Transient separation of refrigerant from oil/refrigerant mixture

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Shizuoka, Japan

To access Shizuoka University

1.5~2 hours from Tokyo or Osaka

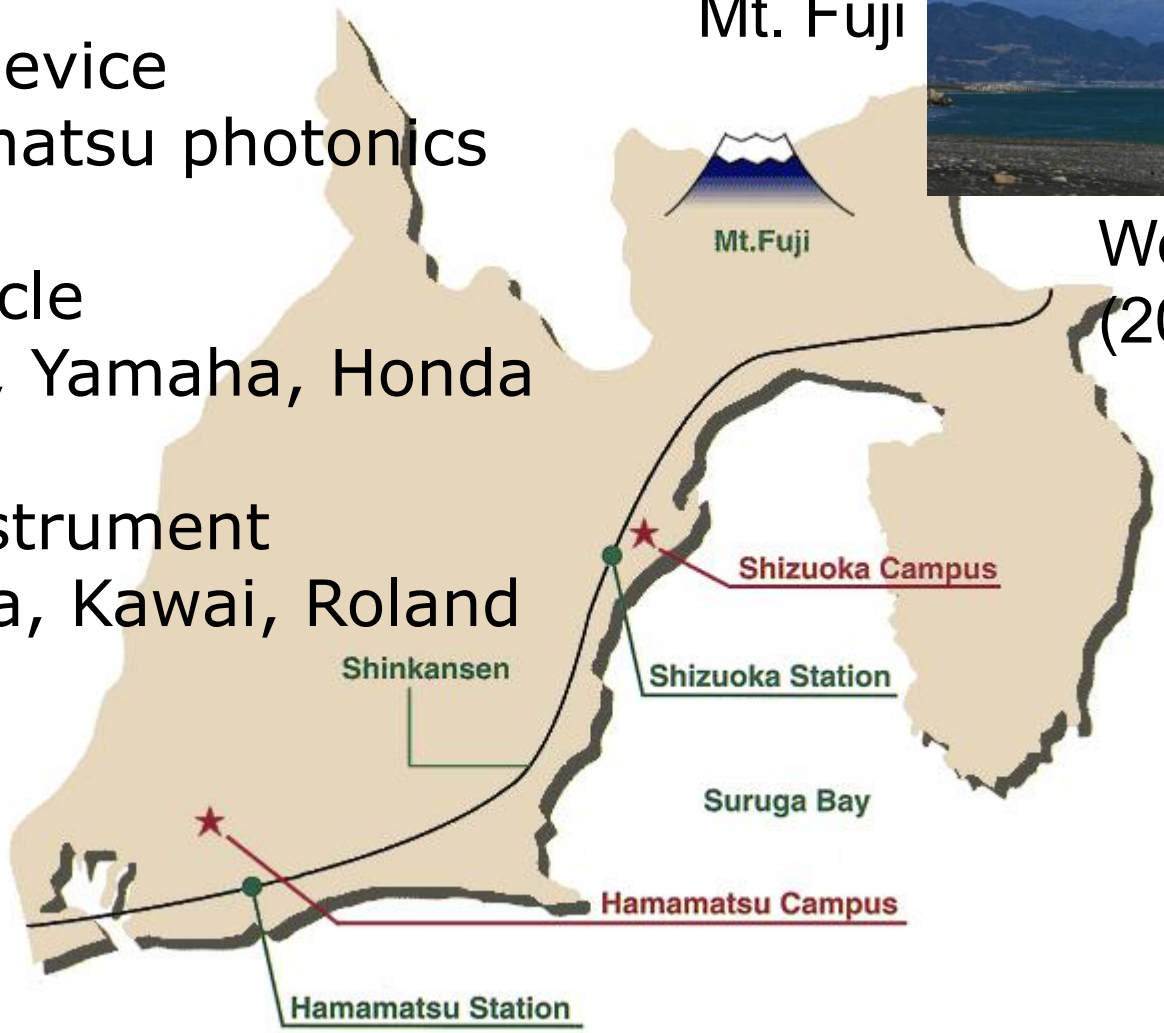
by Shinkansen (bullet train)

Campus Location

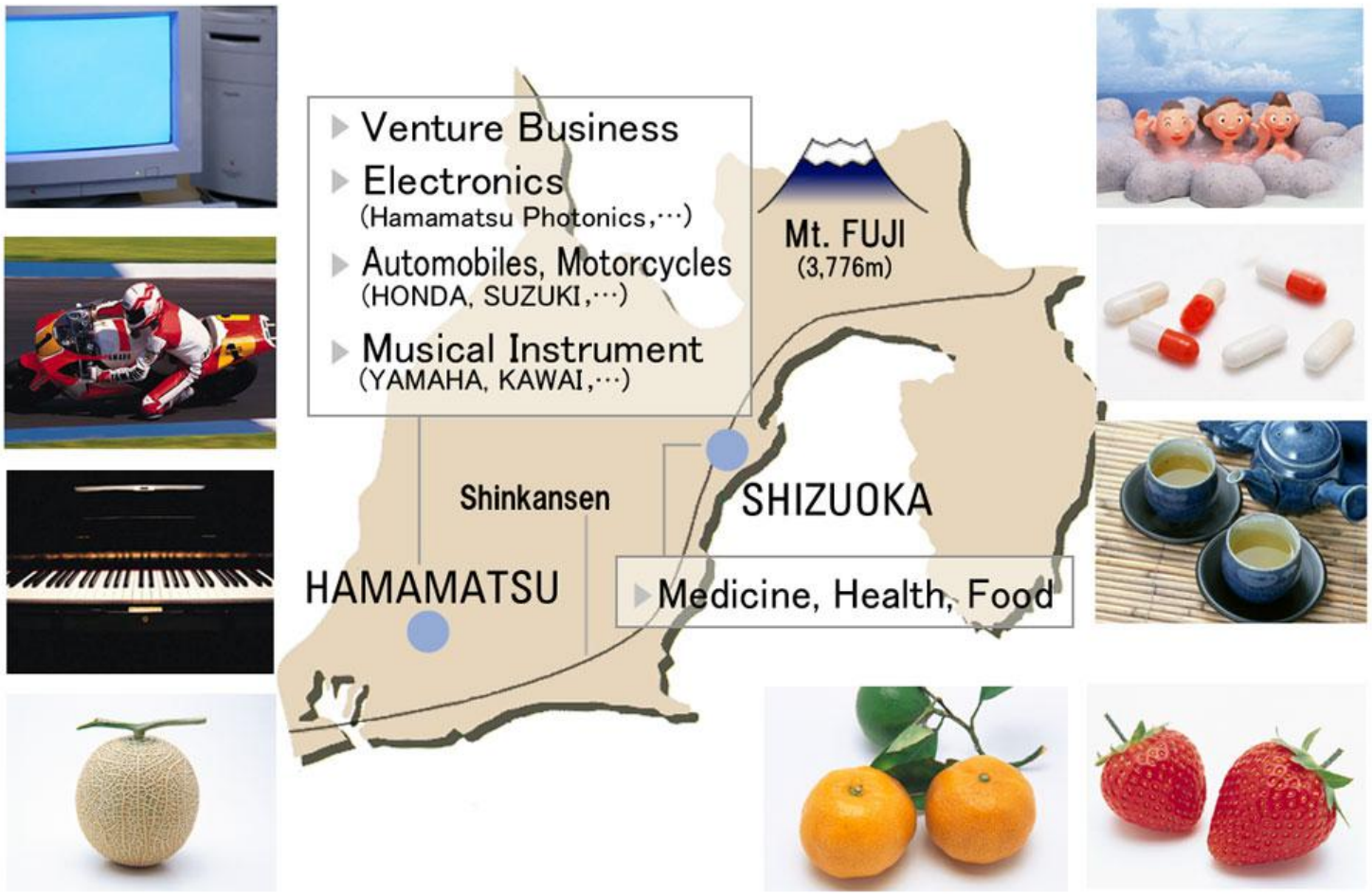
- Optical device
  Hamamatsu photonics
- Motor cycle
  Suzuki, Yamaha, Honda
- Music instrument
  Yamaha, Kawai, Roland

Mt. Fuji

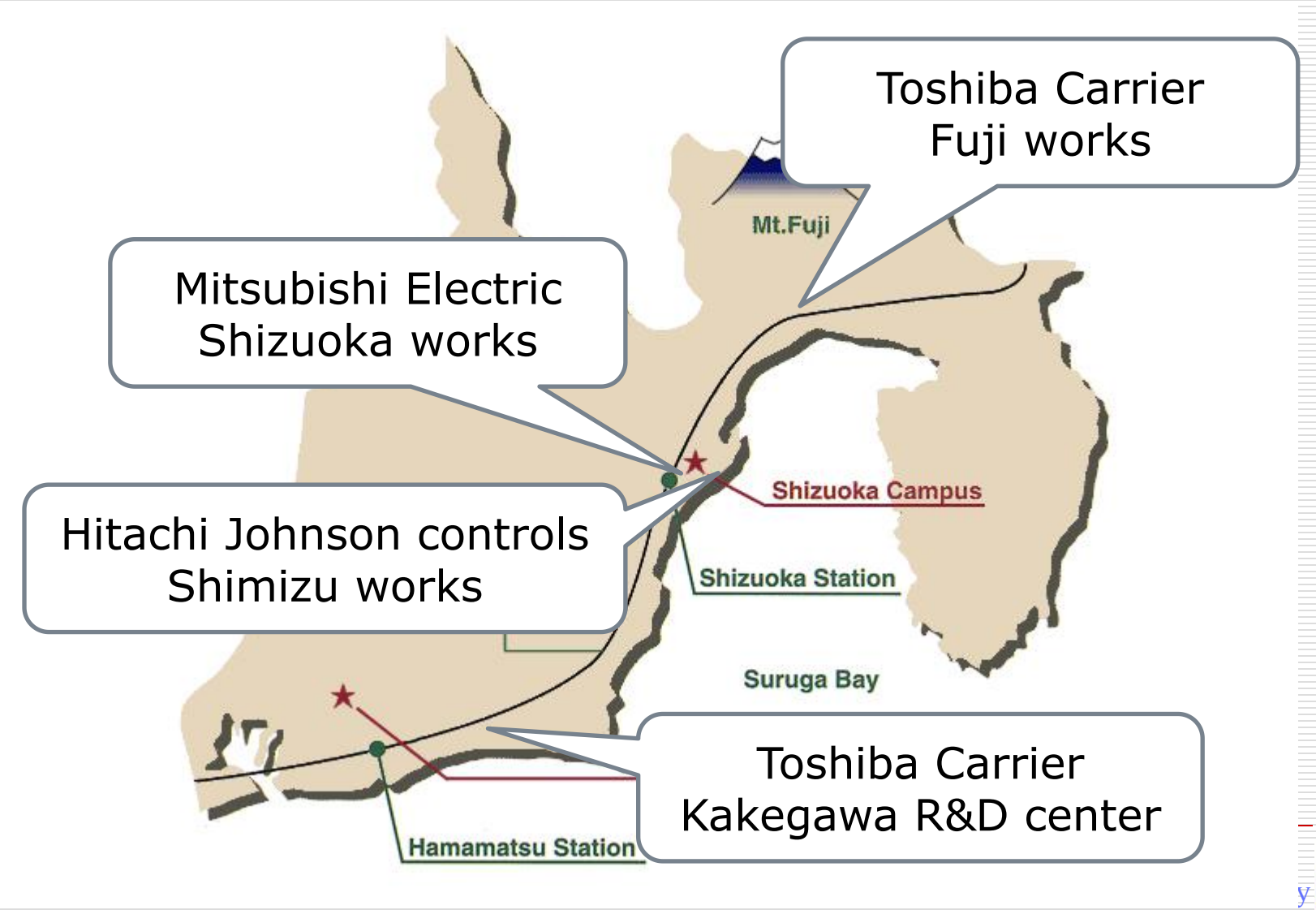
World Heritage
(2013～)



Major Products of Shizuoka Prefecture



Refrigeration industry in Shizuoka



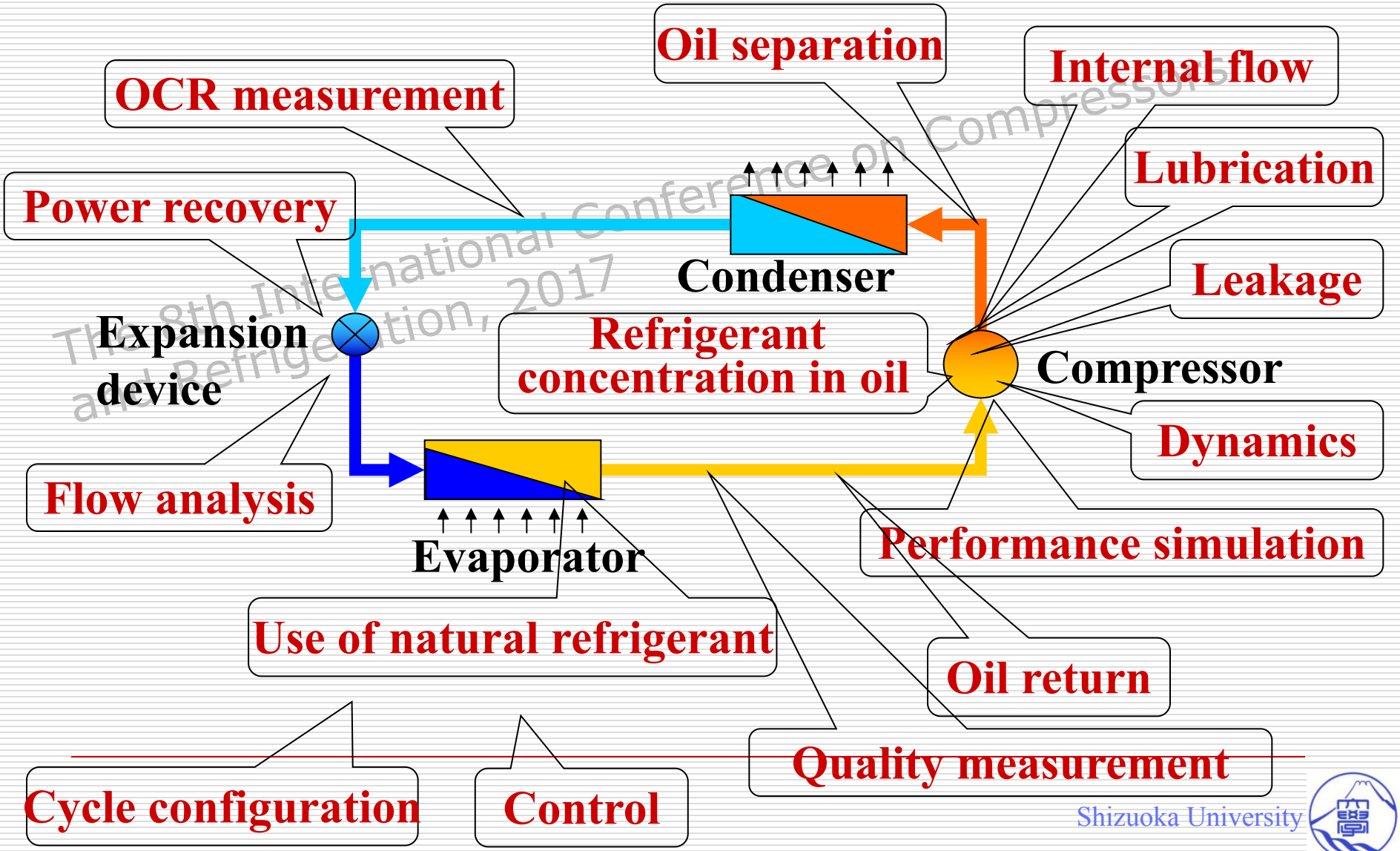
Research activities in our laboratory

- Compressor and expander
- Refrigeration system
- Functional fluid

Research activities in our Lab.

- Compressor and expander
  - Operating characteristics, High performance, High reliability
- Refrigeration system
  - Instrumentation techniques
  - Clarifying flow phenomena
    - Two-phase flow, Foam, Oil droplet…
  - Properties of oil/refrigerant mixture
  - Nano-oil
- Functional fluid
  - Drag reduction
  - Measurement of physical properties
  - Enhancement of heat transfer

Research activities



Refrigeration cycle and Refrigeration oil

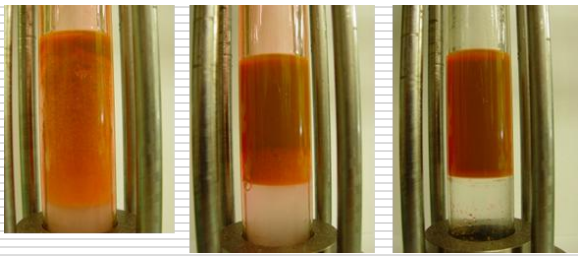
How complicated the oil related matters are.

Refrigeration cycle and refrigeration oil

- Roles of refrigeration oil
  - Lubrication
  - Seal of compression chamber
  - Cooling
  - Cleaning

Refrigeration cycle and refrigeration oil

- Required properties
  - Lubricity（appropriate viscosity, strong oil film）
  - Stability（against heat, acid, and moisture）
  - Fluidity (low freezing point)
  - Material compatibility
  - Miscibility with refrigerant
    ← Oil return, Lubrication
  - ~~Electric insulation~~
    (hermetic compressor)



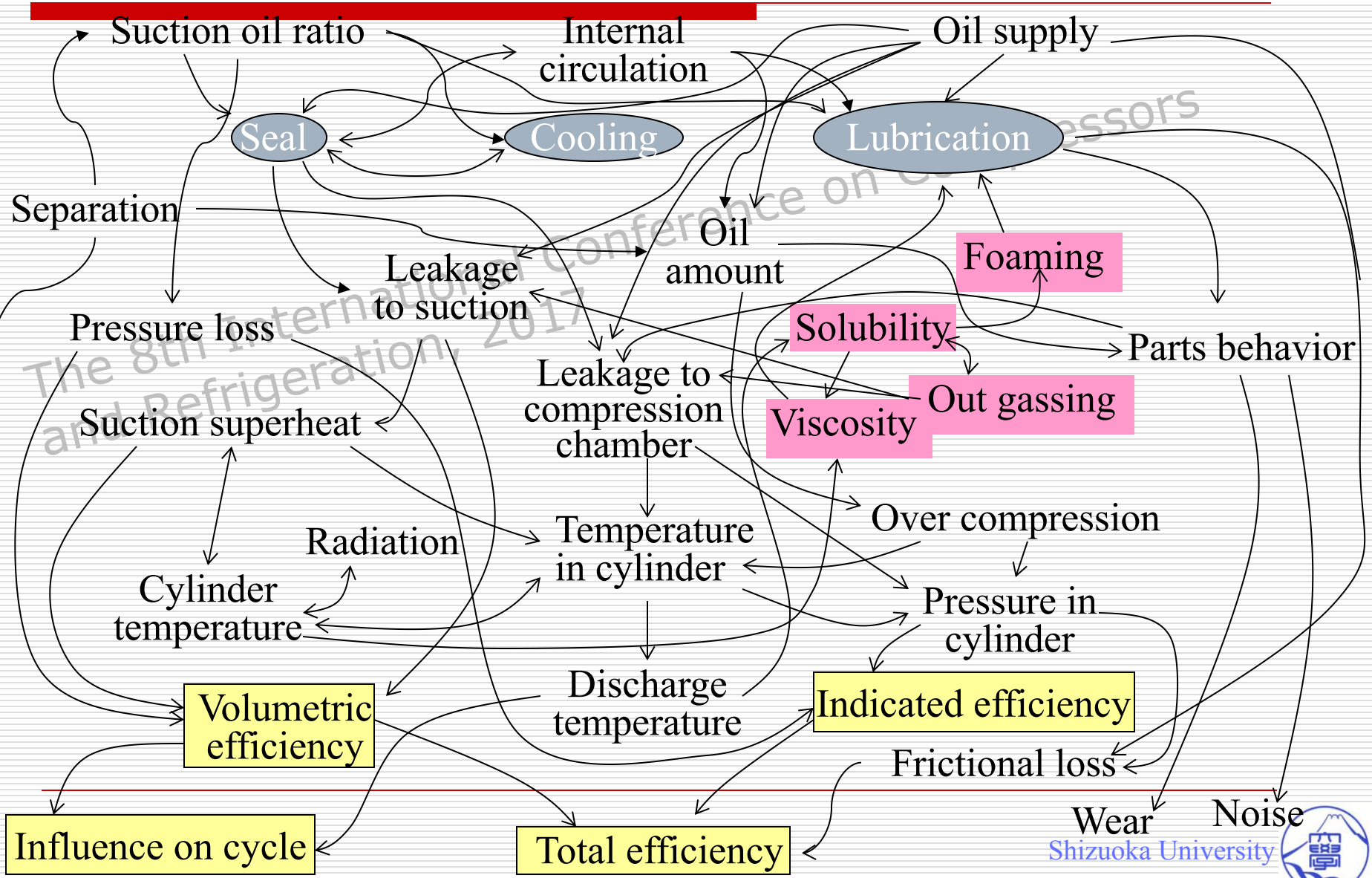
Refrigerant/Oil mixture

- Good solubility of oil with refrigerant

Influence on operating characteristics of compressors and cycles

- Viscosity of oil
- Foaming phenomenon in compressor shell
- Oil return to compressor
- Amount of refrigerant circulating in cycle
- Heat transfer and pressure drop in heat exchangers

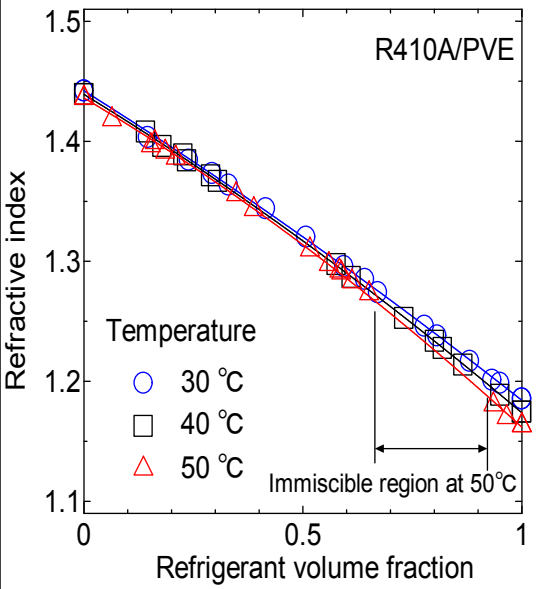
Influence of refrigeration oil



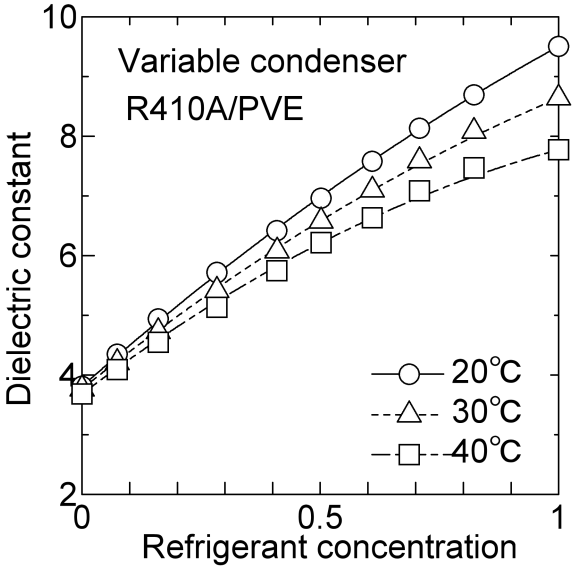
Properties of refrigerant/oil mixture

- Refractive index
- Dielectric constant
- Acoustic velocity
- Density
- Surface tension

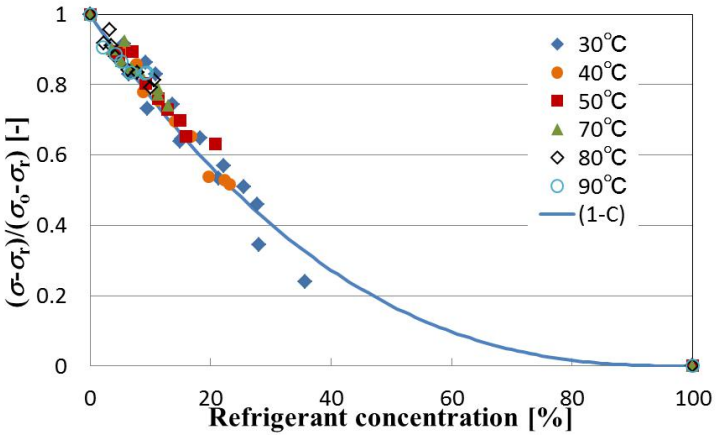
Properties of oil/refrigerant mixture



Refractive index



Dielectric constant

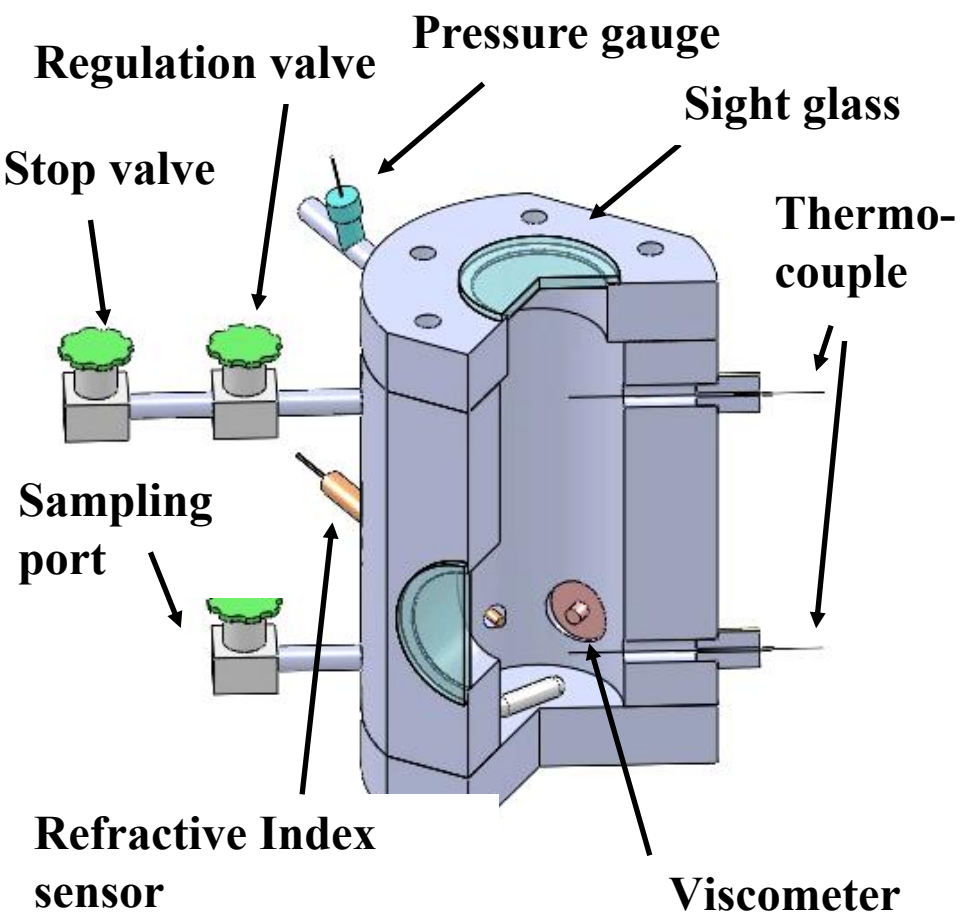


Surface tension

Transient separation of CO_2 from PAG

- Measurements of concentration and viscosity of CO_2/PAG mixture
- Separation characteristics
  - Depressurization in pressure vessel
  - Depressurization through valve

Experimental setup for concentration and viscosity measurement



Refrigerant : CO_2
Refrigeration oil : PAG

Procedure

1. Evacuation after charging oil
2. Refrigerant charge with stirring
3. Set to given pressure and temperature

▼

4. Measurement of pressure, temperature, refractive index, viscosity
5. Sampling

Concentration measurement based on refractive index

$$n = \beta n_r + (1-\beta) n_o + c\beta(1-\beta)$$

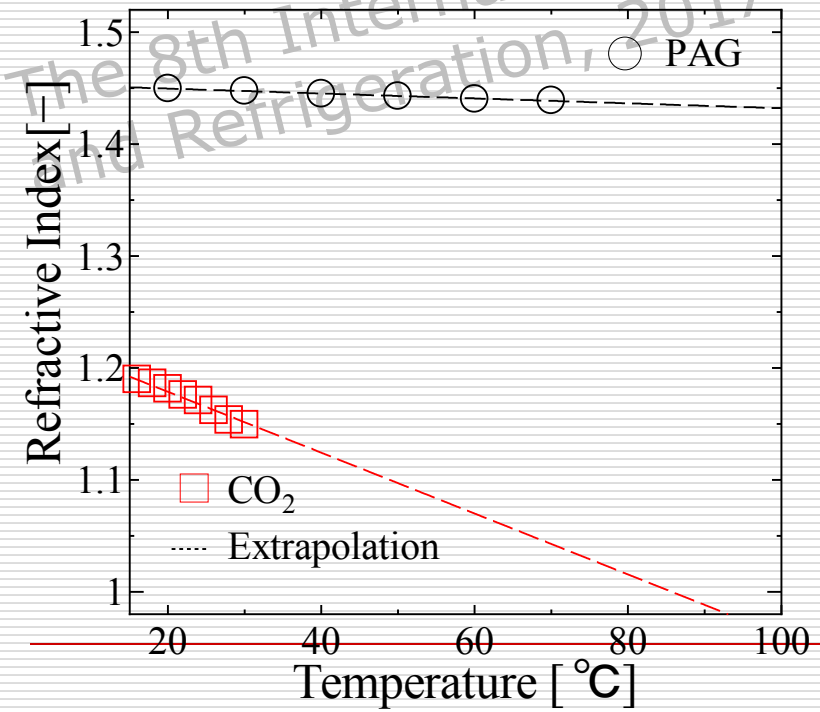
n : Refractive index of mixture

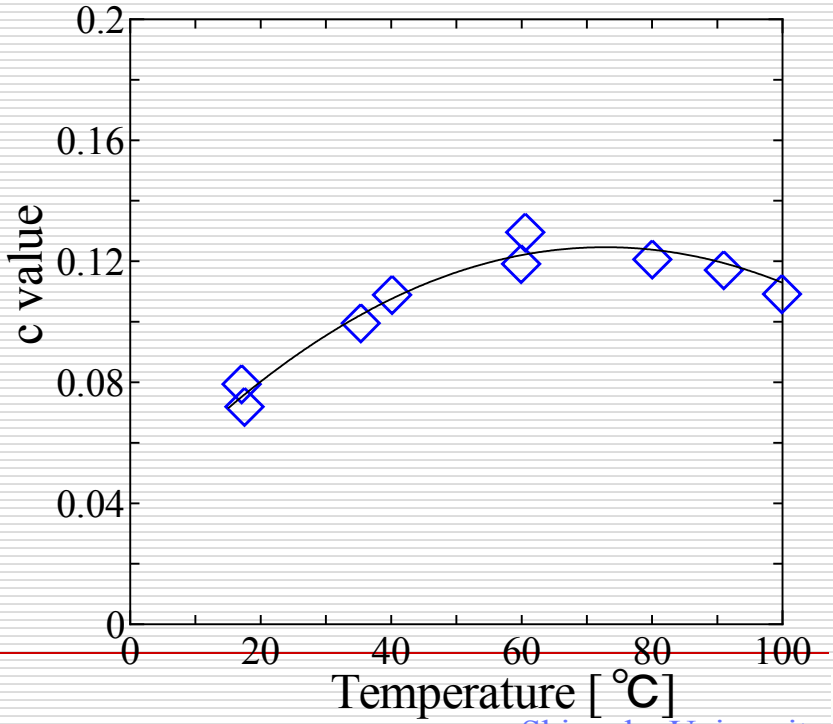
n_r: Refractive index of refrigerant

n_o: Refractive index of oil

c : Coefficient

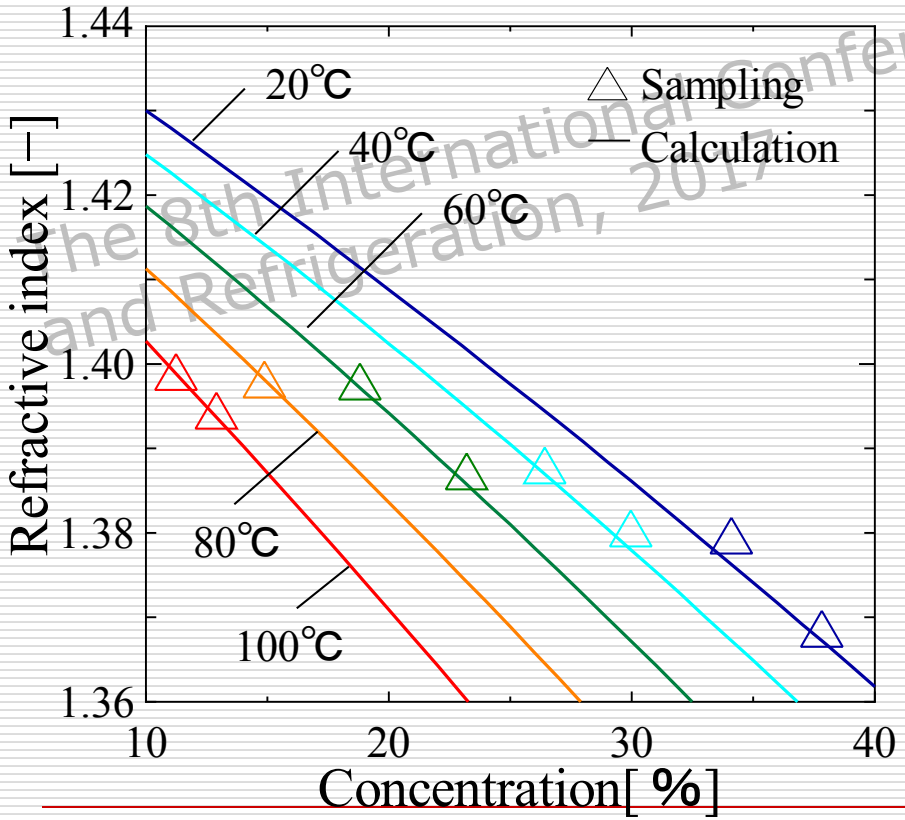
β: Weight fraction of refrigerant





Correlation curve

$$n = \beta n_r + (1-\beta) n_o + c\beta(1-\beta)$$



Deviation from sampling value

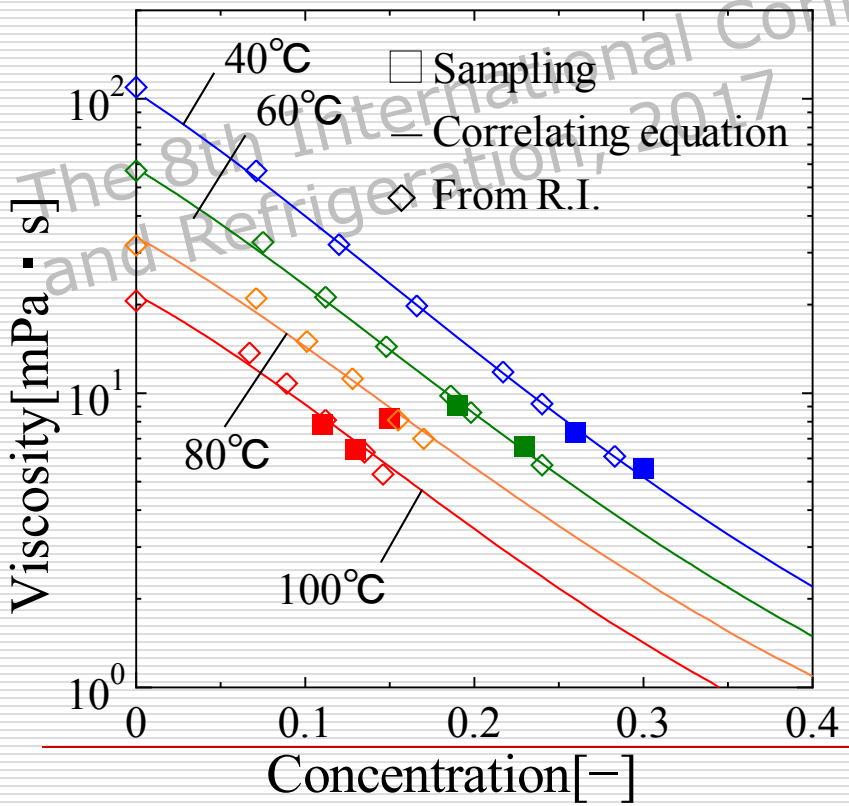
Approx. 0.5%

Refrigerant concentration can be obtained from refractive index and temperature from 20 ℃ to 100℃.

Correlation of viscosity

$$\log\left(\log\left(\frac{\mu}{\rho}\times 1000 + 0.7\right)\right) = A - B\log(273.15 + T)$$

μ : **Viscosity [mPa·s]**
ρ : **Density [kg/m³]**
T : **Temperature [℃]**
A,B : **Coefficients**

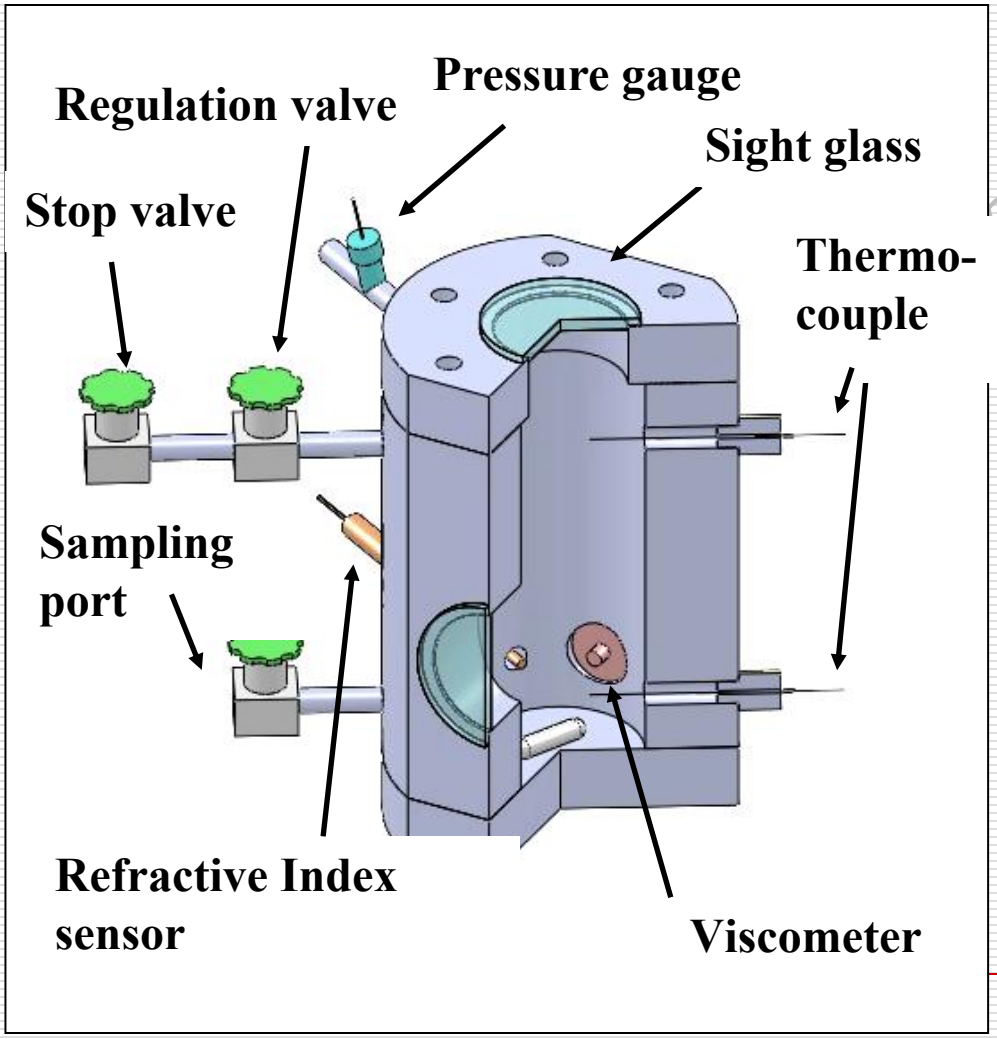


Relative error:
approx. 10 %

Separation characteristics

- Depressurization in pressure vessel

Experimental setup for depressurization in vessel



Refrigerant : CO_2
Refrigeration oil : PAG

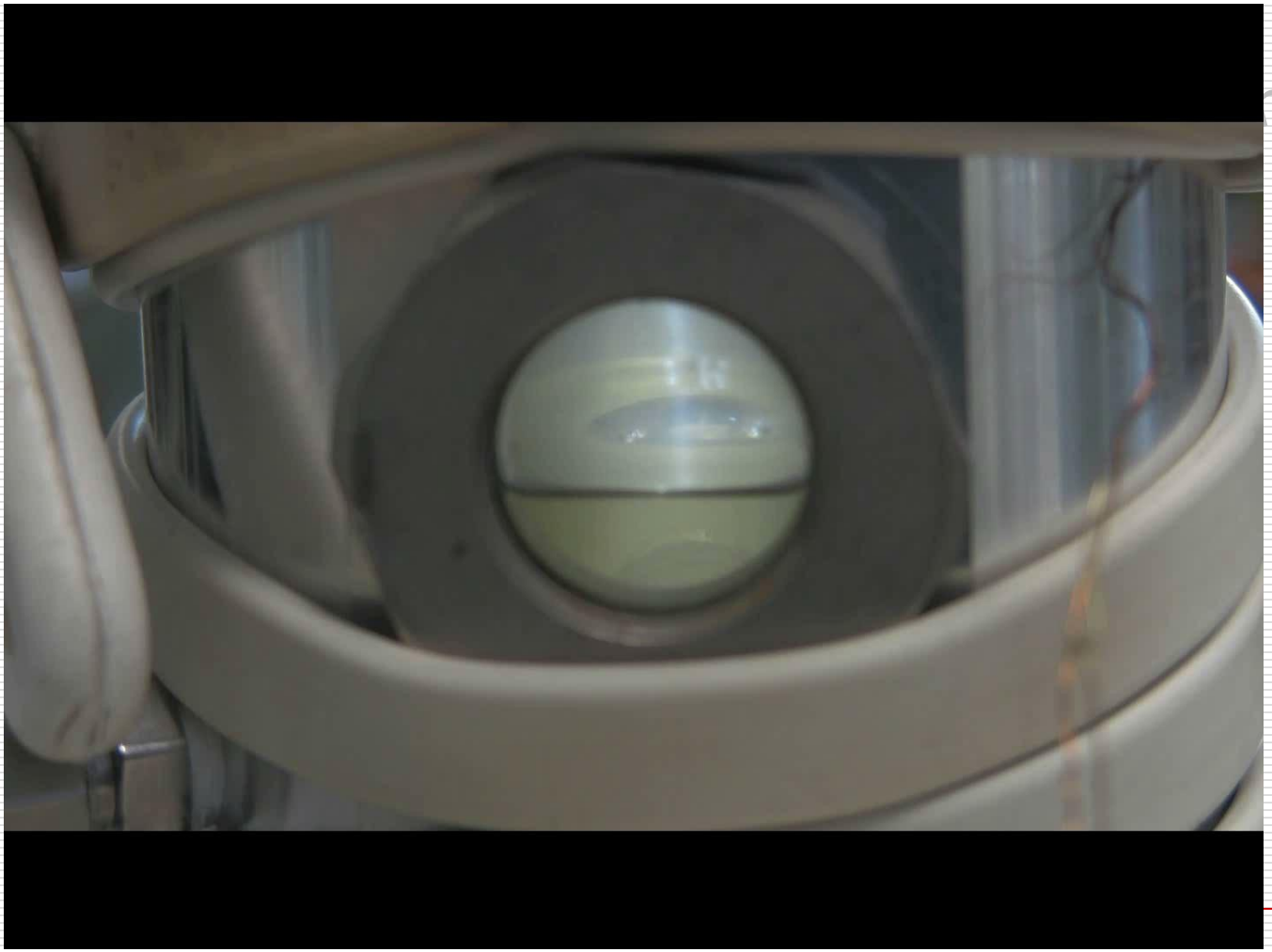
Procedure

1. Evacuation after charging oil
2. Refrigerant charge with stirring
3. Set to given pressure and temperature

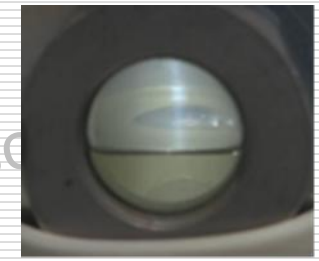
▼

4. Open the stop valve to reduce pressure in the vessel

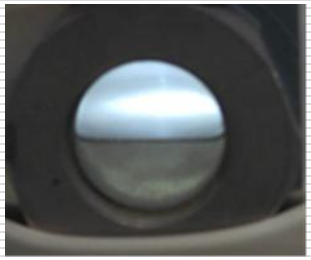
Mixture under depressurization



0 sec

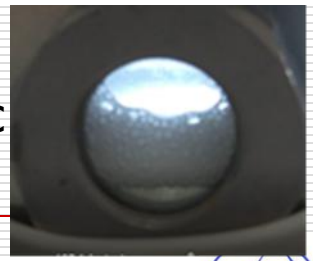


1 sec



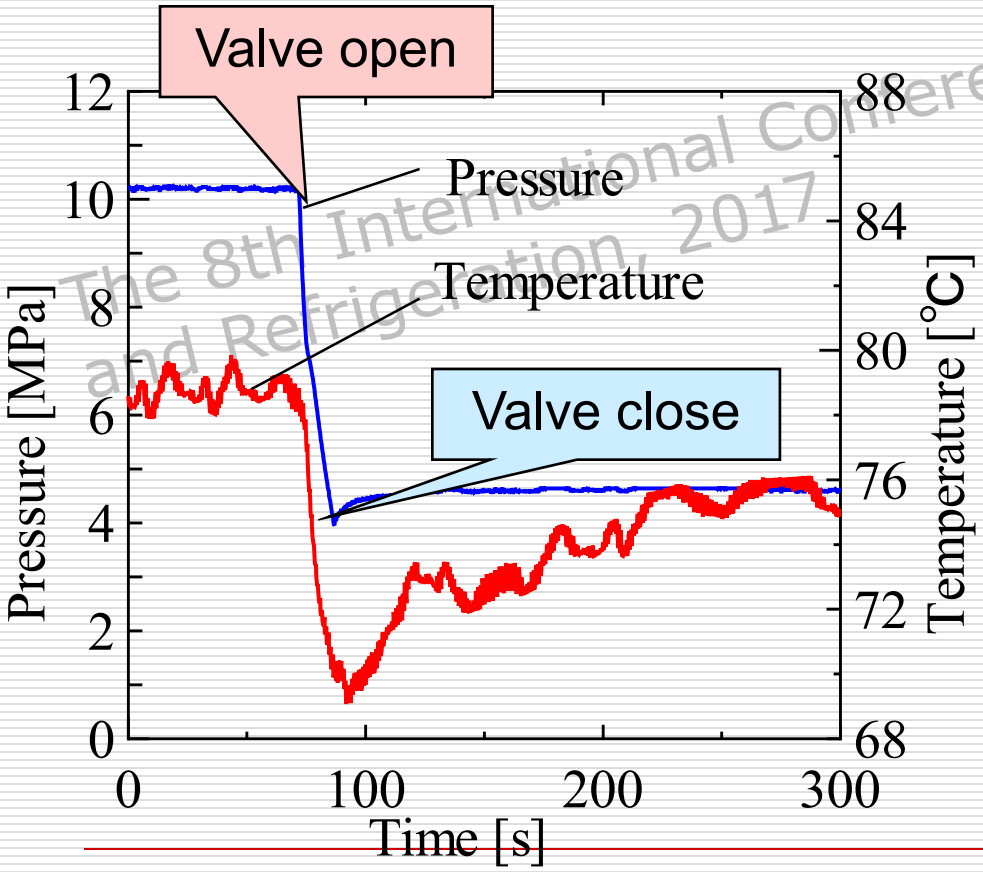
6 sec

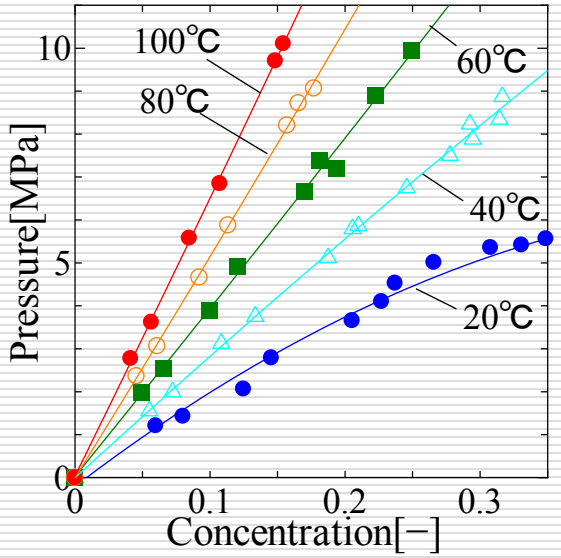
16 sec



Pressure and temperature change

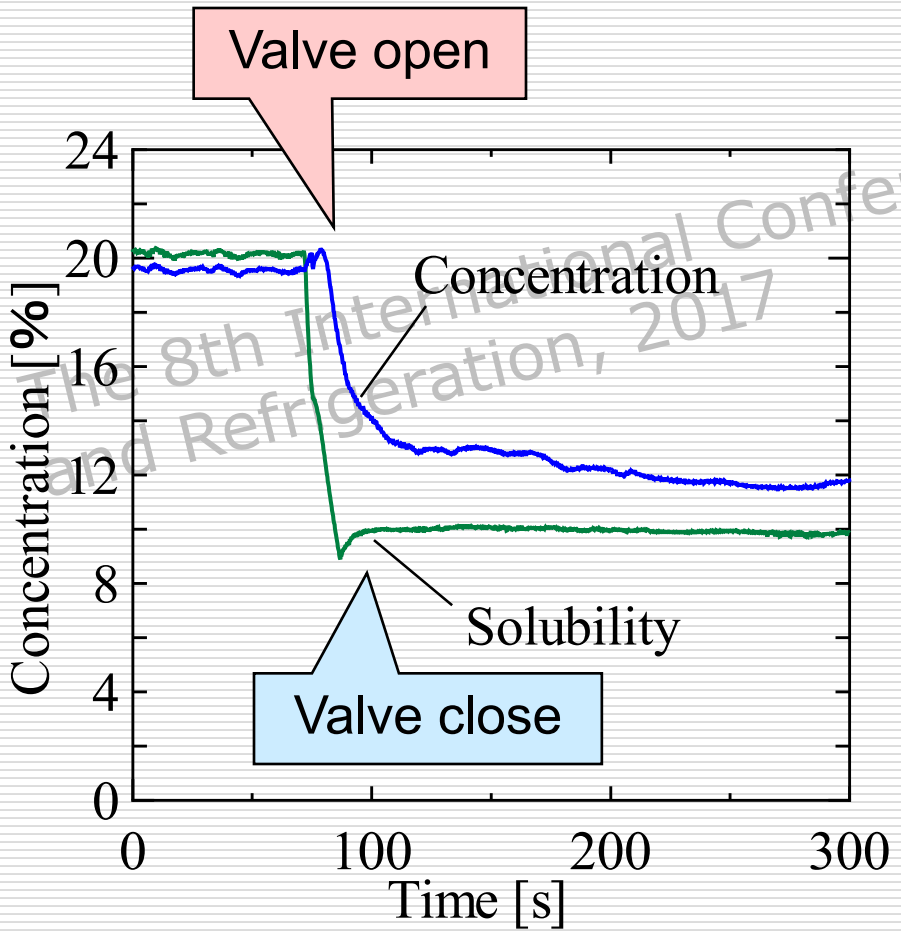
Pressure : 10.2 MPa ▶ 4.0 MPa
Initial temp.: 78 ˚C Duration: 14.6 s





Solubility is obtained from pressure and temperature

Solubility and concentration



The concentration has larger value than the solubility

The mixture becomes super-saturated condition.

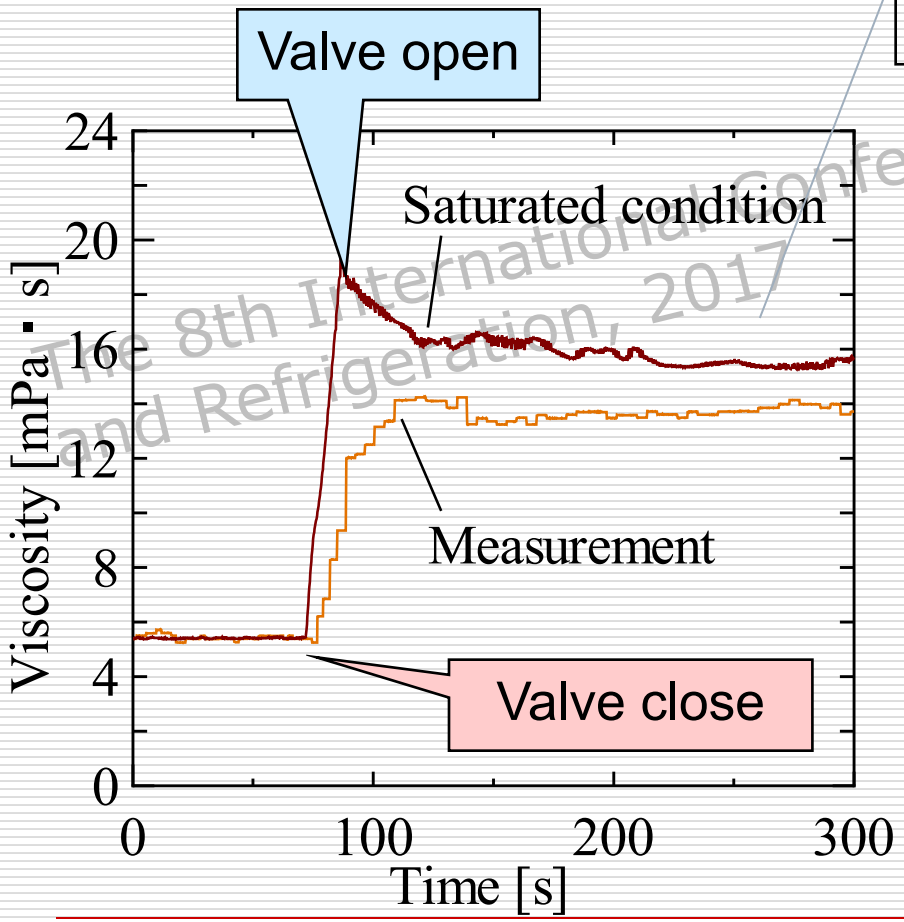
Super-saturation degree

Maximum : 7.8%

After 100 seconds : 2.2%

Viscosity change

Viscosity under the saturation condition is calculated from temperature and the solubility



The mixture is under the super-saturated condition

Viscosity is lower than that under the saturation condition

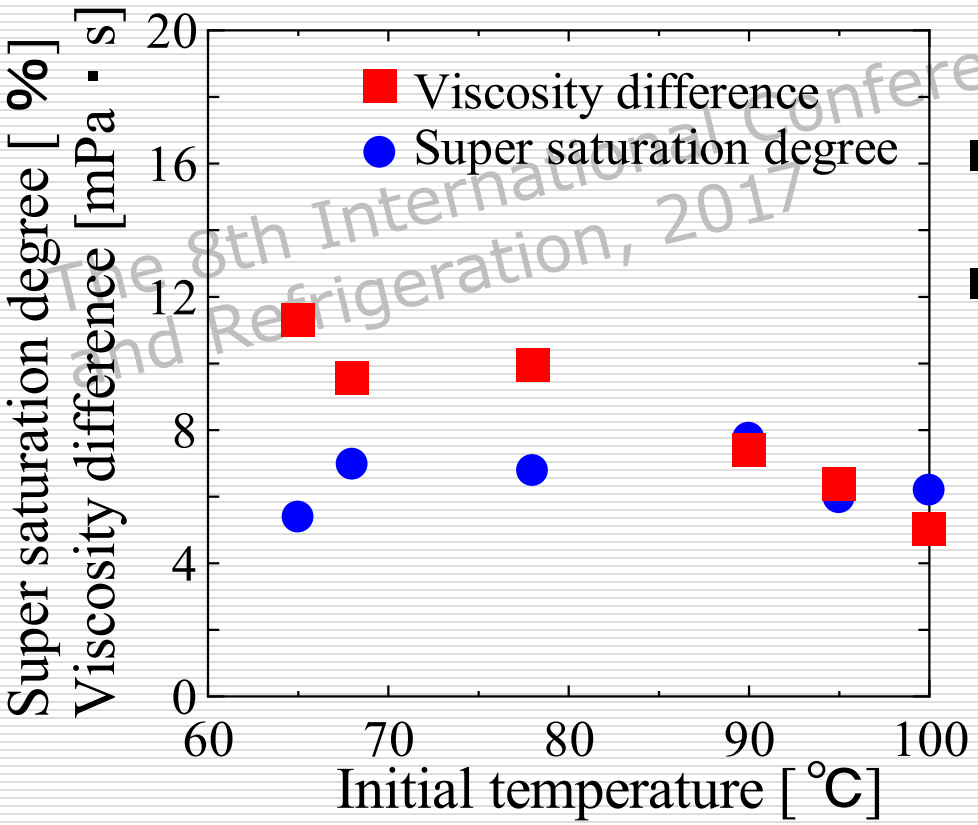
Viscosity difference

Maximum : 10.0 mPa·s

After 100 seconds : 2.2 mPa·s

Influence of initial temperature

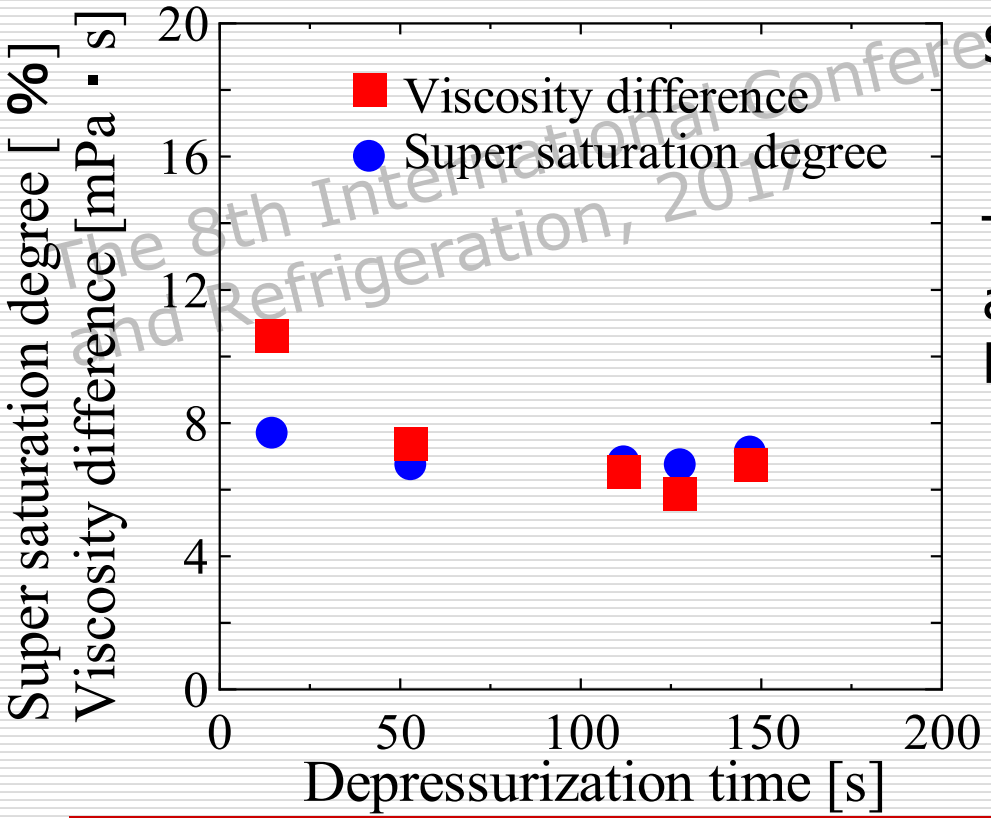
Pressure 10 MPa ⇨ 4 MPa, Duration 15 s



- The super-saturation degree is about 6%.
- The viscosity difference decreases with the initial temperature.

Influence of press. reduction time

Pressure 10 MPa ⇨ 4 MPa, Initial temp. 80°C



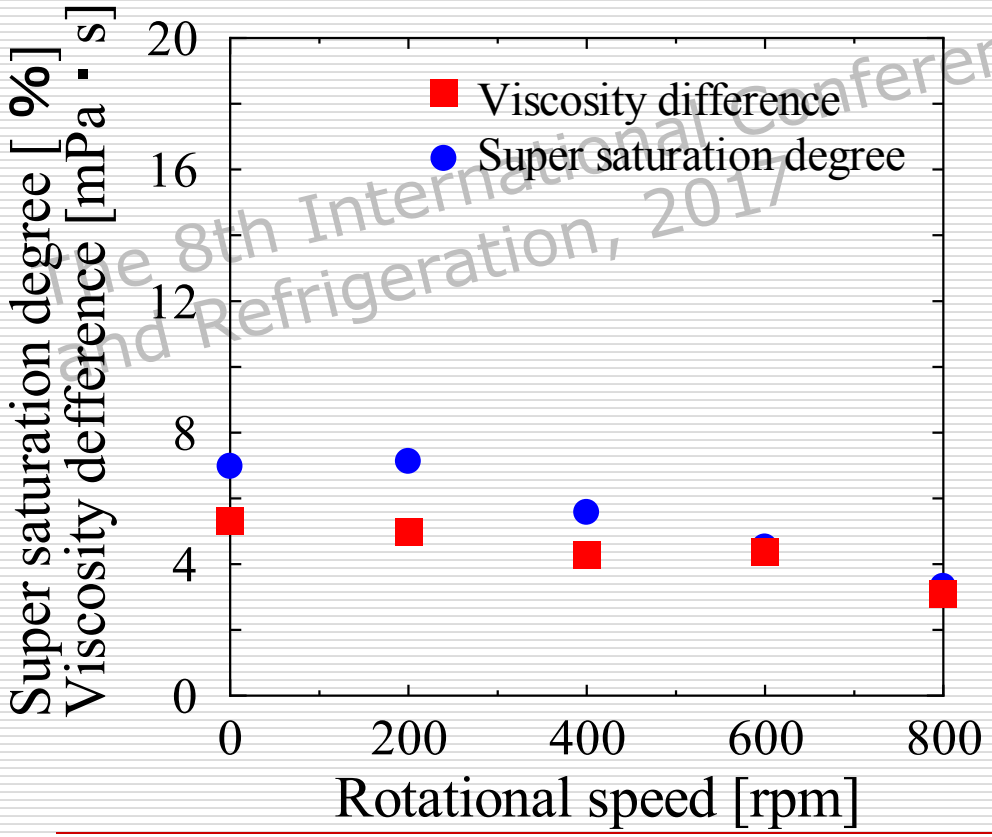
Steep pressure reduction

▼

The super-saturation degree and the viscosity difference become large.

Influence of mechanical stimulation

Pressure 10 MPa ⇨ 4 MPa, Initial temp. 100℃
Duration 30s

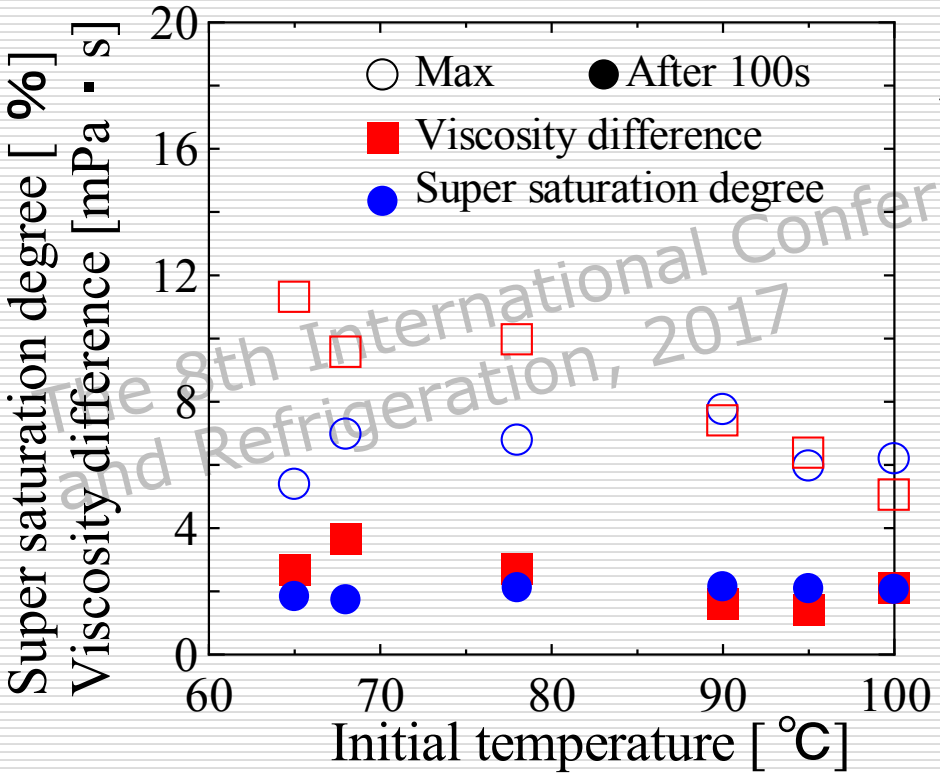


Increase of rotational speed of the stirrer

▼

The super-saturation degree and the viscosity difference become small.

Condition after 100 sec.



At 100 seconds after the pressure reduction

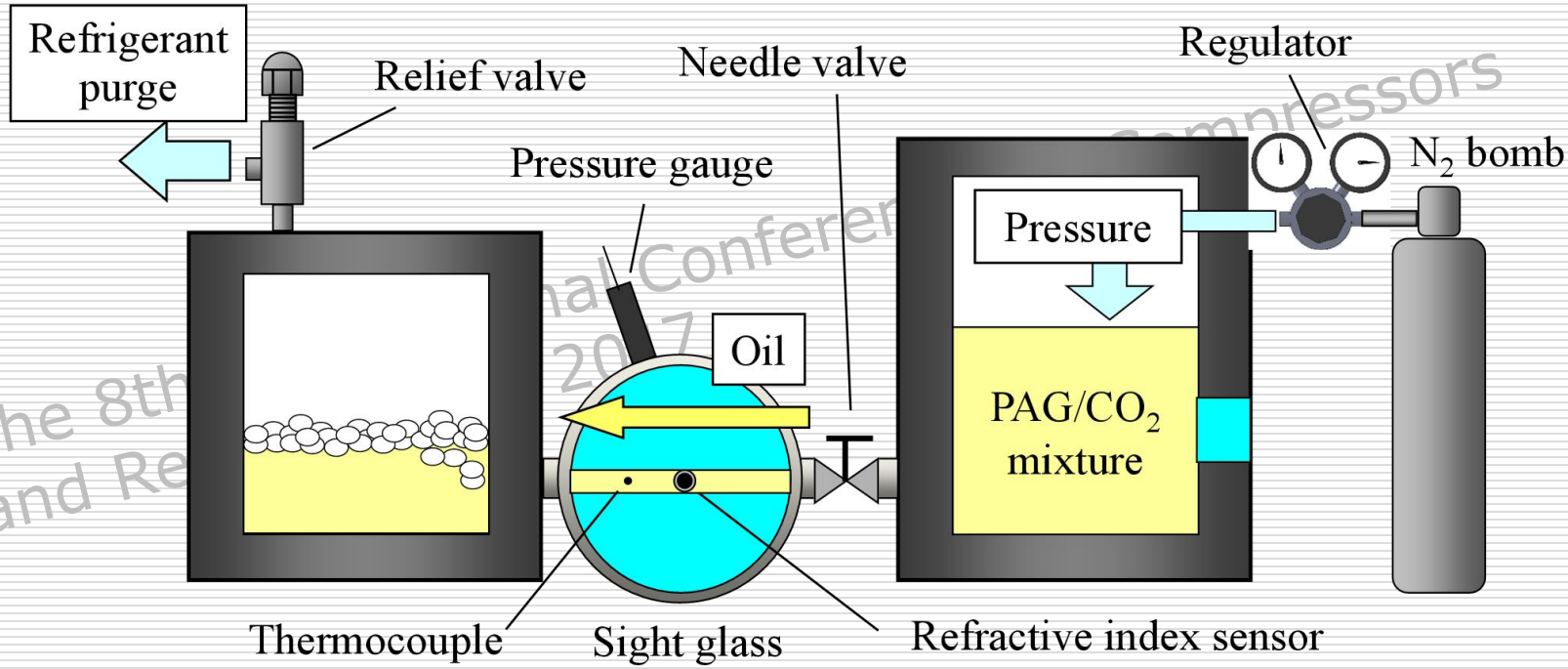
- The super-saturation degree : 2%
- The viscosity deference : 2 mPa·s

The super-saturation condition continues relatively long time after the pressure reduction

Separation characteristics

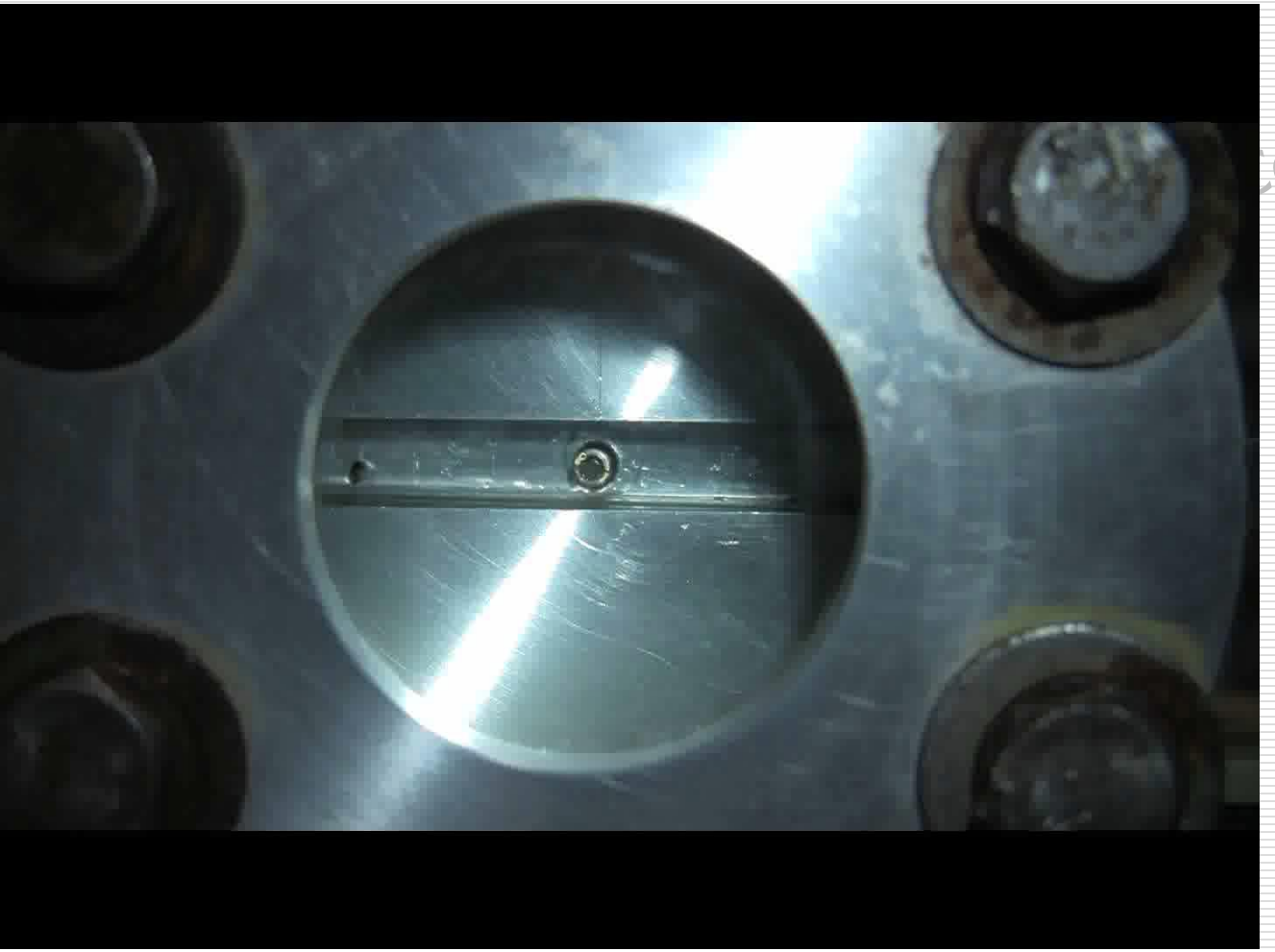
- Depressurization through valve

Experimental setup for depressurization through valve

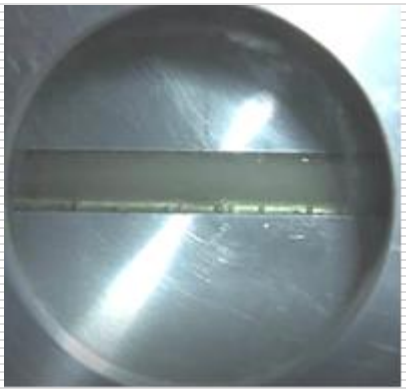


Refractive index → <R.I.-Temperature> Concentration → <Temp.−Concentration> Viscosity

Flow after passing valve



Channel with sensors

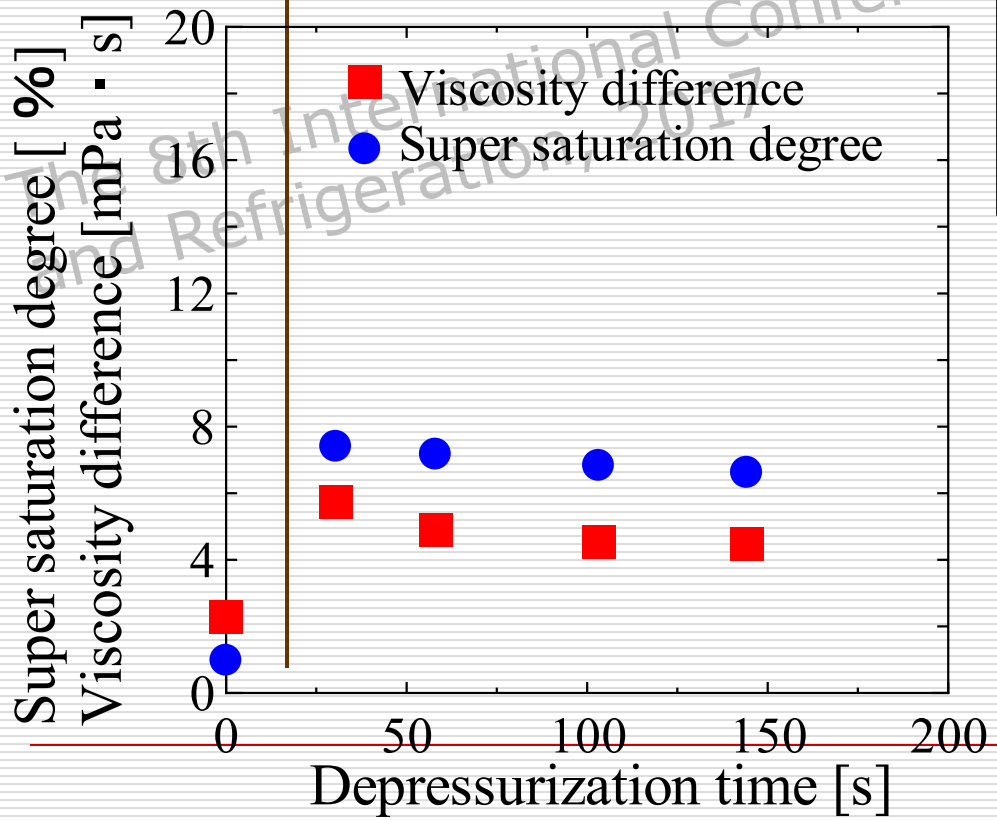


Flow pattern with separation

Comparison between two ways of depressurization

Through valve

Pressure vessel



Depressurization through valve

Super-saturation degree 0.98%

Viscosity difference 2.28mPa·s

Under vigorously-stirred condition

separation is promoted.

Ongoing project

- Transient dissolution of refrigerant into oil during compression
  - Pressure increase by compression

Refrigerant dissolves?

Compression is too fast to dissolve?

Influence of oil film thickness?

Conclusions

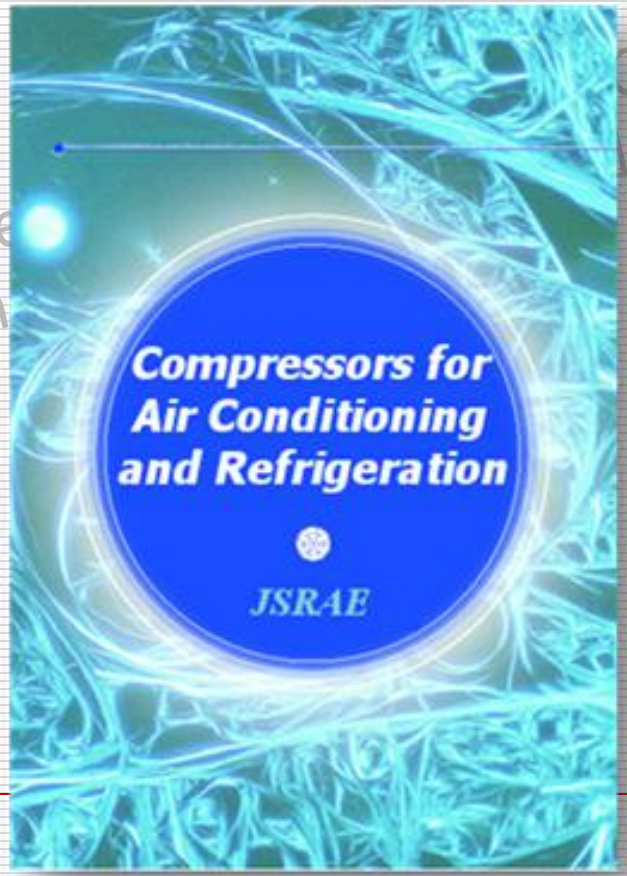
- Transient change of the concentration can be measured by the refractive index.
- The separation of refrigerant from PAG/CO_2 mixture by the depressurization is accompanied by super-saturated condition. It causes viscosity reduction.
- In the case of depressurization through valve, the super-saturation degree and the viscosity reduction have smaller value as compared with those by the depressurization in the vessel.

Summary

- The existence of oil makes phenomena in the compressor complicated, and influences the performance and reliability of the compressor and heat exchangers.
- It is important to understand characteristics of the refrigerant/oil mixture for better understandings of the refrigeration cycle and consequently for the improvement of the system.

NEW BOOK FROM JSRAE

Compressors for Air Conditioning and Refrigeration



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