High-Temperature Heat Pumps in Japan

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# National Team of Japan for Annex 58

## 3 Experts
- Prof. Hitoshi Anano [Heat Exchanger]
  Kobe University
- Prof. Keiko Anami [Compressor]
  Osaka Electro-Communication University
- Prof. Katsuyuki Tanaka [Refrigerant]
  Nihon University

## 1 RTO
- CRIEPI
  (Central Research Institute of Electric Power Industry)

## 3 Manufacturers
- Fuji Electric
- Kobelco Compressors Corporation
- Mayekawa

## 2 Information Centers
- HPTCJ
  (Heat Pump & Thermal Storage Technology Center of Japan)
- JEHC
  (Japan Electro-Heat Center)

## 1 National Agency
- NEDO
  (New Energy and Industrial Technology Development Organization)
HTHP Industry in Japan

- 24 Manufacturers for industrial heat pumps (IHPs)
  - 9 Companies specialize in mechanical vapor recompressions (MVRs)
  - 15 Companies produce closed-system IHPs
    - 4 Companies produce high-temperature heat pumps (HTHPs) with the supply temperatures of 100°C or higher

![Diagram showing 15 Manufacturers for IHPs (Closed System), 4 Manufacturers for HTHPs, and 11 Manufacturers for MVRs]
History of HTHP Developments in Japan

- **Main drivers**
  - Electric utilities before the 3.11 disaster in 2011
  - Recently some national R&D projects by NEDO

- **Commercialization**
  - Since the latter half of the 2000s
  - Currently market available up to 165°C steam supply
# Market Available HTHPs over 100°C in Japan

<table>
<thead>
<tr>
<th>External Appearance</th>
<th>Mayekawa</th>
<th>KOBELCO</th>
<th>KOBELCO</th>
<th>MHI Thermal Systems</th>
<th>Fuji Electric</th>
<th>Mayekawa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercialized Year</td>
<td>2009</td>
<td>2011</td>
<td>2011</td>
<td>2011</td>
<td>2015</td>
<td>2021</td>
</tr>
<tr>
<td>Product Name</td>
<td>Eco Sirocco</td>
<td>SGH120</td>
<td>SGH165</td>
<td>ETW-S</td>
<td>—</td>
<td>Eco Circuit 100</td>
</tr>
<tr>
<td>Heat Source/Sink</td>
<td>Water/Air</td>
<td>Water/Steam</td>
<td>Water/Steam</td>
<td>Water/Water</td>
<td>Water/Steam</td>
<td>Water/Air</td>
</tr>
<tr>
<td>Supply Temperature</td>
<td>60-120°C</td>
<td>100-120°C</td>
<td>135-175°C</td>
<td>130°C</td>
<td>100-120°C</td>
<td>100°C</td>
</tr>
<tr>
<td>Heat Source Temperature</td>
<td>0-40°C</td>
<td>25-65°C</td>
<td>35-70°C</td>
<td>55°C</td>
<td>60-80°C</td>
<td>0-40°C</td>
</tr>
<tr>
<td>Heating Capacity (Steam Rate)</td>
<td>110 kW (0.51 ton/h)</td>
<td>370 kW (0.89 ton/h)</td>
<td>624 kW (0.89 ton/h)</td>
<td>627 kW</td>
<td>30 kW (45 kg/h)</td>
<td>100 kW</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R744 (CO₂)</td>
<td>R245fa</td>
<td>R245fa+R134a, R718 (H₂O)</td>
<td>R134a</td>
<td>R245fa</td>
<td>R1234ze(E)</td>
</tr>
<tr>
<td>Compressor</td>
<td>Reciprocating</td>
<td>Screw</td>
<td>Screw</td>
<td>Centrifugal</td>
<td>Reciprocating</td>
<td>Reciprocating</td>
</tr>
<tr>
<td>Heat Pump Cycle</td>
<td>Transcritical</td>
<td>Subcritical</td>
<td>Subcritical + Steam compressor</td>
<td>Transcritical</td>
<td>Subcritical</td>
<td>Subcritical</td>
</tr>
</tbody>
</table>
Heat demands below 200°C

- Account for 28% (=1,250 PJ, 347 TWh) of the total industrial heat demand
- Used in various industries and various processes (cleaning, drying, distillation, concentration, ...)
- Used mainly as a form of steam

*Note: The heat demands mean utility supply temperatures, not process demand temperatures.*
2 Approaches for Spreading IHPs

- **Higher Temperature HPs**
  - Extend the territory of HP application
  - Much potential
  - Not much customer’s benefit yet

- **Process Innovation and Integration**
  - Shift heat demand and use not so high temperature HPs for better COP
  - Need to involve customer (process operator) and engineering company

Development Perspectives for HTHP Technologies

- Lower GWP refrigerants: HFCs → HFOs, HCFOs or Natural refrigerants
- Higher temperature supply: Becoming possible with new refrigerants
- In parallel development of lubricant oils
- New steam generation system

**Working domain analysis** (2-stage economizer cycle, $\Delta T_h = \Delta T_c = 5$ K, COP $\geq 4$, VHC $\geq 2$ MJ/m$^3$)

**HFCs and R718 (10 years ago)**

- R134a
- R245fa
- R718

**HFOs, HCFOs and R718 (Current)**

- R1234ze(Z)
- R1224yd(Z)
- R1233zd(E)
- R1336mzz(Z)
- R1234yf

**Natural refrigerants (if accepted)**

- R717
- R600
- R601a
- R601
- R718
National R&D Projects by NEDO

- Fuji Electric
  - 150°C steam supply heat pump [FY2016-FY2018]

- Mayekawa
  - 150°C steam supply heat pump [FY2009-FY2012]
  - 180°C supply heat pump (Large $\Delta T_h$) [FY2013-FY2022]

- MHI Thermal Systems
  - 160°C supply heat pump (Large $\Delta T_h$) [FY2013-FY2022]
  - 200°C supply heat pump (Large $\Delta T_h$) [FY2013-FY2022]
1 | 150°C steam supply heat pump

Outline

- Fuji Electric already produces 120°C steam supply heat pump
- For more market penetration, developing 150°C steam supply heat pump

<table>
<thead>
<tr>
<th>Items</th>
<th>Development specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply steam temperature</td>
<td>120-150°C (saturated steam)</td>
</tr>
<tr>
<td>Heat source temperature</td>
<td>60-90°C</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>30 kW</td>
</tr>
<tr>
<td>Steam flow rate</td>
<td>45 kg/h</td>
</tr>
<tr>
<td>Maximum integration unit</td>
<td>10 units</td>
</tr>
<tr>
<td>COP</td>
<td>&gt; 3.2</td>
</tr>
<tr>
<td>Size W × D × H</td>
<td>&lt; 1.5 × 1.0 × 1.8 m</td>
</tr>
</tbody>
</table>

1 | 150°C steam supply heat pump

Technologies

- Direct steam generation in refrigerant condenser
- Pressurized pump less with natural convection water circulation
- R1336mzz(Z)
- 2-stage economizer cycle
- 2 compression rooms in 1 scroll
- Optimized design of scroll wrap height
2 | 150°C steam supply heat pump

Outline

- Mainly development of **R601 screw** compressor
- Steam generation is not verified yet

<table>
<thead>
<tr>
<th>Items</th>
<th>Development objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply steam temperature</td>
<td>150°C (saturated steam)</td>
</tr>
<tr>
<td>Condensation temperature</td>
<td>160°C</td>
</tr>
<tr>
<td>Evaporation temperature</td>
<td>80°C</td>
</tr>
<tr>
<td>COP</td>
<td>&gt; 3.0</td>
</tr>
<tr>
<td>GWP</td>
<td>&lt; 150</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items</th>
<th>Development specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant</td>
<td>R601 (n-pentane)</td>
</tr>
<tr>
<td>Lubricant oil</td>
<td>PAG</td>
</tr>
<tr>
<td>Design pressure</td>
<td>2.0 MPaG</td>
</tr>
<tr>
<td>Design temperature</td>
<td>200°C</td>
</tr>
<tr>
<td>Max. discharge pressure</td>
<td>1.9 MPaG</td>
</tr>
<tr>
<td>Max. suction pressure</td>
<td>0.5 MPaG</td>
</tr>
</tbody>
</table>

H. Fuchikami et al., Development of a steam generation heat pump using a natural refrigerant, JSRAE Annual Conference, Tokyo, September 2013. [in Japanese]
 Technologies

- R601, screw compressor, single-stage cycle
3 | 180°C supply heat pump

Outline

- Development of very HTHP
- Mainly developments of centrifugal compressor and gas cooler (brazing plate heat exchanger)
- Oil free compressor with magnetic bearing
- Large temperature glide in heat sink → Transcritical cycle
- R600 (n-butane) was selected at the first prototype → R1336mzz(Z) at the second prototype

<table>
<thead>
<tr>
<th>Items</th>
<th>Development specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply temperature</td>
<td>80°C in / 180°C out</td>
</tr>
<tr>
<td>Heat source temperature</td>
<td>80°C</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>500 kW</td>
</tr>
<tr>
<td>COP</td>
<td>&gt; 3.5</td>
</tr>
</tbody>
</table>
3 | 180°C supply heat pump

- Technologies
  - R1336mzz(Z), centrifugal compressor, transcritical cycle

Compressor system at the second prototype
- 2-stage turbo compressor × 2 set (in series)
- Built-in motor
- Magnetic bearing

T. Kimura et al., Development of a high temperature heat pump using reusable heat as the heat source, JRAIA International Conference, October 2021.
Outline

- Development of very HTHP with large temperature glide in heat sink
- Including development of new refrigerant by Central Glass

### 160°C supply heat pump

<table>
<thead>
<tr>
<th>Items</th>
<th>Development specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply temperature</td>
<td>70°C in / 160°C out</td>
</tr>
<tr>
<td>Heat source temperature</td>
<td>80°C in / 70°C out</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>600 kW</td>
</tr>
<tr>
<td>COP</td>
<td>&gt; 4.0</td>
</tr>
</tbody>
</table>

### 200°C supply heat pump

<table>
<thead>
<tr>
<th>Items</th>
<th>Development specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply temperature</td>
<td>100°C in / 200°C out</td>
</tr>
<tr>
<td>Heat source temperature</td>
<td>95°C in / 90°C out</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>600 kW</td>
</tr>
<tr>
<td>COP</td>
<td>&gt; 3.5</td>
</tr>
</tbody>
</table>
4 & 5 | 160°C & 200°C supply heat pumps

- Technologies
  - **2-stage extraction** (or bleeding) cycle*
  - **R1336mzz(Z)** for 160°C supply and **HFE356mmz** for 200°C supply
  - **Centrifugal** compressor

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HFE356mmz

- $M = 182.1$ g/mol
- $T_{\text{crit}} = 186.4^\circ$C
- $P_{\text{crit}} = 2.70$ MPa
- GWP = 2
- A2L (expected)
Future Perspectives in Japan

- Some HTHPs above 150°C are under development.
- These are planned to be put on the market from around 2025.
- It is expected to be applied to processes that have been difficult to date such as spray dryer, paint drying booth and CO₂ absorption column.
From Developments to Deployments

National projects of Japan
- So far, focusing on technological development of heat pump equipment
- Successfully improved the technical potential and maturity of heat pumps
- However, lack of demonstration and deployment projects

For the widespread adoption of industrial heat pumps
- Necessary to build process integration methodology with involving end-users, engineering companies and energy service companies
- Necessary to cultivate process integrators
Thank you for your attention.

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