1.7

Diesel Combustion of Oil and Refrigerant Mixture during Pump Down of Air Conditioners

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1. BACKGROUND

1-1. Refrigerants for Air Conditioner

Transition of refrigerants in air conditioning Applications

Ammonia

CFC(Chlorofluorocarbon)
HCFC(Hydro-CFC)

- R11 ($CFCl_3$)
- R22 (CHF_2Cl)

HFC(Hydrofluorocarbon)

- R410A (CH_2F_2 + C_2HF_5)
- R134a ($C_2H_2F_4$)

Concern over toxicity and flammability

Concern over high ODP

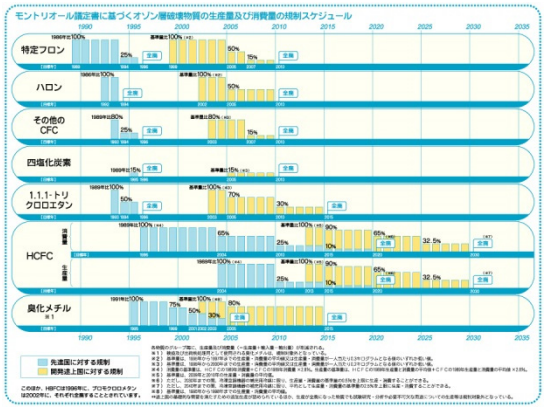
Concern over high GWP

New Low GWP Refrigerants

- R32 (CH_2F_2)
- R1234yf ($CH=CF-CF_3$)
- etc

※mildly flammable

Low Flammability ⇔ Low GWP (trade-off)



Ozone depletion material reduction schedule based on Montreal Protocol (Ministry of the Environment)

⇒New low GWP refrigerants (R1234yf, R32) are drawing increasing attention, but are mildly flammable

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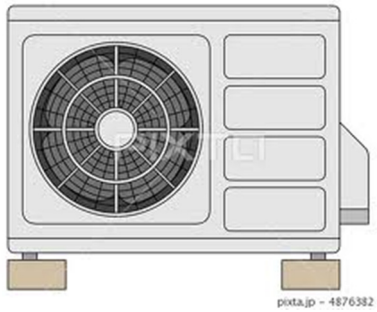
1-2. Heat Pump and Pump Down



※Cooling condition

Indoor Unit

Outdoor Unit

Evaporator

Refrigerant Flow

Condenser

Compressor

Valve

膨張弁

PUMP DOWN

Recovering the refrigerant from indoor unit as liquid and store it in the outdoor unit

1-3. Accident during Pump Down

- Explosion of outdoor unit happened during pump down.
- According to report of Tokyo metropolitan government,
  the accidents were caused by the air leakage into the refrigerant tube by operation error during pump down. (Diesel explosion)
  （Tokyo metropolitan government）

How to operate pump down
(エアコン処分。com)

Explosion accident
(Tokyo metropolitan government)

1-4.Purpouse

Background①
Flammability of Refrigerants

- Low GWP
- Mild flammability

Background②
Accident during Pump Down

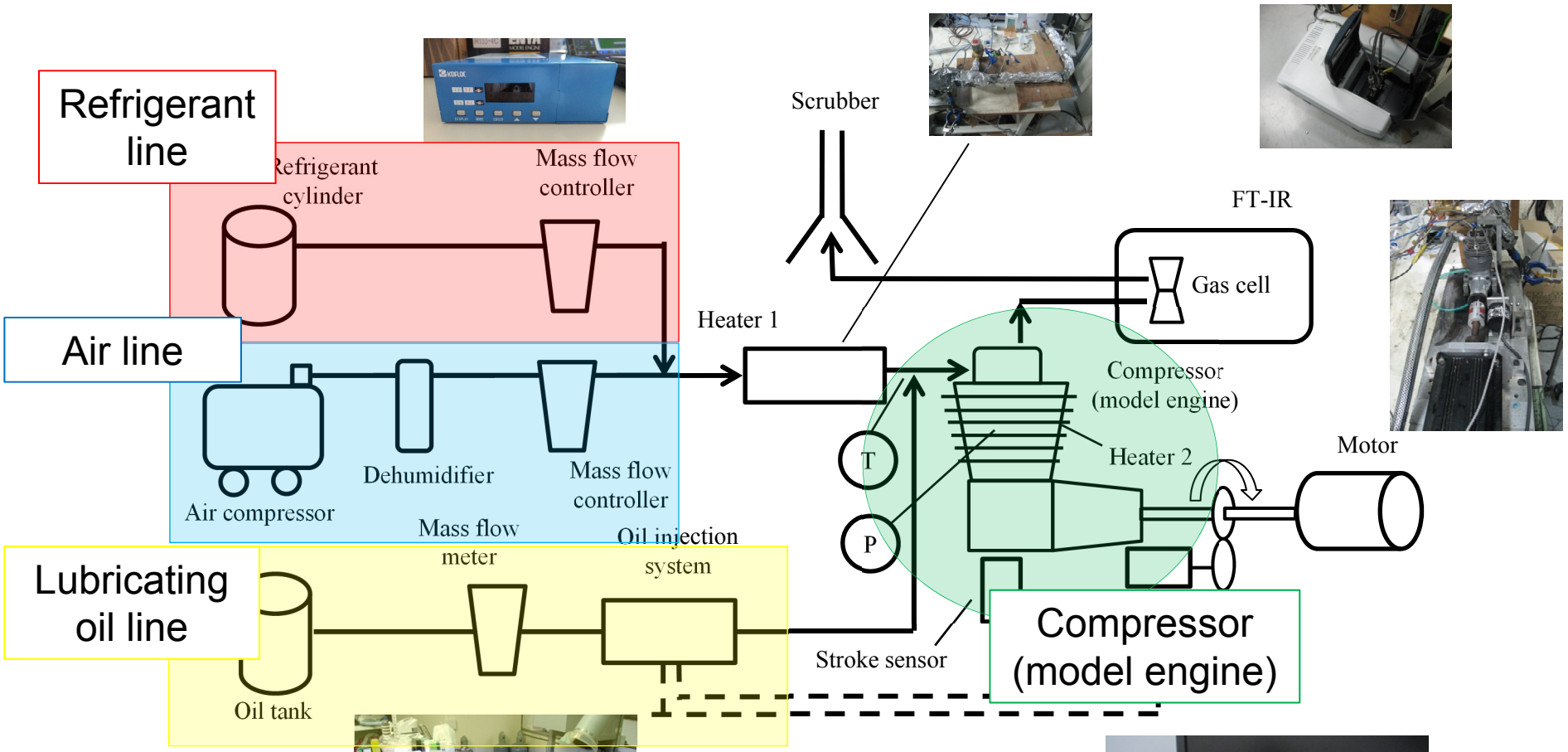
- Accidents happen during pump down
- No research have been conducted about conditions of explosion

PURPOUSE

1. To investigate the conditions of self explosion of air, refrigerant and lubricating oil mixture in the compressor of an air conditioner.
2. To estimate the safety of the new refrigerants by comparing to conventional refrigerants

2. MATERIALS AND METHODS

2-1.Experimental Apparatus



Stroke volume: 25.42 cc
Compression ratio: 16.0
Four-stroke engine

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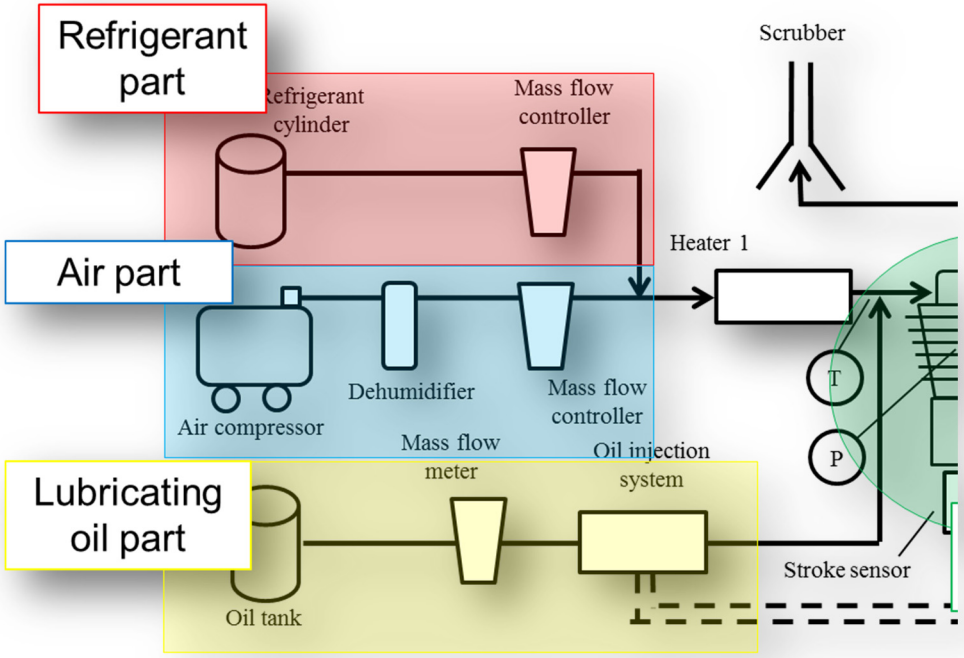
2-1. Experimental Conditions

- Experiment 1
  Air + Oil
- Experiment 2
  Air + Refrigerant
- Experiment 3
  Air + Refrigerant + Oil



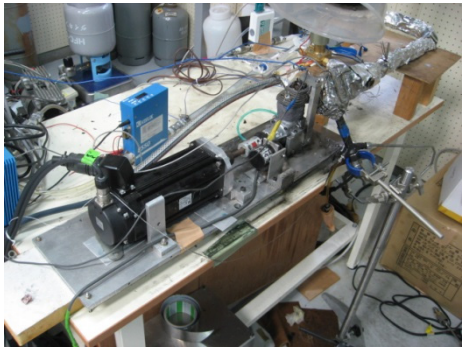
2-2.Experimental Methods

① Control the flow ratio of the air, refrigerant and the lubricating oil independently, mix them, adjust the inlet temperature

- Oil is sprayed into air/refrigerant mixture.
- Oil flow ratio was controlled by injection time.

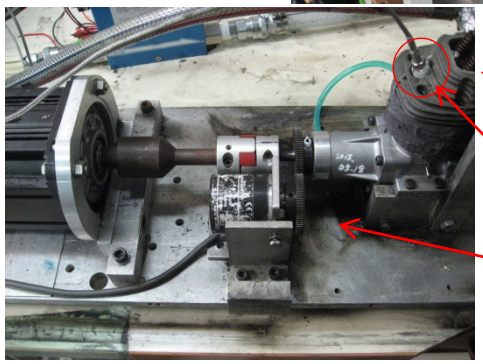
Experiment apparatus

Injector



②Adiabatic compression by the engine, self ignition inside.

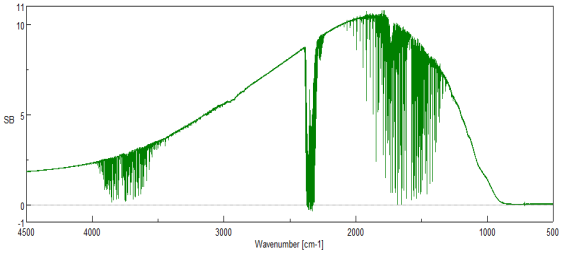
- Engine is driven by motor.
- Encoder measures clank angle.
- Pressure inside engine is measured.



③FT-IR analyzes the exhaust gas

- Infrared absorption spectrum.
- Take BKG before experiment.

FT-IR



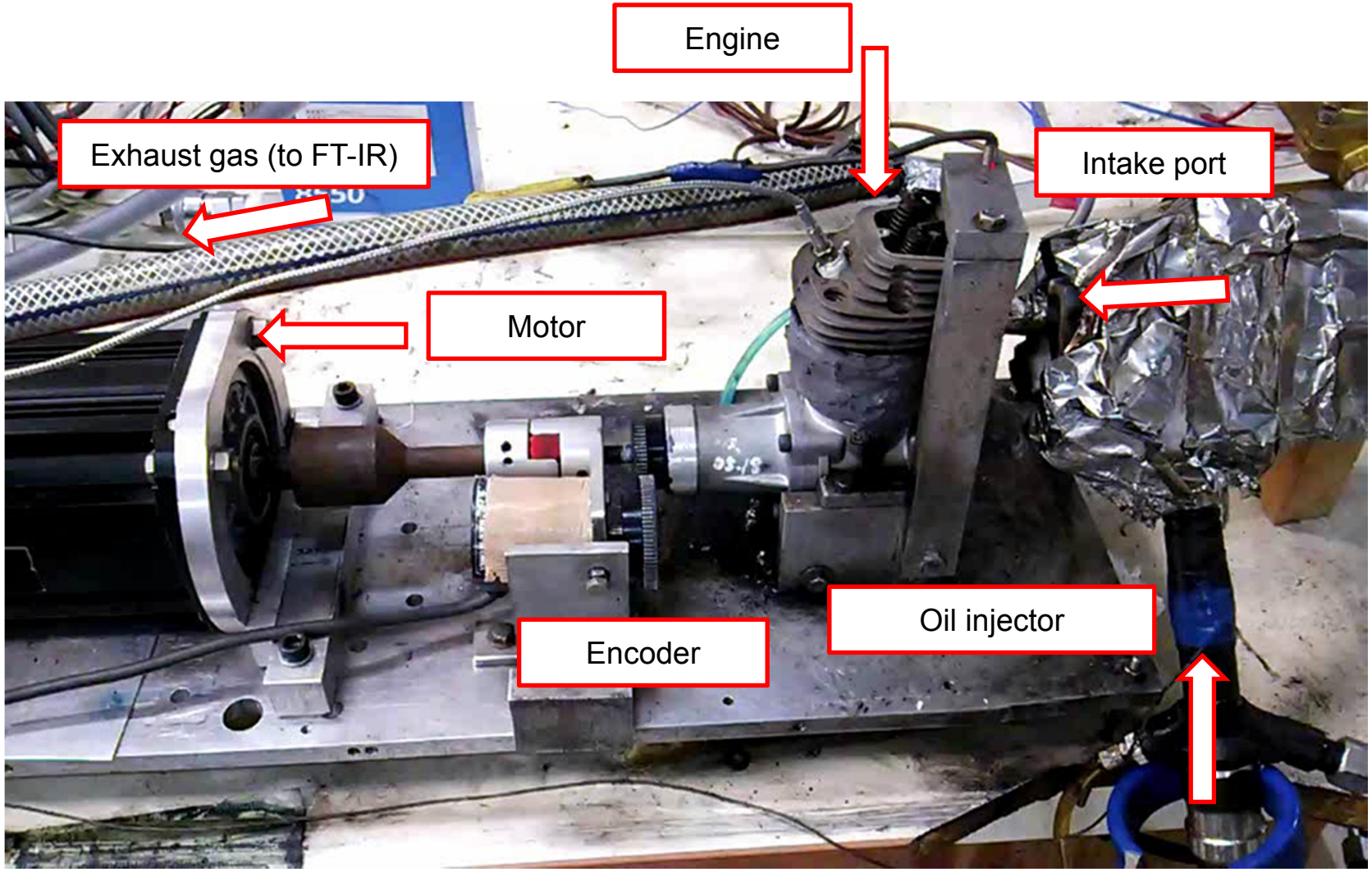
Example of BKG

2-3. Experimental Parameters

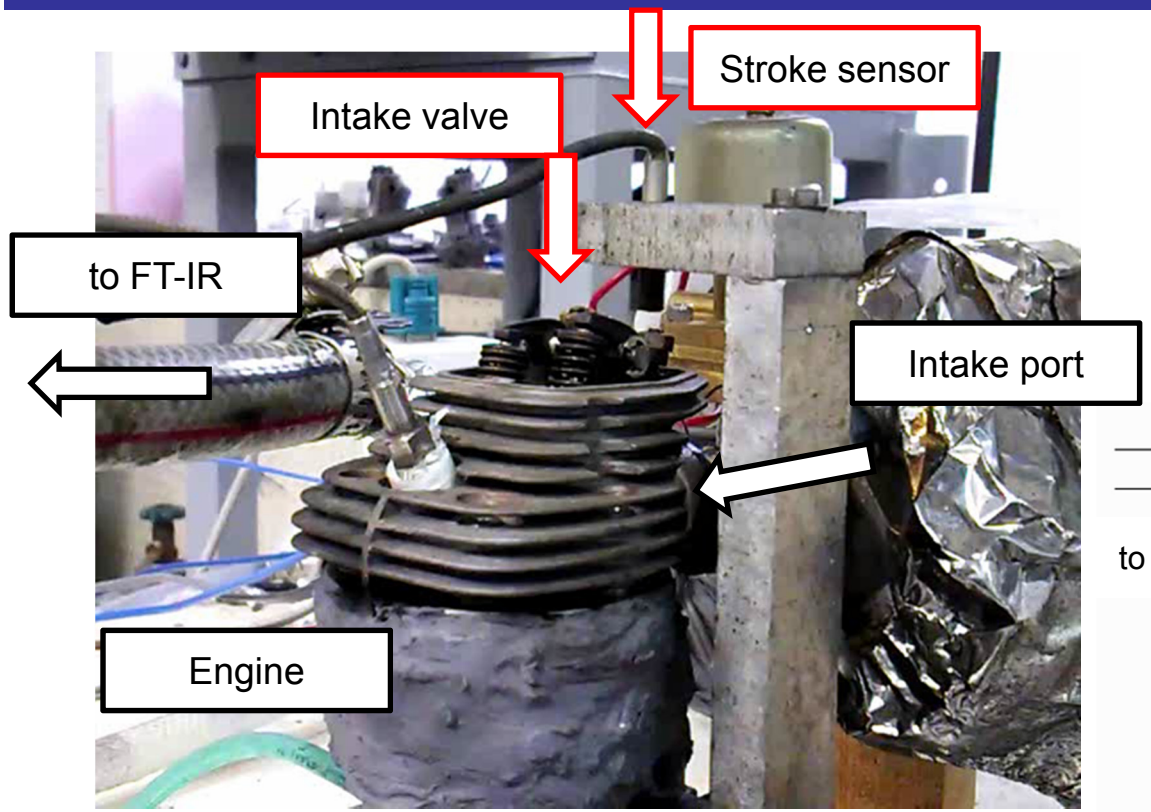
- Engine rotation speed: 1500 [rpm]
- Inlet gas mixture temperature: 260 [℃]
- Refrigerants：
  R1234yf, R32 (Low GWP refrigerants, mildly flammable)
  R410A (conventional, nonflammable, mixture) ※R32：R125 = 1:1
  R134a, R22, R125 (Nonflammable pure refrigerants)
  N_2 (Inert gas)
- Refrigerant concentration: 0 to 100 [vol%]
- Oil flow rate: 0 (without oil),
  2.295×10^{-4} [L/min] (injection time: 0.7msec per one time)
  (stoichiometric air-fuel ratio based on the air flow ratio when refrigerant concentration is 0 %)
- Injection timing: 90° (crank angle of the engine)

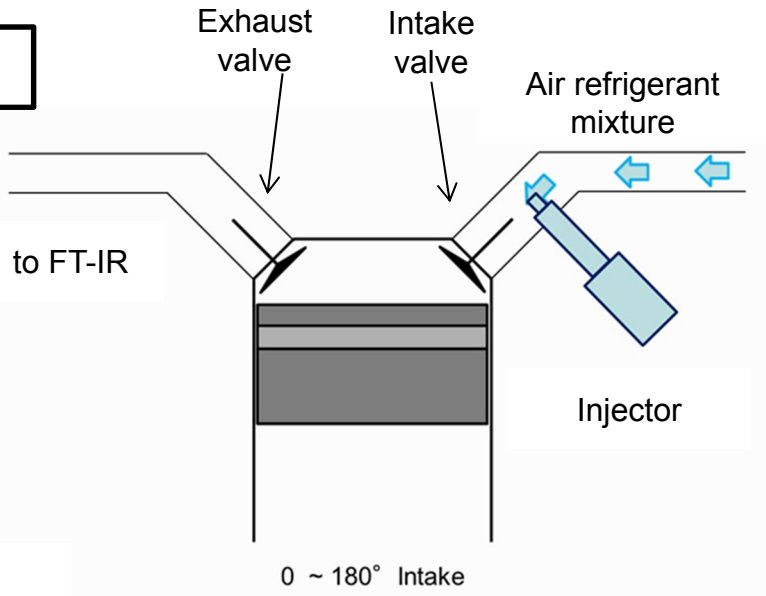
※Oil flow ratio is kept constant at any refrigerant concentration.

2-4. Appearance of Experiment 1



2-5. Appearance of Experiment 2



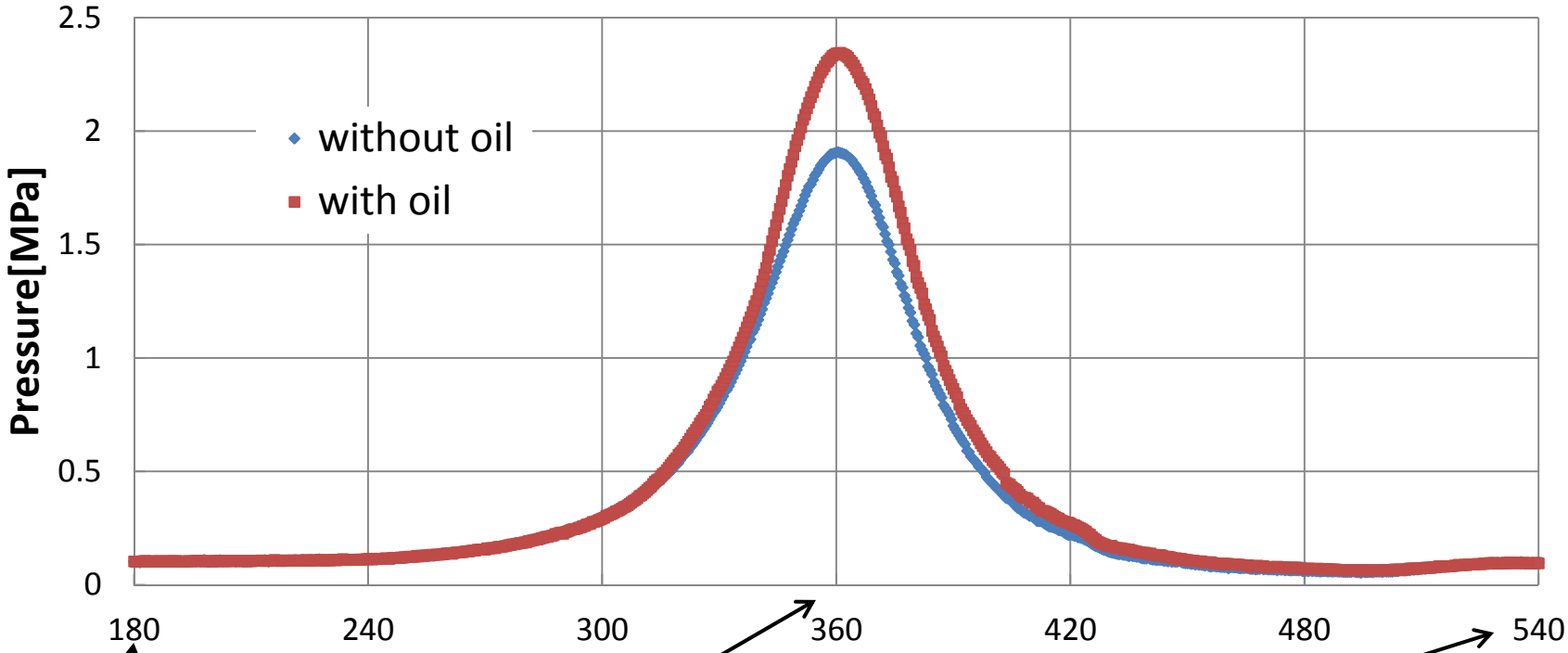


4 cycle engine ⇒720° for total stroke
Stroke sensor detects intake valve's opening during intake stroke.
⇒Distinguish 0 to 360°,
Control injection timing with encoder.

※Timing of Injection
90 to 96.3° (crank angle)

3. RESULTS AND ANALYSIS

3-1. Pressure Change for Air-Oil Mixture



B.D.C
(Initial compressing point)

T.D.C
(Maximum compressing point)

B.D.C

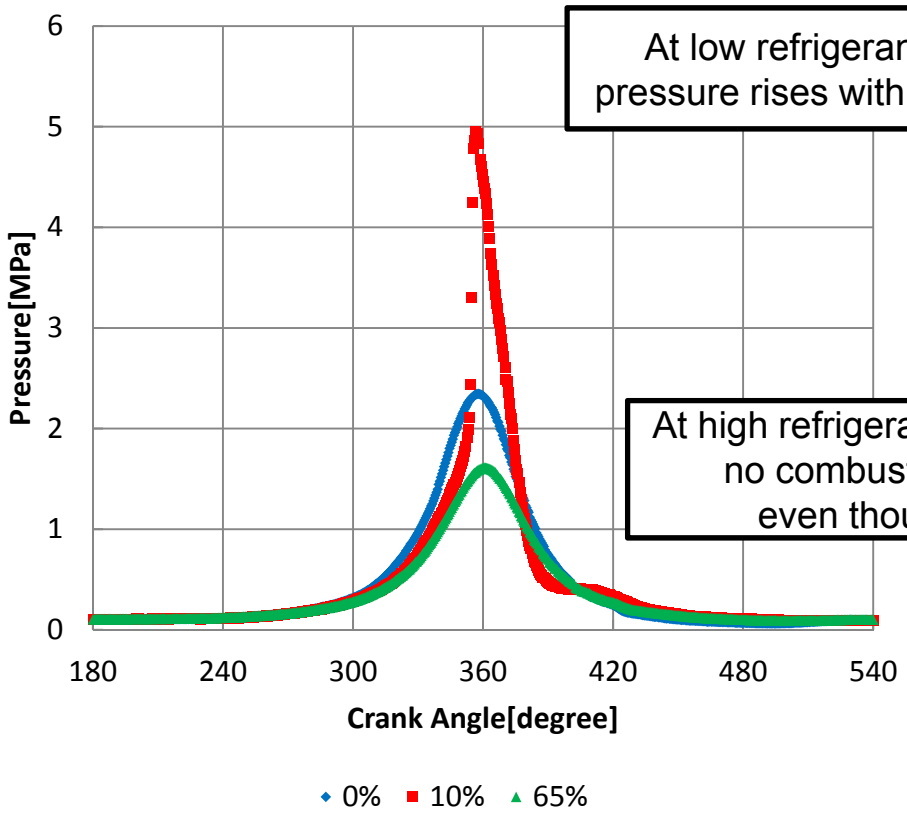
TDC: Top Dead Center
BDC: Bottom Dead Center

- Combustion occurred with oil injection
- Pressure increased
- Loud noise and strong vibration

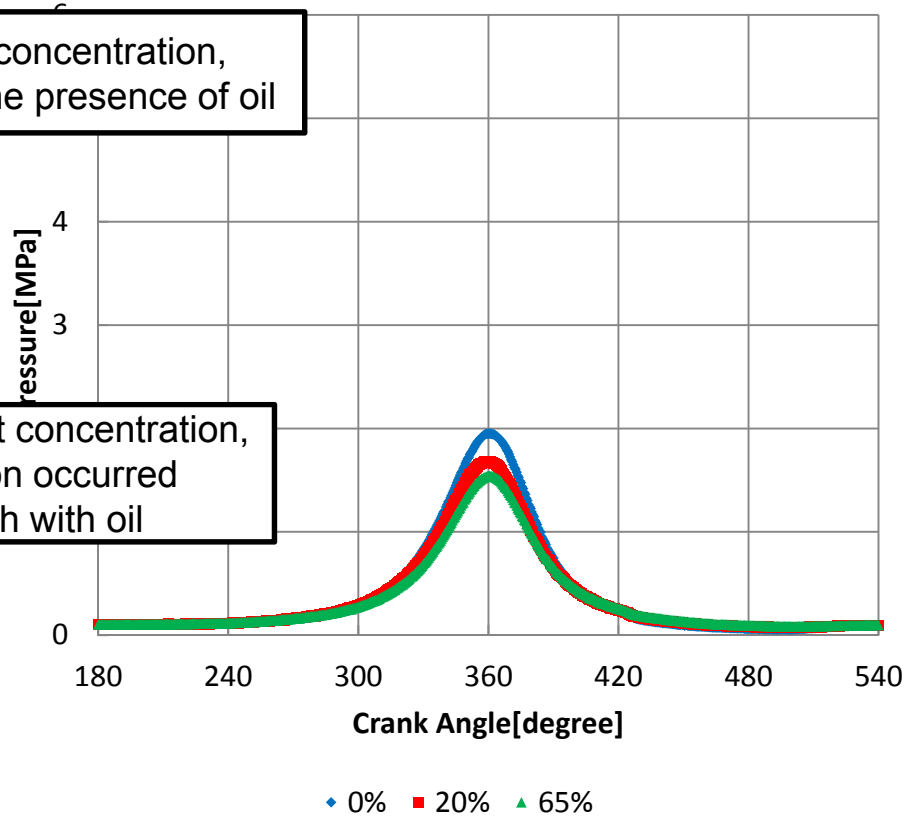
→**Lubricating oil self-ignited**

3-2. Pressure at Different Refrigerant Concentrations

R1234yf, with oil



R1234yf, without oil



At low refrigerant concentration, pressure rises with the presence of oil

At high refrigerant concentration, no combustion occurred even though with oil

- Intense combustion at low concentration
- Black exhaust gas

- No combustion occurred without oil
- Pressure decreased as concentration increased

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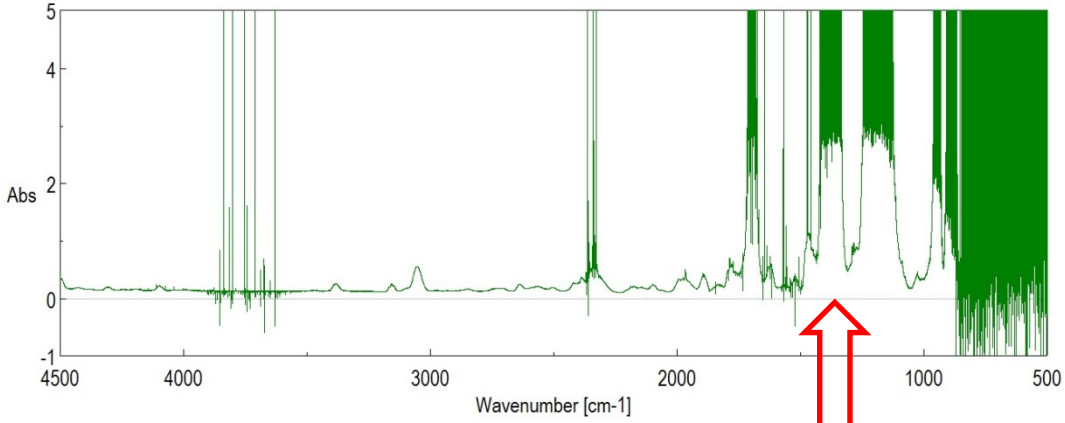
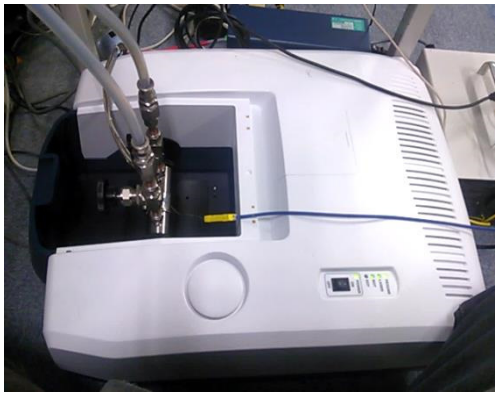
3-3. Analysis of Exhaust Gas 1

R1234yf, with oil, 60%

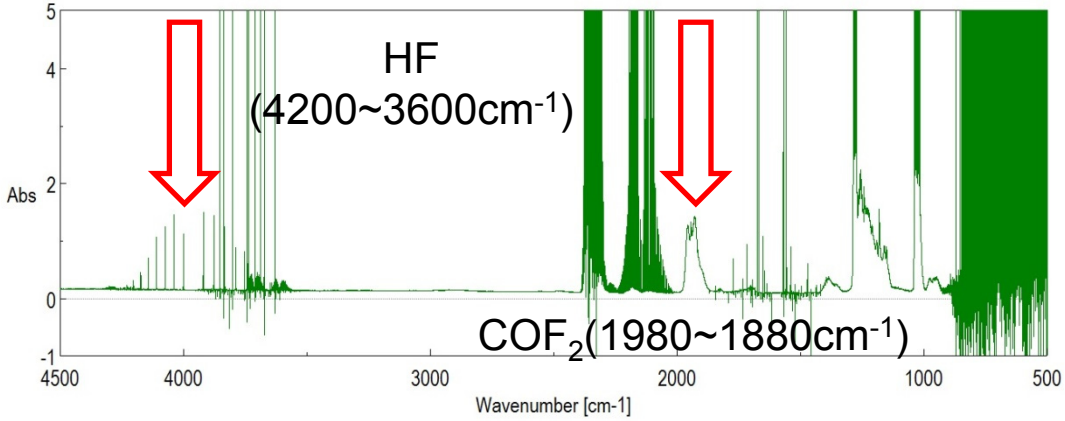


FT-IR

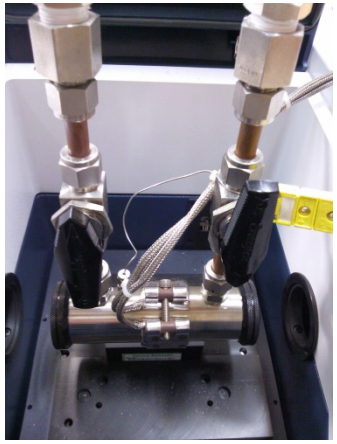


R1234yf, with oil, 10%

R1234yf
(1800~1000cm^{-1})



Gas cell of FT-IR



$C_3H_2F_4$ (R1234yf) + 5/2 O_2 + x H_2O
→(2+x) CO_2 + (2+2x) HF + (1-x) COF_2

HF and COF_2 were produced by combustion of refrigerant

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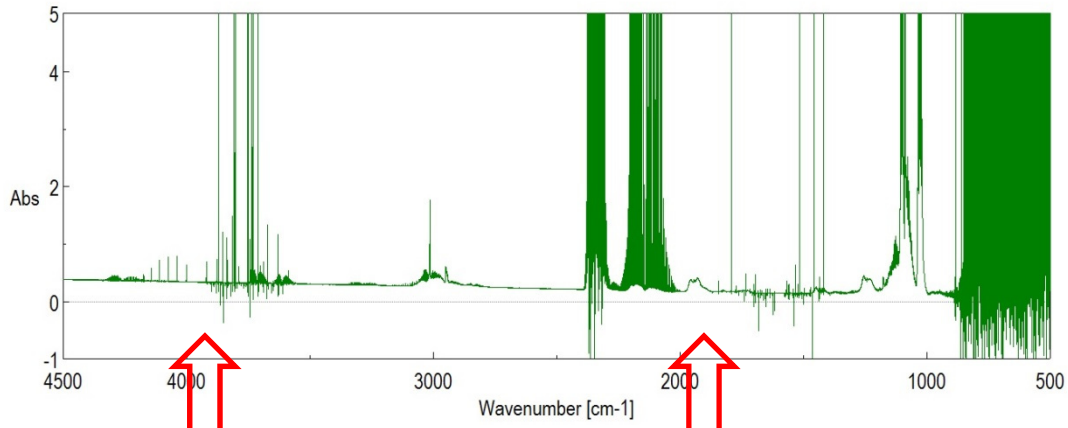
3-4. Analysis of Exhaust Gas 2

R32, with oil, 30%

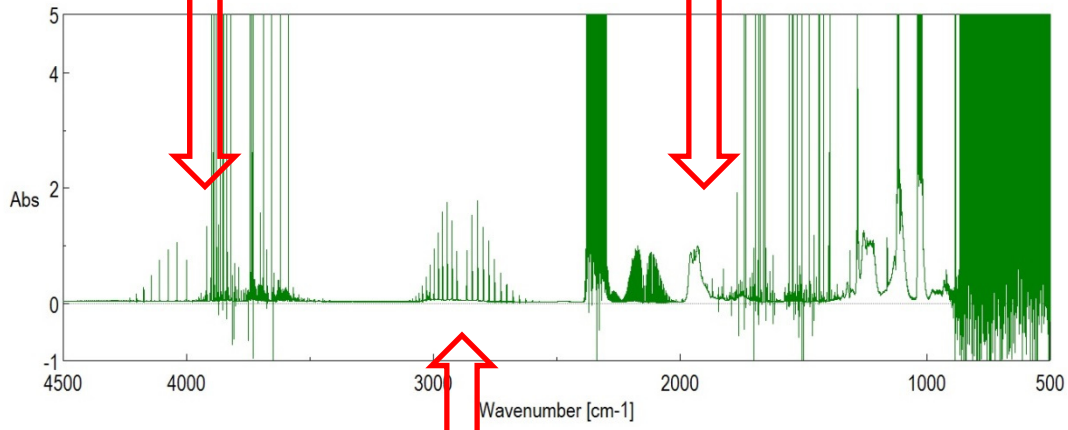


R32: CH_2F_2

HF

COF_2

R22, with oil, 20%



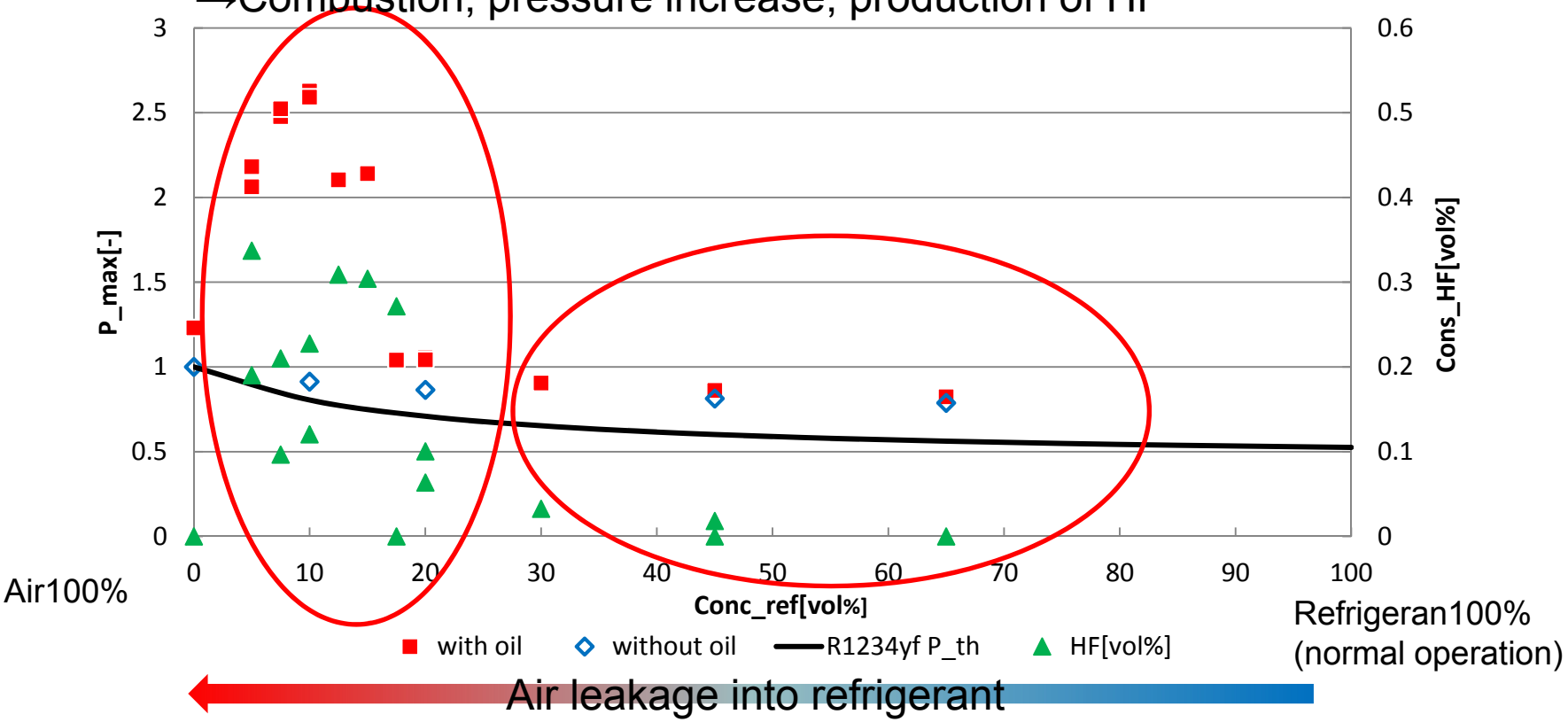
R22: CHF_2Cl

HCl
(3100–2600 cm^{-1})

3-5. Differences in Refrigerant Concentration 1

R1234yf

Low concentration
→Combustion, pressure increase, production of HF



Air100%

Refrigeran100%
(normal operation)

Air leakage into refrigerant

Theoretical pressure rise

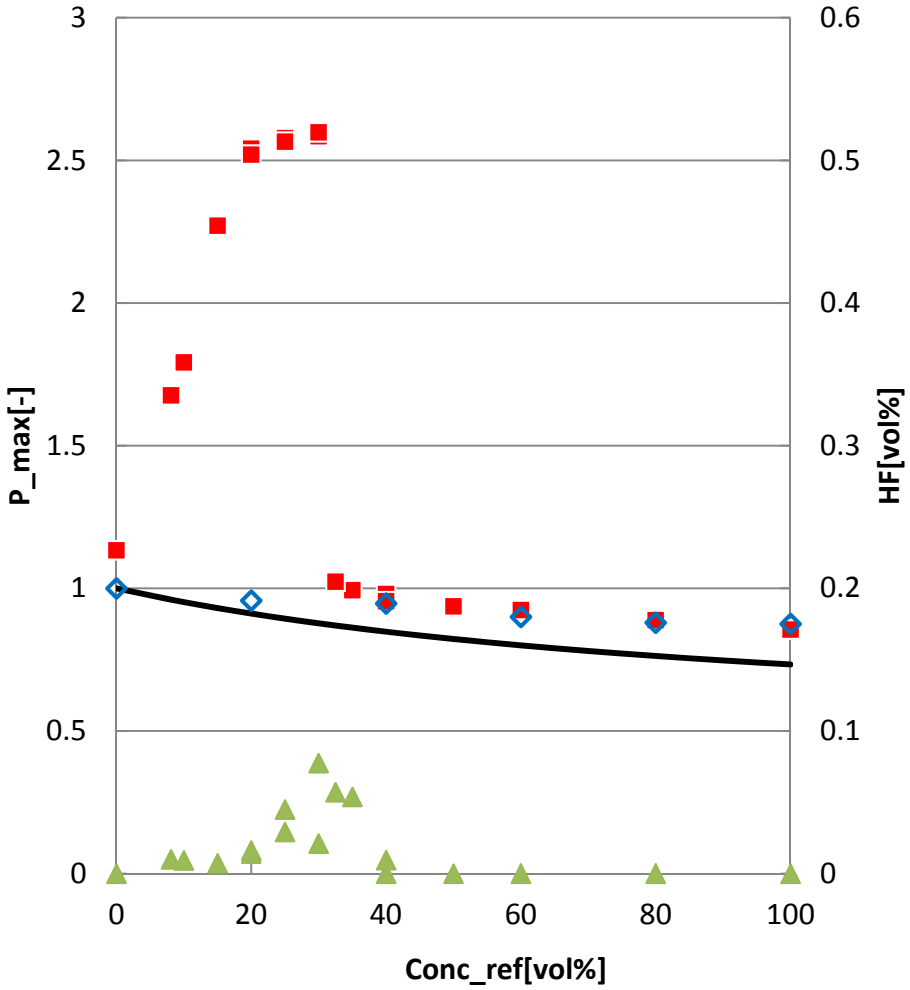
$$\kappa' = \frac{\rho_{ref} x \kappa_{ref} + \rho_{air}(100 - x)\kappa_{air}}{\rho_{ref} x + \rho_{air}(100 - x)}$$

$$P_2 = P_1 \times \gamma^{\kappa}$$

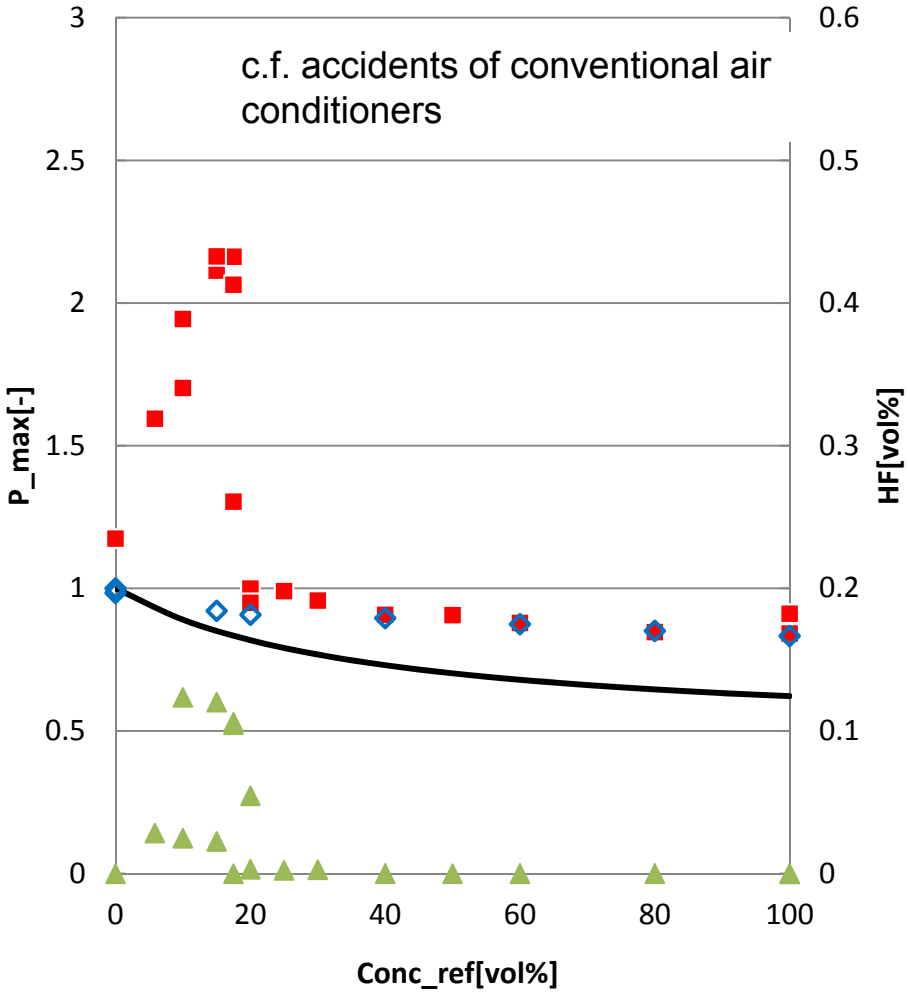
High concentration
→No combustion, similar to without oil
Less HF produced

3-6. Differences in Refrigerant Concentration 2

R32 (CH_2F_2)



R410A (CH_2F_2+C_2HF_5)



HF[vol%] with oil without oil P_th

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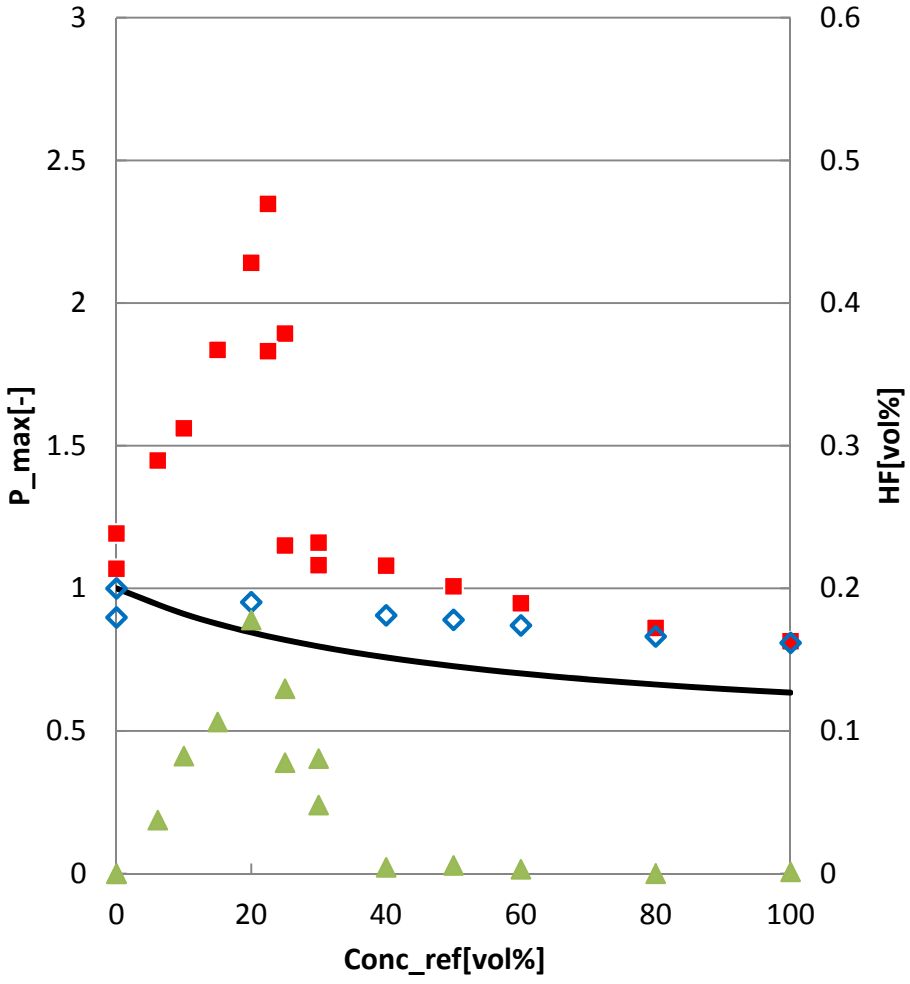
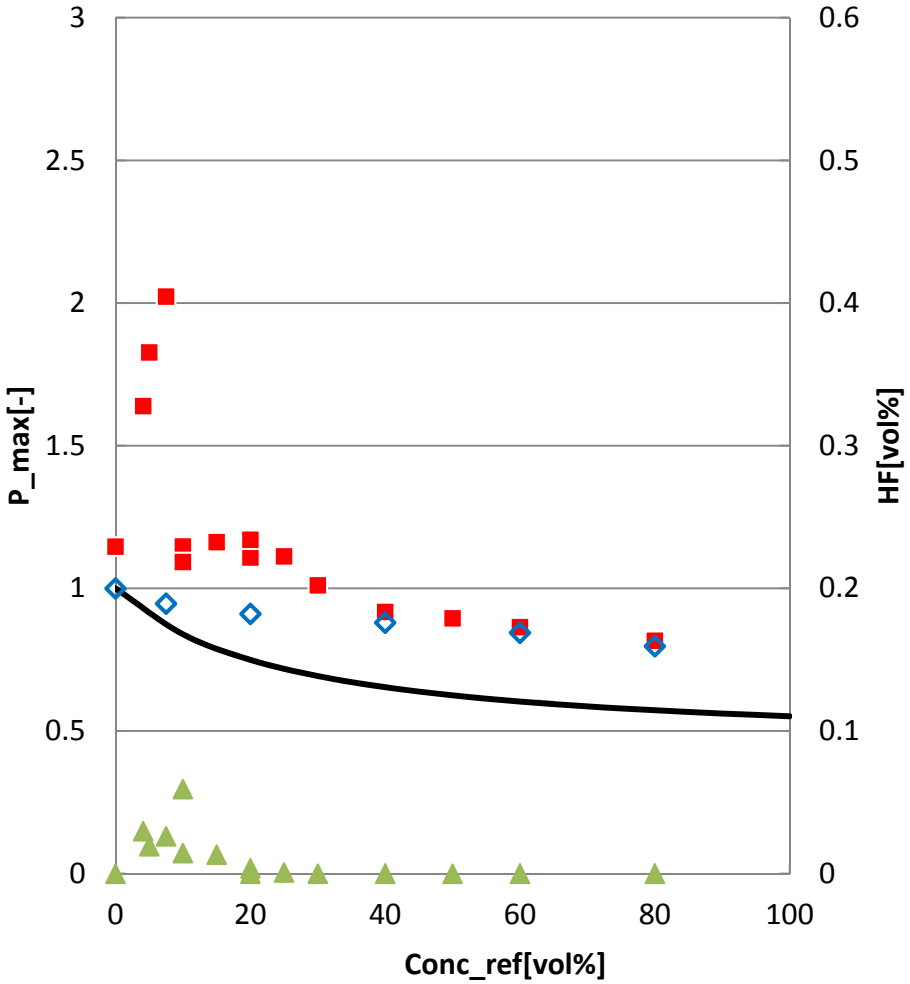
3-7. Differences in Refrigerant Concentration 3

R22 (CHF_2Cl)



R134a ($C_2H_2F_4$)



HF[vol%] with oil without oil P_th

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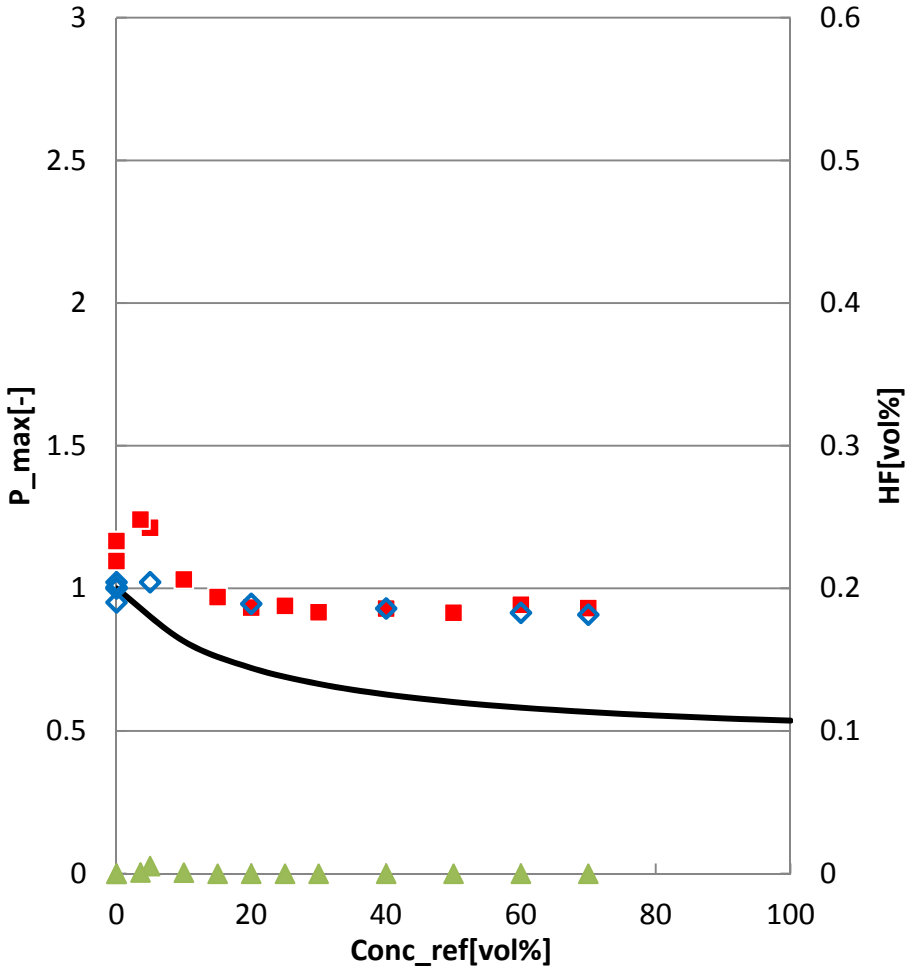
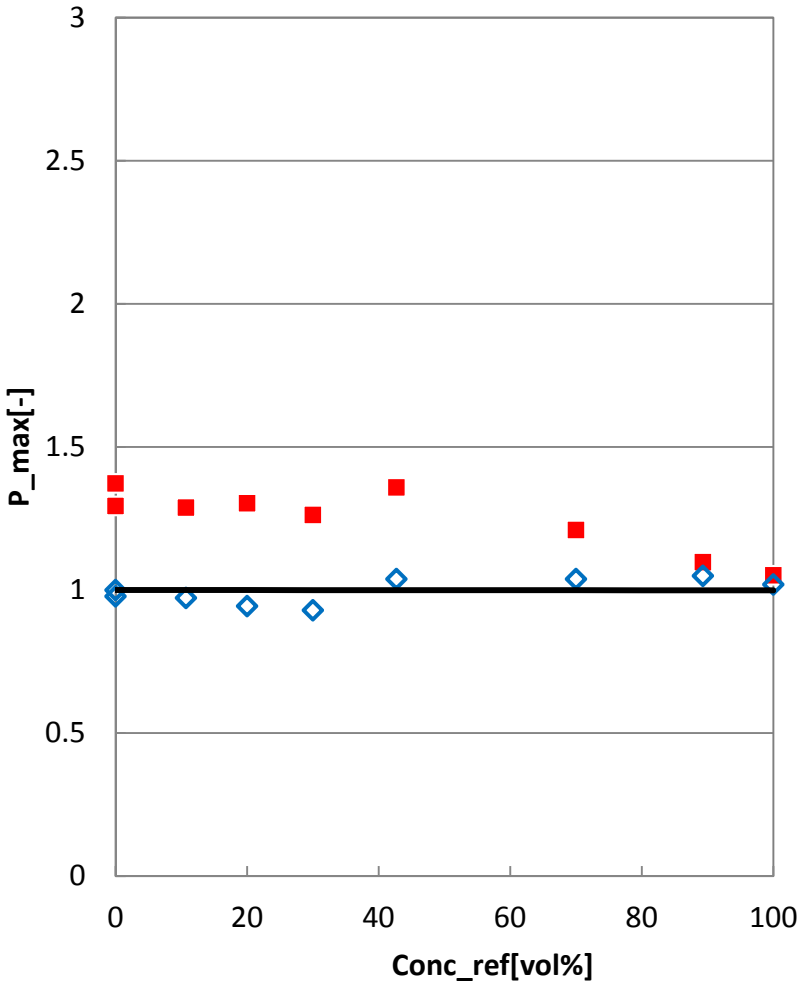
3-8. Differences in Refrigerant Concentration 4

R125 (C_2HF_5)



N_2



HF[vol%] with oil without oil P_th

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4. CONCLUSION

4. Conclusion

- Accidents during pump down are caused by the diesel combustion of a mixture of air, refrigerant and lubricating oil
- Combustion induces pressure rise
  - 【air + refrigerant】(no combustion)
    < 【air + oil】< 【air + oil + refrigerant】
- HF was observed when combustion occurred
  - HF is a production of refrigerant combustion
  - Refrigerant itself was burned
- Self-ignition of lubricating oil → Combustion of refrigerant
  → Pressure increase
- Conventional refrigerants (R410A, R22) were compared with new refrigerants (R1234yf, R32)
  - No significant difference observed in terms of flammable range and pressure

Acknowledgements

This study has been conducted a part of research project on the “Technology Development of High-efficiency Non-fluorinated Air Conditioning Systems” conducted by New Energy and Industrial Technology Development Organization (NEDO)

Thank you for your attention!