ID 1125

Study on a hybrid refrigeration cycle by combining an absorption process with a compression process using Low-GWP refrigerant

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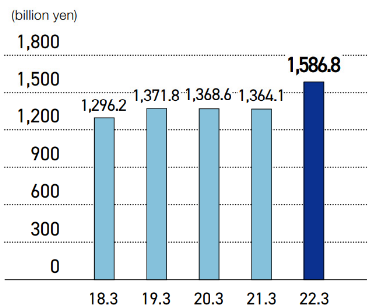
- Hybrid refrigeration cycle
- Our activities for this research
- Measurement of absorption equilibrium solubilities
- Process simulation

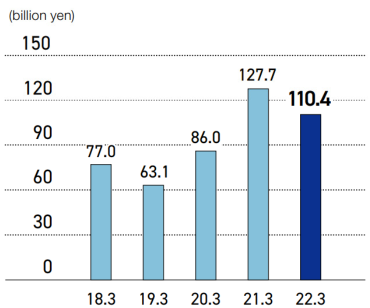
Corporate profile of Osaka Gas

Head Office	**Osaka, JAPAN**
Establishment	**April 10th, 1897**
Capital	**¥132,166 million = $979 million**
Number of employees	**3,189 (Non-consolidated) 20,961 (Consolidated)**

Net sales **$11.8** billion
Fiscal year ended March 31, 2022
¥**1,586.8**billion



Ordinary profit **$0.8** billion
Fiscal year ended March 31, 2022
¥**110.4**billion



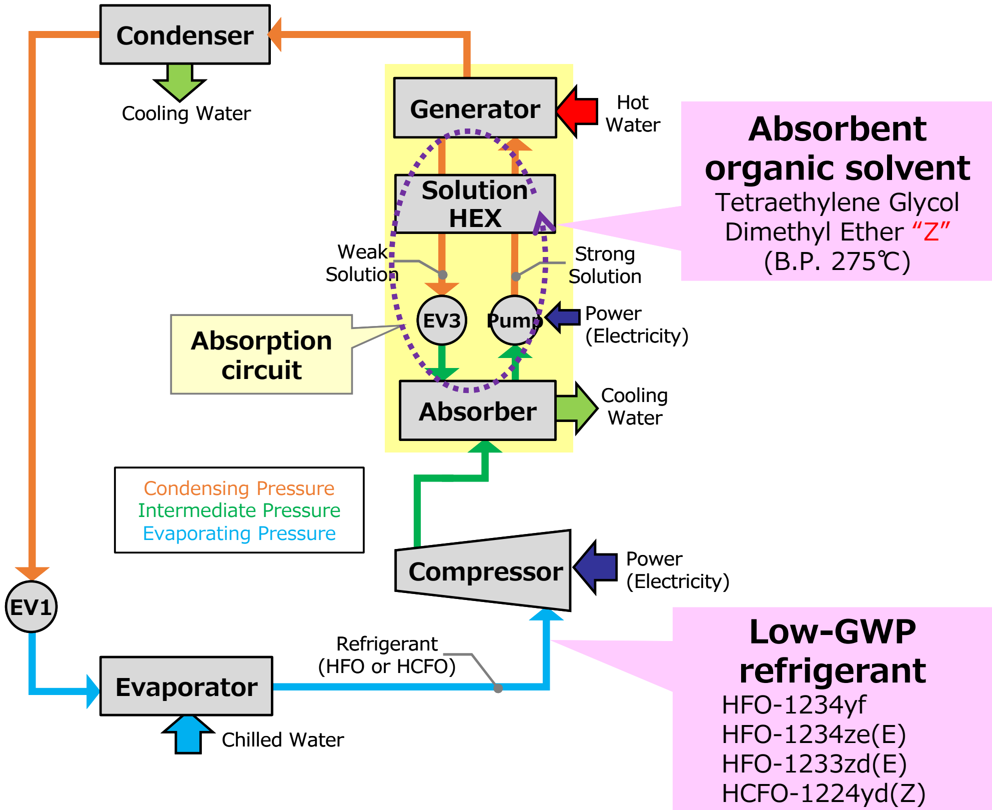
(1dollar =135 yen)

- **Osaka Gas has "Energy Technology Laboratories" as R&D department which conducts R&D in the following areas related to the energy business.**
  - Catalyst
  - Fuel Cell
  - Gas Combustion
  - Waste Heat Utilization
  - Gas sensor
  - Material Evaluation

Energy Technology Laboratories (Osaka Gas)

- **This study was conducted in collaboration with Saito Laboratory (Waseda University), as one of the research projects for waste heat utilization.**

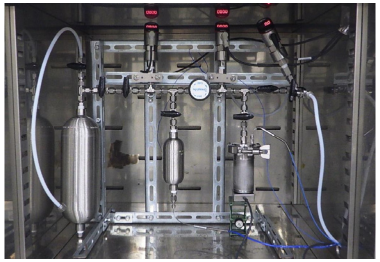
Hybrid refrigeration cycle

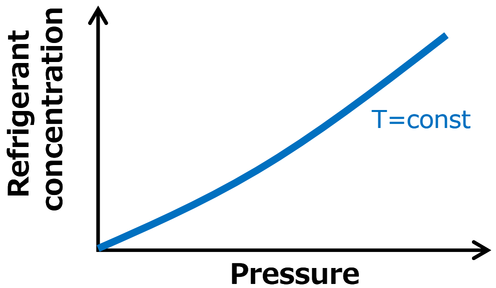


- **Hybrid refrigeration cycle combines absorption process driven by low-temperature waste heat with a compression process in one circulation cycle.**
- **Improved cooling COPc based on the power even with low-temperature waste heat**
- **Low-GWP refrigerant (HFO or HCFO) and an inexpensive organic solvent were used as a working pair for the absorption process for the purpose of improving the circulation ratio.**

Our activities for this research

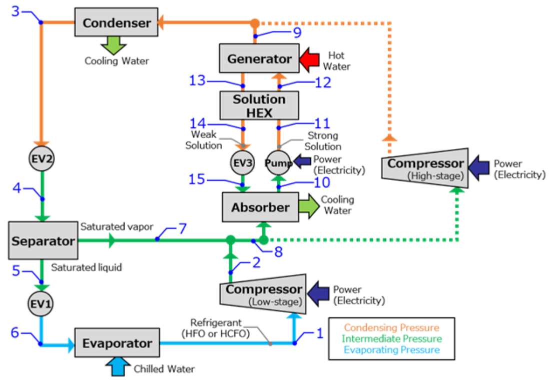
Measurement of absorption equilibrium solubilities
(stationary condition)

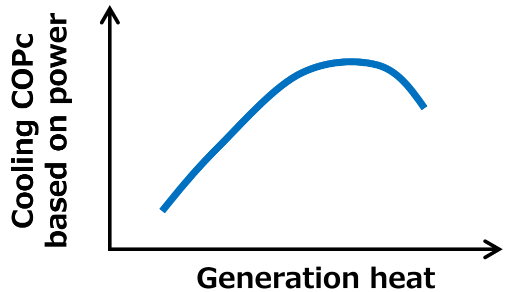




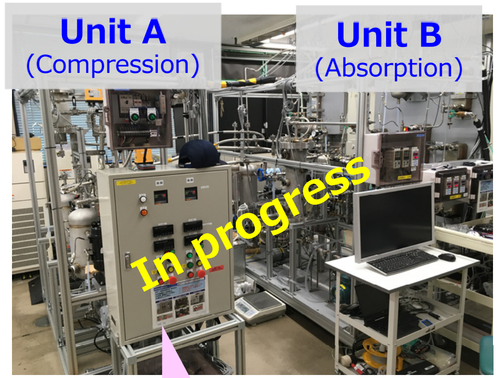
- PTx lines (NRTL model)
- Enthalpy-Concentration diagrams

Process Simulation

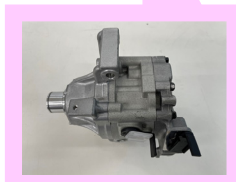




Experiment
(cycle condition)



Prototype
(Q_e=1.5kW)



Compressor
Scroll, R1234yf,
Part of car air conditioner

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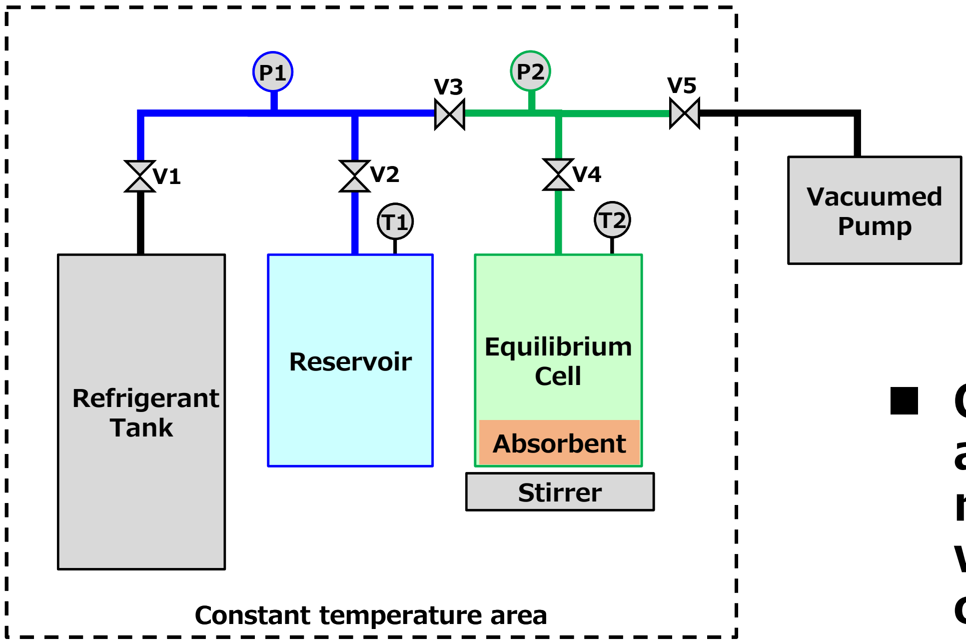
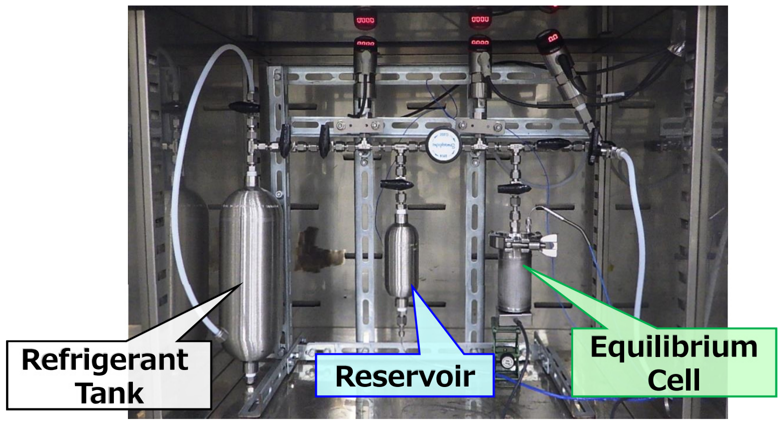
Measurement of absorption equilibrium solubilities

Absorption equilibrium solubilities measurement based on ref[1]



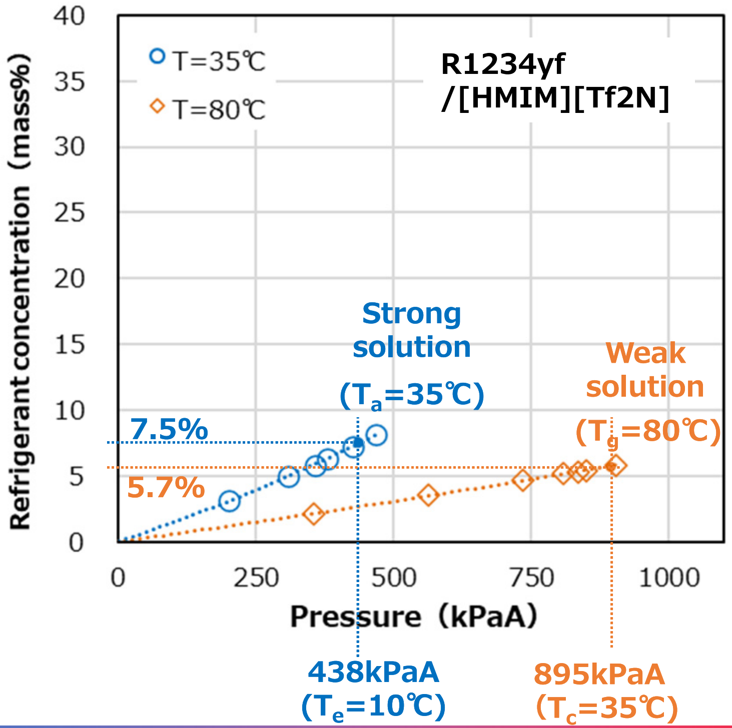


- **Calculation of the amount of refrigerant absorption from the change in the amount of refrigerant in the blue and green volumes when valve V3 is opened and closed, under constant temperature**

Ref. [1] Liu, et al., 2016, Vapor-Liquid Equilibrium of R1234yf/[HMIM][Tf2N] and R1234ze(E)/[HMIM][Tf2N]working pairs for Absorption Refrigeration Cycle, J. Chem. Eng. Data, 61, 3952-3957.

Measurement of absorption equilibrium solubilities

Measurement with the ionic liquid used in ref[1] as absorbent



Refrigerant /Absorbent		Refrigerant concentration (mass%)			circulation ratio (-) $=(100\%-x_w)/(x_s-x_w)$
		Strong solution x_s	Weak solution x_w	$x_s - x_w$	
R1234yf /[HMIM][Tf2N]	This work	**7.5**	**5.7**	**1.7**	**52**
	Ref. [1]	7.3	5.5	1.8	53

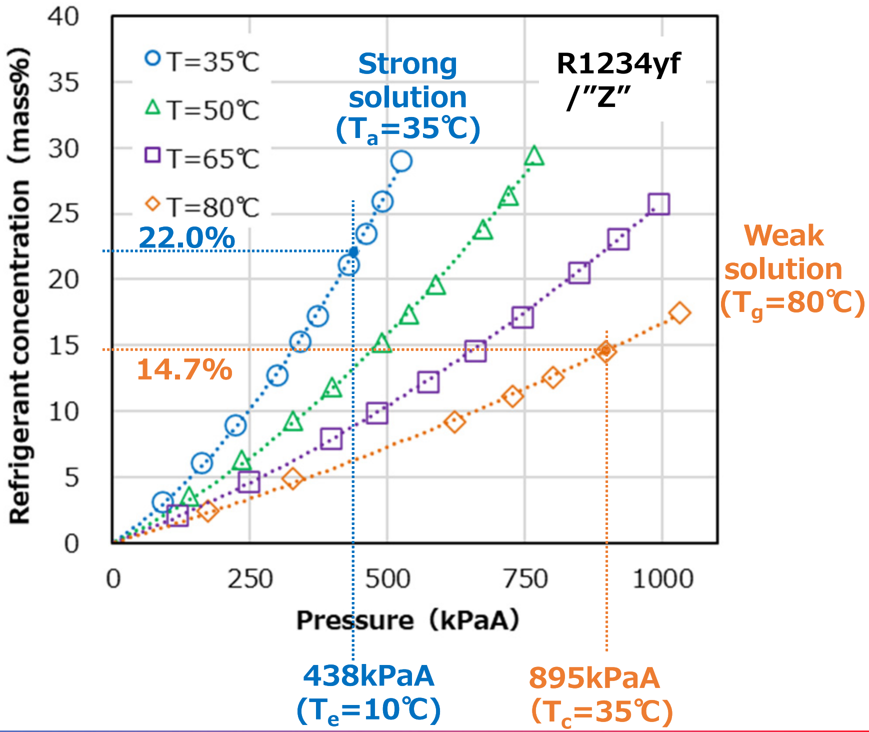
T_e=10℃, T_c=35℃, T_a=35℃, T_g=80℃.

Ref. [1] Liu, et al., 2016, Vapor-Liquid Equilibrium of R1234yf/[HMIM][Tf2N] and R1234ze(E)/[HMIM][Tf2N]working pairs for Absorption Refrigeration Cycle, J. Chem. Eng. Data, 61, 3952-3957.

- **It is confirmed that the refrigerant absorption concentrations are almost same as the results of the past research.**

Measurement of absorption equilibrium solubilities

Measurement with the organic solvent "Z" as absorbent



Refrigerant /Absorbent		Refrigerant concentration (mass%)			circulation ratio (-)
		Strong solution x_s	Weak solution x_w	x_s - x_w	=(100%-x_w) / (x_s-x_w)
R1234yf /[HMIM][Tf2N]	This work	7.5	5.7	1.7	52
R1234yf /"Z"	**This work**	**22.0**	**14.7**	**7.4**	**12**

T_e=10℃, T_c=35℃, T_a=35℃, T_g=80℃.

- **It is confirmed that absorption concentration is higher, and the concentration difference is larger. So, the circulation ratio is improved.**

➡ **PTx lines (NRTL model)**
Enthalpy-concentration diagrams

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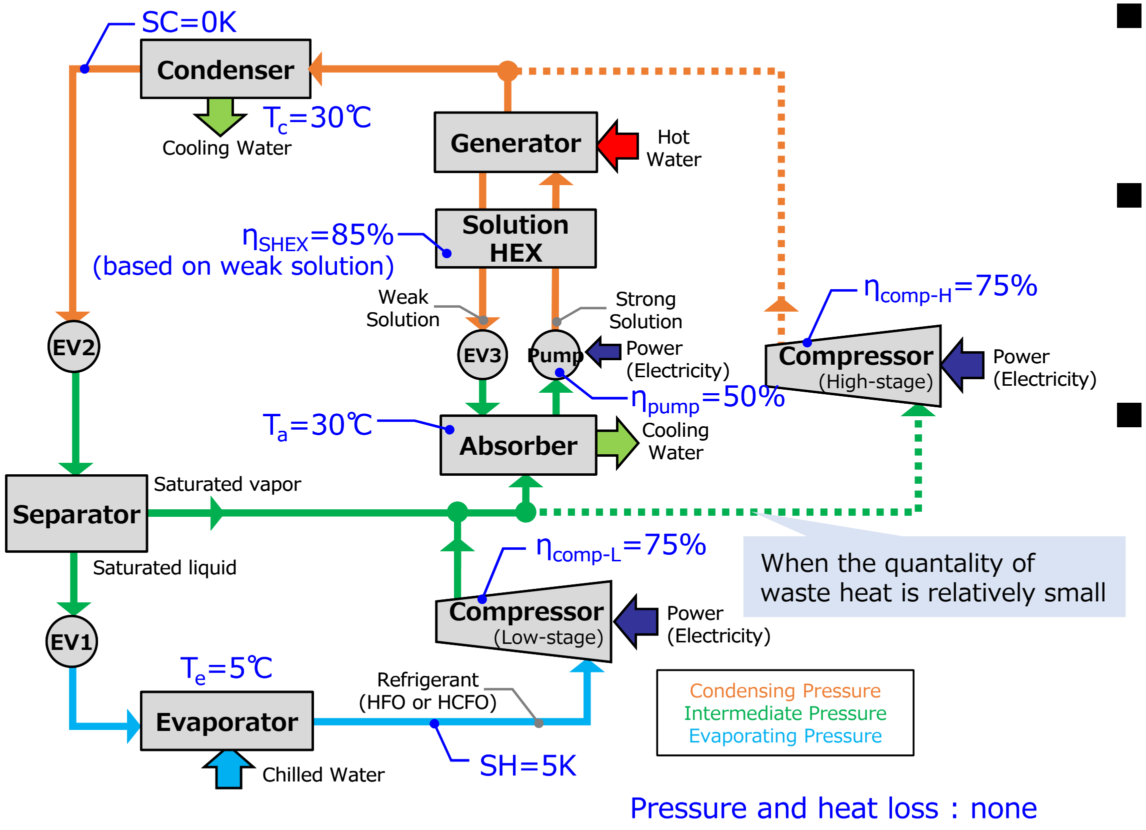
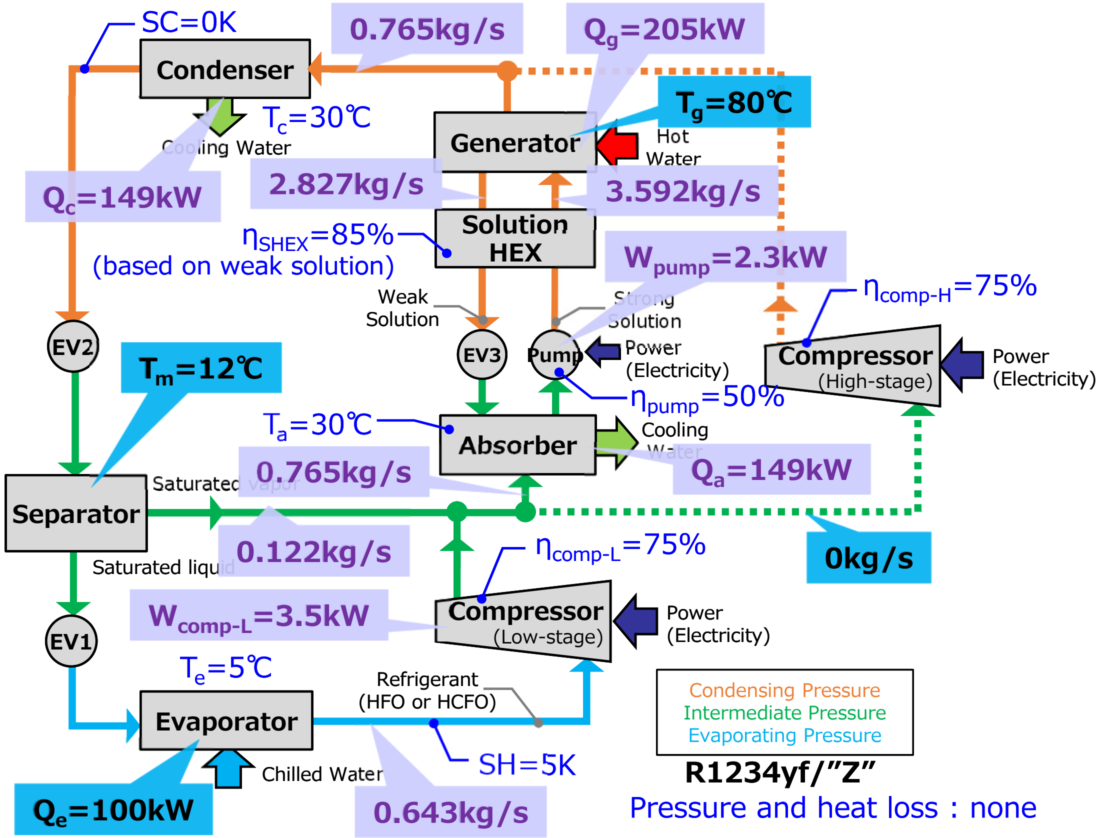
Process simulation



- **The process simulation in case of R1234yf/"Z" for the double expansion flow**
- **Estimation of Cooling COP_c based on power and required generation heat Q_g by changing intermediate temperature T_m and generation temperature T_g**
- **The simulation conditions are as follows.**
  - Evaporation temperature T_e = 5℃
  - Condensation temperature T_c = 30℃
  - Absorption temperature T_a = 30℃
  - Superheat at the outlet of the evaporator = 5K
  - Subcool at the outlet of the condenser = 0K
  - Compression efficiency =75% (=constant)
  - Pump efficiency = 50% (=constant)
  - Temperature efficiency of the solution HEX (based on weak solution) = 85% (=constant)
  - Pressure and heat loss : none.

Process simulation



Example of simulation

- Generation temperature T_g = 80℃
- Intermediate temperature T_m = 12℃
- Evaporation heat Q_e= 100kW
- Compressor (High-stage): not driven

- Power of compressor (Low-stage) W_{comp-L} = 3.5kW
- Power of solution pump W_{pump} = 2.3kW

> **Cooling COP$_c$ based on power**

= $Q_e/(W_{comp-L}+W_{pump})$

=100kW / (3.5kW+2.3kW) = 17.0

=**238%** (vs. single compression=7.2)

- Generation heat Q_g= 205kW

> **Required generation heat ratio**

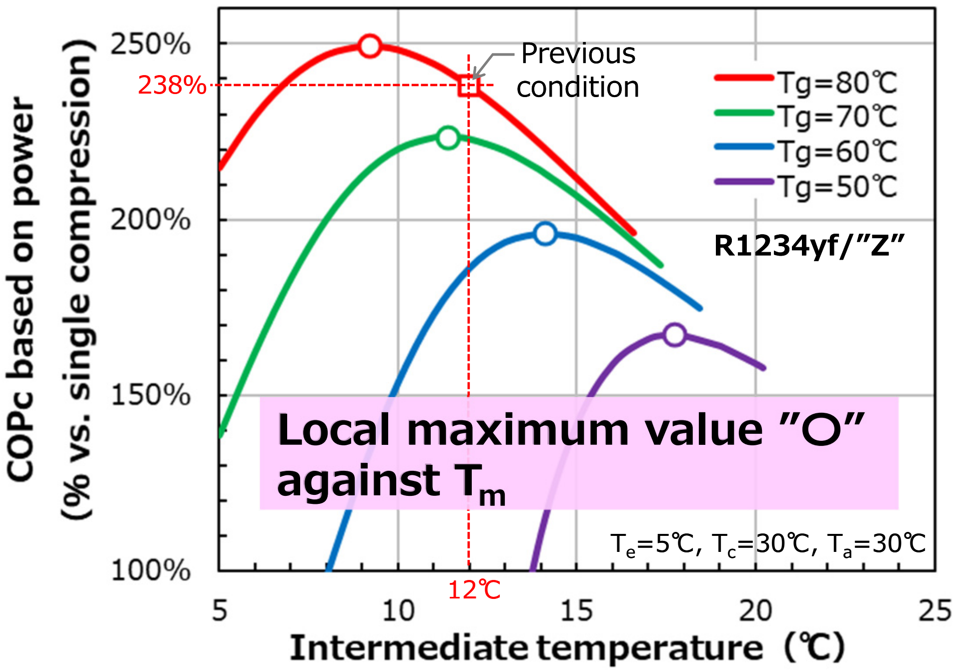
(vs. evaporation heat) **Q_g/Q_e**

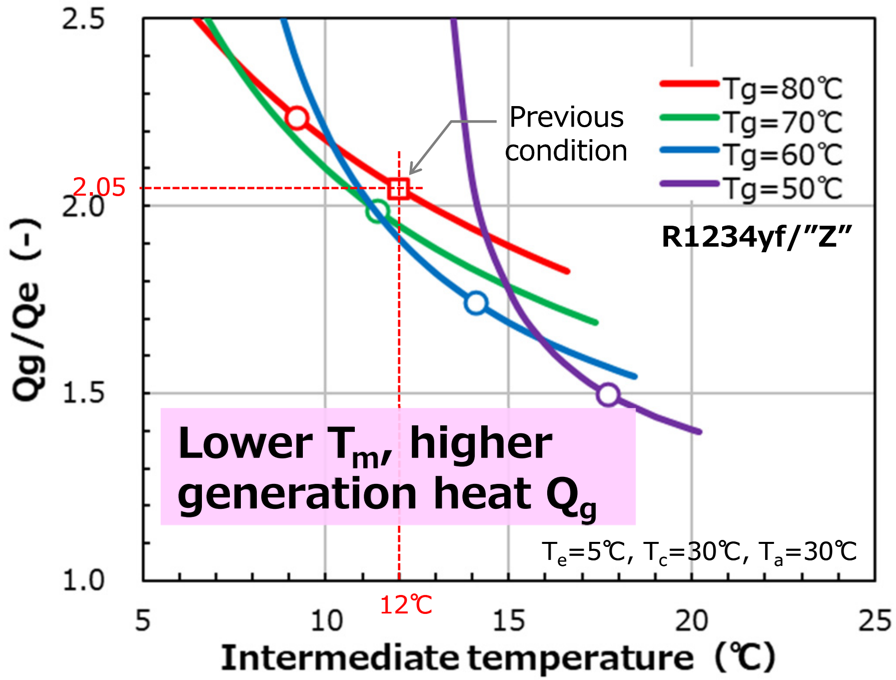
= 205kW/100kW = **2.05**

Process simulation

Simulation results

- Generation temperature T_g = 50℃, 60℃, 70℃, 80℃
- Compressor (High-stage): not driven

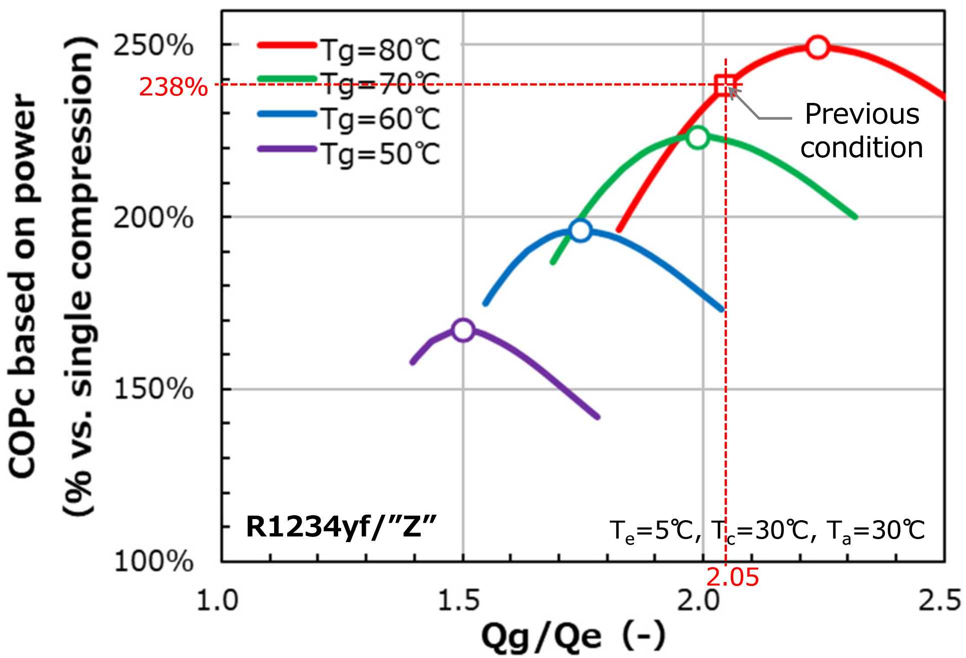




Process simulation

Simulation results

- Generation temperature T_g = 50℃, 60℃, 70℃, 80℃
- Compressor (High-stage): not driven



- **Cooling COP_c has the local maximum value "○" against the generation heat Q_g**
- **When the generation temperature T_g decreases, the maximum value of COP_c decreases. However, the required generation heat Q_g at that time is also reduced.**

Conclusions

After measuring the equilibrium absorption concentration, PTx lines and enthalpy-concentration diagrams were created, and process simulation was performed in the hybrid refrigeration cycle which uses low-GWP refrigerants and Tetraethylene Glycol Dimethyl Ether ("Z") as the absorbent.

- **The circulation ratio using "Z" is significantly lower than that using [HMIM][Tf2N] in case of R1234yf as the refrigerant.**
- **Under the simulation condition of this work, there is a local maximum value of cooling COP_c based on power against generation heat Q_g. It was confirmed that there are the conditions that the estimated cooling COP_c in the hybrid refrigeration cycle can be more than twice as high as that in the single compression refrigeration cycle.**

Thank you very much for your attention.

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