High Temperature Heat Pumps in Japan
- Potential, Development Trends, and Case Studies -

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Keywords:
High temperature heat pump, Potential, Development trend, Case study, Distillation process

Abstract

For significant reduction of greenhouse gas emissions, it is important to decrease the emission factor of electricity, to electrify heat usage, and to use electricity with high efficiency. In particular, industrial sector has much potential for electrifying heat usage and for reducing greenhouse gas emissions. Heat pump is recognized as one of the key technologies for the industrial electrification.

When focusing on steam demand and hot water demand for heat pump application, it is reported that the heat demand between 50°C and 150°C is estimated at 300 PJ/year in Japan [1]. The Japanese Government expects the cumulative shipments of industrial heat pumps achieve the heating capacity of 1,673 MW by FY2030 compared to the actual cumulative shipments of 11 MW in FY2013 [2]. The effect is estimated at 1.35 million ton-CO_2 reduction.

In recent years, various types of industrial heat pumps have been developed and commercialized in Japan [3]. When focusing on high temperature heat pumps (HTHPs) over 100°C, the following 5 products are available in the market; a hot air supply heat pump (Eco Sirocco) by MAYEKAWA, steam supply heat pumps (SGH120 and SGH165) by KOBELCO, a pressurized hot water supply heat pump (ETW-S) by MHI Thermal Systems, and a steam supply heat pump by Fuji Electric. KOBELCO has already prepared the product line-up up to 165°C. Fuji Electric, MAYEKAWA and MHI Thermal Systems prepared HTHPs around 120°C and are developing HTHPs over 150°C by NEDO projects [4].

Generally, coefficient of performance (COP) of heat pump becomes smaller as increasing supply temperature. It depends on the price and emission factor of electricity how much COP is necessary for customer's benefit. Today, in Japan, the emission factor of electricity is about 0.5 kg-CO_2/kWh [5] and the price ratio of electricity to city gas is about 2.8 [6]. These values make a little difficult for applying HTHPs.

The author has performed the experimental performance evaluation of the SGH165 [7]. The performance data were acquired under various conditions on the assumption of actual conditions. As well as extracting technical issues, the competitive condition was clarified compared to existing boiler

system. In addition, the author visited installed sites of SGHs and conducted interview survey to user companies and engineering companies about application of steam supply heat pumps. The effects by applying SGHs were as planned or better than planned, so the users satisfied them and had no additional requests to the heat pumps. The engineering companies recognized the good operability of the heat pumps. But for applying it furthermore, they request higher COP and lower initial cost.

As examples of good practices, two case studies for applying heat pumps to distillation processes are shown in this presentation. Existing distillation column for ethanol or methanol needs the temperature above 100°C. The first case applied 120°C steam supply heat pump for ethanol distillation [8]. The effects were 43% CO_2 reduction and 54% energy cost reduction. On the other hand, the second case applied 90°C hot water supply heat pump for methanol distillation [9]. This could be realized by decompression of distillation column to vacuum pressure. The effects were 60% CO_2 reduction and 63% energy cost reduction. In this way, decreasing heat demand temperature by changing process shows the better effectiveness of heat pump and gives the more opportunity of heat pump even when electricity situation is not so good economically and environmentally like at this time in Japan.

In conclusions, toward electrification and decarbonisation for future, both higher temperature heat pump for extending the territory of heat pump application and process innovation for shifting heat demand to lower temperature are important realistically for spreading industrial heat pumps.

[1] MRI, Survey report on heat demand and supply equipment, commissioned by enecho, February, 2018. [in Japanese] https://www.meti.go.jp/meti_lib/report/H29FY/000018.pdf

[2] MOE, The Plan for Global Warming Countermeasures, decided by the Japanese Cabinet on 13th May, 2016. http://www.env.go.jp/en/headline/2238.html

[3] JEHC, Guideline for use of industrial heat pump, March, 2017. [in Japanese] http://www.jeh-center.org/asset/00032/HeatPump_Guide/Heatpump%20Guide.pdf

[4] NEDO, ENEX 2019, February, 2019. [in Japanese] https://www.nedo.go.jp/content/100891001.pdf https://www.nedo.go.jp/content/100891002.pdf

[5] FEPC, INFOBASE 2018. [in Japanese] https://www.fepc.or.jp/library/data/infobase/

[6] METI, Energy White Paper 2019. https://www.enecho.meti.go.jp/en/category/whitepaper/

[7] T. Kaida et al., Experimental performance evaluation of heat pump-based steam supply system, 9th International Conference on Compressors and their Systems, London, September, 2015. https://iopscience.iop.org/article/10.1088/1757-899X/90/1/012076

[8] JEHC, Collection of case studies for industrial electrification, Vol. 4, March, 2015. [in Japanese] http://www.jeh-center.org/asset/00032/monodukurinidenki/vol4_hokkaidobaioetanoru.pdf.pdf

[9] JEHC, Collection of case studies for industrial electrification, Vol. 6, March, 2019. [in Japanese] http://www.jeh-center.org/asset/00032/monodukurinidenki/vol6_meitousangyou.pdf

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Central Research Institute of Electric Power Industry

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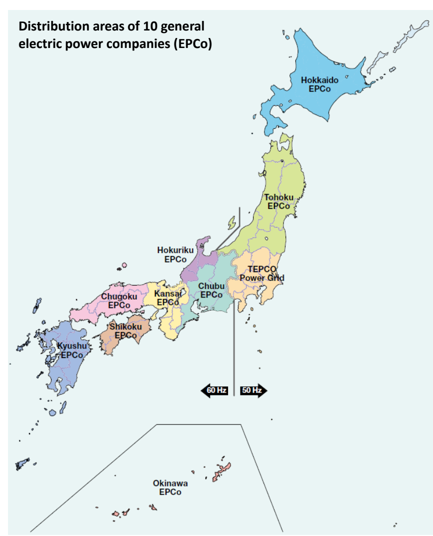
2nd Conference on High Temperature Heat Pumps
9th September, 2019 | Copenhagen, Denmark

Takenobu KAIDA
Central Research Institute of Electric Power Industry (CRIEPI)

What is CRIEPI?

- **Common research institute**
  of 10 general electric utilities in Japan
- **Academic research institute**
  based on objective scientific knowledge
- **In-house research institute**
  with own experimental facilities and research tools



Based on: JEPIC, The Electric Power Industry in Japan 2019.
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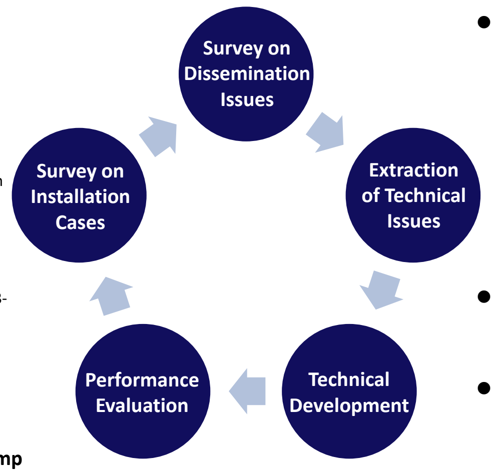
CRIEPI's Activities about Industrial Heat Pumps

- **Survey of installation cases and dissemination issues**
  (IEA HPT Annex 48, FY2016-2018)
  (Sharing information with JEHC & HPTCJ)

  *JEHC = Japan Electro-Heat Center
  *HPTCJ = Heat Pump & Thermal Storage Technology Center of Japan

- **Performance evaluation of heating tower defrosting**
  (Joint research with KUKEN, FY2013-2014)
- **Performance evaluation of steam supply heat pump**
  (Contract research from electric utilities, FY2014-2015)
- **Performance evaluation of DX-type industrial heat pump**
  (Contract research from electric utility, FY2016)



- **Extraction of technical issues**
  (FEPC, METI, enecho, NEDO)

  *FEPC = Federation of Electric Power Companies of Japan
  *METI = Ministry of Economy, Trade and Industry
  *enecho = Agency for Natural Resources and Energy
  *NEDO = New Energy and Industrial Technology Development Organization

- **Development of lumber drying system with heat pump**
  (Joint research with Shimane prefecture and Toshiba Carrier, FY2013-2015)
- **Application of low GWP refrigerant to high temperature heat pump**
  (Independent research with the cooperation of AGC and KOBELCO, FY2017-2018)

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Outline

- **Potential & Development Trends**
  - Overview of Industrial heat pumps (IHPs)
  - Recent development trends of high temperature heat pumps (HTHPs)
- **Case Studies**
  - Performance evaluation of steam grow heat pump « SGH165 »
  - Interview survey about SGHs
  - Application for distillation process

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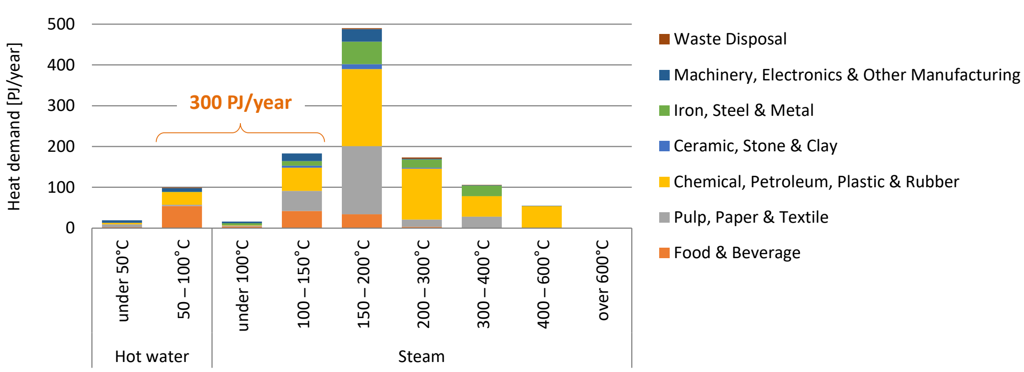
Potential & Development Trends

Potential of IHPs in Japan

- Focusing on **steam demand** and **hot water demand** for HP application
- Heat demand potential of IHPs: **300 PJ/year** (= 83.3 TWh/year)
- Large Potential industry: « Chemical », « Food », « Paper », « Machinery »



Based on: MRI, Survey report on heat demand and supply equipment, commissioned by enecho, 2018. [in Japanese]
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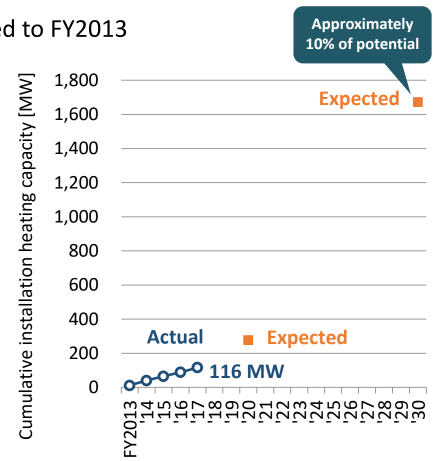
Expectation of Spreading IHPs

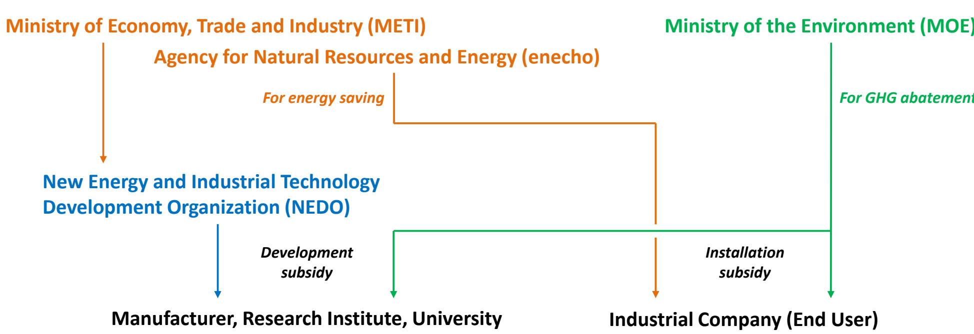
- "The Plan for Global Warming Countermeasures"
  - Decided by the Cabinet on 13th May, 2016
  - 26% reduction of GHG emissions by FY2030 compared to FY2013 (= 367 million ton-CO_2 reduction)
- Role of IHPs
  - **Over 150 times spread** (11 MW in FY2013 to 1,673 MW in FY2030)
  - 1.35 million ton-CO_2 reduction (= about 0.4% of total GHG emissions reduction)



Based on: METI & MOE Joint Meeting, 1st March, 2019. [in Japanese]

FYI | Government Support in Japan

- Two types of subsidies
  - Development subsidy (Higher efficiency, Higher temperature, Lower GWP)
  - Installation subsidy



Commercialized HTHPs over 100°C

	MAYEKAWA	KOBELCO	KOBELCO	MHI Thermal Systems	Fuji Electric
External Appearance					
Commercialized Year	2009	2011	2011	2011	2015
Product Name	Eco Sirocco	SGH120	SGH165	ETW-S	—
Heat Source/Sink	Water/Air	Water/Steam	Water/Steam	Water/Water	Water/Steam
Supply Temperature	60-**120**°C	100-**120**°C	135-**175**°C	**130**°C	100-**120**°C
Heat Source Temperature	0-40°C	25-65°C	35-70°C	55°C	60-80°C
Heating Capacity (Steam Rate)	110 kW[*1]	370 kW[*2] (0.51 ton/h)	624 kW[*3] (0.89 ton/h)	627 kW[*4]	30 kW[*5] (45 kg/h)
COP	3.7[*1]	3.5[*2]	2.5[*3]	3.0[*4]	3.5[*5]
Refrigerant	R744 (CO_2)	R245fa	R245fa+R134a	R134a	R245fa
Compressor	Reciprocating	Screw	Screw	Centrifugal	Reciprocating
Heat Pump Cycle	Transcritical	Subcritical	Subcritical + Steam Compression	Transcritical	Subcritical

*1 Heat source: 30-25°C, Heat sink: 20-100°C *2 Heat source: 65-60°C, Heat sink: 20-120°C *3 Heat source: 70-65°C, Heat sink: 20-165°C *4 Heat source: 55-50°C, Heat sink: 70-130°C *5 Heat source: 80-75°C, Heat sink: 20-120°C

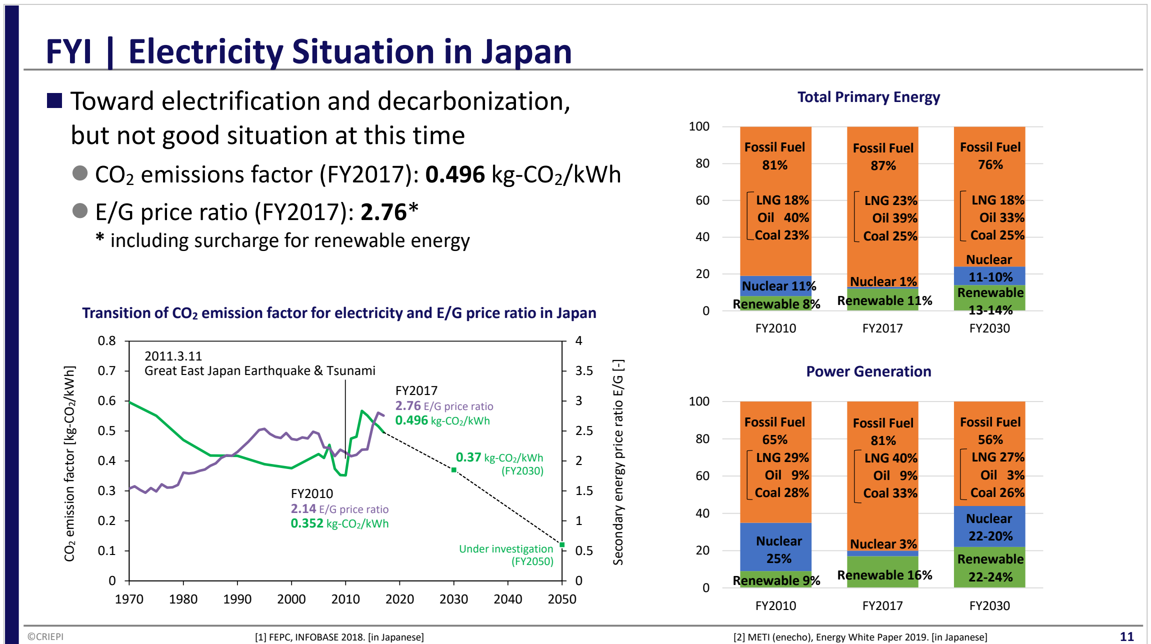
 Based on: Manufacturers' brochure 9

Recent National R&D Projects for HTHPs over 150°C

- NEDO Projects
  - Program for Strategic Innovative Energy Saving Technology
    - Steam supply heat pump (**Fuji Electric**, FY2015-FY2018)
  - R&D Project for Innovative Thermal Management Materials and Technologies (TherMAT)
    - High temperature heat pump (**MAYEKAWA**, FY2015-FY2022)
    - High temperature heat pump (**MHI Thermal Systems**, FY2015-FY2022)

	Fuji Electric	MAYEKAWA		MHI Thermal Systems	
Supply Temperature	**150**°C	**160**°C	**200**°C	**160**°C	**200**°C
Heat Source Temperature	70-90°C	80°C	100°C	80°C	100°C
Heating Capacity	30 kW	300 kW	—	600 kW	—
Target COP	≥ 3.3	≥ 3.5	≥ 3.5	≥ 3.5	≥ 3.5
Refrigerant	R1336mzz(Z)	R600	—	R1336mzz(Z)	—
Compressor	Scroll	Centrifugal	Centrifugal	Centrifugal	Centrifugal
Heat Pump Cycle	Subcritical	Transcritical	—	Subcritical	—

 Based on: Document by NEDO 10


FYI | Electricity Situation in Japan
Toward electrification and decarbonization, but not good situation at this time
CO2 emissions factor (FY2017): 0.496 kg-CO2/kWh
E/G price ratio (FY2017): 2.76*
* including surcharge for renewable energy
Transition of CO2 emission factor for electricity and E/G price ratio in Japan
2011.3.11
Great East Japan Earthquake & Tsunami
FY2017
2.76 E/G price ratio
0.496 kg-CO2/kWh
0.37 kg-CO2/kWh
(FY2030)
FY2010
2.14 E/G price ratio
0.352 kg-CO2/kWh
Under investigation
(FY2050)
CO2 emission factor [kg-CO2/kWh]
Secondary energy price ratio E/G [-]
Total Primary Energy
Fossil Fuel 81%
LNG 18%
Oil 40%
Coal 23%
Nuclear 11%
Renewable 8%
Fossil Fuel 87%
LNG 23%
Oil 39%
Coal 25%
Nuclear 1%
Renewable 11%
Fossil Fuel 76%
LNG 18%
Oil 33%
Coal 25%
Nuclear 11-10%
Renewable 13-14%
FY2010
FY2017
FY2030
Power Generation
Fossil Fuel 65%
LNG 29%
Oil 9%
Coal 28%
Nuclear 25%
Renewable 9%
Fossil Fuel 81%
LNG 40%
Oil 9%
Coal 33%
Nuclear 3%
Renewable 16%
Fossil Fuel 56%
LNG 27%
Oil 3%
Coal 26%
Nuclear 22-20%
Renewable 22-24%
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[1] FEPC, INFOBASE 2018. [in Japanese]
[2] METI (enecho), Energy White Paper 2019. [in Japanese]
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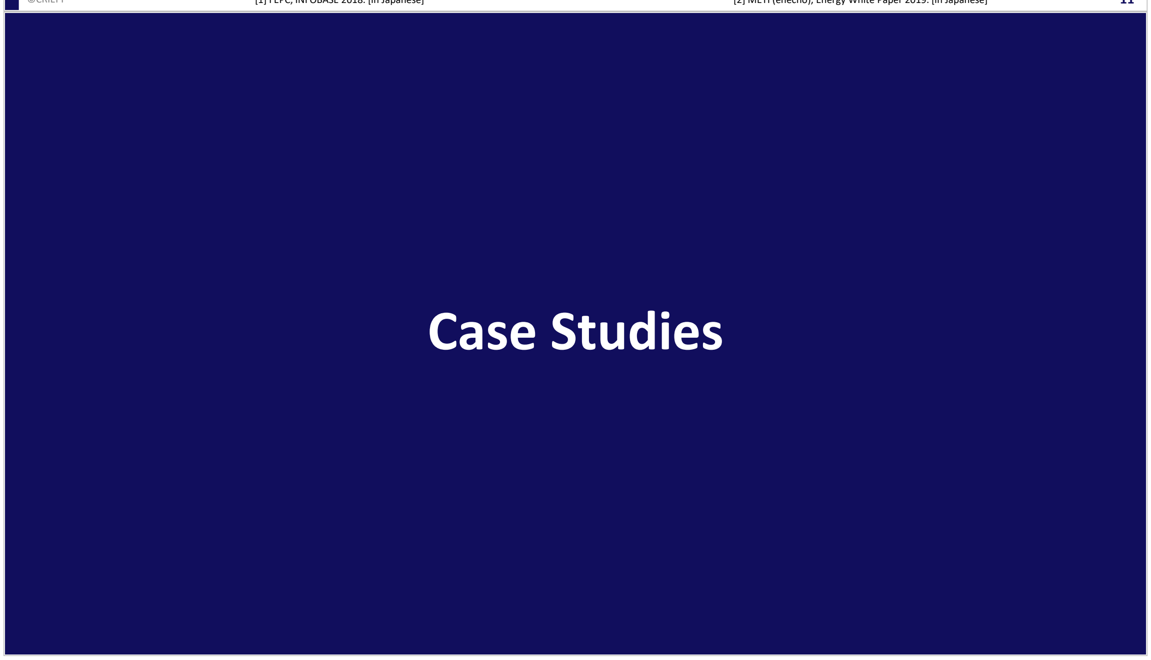
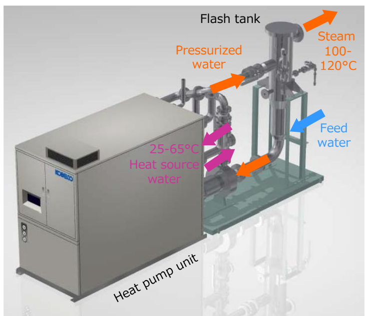

Case Studies

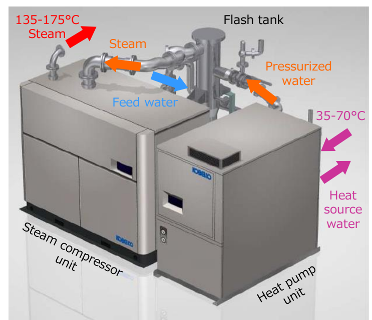
Steam Grow Heat Pumps (SGHs)

- Developed by **KOBELCO** and Japanese electric utilities
- Commercialized in 2011 (just before 3.11 disaster)



SGH120

R245fa
Two-stage screw compressor
COP = 3.5, *Q* = 370 kW (0.5 ton/h)
Steam = 120°C, Heat source = 65°C



SGH165

R245fa + R134a (mixture)
Single-stage screw compressor + Steam compressor
COP = 2.5, *Q* = 660 kW (0.9 ton/h)
Steam = 165°C, Heat source = 70°C

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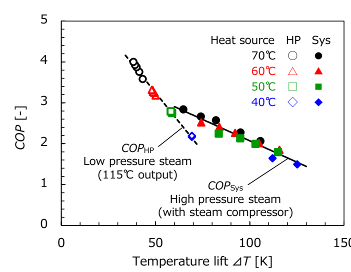
Performance Evauation of SGH165

- Performance evluation of SGH165
  - Tested at **CRIEPI** Lab in FY2014
  - Energy performance
    - Influence of heat source temperature, steam discharge pressure, feed water temperature
    - Part-load performance
    - Effect of waste heat recovery from drainage
  - Operating characteristics
    - Start-up, shut-down
    - Condensed water blow
    - Load following capability
- Interview survey about SGHs
  - Visited to installed sites in FY2015
  - To user companies and engineering companies



 Ref: T. Kaida et al., 9th International Conference on Compressors and their Systems, 2015. https://iopscience.iop.org/article/10.1088/1757-899X/90/1/012076 14

Interview Survey about SGHs

		Case 1	Case 2	Case 3
Outline	Industry	Chemical	Chemical (Medicine)	Waste Disposal
	Process	**Distillation** of ethanol	**Sterilization** of chemical container	**Drying** sewage sludge
	Installed HP	**SGH 120** × 5 units	**SGH165** × 1 unit	**SGH165** × 1 unit
	Installed year	2012	2014	2016
	Installation type	Renewal from steam boiler	Addition to existing steam line	Newly established
User company	Background	• Considered improvement measures • Suggestion from engineering company	• Considered improvement measures • Suggestion from engineering company	Not yet
	Objective (needed payback period)	• Reduction of running cost (**3.5 years with subsidy**)	• Reduction of running cost (**3 years without subsidy**)	Not yet
	Initial concerns	• Reliability and durability	• Durability	Not yet
	Effects	• **Better than planned**	• **As planned**	Not yet
	Requests	• Nothing	• Nothing	Not yet
Engineering company	Handling	• Easy because unitized	• Easy because unitized	• Easy because unitized
	Reason of selection	• Shorter delivery date and better operability compared to MVR	• Effective use of waste heat	• Effective use of waste heat
	Requests	• **Higher COP** • Smaller capacity (around half size) • Specification for explosion resistance	• **Lower initial cost** • Larger capacity (around 2 times size) • Specification for explosion resistance	• **Lower initial cost** • Increasing tolerance of water quality • Simpler drain piping

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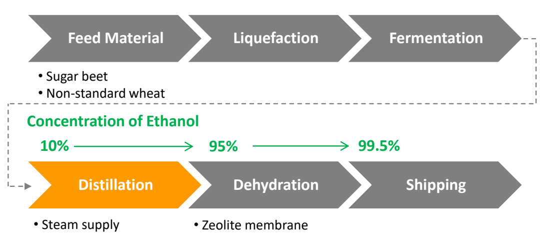
Case 1 | Distillation Process in Bio-ethanol Production

Outline of Installation

Industry	Chemistry
Production	Bio-ethanol
User company	Hokkaido Bioethanol Co., Ltd.
Installed year	2012
Process	Distillation of ethanol
Application	**Steam (120°C)**
Engineering company	Japan Chemical Engineering & Machinery Co., Ltd.
HP manufacturer	Kobe Steel, Ltd. (KOBELCO)
HP System	**SGH120** (× 5 units) Refrigerant: R245fa Steam flow: 2 ton/h
Effects	CO_2 reduction: 43%*1 Primary energy reduction: 40%*2 Energy cost reduction: 54%

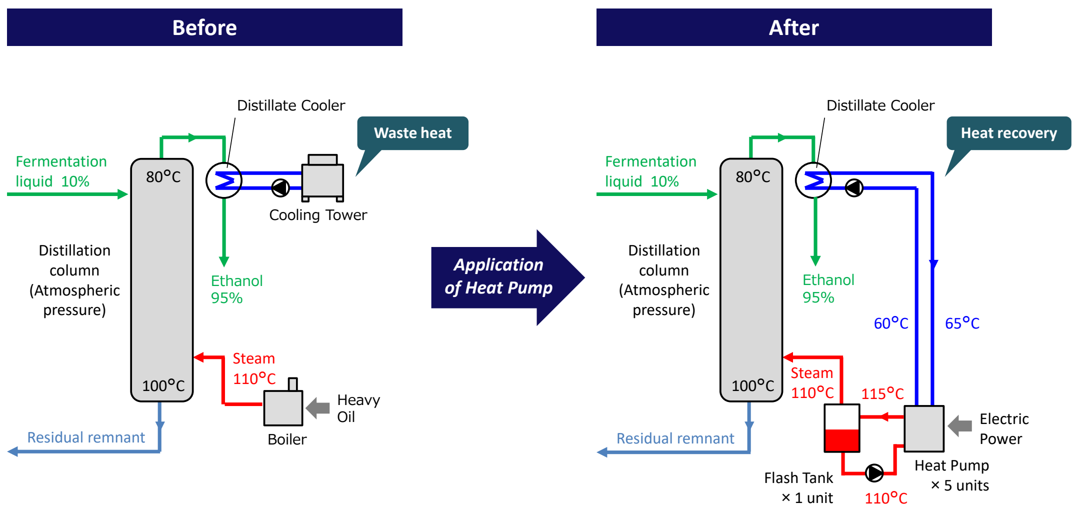
*1 Electricity: 0.681 kg-CO_2/kWh (Hokkaido EPCo, FY2013), Heavy oil: 2.71 kg-CO_2/L
*2 Electricity: 9.76 MJ/kWh, Heavy oil: 39.1 MJ/L

Process and Application



 Ref: JEHC, Collection of case studies for industrial electrification, Vol. 4, March. 2015. [in Japanese] 16

Case 1 | Distillation Process in Bio-ethanol Production



Ref: JEHC, Collection of case studies for industrial electrification, Vol. 4, March. 2015. [in Japanese]

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Interview Survey about SGHs

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	Installation type	Renewal from steam boiler	Addition to existing steam line	Newly established
User company	Background	• Considered improvement measures • Suggestion from engineering company	• Considered improvement measures • Suggestion from engineering company	Not yet
	Objective (needed payback period)	• Reduction of running cost (**3.5 years with subsidy**)	• Reduction of running cost (**3 years without subsidy**)	Not yet
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Interview Survey about Steam Supply Heat Pumps

■ To engineering companies for distillation and concentration

	Company A	Company B	Company C
Strong field	Distillation of alcohol	Concentration of food and beverage	Water treatment
Estimated steam unit price	N/A	4,000 JPY/ton	5,000 JPY/ton
Estimated payback period	• Basically **3 years** • Sometimes 5 years with subsidy	• Basically **3 years** • Sometimes 5 years with subsidy	• 2 years for semiconductor industry • up to 5 years for food industry
Comparison to competing technologies	• **MVR** applied for large capacity (alcohol production: 200 kL/day) • **Double-effect evaporator** for middle capacity • **HP** considered for small capacity (alcohol production: 20–50 kL/day)	• **MVR** applied (steam 5–20 ton/h) • **SGH120** has the similar economic effect with **double-effect evaporator.** • **HP** will be considered for the processes **MVR** cannot apply: concentration of hydrofluoric acid, hydrochloric acid, etc.	• **MVR** considered first of all • **HP** will be considered for the processes **MVR** cannot apply: processes which may splash solvent or need high Boiling Point Rising (BPR), etc.
Market trends in Japan	• Number of newly-established or renewal of distillation columns: only several units/year in Japan • Small sized distillation columns use steam of several hundreds kg/h	• Intermediary material of food or medicine (ex. molasses)	• Increasing concentration needs for waste liquid treatment • Increasing factories of Zero Liquid Discharge (ZLD): concentration, drying, solidification

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Case 4 | Distillation Process in Dextran Production

Outline of Installation

Industry	Chemistry
Production	Dextran (Polysaccharides)
User company	Meito Sangyo Co., Ltd.
Installed year	2017
Process	Distillation of methanol
Application	**Hot water (90°C)**
Engineering company	Kimura Chemical Plants Co., Ltd.
HP manufacturer	Kobe Steel, Ltd. (KOBELCO)
HP System	**HEM-HR90** (× 2 units) Refrigerant: R134a+R245fa Heating capacity: 800 kW
Effects	CO_2 reduction: 60%*1 Primary energy reduction: 60%*2 Energy cost reduction: 63%

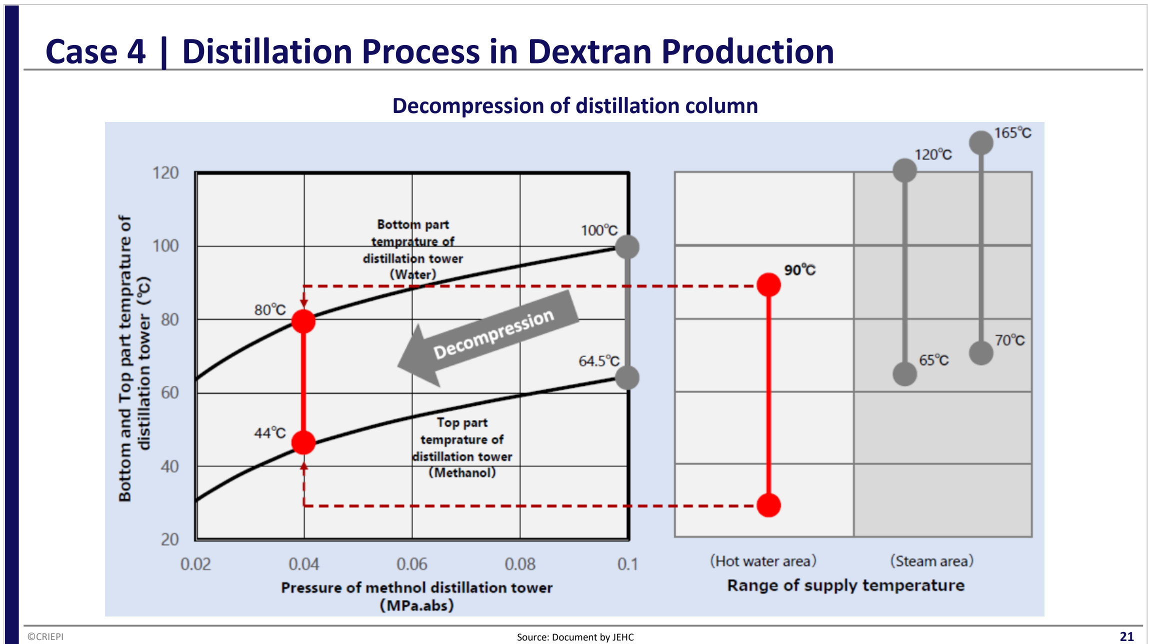
*1 Electricity: 0.491 kg-CO_2/kWh (TEPCO, FY2015), City gas: 2.29 kg-CO_2/Nm^3
*2 Electricity: 9.97 MJ/kWh, City gas: 45.0 MJ/Nm^3

Process and Application

Feed Material → Fermentation → Collection of Precipitation → Acid Hydrolysis
• Sugars
• Distillation of methanol

→ Collection of Precipitation → Vacuum Concentration → Spray Drying → Dextran (Powder)
• Distillation of methanol

 Ref: JEHC, Collection of case studies for industrial electrification, Vol. 6, March. 2019. [in Japanese] 20


Case 4 | Distillation Process in Dextran Production
Decompression of distillation column
Bottom and Top part temprature of distillation tower (°C)
120
100
80
60
40
20
0.02
0.04
0.06
0.08
0.1
Bottom part temprature of distillation tower (Water)
100°C
80°C
Decompression
64.5°C
44°C
Top part temprature of distillation tower (Methanol)
Pressure of methnol distillation tower (MPa.abs)
165°C
120°C
90°C
70°C
65°C
(Hot water area)
(Steam area)
Range of supply temperature
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Source: Document by JEHC
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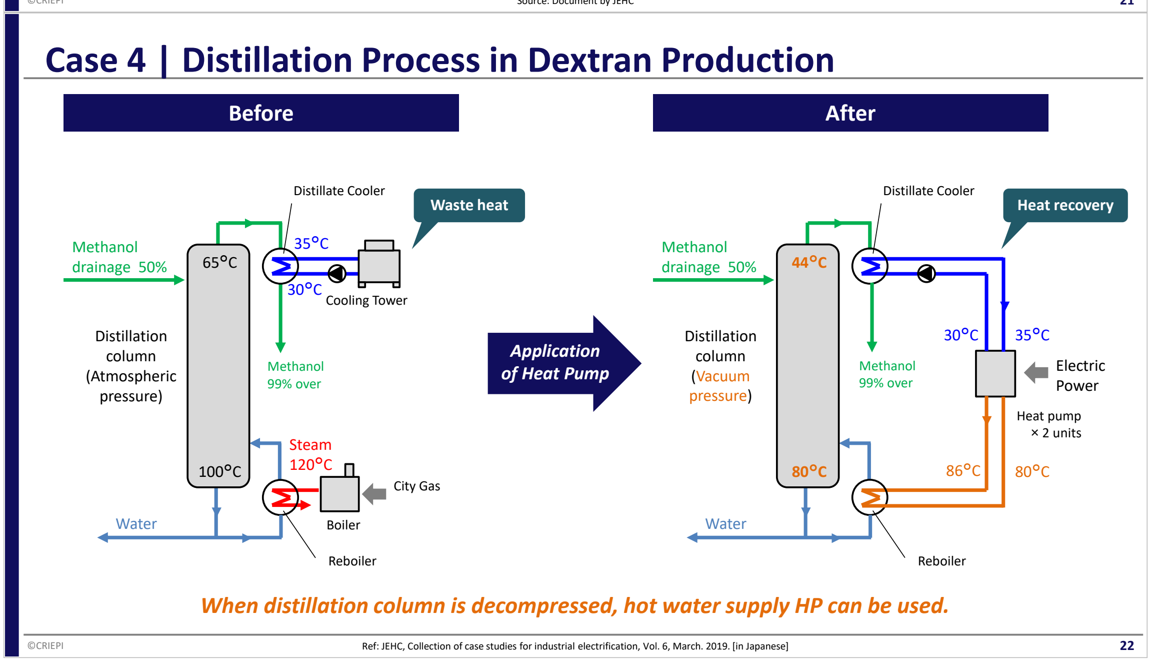
Case 4 | Distillation Process in Dextran Production
Before
After
Distillate Cooler
Waste heat
Methanol drainage 50%
65°C
35°C
30°C
Cooling Tower
Distillation column (Atmospheric pressure)
Methanol 99% over
Steam 120°C
100°C
City Gas
Boiler
Water
Reboiler
Application of Heat Pump
Distillate Cooler
Heat recovery
Methanol drainage 50%
44°C
Distillation column (Vacuum pressure)
Methanol 99% over
30°C
35°C
Electric Power
Heat pump × 2 units
80°C
86°C
80°C
Water
Reboiler
When distillation column is decompressed, hot water supply HP can be used.
©CRIEPI
Ref: JEHC, Collection of case studies for industrial electrification, Vol. 6, March. 2019. [in Japanese]
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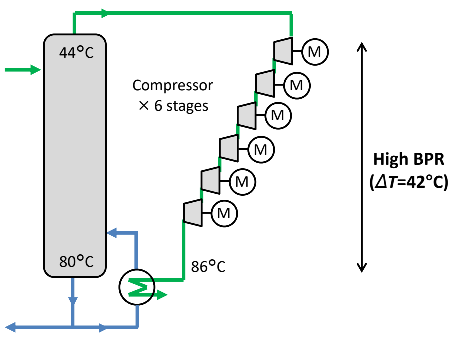
Case 4 | Distillation Process in Dextran Production

Why MVR was not selected?

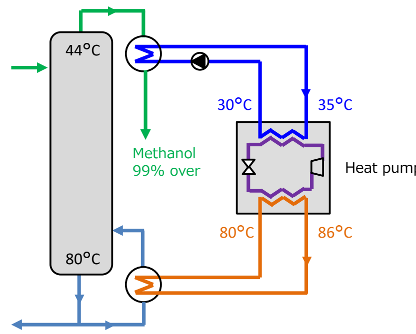
MVR

- Require a special specification compressor because of methanol vapor compression
- Require 6 stage compressors because of high BPR → high cost and complicated operation



Heat Pump

- Lower risk of methanol flammability
- Use a general-purpose heat pump → lower cost and better operability



Based on: Document by JEHC

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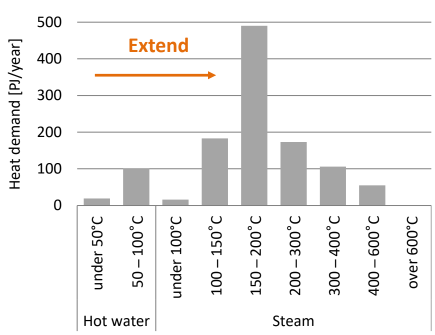
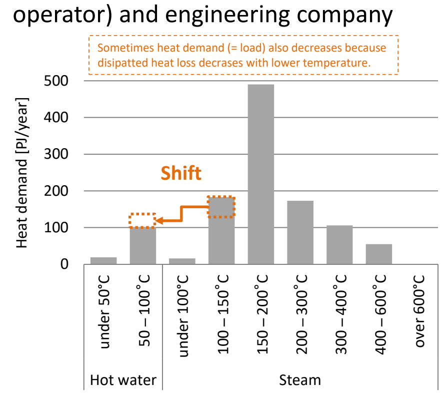
For Spreading IHPs

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



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



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Conclusions

Conclusions

- HTHPs potential in Japan
  - Industrial heat demand: **300 PJ/year under 150°C**
  - Expectation of spreading IHPs: **1,673 MW by FY2030** (over 150 times installation by FY2013)
- HTHPs development trends in Japan
  - **KOBELCO**: already prepared the product line-up **up to 175°C**
  - **Fuji Electric**, **MAYEKAWA** and **MHI Thermal Systems**: already prepared HTHPs **around 120°C**, developing HTHPs **over 150°C** (up to 200°C) by **NEDO** projects
- Electricity situation in Japan
  - Toward electrification and decarbonization, but not good situation at this time
  - CO_2 emissions factor (**0.5 kg-CO_2/kWh**) and economic factor (**E/G = 2.8**)
- Realistic another approach for applying IHPs at this situation
  - Shifting heat demand by **process innovation**
  - An example: decompression of distillation column and application of 90°C hot water supply HP

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