Achievement report of NEDO R&D Project on Innovative Thermal Management Materials and Technologies

May 17, 2023

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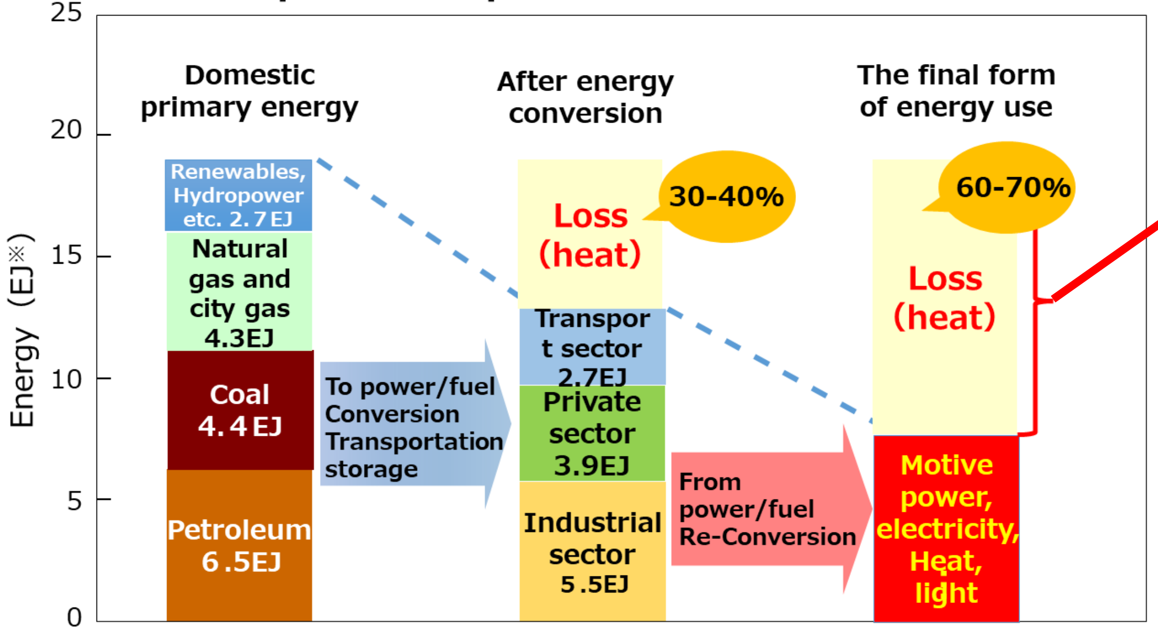
Unutilized Thermal Energy in Japan

Most of the primary energy have not been used effectively since most of energy in every stage, of which about 40% are from industrial and transportation sectors, are discharged as heat (Unutilized thermal energy).

Energy flow from primary energy supply to final consumption in Japan



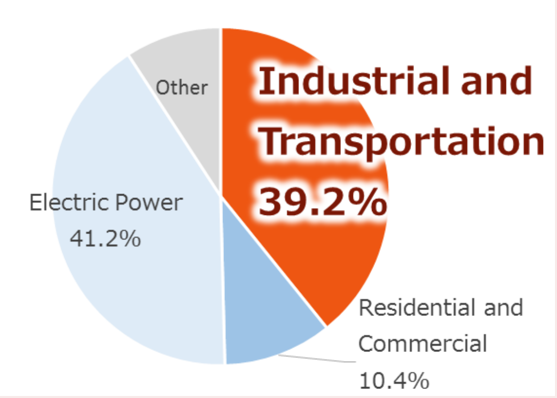
※EJ=10^{18} J

Source：Prepared by NEDO based on FY2020 Energy demand-supply data by Agency for Natural Resources and Energy

Most of the primary energy are discharged as heat without any recovery

Unutilized Thermal Energy

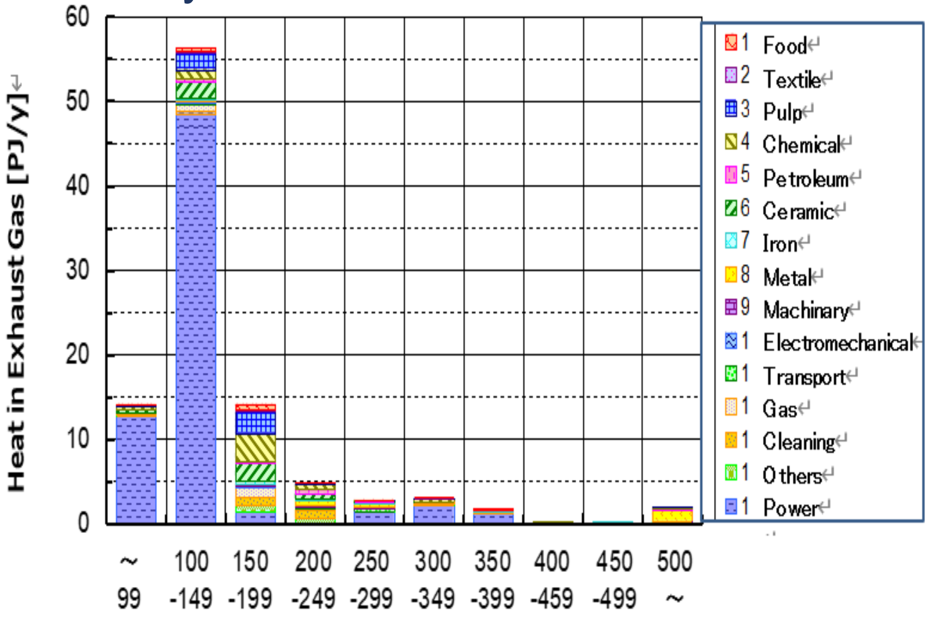
About 40%: from industrial and transportation sectors



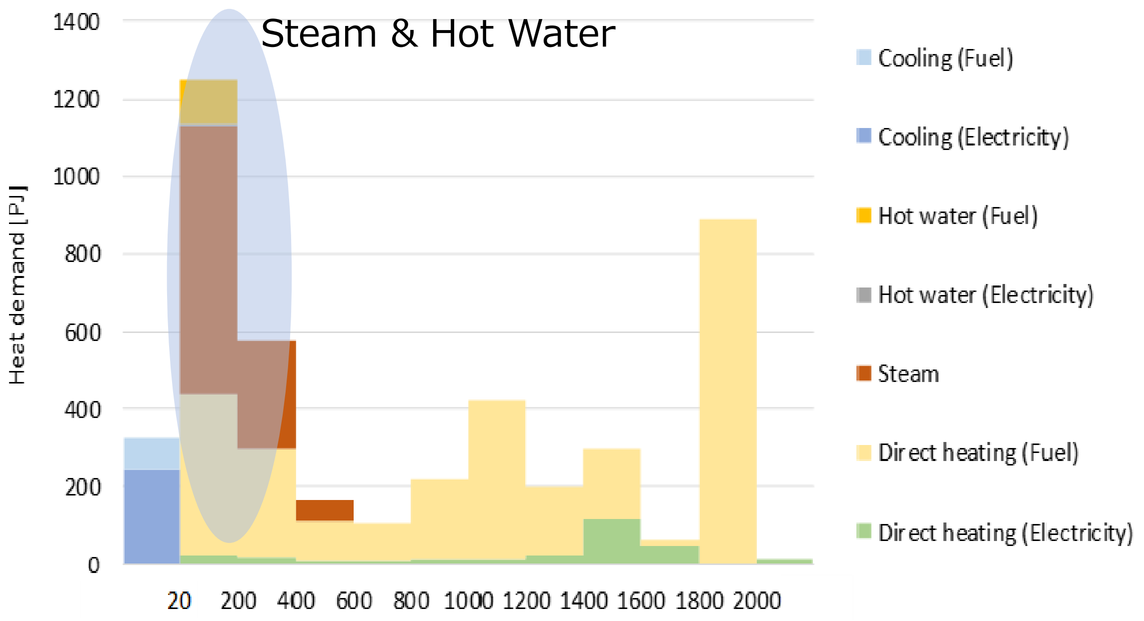
Exhaust heat and heat demand of Industrial process

1.Temperature distribution of exhaust heat and heat demand are overlapping each other.
2.Heat demand area below 200°C becomes 1250 PJ and accounts for 28% of the total industrial heat demand. Heating methods are steam & hot water.

Exhaust gas temperature Distribution depends on type of Industry



Heat demand by heating methods for temperature Range



Potential of Heat Pumps for below 200℃ Heat demand

There is largest demand at 150 - 200°C range but TRL of Heat Pump is ● 6-7:Pre-commercial demonstration or ● 4-5:Early prototype above 150°C.

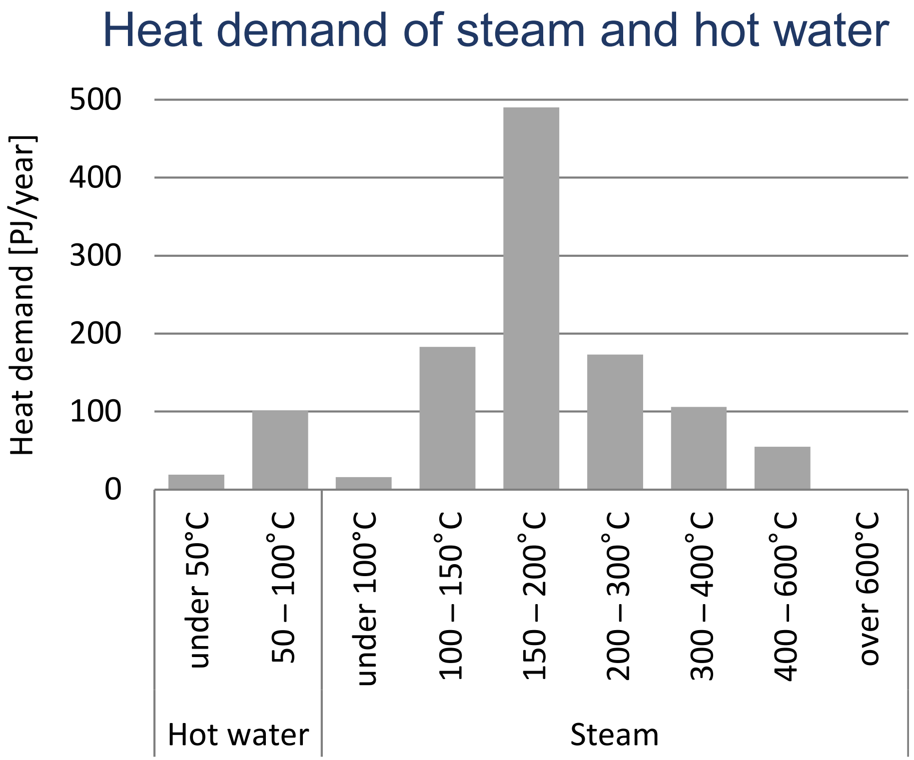


Table 1.2 ▷ Industrial heat pump technology readiness by temperature range

Temperature range	Technology readiness level (TRL)	Example process
<80 °C	TRL 11: Proof of market stability	Paper: De-inking Food: Concentration Chemical: Bio-reactions
80 °C to 100 °C	TRL 10: Commercial and competitive, but large-scale deployment not yet achieved	Paper: Bleaching Food: Pasteurisation Chemical: Boiling
100 °C to 140 °C	TRL 8-9: First-of-a-kind commercial applications in relevant environment	Paper: Drying Food: Evaporation Chemical: Concentration
140 °C to 160 °C	TRL 6-7: Pre-commercial demonstration	Paper: Pulp boiling Food: Drying Chemical: Distillation Various industries: Steam production
160 °C to 200 °C	TRL 8-9: First-of-a-kind commercial applications for small-scale MVR systems and heat transformers TRL 4-5: Early to large prototype	Various industries: High-temperature steam production
>200 °C	TRL 4: Early prototype	Various industries: High-temperature processes

Readiness level: ● TRL 1 to 5 ● TRL 6 to 7 ● TRL 8 to 11

Notes: MVR = mechanical vapour recompression. TRLs can vary for specific processes or different heat pump capacities.

Source : The Future of Heat Pumps, p36

R&D - Utilizing Waste Heat (NEDO)

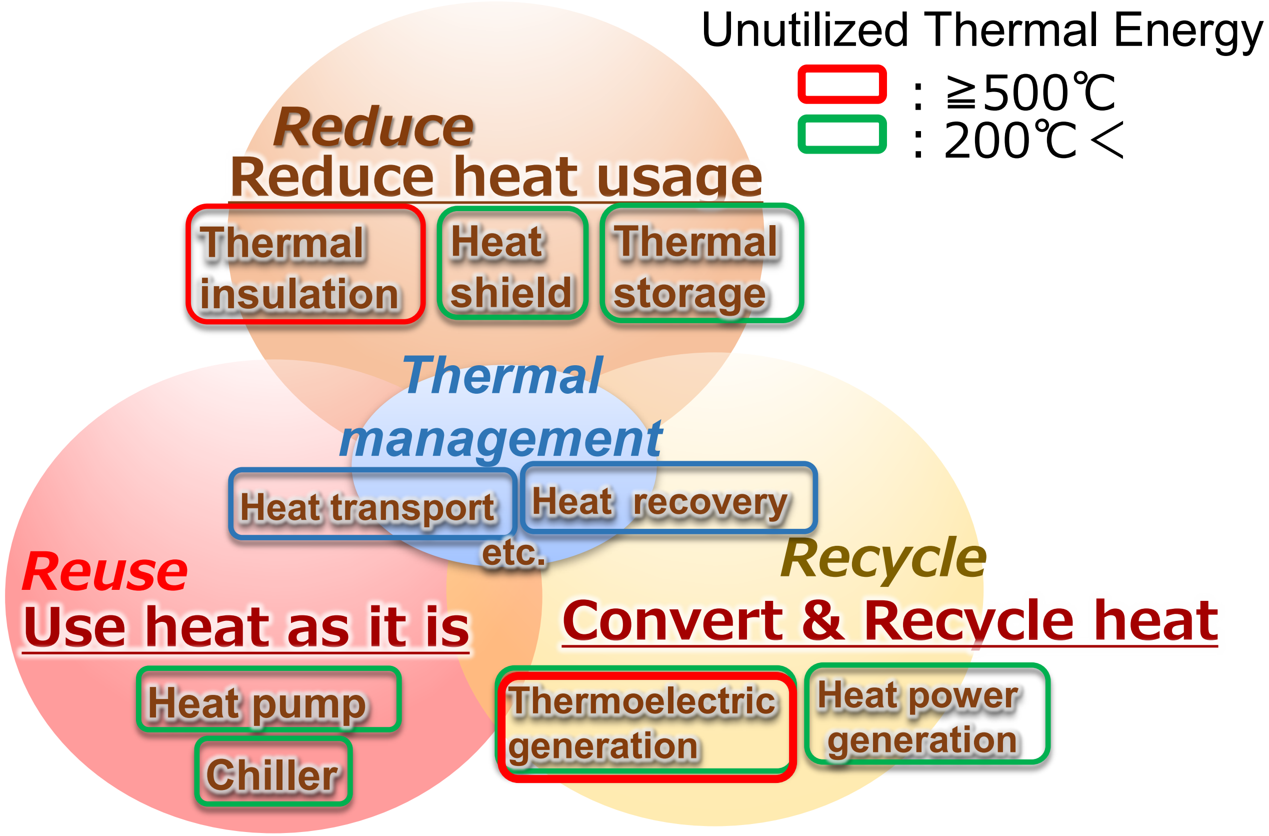
R&D Project on Innovative Thermal Management Materials and Technologies

Period：FY 2015 – 2022

Budget : 6.75 billion USD

Development :

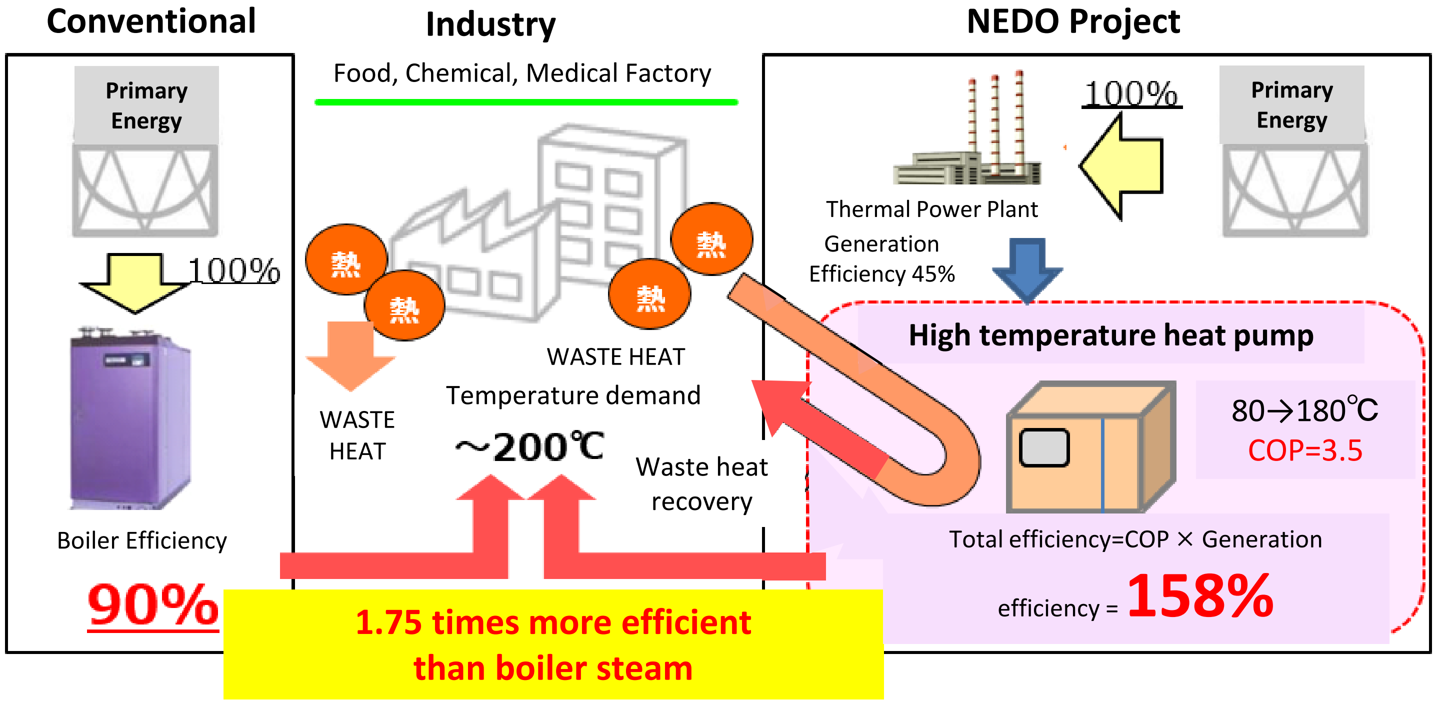
- Technology to effectively **Reduce**, **Reuse** and **Recycle** untapped thermal energy
- Crosscutting **Thermal management** technologies
- Heat pumps can play a role in reusing thermal energy (e.g. **High temperature Heat pumps**, High-efficiency chiller…)



Development of High temperature Heat Pump

- Heat pump system that collects unused heat of 80～100 °C that is discharged from heating process and supplies 160～200 °C of thermal liquid/air with high efficiency (COP=3.5).

Boilers using a large amount of fossil fuel to be replaced by High temperature heat pumps



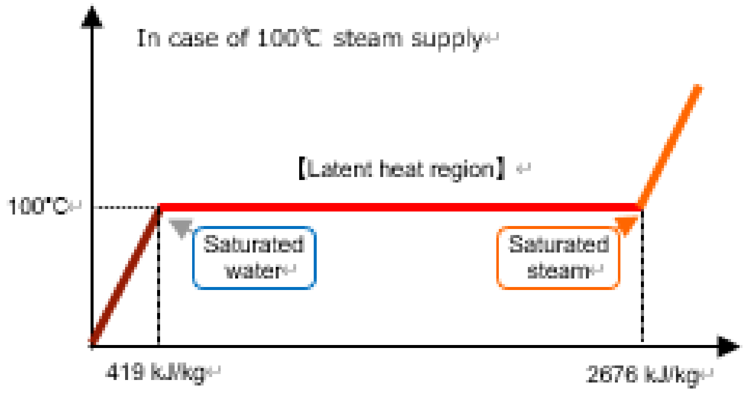
2 type of High temperature Heat Pump

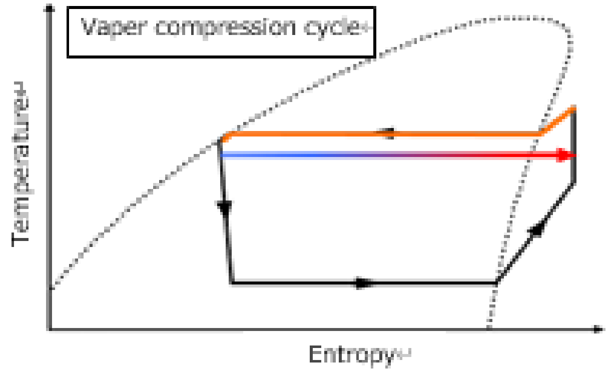
Type-1. Steam supply with small ΔT
・Aiming to supply steam
⇒The heating medium is circulating type
⇒Temperature is constant in heating process during phase change from water to steam
⇒Above 150 °C steam generation is difficult with present available refrigerant

Type-2. Thermal oil or air supply with large ΔT
・Aiming to supply oil or air
⇒The heating medium is transient type
⇒There is no constant temperature in heating process.
⇒Above 150 °C supply is possible with present available refrigerant

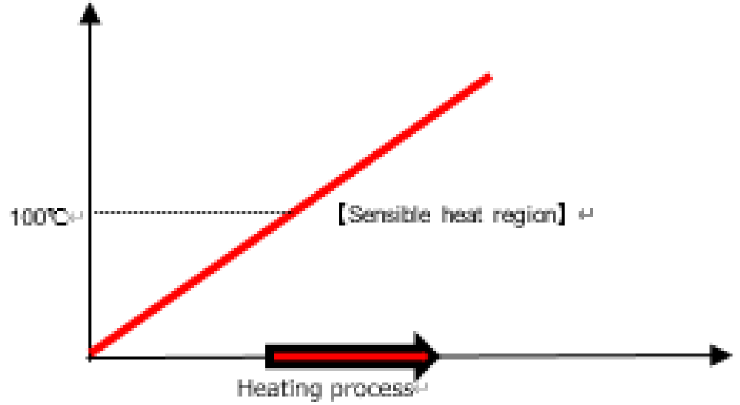
Type-2 is adopted to achieve 180 °C

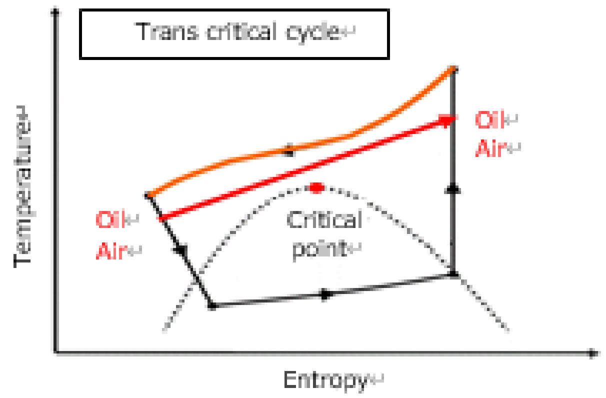
Type-1. Steam supply with small ΔT





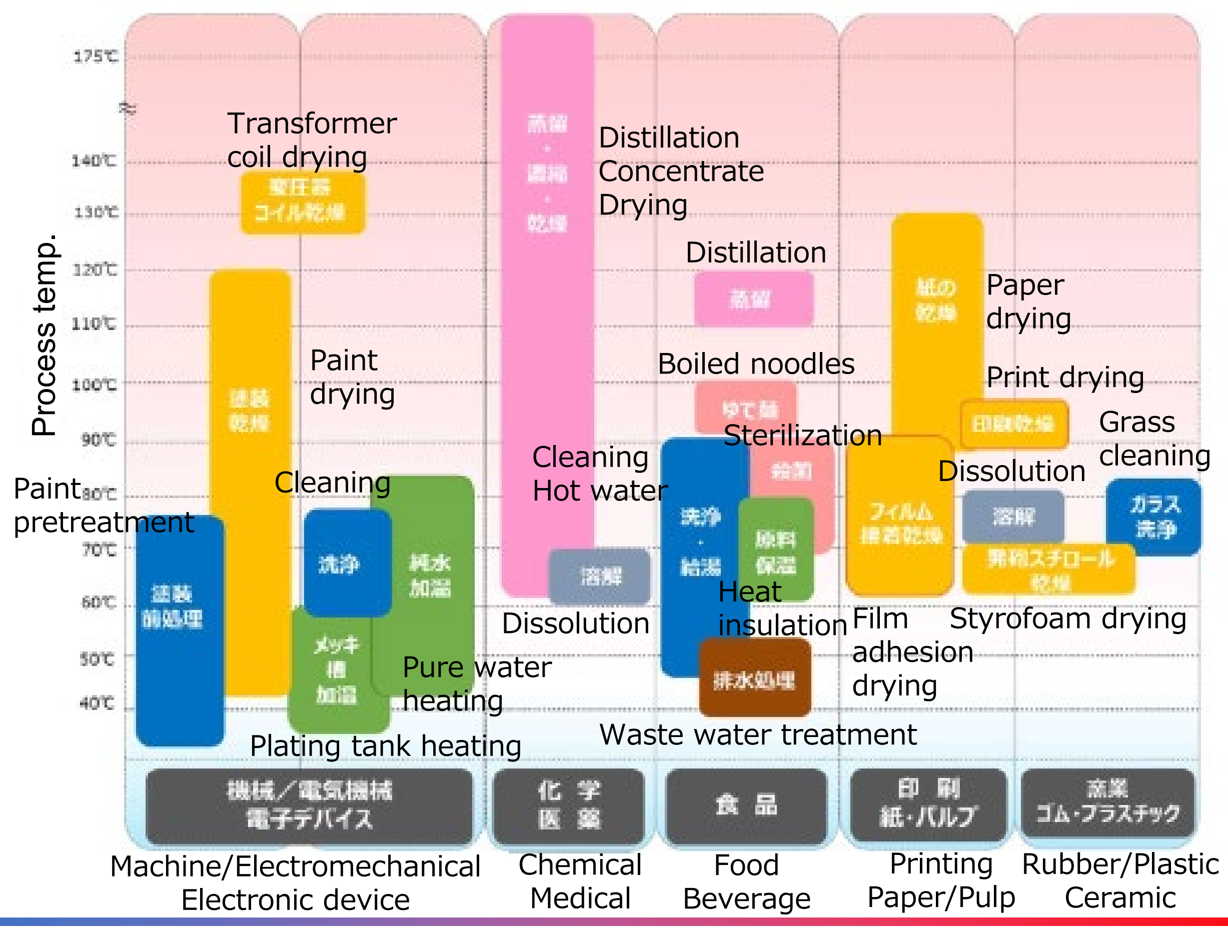
Type-2. Thermal oil or air supply with large ΔT



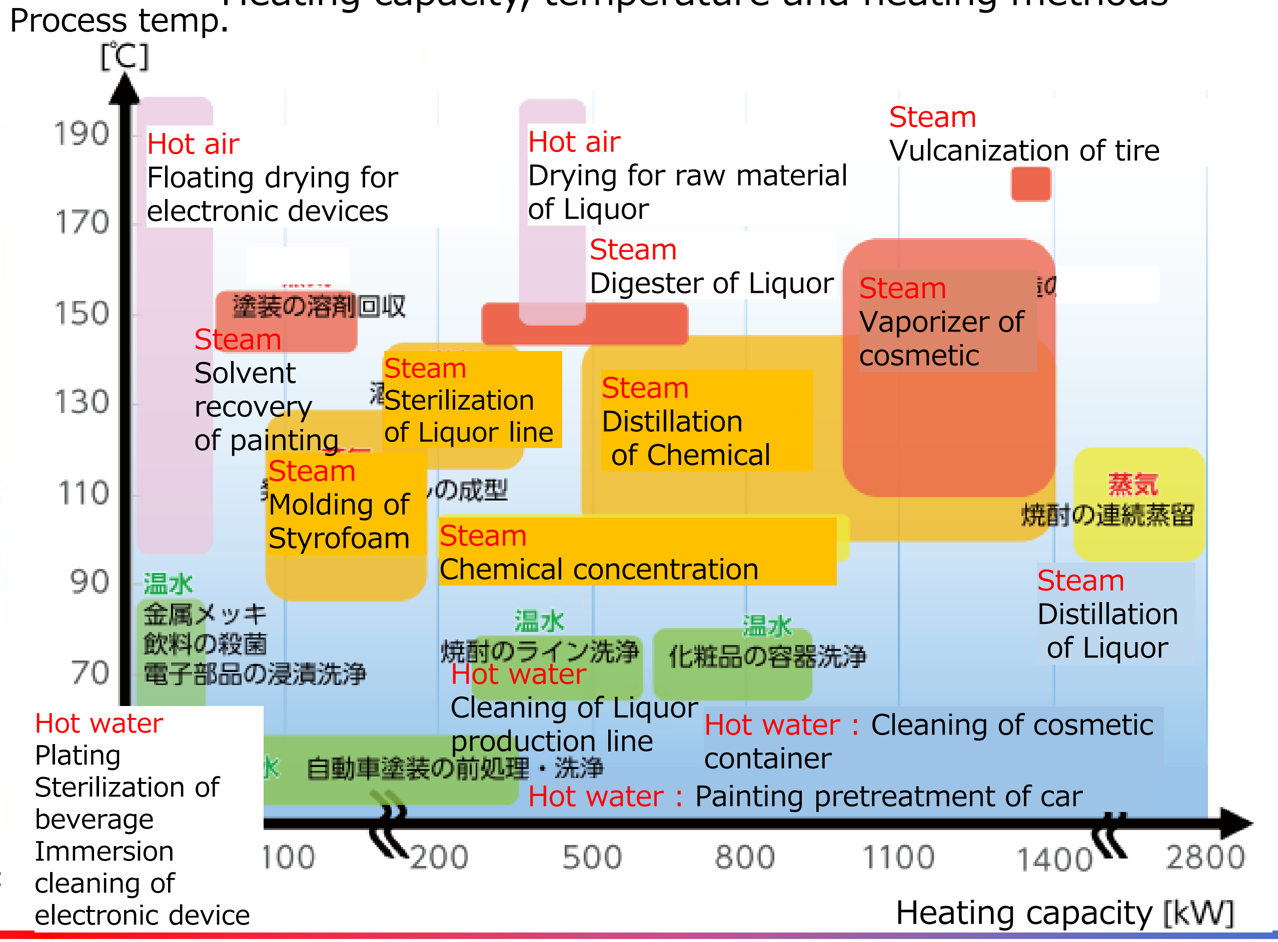


Potential process for Industrial Heat Pump

Process temperature depends on type of Industry



Heating capacity, temperature and heating methods



Target of Development

Maximum supply temperature **200 °C** 、COP=**3.5**

Feature：Low GWP refrigerant (GWP=2)

Casing of Prototype

Inside of Casing

Side view of Prototype

Oil free Centrifugal compressor

Project developer：MAEKAWA MFG. CO., LTD.

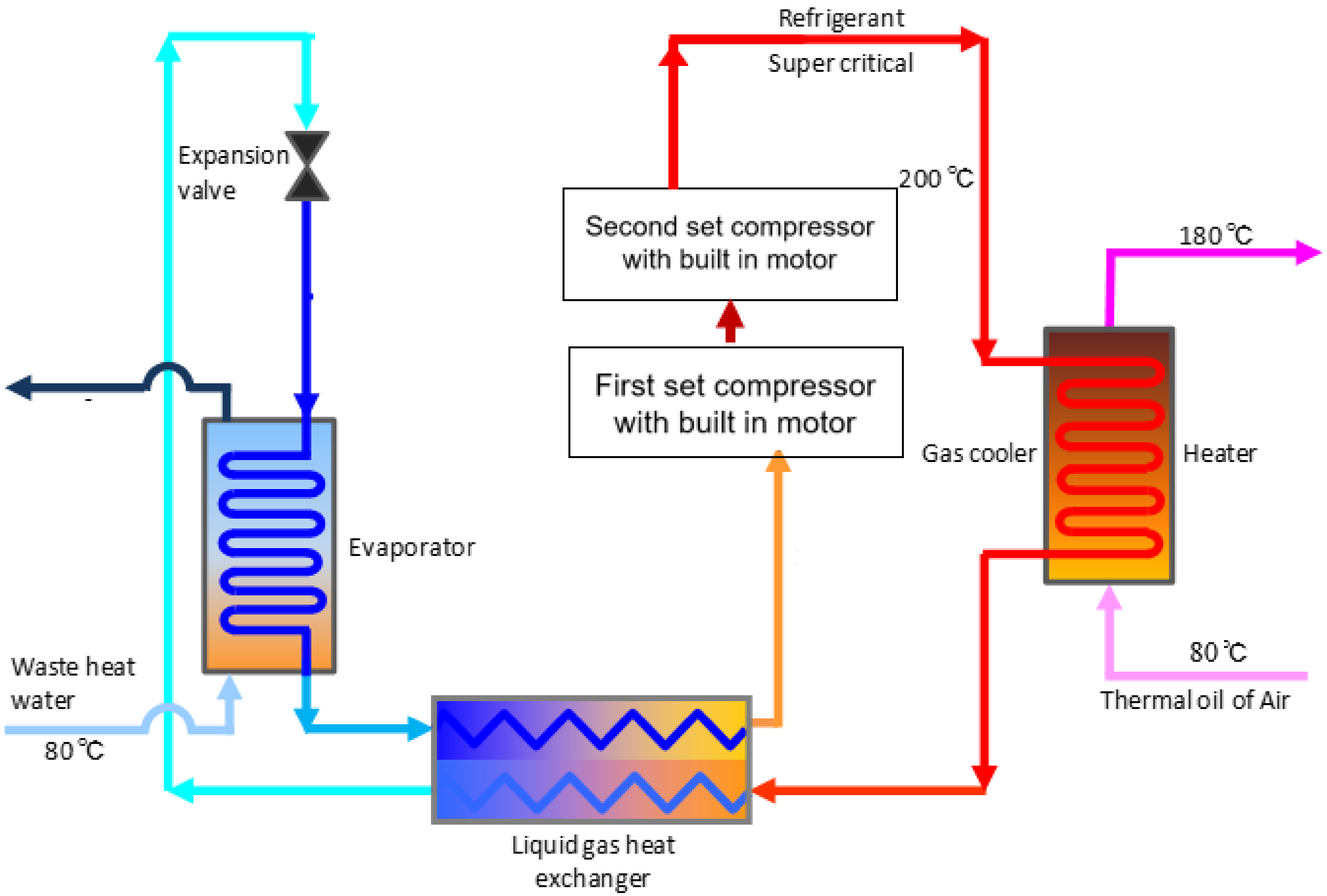
Specifications of prototype

Item	Design
Refrigerant	HFO (R1336mzz(Z))
Comperessor	Centrifugal
Lubricating oil	Oil free
Design pressure	5.2MPaA
Heating capacity	300kW
COP	3.5
Heat source	80℃
Heat supply	80 → 180℃
Maxmum supply temperature	200℃

Applied to

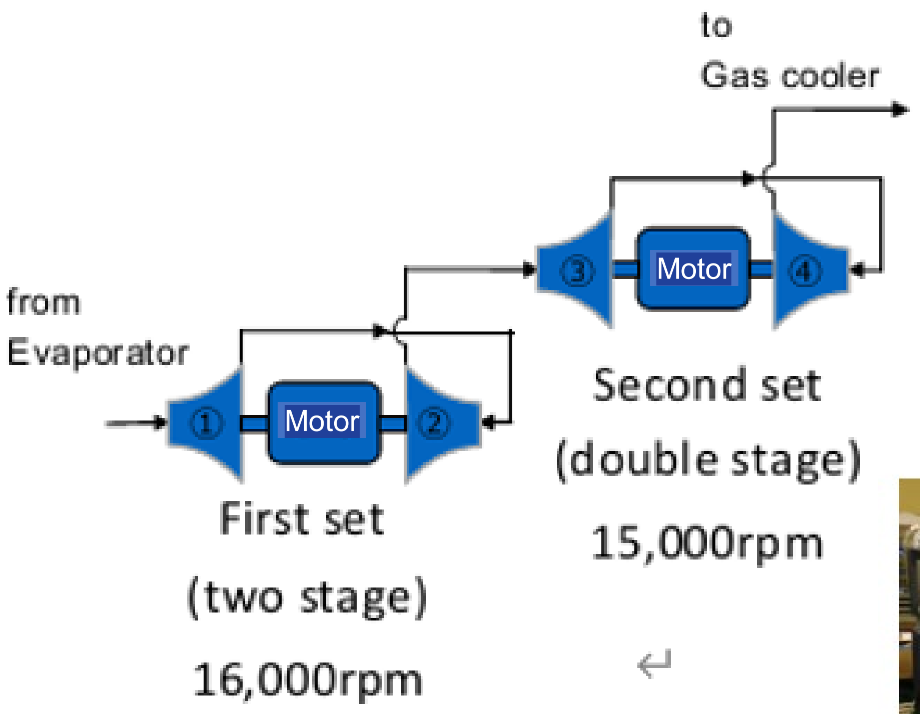
Food, Beverage, Medical, Chemical etc.

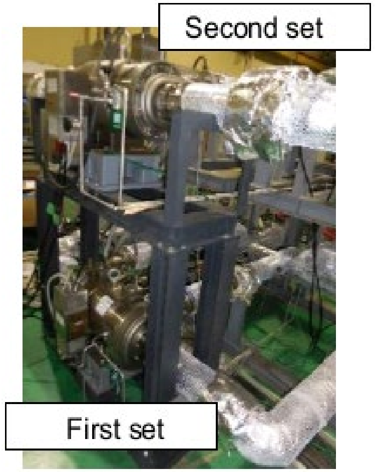
Schematic diagram of the High temperature Heat Pump



- The heating medium flowing through the gas cooler is thermal oil
- 80°C of waste heat is extracted by the evaporator as the heat source
- Trans critical cycle is adopted because of big temperature difference of thermal oil (ΔT=100K)
- Multi stages compression because pressure head is large between high side and low side

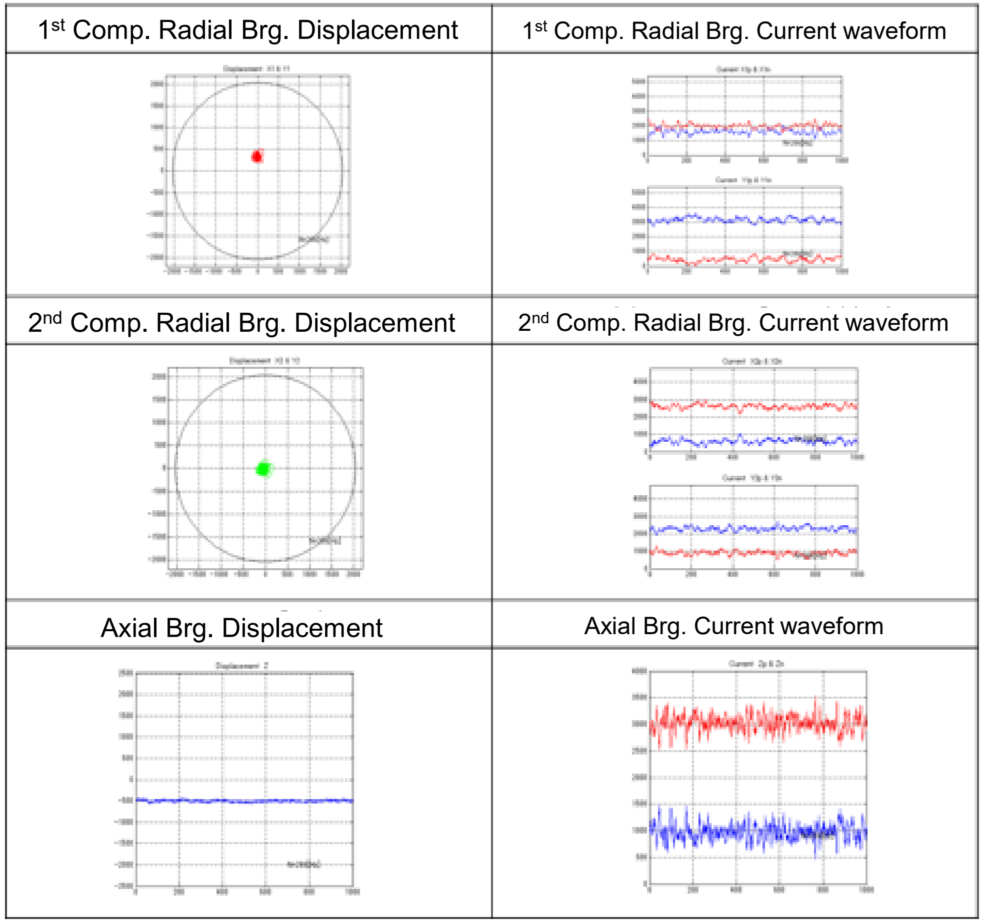
Compressor of the High temperature Heat Pump





- Two sets of compressors each with two stages, which makes it four stages compression
- Two impellers being back-to-back structure to reduce thrust load of axial bearing
- Oil-free centrifugal compressor with magnetic bearings
- The high-speed built-in motor with high heat resistance is located between the magnetic bearings at both ends

Evaluation of Magnetic Bearings control (1)



First set compressor condition

Waste heat water inlet temperature : 75[°C]
Thermal oil inlet temperature : 78[°C]
Rotation frequency : 16,000[rpm]

1st compressor inlet condition

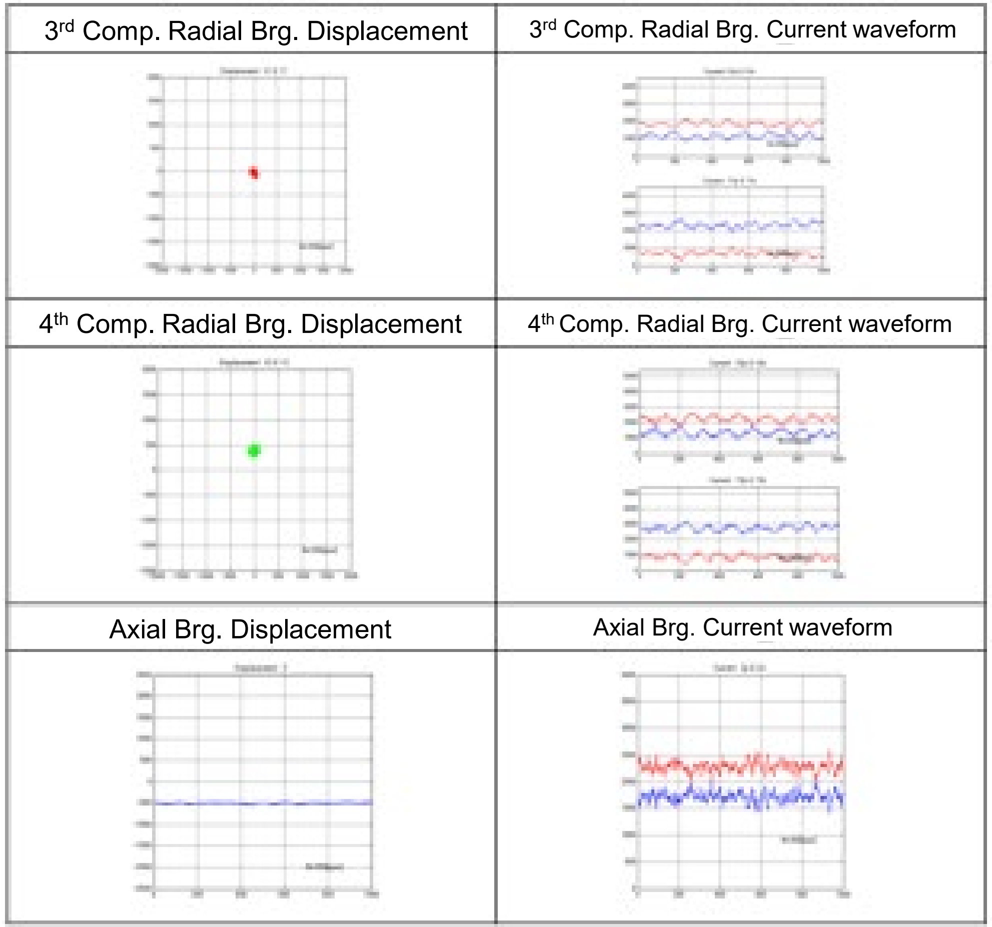
Inlet temperature : 118.5[°C]
Suction pressure : 0.34[MPaA]

2nd compressor inlet condition

Inlet temperature : 172.8[°C]
Suction pressure : 1.13[MPaA]

Stable control was confirmed at both radial bearings and axial bearing

Evaluation of Magnetic Bearings control (2)



Second set compressor condition

Waste heat water inlet temperature : 75[°C]

Thermal oil inlet temperature : 78[°C]

Rotation frequency : 15,000[rpm]

3rd compressor inlet condition

Inlet temperature : 171.7[°C]

Suction pressure : 1.10[MPaA]

4th compressor inlet condition

Inlet temperature : 184.8[°C]

Suction pressure : 1.61[MPaA]

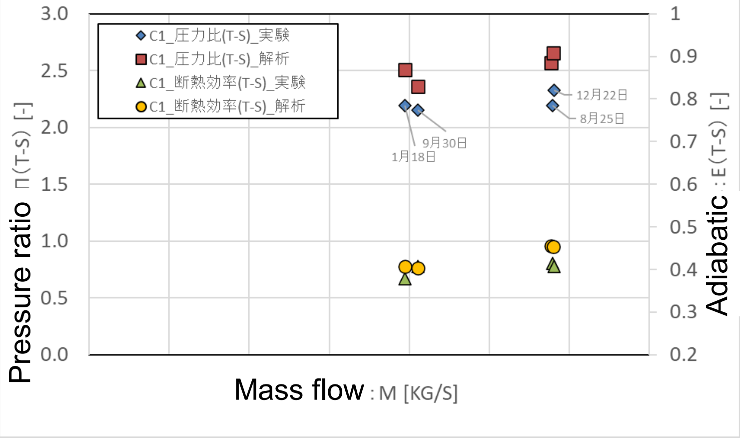
Stable control was confirmed at both radial bearings and axial bearing

Evaluation of Compressor performance

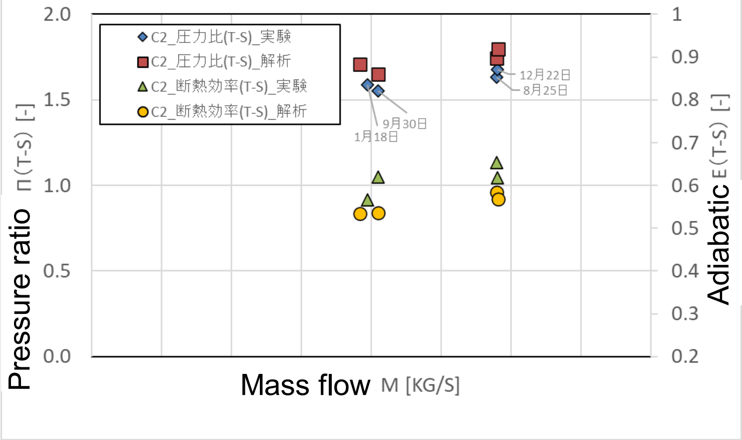
An example of actual measurement for analysing compressor performance

	1st Comp. inlet		2nd Comp. outlet	3rd Comp. inlet	4th Comp. outlet
Rotation frequency [rpm]	16,000			15,000	
Pressure [MPaA]	0.34		1.13	1.10	1.61
Temperature [℃]	118.5		172.8	171.7	184.8

Comparison of theoretical value and actual measurement of Mass flow, pressure ratio and adiabatic efficiency (1st Comp.)



Comparison of theoretical value and actual measurement of Mass flow, pressure ratio and adiabatic efficiency (2nd Comp.)



According to comparison of theoretical values and actual measurements, there is prospect of achieving COP=3.5

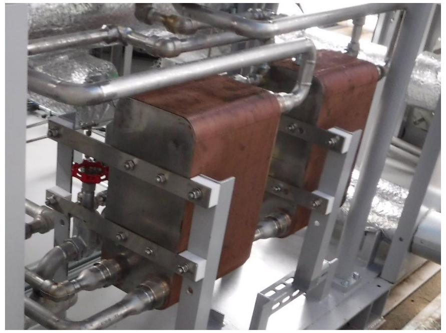
Evaluation of Heat Exchanger

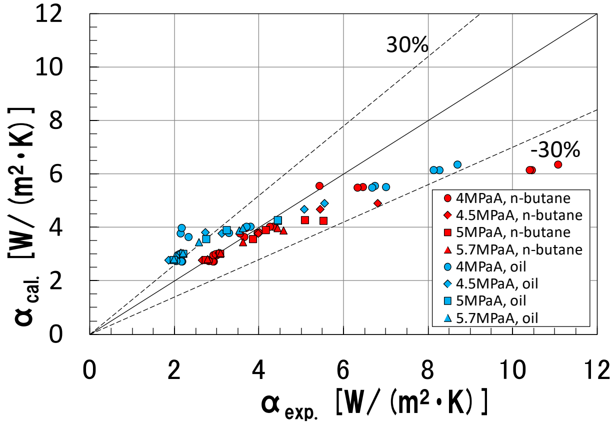
15 years of life is assured by heat cycle test with 100 °C of ΔT

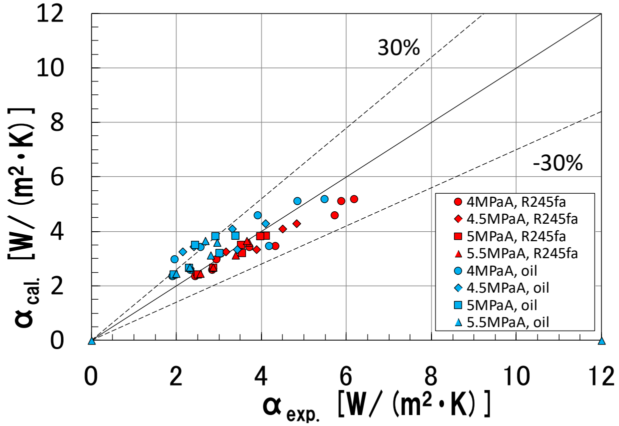
Heat cycle test results

BPHE ID	Test ID	ΔT (°C)	No. of Cycles	Note	Passed
DP-170911-02-01	1752-172	100	11000	stopped	Yes
DP-170911-02-02	1752-173	100	11000	stopped	Yes
DP-170911-03-02	1752-174	100	11000	stopped	Yes
DP-170911-03-01	1752-175	100	11000	stopped	Yes

Heat Exchangers of prototype





Heat transfer correlations and actual measurements

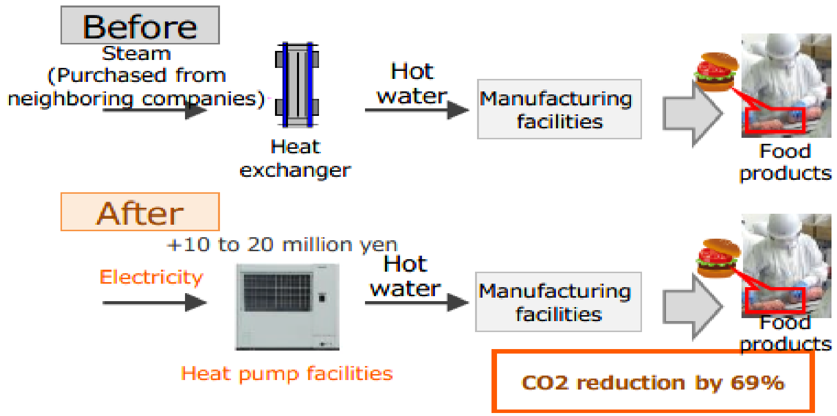
Future Direction of Industrial heat demand

Future direction of industrial heat demand for temperature range had been stated in Interim Report of the Clean Energy Strategy from METI (Ministry of Economy, Trade and Industry) in May 2022.

Temperature Range		Possible direction toward decarbonization of heat source	Period
Overall		・High-efficiency heat utilization, Energy efficiency/conservation, Inforce support to small and medium size d enterprises	present
	Below 200℃	・Dissemination, promotion and development of Heat pumps	present
	100～1500℃	・Decarbonization of power + Electrification	after 2030
		・Practical use of non-fossil fuels such as Hydrogen, Ammonia, E-methane and Biomass / Provide support based on cost differentials with conventional fuels	present to after2020
		・Shift to natural gas → Conversion to non-fossil fuels / Provide support based on cost differentials with conventional fuels	present to after2020
	2000℃	・Innovative technologies such as hydrogen-reduction steelmaking / / Provide support based on cost differentials with conventional fuels	after 2030

■Heat pump is specified as possible direction at below 200℃ of Low temperature range.
■Acceleration of development of High temperature heat pump is expected in Japanese manufactures.

◆Example 2 Electrification of heat demand (SME in the food manufacturing industry)



Summary

-R&D Project on Innovative Thermal Management Materials and Technologies had been completed in 2022 and there are some outstanding achievement such as high temperature heat pump.

-Development of high temperature heat pump which can supply up to 200℃ is completed and its social implementation will start from 2025 after subsequent demonstration project.

-NEDO will continue to contribute to decarbonized society by accelerating innovation and achieving results in a timely manner.

Thank you!

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