Analysis of heat pump integration into drying process for decarbonization in industry

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Keywords

waste heat recovery, heat pump, dryers, case studies, CO_2 reduction

Abstract

Heat pump is one of the key technologies for decarbonization in industry. A large part of the final energy used for industrial thermal purposes is wasted through heat losses. Heat pump can recover the waste heat and convert it into useful heat by adding relatively small amounts of electric power. When the power derives from low carbon electricity, heat pump has two positive coupled effects: energy saving and CO_2 emissions reduction. Among various industrial heating processes, drying is a highly energy-intensive process. Some estimations have reported that drying process accounts for 10–25 % of total industrial energy consumption in most developed countries. Currently, however, waste heat recovery from drying process is still limited to air preheating by heat exchangers. Heat pump can valorize more waste heat and lift up the decreased temperature to the temperature required by the drying process. The recent availability on the market of high temperature heat pumps (>100 °C) allows to consider heat pumping technology for a wide range of dryer applications.

This paper focuses on drying process as a typical example of decarbonization in industry by waste heat recovery with heat pumps. As the heat pump supply temperature increases, the applicable process range expands, but the coefficient of performance (COP) decreases because of larger temperature lift. Hence it is necessary to design the heat pump integration at an appropriate heat pump supply temperature. Using a simple thermodynamic modelling of heat pump integration into drying process, the optimum heat pump supply temperature is identified, and the heat pump contribution to decarbonization is estimated as well as the contribution to energy saving and energy cost reduction for three different assumed cases for the surrounding energy system: EU average conditions, France and Japan. As a result, it is found that the energy cost reduction effect is maximized when the heat pump supply temperature is set around 130 °C in EU and in Japan, and the optimum temperature is around 170 °C in France. In this case, the CO_2 emissions reduction is estimated to be 50 % in Japan, 60 % in EU and 95 % in France compared to existing natural gas fired steam boiler system.

Introduction

Heat pump is one of the key technologies for efficient electrification. For significant reduction of CO_2 emissions, it is important to decrease the emission factor of electricity, to electrify energy usage, and to use electricity with high-efficient process and equipment. In industrial sector, a large part of the final energy is used for thermal processes; drying, washing, sterilization, distillation, concentration, and so on. However, after the process, much essentially useful heat is wasted through heat loss. Heat pump can recover the waste heat and convert it into the useful heat by adding relatively small amounts of electric power. When the power derives from low carbon electricity, heat pump has two positive coupled effects; energy saving and CO_2 emissions reduction.

Among various industrial heating processes, drying is recognized as a highly energy-intensive process. Some estimations have reported that drying processes account for 10–25 % of total industrial energy consumption in most developed countries (Kemp 2012, Munjumdar 2014). Currently, however, waste heat recovery from drying process is still limited to air preheating by heat exchangers. Heat pumps can valorize more waste heat and lift up the temperature to the temperature required by the drying process. The recent availability on the market of high temperature heat pumps (>100 °C) allows to consider heat pumping technology for a wide range of dryer applications.

This paper focuses on drying process as a typical example of decarbonization in industry by waste heat recovery with heat pumps. First, the current high temperature heat pump specifications for drying processes are categorized by reviewing the products available on the market and the development trends. Then, in order to illustrate the application of heat pumps in drying processes, two examples of "good practices" in Japan are presented. Finally, using a simple thermodynamic modelling of heat pump integration into drying process, the optimum heat pump supply temperature is clarified, and the heat pump contribution to decarbonisation is estimated as well as the contribution to energy saving and energy cost reduction for three different assumed cases for the surrounding energy system: EU average conditions, France and Japan.

Heat pumps for drying processes

DRYING PROCESSES

Drying is an operation that evaporates and removes liquid component in material by heating. When changing the state from water liquid to water vapor, the latent heat of about 2,500 kJ/kg (=0.7 kWh/kg) must be transferred to the material by use of some heating equipment. A wide variety of materials to be dried have temperature limitation for product quality preservation, and thus a drying method that matches the quality requirement of the dried product must be adopted. Actually, many types of dryers are used. The method of taking out dried product is divided into continuous type and batch type. The heat transfer method is categorized into convection, conduction and radiation. Hot air convection drying is the most popular in various industries, and furthermore these air convection dryers are classified into tray dryer, belt conveyer dryer, fluidized bed dryer, rotary dryer, flash dryer, spray dryer and others.

Although the hot air convection drying has various dryer types as mentioned above, the heat to air is commonly supplied from gas burner or steam boiler. In general, direct heating with gas burner has the thermal efficiency of about 90 %, whereas indirect heating with steam boiler has relatively lower efficiency as described in Figure 1. The steam boiler system efficiency of 54 % is the averaged value of 29 factories based on an actual measurement survey in Japan (JEHC 2017). This reveals that general boiler alone has the thermal efficiency of 90 % but the use-end efficiency is only about half of the input energy. This derives mainly from the heat loss from piping, which depends on the piping length from boiler to process. Some factories with long steam piping revealed the system efficiency of below 30 %.

As shown in Figure 2, replacing centralized steam boiler system by distributed heat pumps can reduce the heat loss from piping and utilize waste heat from process. This has a greater effect than the simple conversion of heat supply equipment from boiler to heat pump.

HEAT PUMPS

About 10 years ago, the supply temperature of heat pumps available on the market was limited to 90 °C. Recently, however, some high temperature heat pumps (>100 °C) have been commercialized (Arpagaus et al. 2018), and the maximum supply temperature reaches 175 °C. Table 1 and Table 2 show the available high temperature heat pumps currently available from Japanese and European manufacturers, respectively. These data are organized from the manufacturers' brochures and enquiries among the manufacturers. All of these heat pumps use water as the heat source and supply pressurized hot water, hot air or steam. The heating capacity ranges from 30 kW to 2,000 kW per unit. The refrigerant is selected suitable for each heat pump cycle. The refrigerants which have high critical temperatures are used for subcritical heat pump cycle; R245fa (critical temperature 154 °C) up to 120 °C and R1336mzz(Z) (critical temperature 171 °C) up to 160 °C. Relatively low critical temperature refrigerants, R744 (CO_2, critical temperature 31 °C) and R134a (critical temperature 101 °C) are used for transcritical heat pump cycle. Absorption-compression hybrid heat pump cycle using a mixture of R717 (NH_3) and R718 (H_2O) has also been commercialized.

Here the brief explanation of these heat pump cycles is described. Figure 3 shows the configurations and temperature profiles of each cycle. The subcritical cycle with pure refrigerant or azeotropic mixed refrigerant is used when the temperature change of heat source and heat sink is small (generally ΔT_c < 10 K, ΔT_h < 10 K). Therefore, this cycle is suitable for circulation heating, such as when keeping a room warm. Next, the transcritical cycle is used when the temperature change of heat sink is large because this can reduce the irreversible heat transfer loss in gas cooler compared to the subcritical cycle with condenser. Therefore, this cycle is suitable for once-through

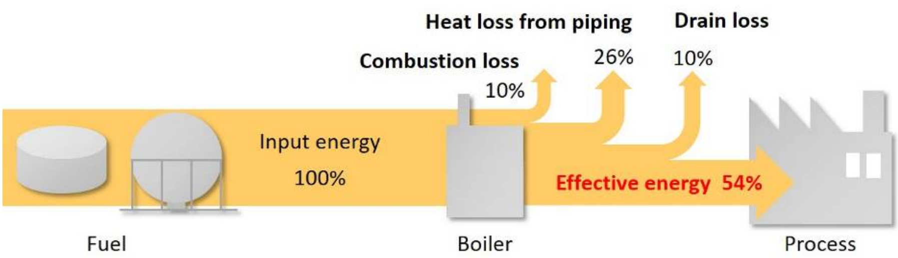

Figure 1. Actual performance of existing steam boiler system.

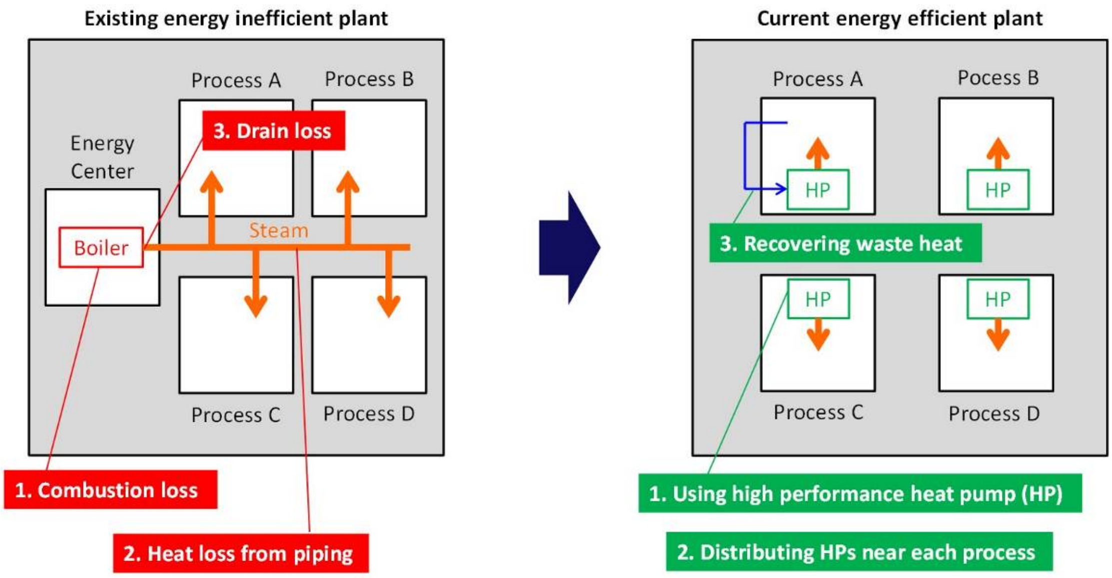

Figure 2. Replacement of centralized steam boiler system by distributed heat pumps.

Table 1. Available high temperature heat pumps in Japan.

Manufacturer	Fuji Electric	KOBELCO	KOBELCO	MAYEKAWA	MHI Thermal Systems
Product name	n/a	SGH120	SGH165	Eco Sirocco	ETW-S
Commercialized year	2015	2011	2011	2009	2011
Heat source/sink	Water/Steam	Water/Steam	Water/Steam	Water/Air	Water/Water
Heat supply temperature [°C]	100–120	100–120	135–175	60–120	130
Heat source temperature [°C]	60–80	25–65	35–70	0–40	55
Heating capacity [kW] (Steam flow rate [kg/h])	30*1 (45)	370*2 (510)	624*3 (890)	110*5	627*4
COP	3.5*1	3.5*2	2.5*3	3.7*5	3.0*4
Refrigerant	R245fa	R245fa	R245fa+R134a	R744	R134a
Compressor	Reciprocating	Screw	Screw	Reciprocating	Centrifugal
Heat pump cycle	Subcritical	Subcritical	Subcritical*6	Transcritical	Transcritical

**1 Heat source:80/75 °C, Heat sink: 20/120 °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: 30/25 °C, Heat sink: 20/100 °C *6 Heat pump unit consists of a subcritical vapor-compression cycle. This system has also a steam compressor unit.*

heating, such as domestic water heater. Finally, the absorption-compression hybrid cycle is useful when both the heat source and heat sink temperature changes are relatively large. In many cases of drying processes, the transcritical cycle would be applied, for the heat source temperature change is relatively small because of recovering latent heat of humid exhaust air and the heat sink temperature change is large due to heating fresh air.

As stated earlier, the recent availability on the market of these high temperature heat pumps allows to consider heat pumping technology for many more dryers. In addition, some developments of high temperature heat pumps for drying processes are ongoing. Table 3 shows the outline of the ongoing projects in Europe. Austrian Institute of Technology (AIT) is developing two types of high temperature heat pumps for drying processes as the Horizon 2020 project "DryFiciency" (Wilk et al. 2019). One is based on the reciprocating compressor by Viking Heat Engines, and another heat pump uses a screw compressor by Bitzer. Both heat pumps use R1336mzz(Z) as the refrigerants and the maximum supply water temperatures are 160 °C. The two heat pumps prototypes will be demonstrated in two drying processes for starch industry and bricks industry.

The developments of transcritical heat pumps which can supply high temperatures are being actively conducted by the following four projects. EDF is developing a transcritical heat pump with R1234ze(E) up to 150 °C as a collaboration with MINES ParisTech for paper industry (Chahla et al. 2019). GEA is developing a transcritical heat pump with R744 (CO_2) up to 135 °C for spray drying (Bellemo et al. 2019). Similarly, SINTEF is developing a R744 transcritical heat pump for food drying (Jokiel et al. 2019). TU Graz is also developing a transcritical heat pump with R600 (butane) up to 170 °C as a collaboration with Frigopol (Verdnik et al. 2019).

Heat pump application examples

In this section, in order to illustrate the application of heat pumps in drying processes, two examples of good practices in Japan are presented (JEHC 2013). In both cases, exhaust heat

Table 2. Available high temperature heat pumps in Europe.

Manufacturer Product name	Combitherm HWW	ENGIE Refrigeration thermeco$_2$	Hybrid Energy HyPAC-R	Ochsner IWWDS ER3b	Viking Heat Engines HeatBooster S4
Heat source/sink	Water/Water	Water/Water	Water/Water	Water/Water	Water/Water
Heat supply temperature [°C]	95–120	–110	75–120	70–130	–160
Heat source temperature [°C]	30–70	–40	15–65	35–55	–120
Heating capacity [kW]	62–252	45–1440	750–2,000	170–750	–250
Refrigerant	R245fa	R744	R717+R718	ÖKO 1	R1336mzz(Z)
Compressor	Reciprocating	Reciprocating	Reciprocating	Screw	Reciprocating
Heat pump cycle	Subcritical	Transcritical	Absorption-compression	Subcritical	Subcritical

Table 3. Ongoing development projects of high temperature heat pumps for drying processes.

Project leader or main actor Project name	AIT DryF	EDF / MINES ParisTech TRANSPAC	GEA n/a	SINTEF SusOrgPlus	TU Graz/ Frigopol TransCrit
Heat source/sink	Water/Water	Air/Air	Water/Water	Air/Air	Water/Water
Heat supply temperature [°C]	–160	–150	–135	n/a	–170
Heating capacity [kW]	200	n/a	1,500	n/a	n/a
Refrigerant	R1336mzz(Z)	R1234ze(E)	R744	R744	R600
Compressor	Reciprocating and screw	n/a	Reciprocating	n/a	n/a
Heat pump cycle	Subcritical	Transcritical	Transcritical	Transcritical	Transcritical

from dryer is used as the heat source of heat pump. The first case is limited to preheating, whereas in the second one the heat demand of the dryer can be successfully met only with heat pump.

PLASTIC FILM COLORING

As one can often see the plastic film in supermarkets, many colored plastic films are used for product packaging. There are mainly two methods of colored plastic film production. One is gravure printing, and another is dry lamination. In the gravure printing, plastic film is colored during being pressed between two cylinders. The lower cylinder catches the ink, and the upper cylinder presses and colors the film. The colored film is needed to be dried before it moves to the next color. On the other hand, dry lamination is the method of laminating different two films. The film is coated by adhesive, and needed to be dried before lamination.

Figure 4 shows a heat pump application to the dry lamination process. In the previous system described on the left, hot air was produced by steam boiler. In general, exhaust air from dry laminator includes volatile organic compounds (VOC). In Japan, VOC emission regulation is implemented from FY2010 by Air Pollution Control Law, thus the VOC is cleaned mainly by combustion. However, there occurs exhaust gas at the relatively high temperature of 55 °C. In this factory, at the same time of installing the VOC treatment equipment in 2011, a heat pump was installed for heat recovery from the exhaust gas. R744 transcritical heat pump "EcoSirocco" produced by MAYEKAWA was selected. This heat pump is located near the VOC treatment and preheats the fresh air up to 80 °C. The boiler is still used, but the fuel demand can be reduced. The average heat pump COP is 5.3 when the average fresh air temperature is 25 °C, measured from 6 °C to 35 °C.

The application of heat pump for plastic film drying is getting common in Japan. An engineering company, Nihon Dengi offers two heat pump systems for film drying; "WECON" with water-source hot air supply heat pump "EcoSirocco" by MAYEKAWA and "eneRAssist" with air-source hot air supply heat pump "Neppu-ton" by MHI Thermal Systems (Nihon Dengi 2017). WECON realizes heat recovery from VOC treatment or simultaneous heating and cooling by combining with other process. Whereas, eneRAssist cannot recover waste heat but is easier to be installed because of air-source type.

ELECTRIC TRANSFORMER

A coil of electric transformer is made of copper wire and paper coated with a special resin. By heating the coil, the resin melts, and the paper and the copper wire adhere. The adhesiveness affects the product quality; thus the drying is one of the most important processes.

Figure 5 shows a heat pump application to drying the coil. In the previous system described on the left, steam boiler was used for producing hot air. The exhaust heat from drying furnace was not recovered. Likewise, in another process of annealing process, there occurred waste heat. In 2012, a heat pump was installed using both exhaust heats from the drying furnace and the annealing furnace as the heat source. However, the operation time of annealing furnace is not the same as the drying furnace, therefore a thermal storage tank was also installed in order to ensure the stable heat source. R134a transcritical heat pump "ETW-S" produced by MHI Thermal Systems was selected. This heat pump supplies pressurized hot water at 130 °C and produces hot air at 125 °C. The previous boiler is used for the backup although only the heat pump can cover the heat demand. If there is something wrong with the heat pump, the backup boiler operates. The average heat pump COP is 3.0.

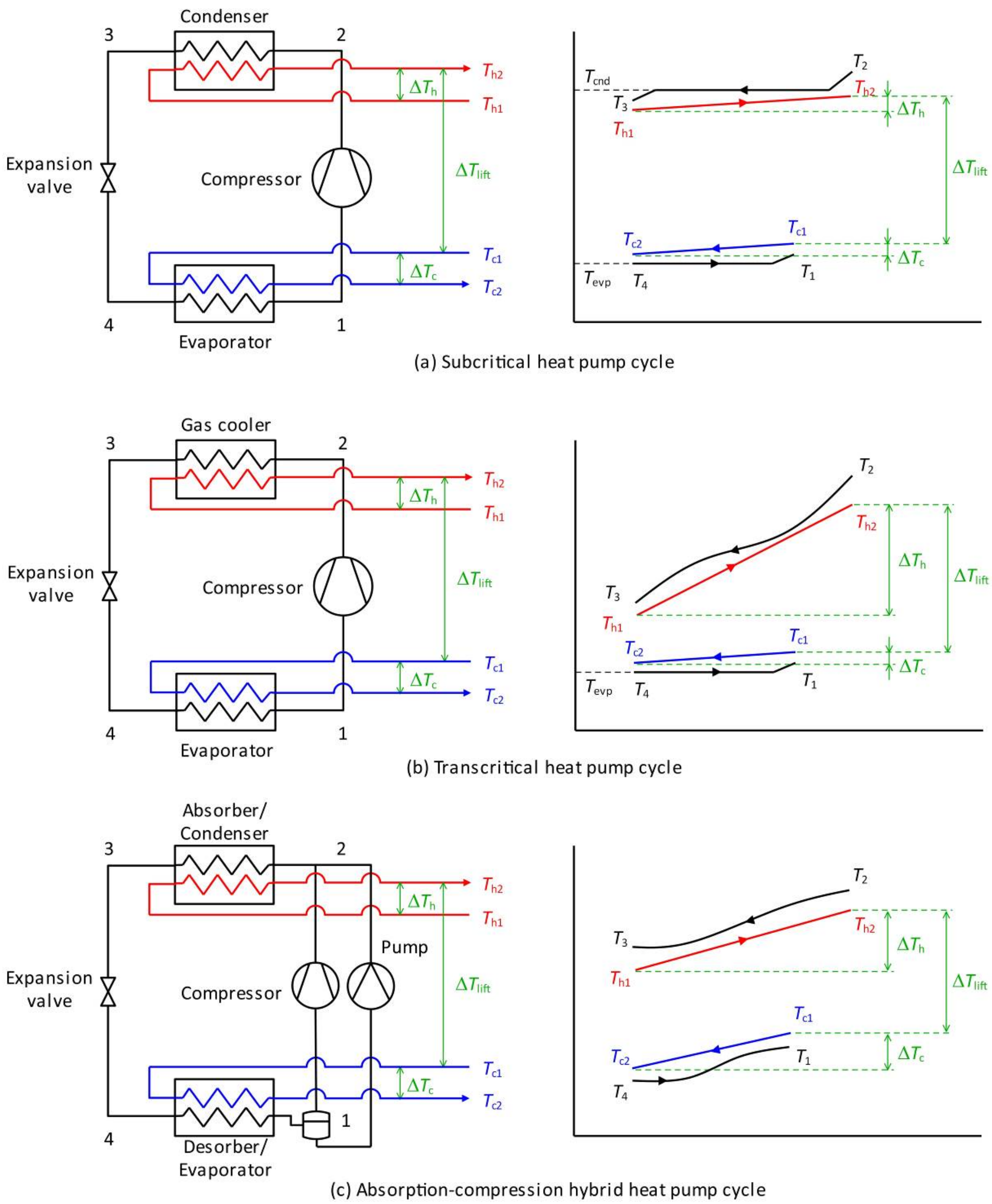

Figure 3. Comparisons of heat pump cycle configurations and temperature profiles.

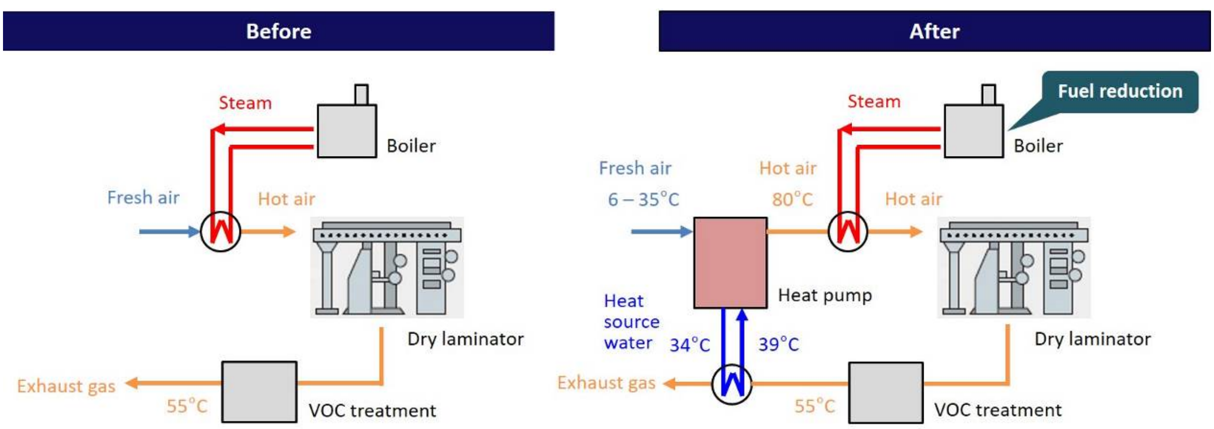

Figure 4. Heat pump application to drying for plastic film coloring.

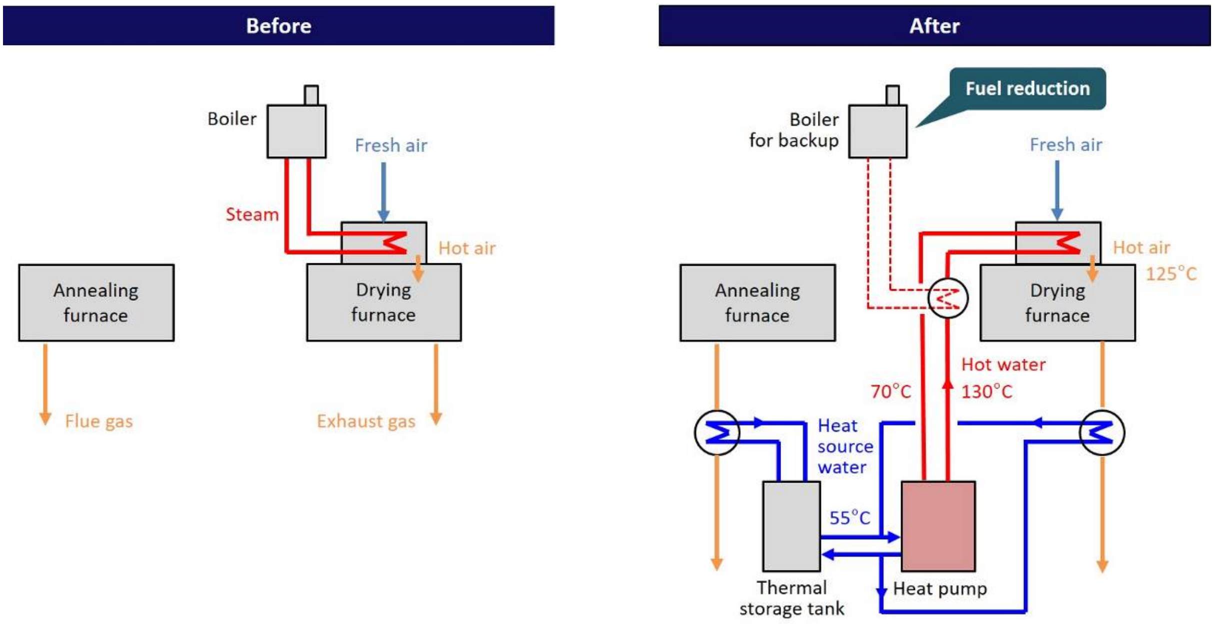

Figure 5. Heat pump application to drying for electric transformer.

Analysis of heat pump integration

As mentioned above, the development of high temperature heat pumps has been progressing steadily, and some examples of heat pump application to drying process have been reported. As the heat pump supply temperature increases, the applicable process range expands, but the COP decreases because of larger temperature lift. Hence it is necessary to design the heat pump integration at an appropriate heat pump supply temperature. In this section, using a simple thermodynamic modelling of heat pump integration into drying process, the optimum heat pump supply temperature is clarified. Also, the heat pump contribution to decarbonisation is estimated as well as the contribution to energy saving and energy cost reduction for three different assumed cases for the surrounding energy system: EU average conditions, France and Japan.

METHOD

Figure 6 shows the configuration of a dryer integrated with a heat recovery heat exchanger (HEX) and a heat pump (HP). Fresh air is heated following this order; heat exchanger, heat pump and fuel combustion heater, and then it is supplied to the dryer at the required temperature. The exhaust heat from the dryer is recovered by the heat exchanger and the heat pump evaporator.

In this study, a thermodynamic calculation was performed based on the actual operation of some dryers. For each of the six materials shown in Table 4, each air state points and the energy consumption were calculated with the heat pump supply temperature T_2 as a parameter. The specifications of these six dryers were collected from published data (Kubota 2004, Nakamura and Tatemoto 2013, Toei 1978). When calculating the mass and heat balances of hot air and material in each dryer, the counter-current type was assumed. Exhaust air recirculation was not considered due to the lack of information on required humidity in each dryer.

Fresh air temperature T_0 and relative humidity ϕ_0 were fixed at 20 °C and 70 %RH, respectively. The material inlet temperature T_{M1} was also set at 20 °C, although generally affected by the previous process. The heat exchanger effectiveness η_{HEX}, eq. (1), defined as the ratio of the temperature rise of the inlet air compared to the potential temperature rise, was set to 70 %.

$$\eta_{HEX} = \frac{T_1 - T_0}{T_4 - T_0} = 0.7 \quad (1)$$

The temperature lift ΔT_{lift}, eq. (2), was defined as the difference between the heat sink outlet temperature and the heat source inlet temperature. The heat pump COP was calculated by the following equations. The efficiency η_{HP}, defined as the ratio of the actual COP to the ideal COP, eq. (3), was correlated from the performance data of EcoSirocco, eq. (4), (MAYEKAWA 2016). As shown in Figure 7, this correlation also agrees well with the experimental data of a transcritical heat pump with R32 tested by EDF and MINES ParisTech (Besbes 2015). This correlation is valid for the temperature lift ΔT_{lift} up to 90 K. When the temperature lift ΔT_{lift} exceeds 90 K, the efficiency was set to a fixed value of 0.71.

$$\Delta T_{lift} = T_2 - T_5 \quad (2)$$

$$COP = \eta_{HP} \cdot COP_{ideal} = \eta_{HP} \cdot T_2 / \Delta T_{lift} \quad (3)$$

$$\eta_{HP} = 0.18 + 0.013\Delta T_{lift} - 7.9 \times 10^{-5} \Delta T_{lift}{}^2 \quad (4)$$

The following two types of heater thermal efficiency were assumed; burner efficiency of 90 % and steam boiler system efficiency of 54 %. The heater fuel was assumed as natural gas for both heaters. Table 5 shows the available latest factors related to CO_2 emissions, primary energy consumption and energy prices of natural gas and electricity in EU, in France and in Japan (EEA 2020, ELCS 2020, IEA 2019, ISO 2017, METI 2018). The CO_2 emissions factors of EU and France were taken from statistical data for 2016, and the others were for 2018. By use of these factors, CO_2 emissions reduction, primary energy reduc-

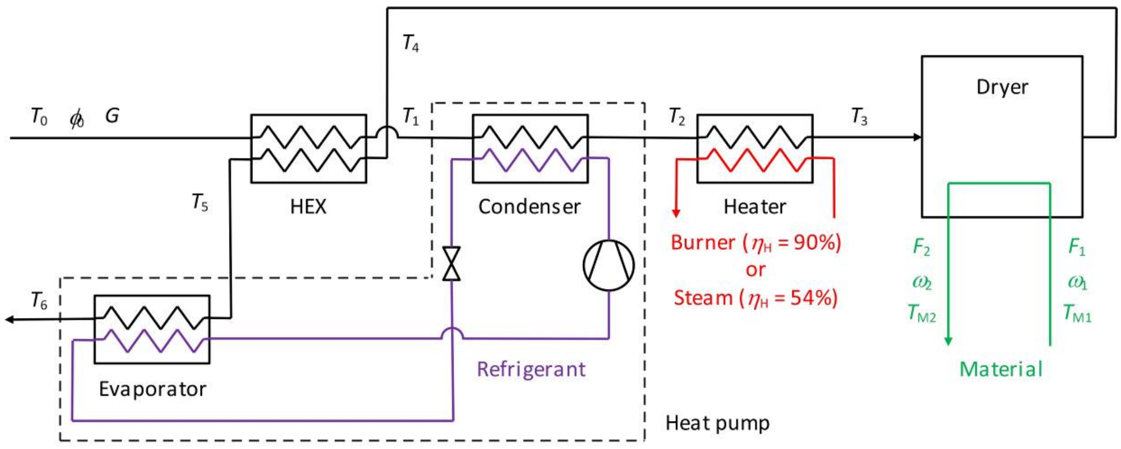

Figure 6. Simple thermodynamic modelling of a dryer integrated with a heat exchanger and a heat pump.

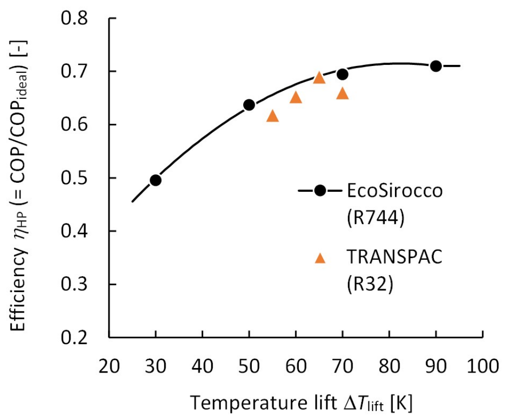

Figure 7. Transcritical heat pump performance correlation.

Table 4. Specifications of dryers.

Product	ABS resin	PVC resin	Organic residue	Starch	Glutamic acid	Nori seaweed
Feed material F_1 [kg/h]	500	2,000	1,100	2,000	400	170
Water content of material ω_1 [%W]	30	17	38	42	17	13
Water content of product ω_2 [%W]	2	1	10	13	1	8
Product temperature T_{M2} [°C]	47	50	55	45	60	80
Hot air supply temperature T_3 [°C]	140	140	150	175	180	180
Hot air exhaust temperature T_4 [°C]	70	70	75	75	80	120
Hot air flow rate G [kg/h]	10,200	18,000	30,000	30,000	3,600	2,700

Table 5. Key factors related to CO_2 emissions, primary energy consumption and energy price.

Region or country		EU	France	Japan
CO_2 emissions factor [kg-CO_2/kWh]	Natural gas	0.22	0.23	0.18
	Electricity	0.30	0.06	0.46
CO_2 emissions factor ratio [–]	E/G	1.4	0.3	2.6
Primary energy factor [kWh/kWh]	Natural gas	1.1	1	1
	Electricity	2.1	2.58	2.71
Primary energy factor ratio [–]	E/G	1.9	2.6	2.7
Energy unit price [€/MWh]	Natural gas	28	37	39
	Electricity	102	99	136
Energy unit price ratio [–]	E/G	3.6	2.7	3.5

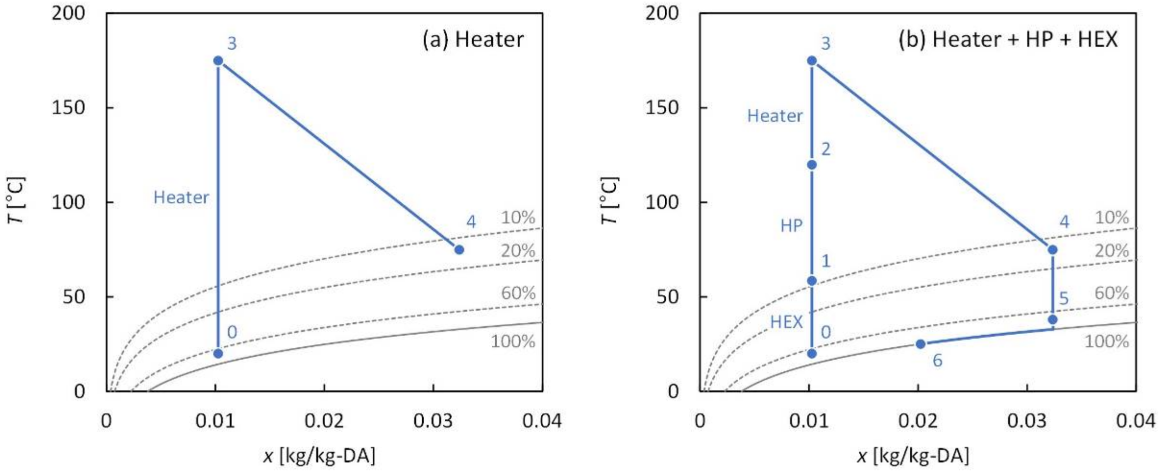

Figure 8. Psychrometric charts (Starch, T_2=120 °C).

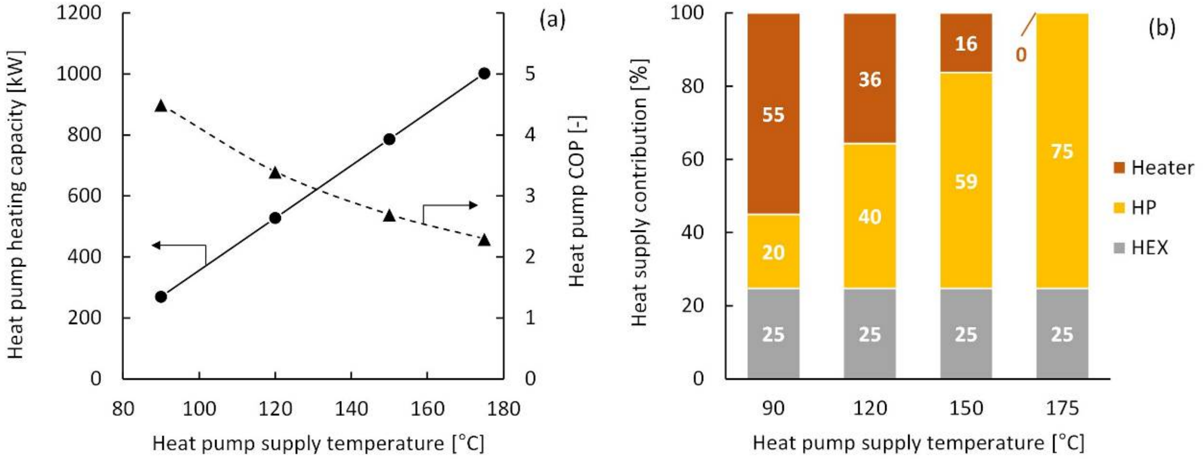

Figure 9. Influences of heat pump supply temperature (Starch).

tion and energy cost reduction were calculated compared to the existing system without heat recovery.

RESULTS

Figure 8 shows an example of the psychrometric chart in the case of heat pump supply temperature at 120 °C for starch drying. As described on the left (a), conventional system without heat recovery emits the waste heat at state 4 with relatively high temperature and humidity compared to the ambient. The right figure (b) describes the heat recovery system with heat exchanger and heat pump. The heat exchanger recovers the sensible heat of exhaust air from state 4 to state 5, and then the heat pump recovers mainly the latent heat from state 5 to state 6. The exhaust air at state 6 approaches the ambient state. The heat recoveries can decrease the heat load of the heater from state 2 to state 3.

Figure 9 (a) shows the effects of heat pump supply temperature on heat pump heating capacity and COP. As the heat pump supply temperature increases, the required heating capacity increases, whereas the COP decreases because of higher temperature lift. As described on the right (b), the couple of heat pump and heat exchanger can completely replace the heater in the case of the heat pump temperature at 175 °C, whereas the COP decreases to 2.3. The heat pump supply temperature can be optimized from the viewpoint of CO_2 emissions reduction, primary energy reduction or energy cost reduction.

Figure 10 shows the CO_2 emissions reduction of the heat recovery system compared to the existing system. As described on the left (a), when assuming the existing heating equipment as the burner of 90 % thermal efficiency, in France, where the CO_2 emissions factor of electricity is low, CO_2 emissions remarkably decrease as the heat pump supply temperature increases. The CO_2 emissions decrease monotonically in EU, although the decreasing rate is relatively lower. Contrary in Japan, where the CO_2 emissions factor of electricity is high, when the heat pump supply temperature exceeds 120 °C, the CO_2 emissions reduction effect decreases, and the effect stops at 175 °C. On the other hand, when assuming the existing heating equipment as the steam system of 54 % thermal efficiency shown in the right (b), CO_2 emissions decrease monotonically to the heat pump supply temperature of 175 °C even in Japan.

As a result, from the viewpoint of CO_2 emissions reduction, the optimum heat pump supply temperature is estimated at 120 °C when comparing to existing burner or 175 °C when comparing to existing steam system in Japan. In France and in EU, the optimum value is estimated at 175 °C. On the other hand, economic performance is required for actual application of heat pump in industry. Figure 11 shows the energy cost change when comparing to existing steam system. In any county or region, the effect of heat pump application is large in the order of CO_2 emissions reduction effect, primary energy reduction and energy cost reduction. When focusing on energy costs in EU and in Japan, there is the optimum point at the heat pump supply temperature between 120 °C and 150 °C.

So far, the results for starch have been shown, similar results were obtained for the other five materials. Figure 12 shows the difference of heat pump capacity and COP for each six materials. The required heat pump heating capacity was less than 1 MW in the range of the dryers targeted in this study. The dryer of nori seaweed was the smallest, less than 70 kW. However, it should be noted that the heating capacity depends on the production. A broad range of heat pump line-up is required for the dissemination. On the other hand, the dryer of nori seaweed with the highest exhaust temperature showed the highest COP. When the exhaust air temperature is relatively high, the heat supply contribution of heat pump decreases because of the temperature rise in heat recovery heat exchanger, whereas the heat pump can be operated with higher COP.

DISCUSSION

This calculation clarifies the optimum heat pump temperature and the effects of heat recovery by heat pump integration to dryer. It is found that the energy cost reduction effect is maximized when the heat pump supply temperature is set around 130 °C in EU and in Japan, and the optimum temperature is

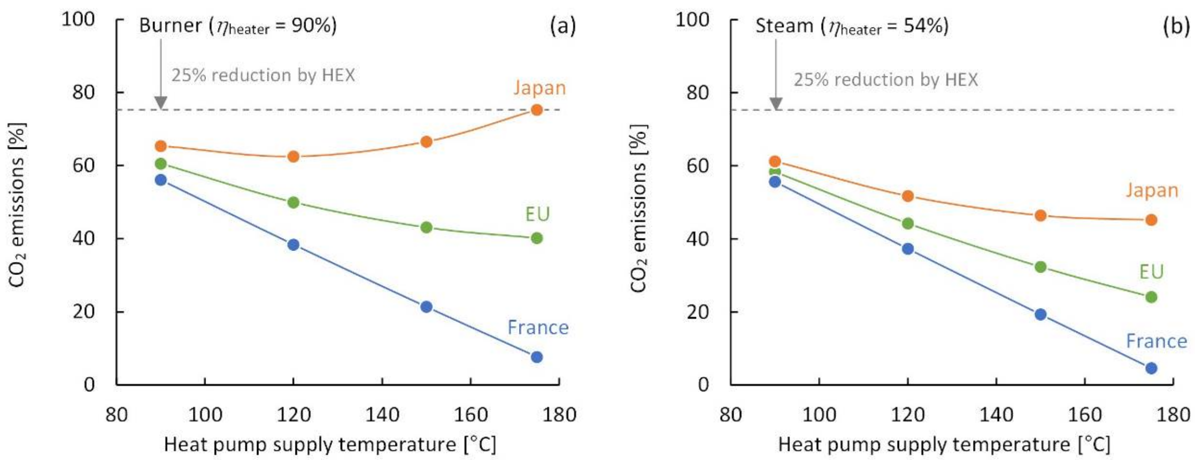

Figure 10. Effects of heat pump supply temperature on CO_2 emissions reduction (Starch).

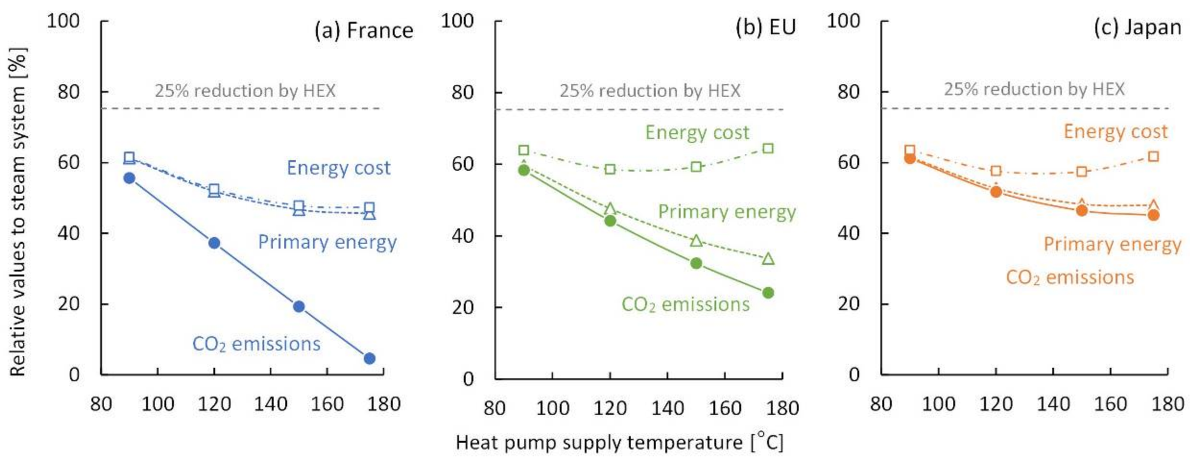

Figure 11. CO_2 emissions reduction, primary energy reduction and energy cost reduction (Starch).

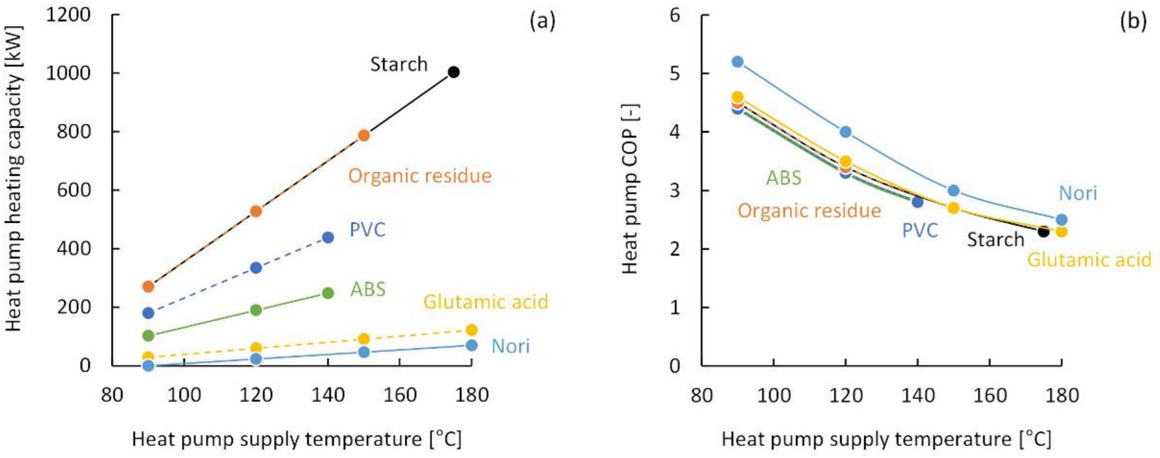

Figure 12. Difference of heat pump specifications and performances for each six materials.

around 170 °C in France. In this case, the CO_2 emissions reduction is estimated to be 50 % in Japan, 60 % in EU and 95 % in France compared to existing natural gas fired steam boiler system.

However, since only six materials were calculated, more materials need to be investigated. And exhaust air recirculation was not considered due to the lack of information on required humidity in each dryer. It is necessary to survey the actual operation cases of the dryers and to collect the operation data. When considering the exhaust air recirculation, the applicability of subcritical heat pumps also needs to be checked because the temperature change of heat sink would be smaller. For estimating this, a more general COP correlation would be required.

Conclusion

Heat pump is recognized as one of the key technologies for decarbonization in industry. Recently, the development of high temperature heat pumps has been progressing steadily, and some examples of heat pump application to drying process have been reported. As the heat pump supply temperature increases, the applicable process range expands, but the COP decreases because of larger temperature lift. Hence it is necessary to design the heat pump integration at an appropriate heat pump supply temperature. In this study, using a simple thermodynamic modelling of heat pump integration into drying process, the optimum heat pump supply temperature was clarified.

As a result, it is found that the energy cost reduction effect is maximized when the heat pump supply temperature is set around 130 °C in EU and in Japan, and the optimum temperature is around 170 °C in France. In this case, the CO_2 emissions reduction is estimated to be 50 % in Japan, 60 % in EU and 95 % in France compared to existing natural gas fired steam boiler system.

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