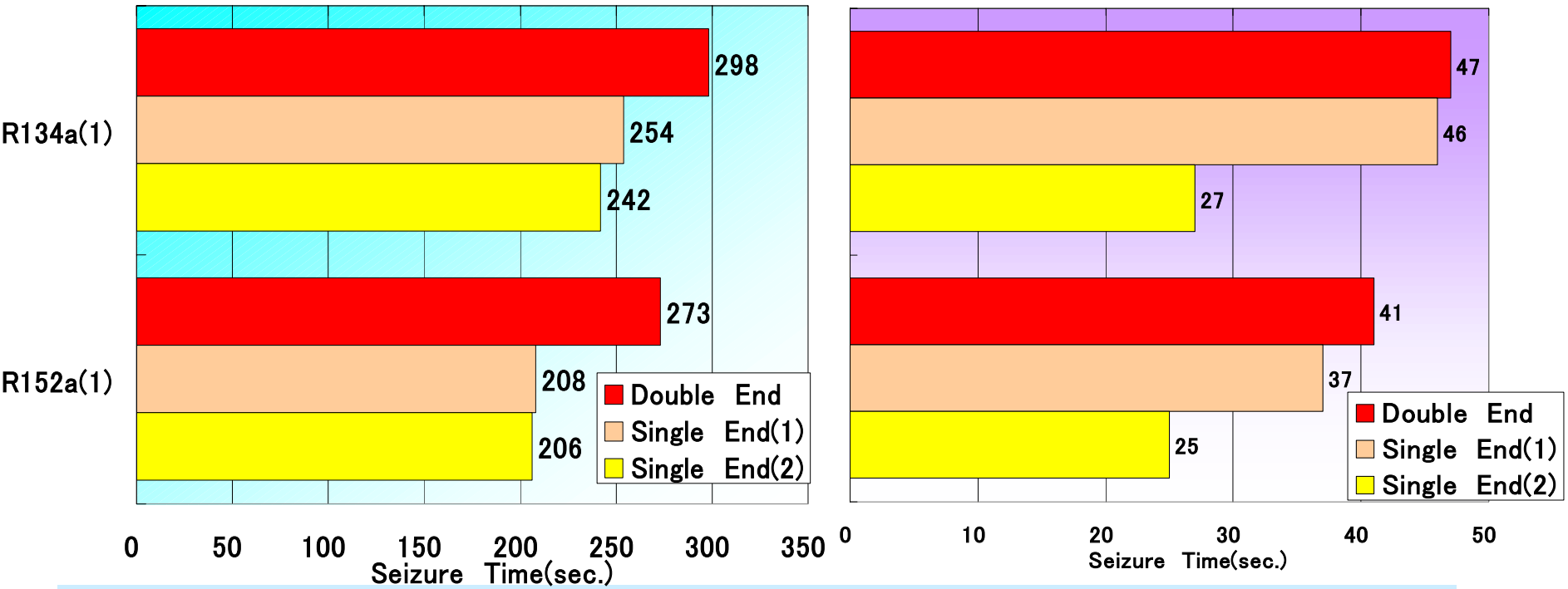
Refrigerant/Oil

	Codition 1	Condition 2	Condition 3
Pin	Fe (SCM415)	Fe (SCM415)	Fe (SUJ2)
Block	Fe (SUJ2)	Fe (SUJ2)	Al (A390)
Rotating Speed	300rpm	1,200rpm	300rpm
Load	1,780N	890N	1,330N
Temperature	RT	RT	RT
Oil Feed Amount	4 μl 0.5Ma	4 μl 0.5Ma	4 μl 0.5MPa
Pressure of HFC134a			

$Q = \mu PV$

FALEX Test Result (1)Fe/Fe

Condition:300rpm × 1,780N × RT × 4 μl × 0.5MPa、1,200rpm × 890N × RT × 4 μl × 0.5MPa



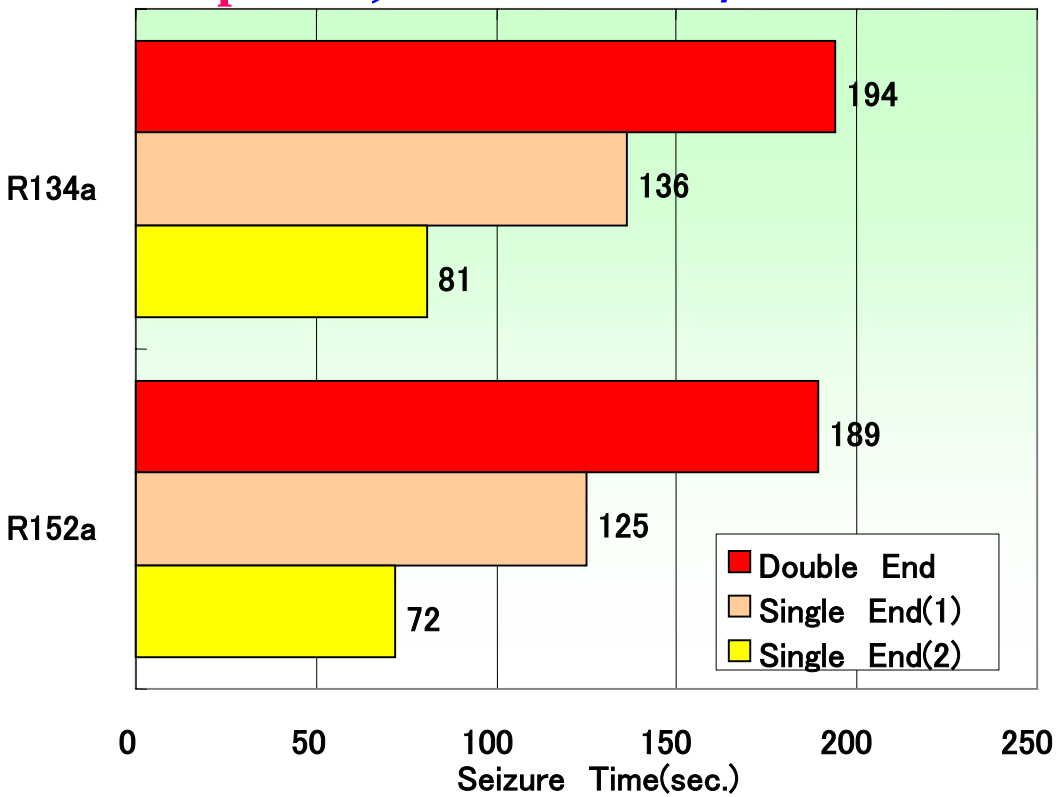
1. Quicker seizure time under R152a than R134a.

   Most likely caused by lower diluted viscosity with R152a than with R134a.

2. Double-end capped PAG shows longer seizure time than single-end capped PAG, both in R134a & R152a.

FALEX Test result (2)Fe/Al

Condition:300rpm × 1,330N × RT × 4 μl × 0.5MPa



1. Quicker seizure time under R152a condition than R134a
2. Oiliness agent improves the lubricity between Fe/AL better than in double-end capped PAG than in single-end capped PAG

Conclusion

1. PAG/R152a mixture shows wider miscible range than PAG/R134a mixture
2. R152a is less soluble with PAG than R134a is

   R152a causes lower diluted viscosity with PAG than R134a does
3. Seizure time with R152a is shorter than R134a condition due to lower diluted viscosity
4. Double-end capped PAG shows a better lubricity result in a R152a system than a single-end PAG

RECOMMENDATION

1. Based on lubricity and solubility results, PAG seems to be the superior lubricant for R152a applications (double-end capped PAG provides even the best result)
2. Regarding the tendency of lower diluted viscosity with R152a, PAG will need an adjustment of the lubricant viscosity.

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