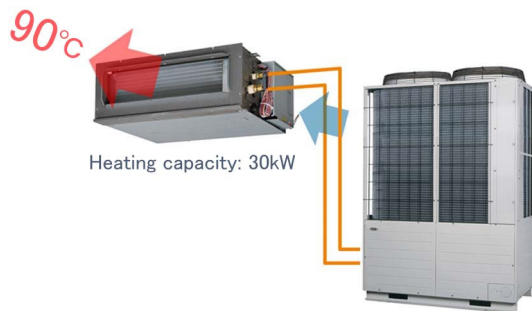


# Development of "Neppu-ton" Hot Wind Generator Using High-efficiency Air to Air Heat Pump



TAKAYUKI KOBAYASHI\*1      SHIGERU YOSHIDA\*2

MASASHI MAENO\*2      TAKACHIKA MORI\*3

TORU KUROIWA\*3

To respond to the needs for the promotion of energy saving in drying processes in industrial fields, Mitsubishi Heavy Industries Thermal Systems, Ltd. developed "Neppu-ton," a hot wind generator using a high-efficiency air-source heat pump, which enables the supply of hot wind of 60°C to 90°C. "Neppu-ton" adopts the separate system with an outdoor unit and an indoor unit separately installed, which allows the indoor unit to be installed directly in a process requiring hot wind and reduces the installation cost. We conducted a demonstration test in the actual environment to verify the energy-saving performance and drying quality under actual use conditions. As a result, we confirmed that there was no problem in its use as a drying system. By promoting the use of "Neppu-ton" in industrial fields, we will reduce energy usage and CO<sub>2</sub> emissions and promote global environmental protection.

## 1. Introduction

In the drying processes using hot wind in industrial fields, drying devices such as fossil fuel-based steam boilers and hot wind generators are widely used, and there is demand for energy saving through the adoption of heat pump systems. Many conventional high-temperature heat pumps are hot wind heat pumps or hot-water generating heat pumps using water-source systems that recover heat from a factory's hot wastewater. Such heat pumps require the installation of water pumps that circulate hot and chilled water and heat exchangers that produce hot wind from hot water, which posed challenges in terms of cost and difficulty in securing installation space.

"Neppu-ton" was jointly developed by Mitsubishi Heavy Industries Thermal Systems, Ltd., The Kansai Electric Power Company, Inc., Tokyo Electric Power Company Holdings, Inc. and Chubu Electric Power Co., Inc. As with general air conditioners, it has a separate-type configuration comprised of an outdoor unit (heat source unit) that takes in heat from the atmosphere and an indoor unit (hot wind generator) that can directly generate hot wind. It generates hot wind of 90°C, which is the highest-temperature hot wind provided by an air-source heat pump in Japan, and has achieved a high-efficiency of a COP of 3.5<sup>(note1)</sup> <sup>(note2)</sup>. This product allows the indoor unit to be installed directly in a process using hot wind at factory, etc., and the outside unit to be installed at any location outdoors and makes it easier to apply heat pump systems to industrial fields. **Table 1** shows the major specifications of "Neppu-ton."

This paper reports the technological background of the first achievement of the supply of hot wind at 60°C to 90°C by an air-source heat pump and the result of the demonstration test conducted under actual use conditions in the field for energy-saving performance and drying quality.

(note 1) COP stands for Coefficient Of Performance and is the value obtained by dividing the heating capacity for supplying hot wind by the electric power consumption. The higher the value, the higher the efficiency of a device.

(note 2) Value under the conditions of an outside air temperature of 25°C (relative humidity 70%), intake of the indoor unit at 20°C and exhaust at 80°C.

\*1 Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

\*2 Chief Staff Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

\*3 Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

**Table 1 Major specifications of "Neppu-ton"**

Item		Performance
Performance	Heating capacity <sup>(note 3)</sup>	30kW
	COP <sup>(note 3)</sup>	3.5
	Indoor unit suction air flow rate <sup>(note 3)</sup>	25.6m <sup>3</sup> /min
Heat source		Air heat source
Exhaust temperature setting range		60~90°C
Indoor unit air flow rate setting range		18~50m <sup>3</sup> /min
Operating range		Outdoor air temperature : -5 - 43°C Intake temperature : -5 - 43°C
Inside and outside piping length		Maximum one-way length 50m
Refrigerant		R134a
Legal refrigerant ton		2.84 ton <sup>(note 4)</sup>
Outside dimension [mm]		Outdoor unit : H2048 × W1350 × D720 Indoor unit : H380 × W1150 (+86 <sup>(note 5)</sup> ) × D648 <Connection duct size : 300 × 900>
Weight		Outdoor unit : 379kg Indoor unit : 66kg

(note 3) Value under the conditions of outside air temperature of 25°C (relative humidity: 70%), indoor unit intake temperature of 20°C and exhaust temperature of 80°C

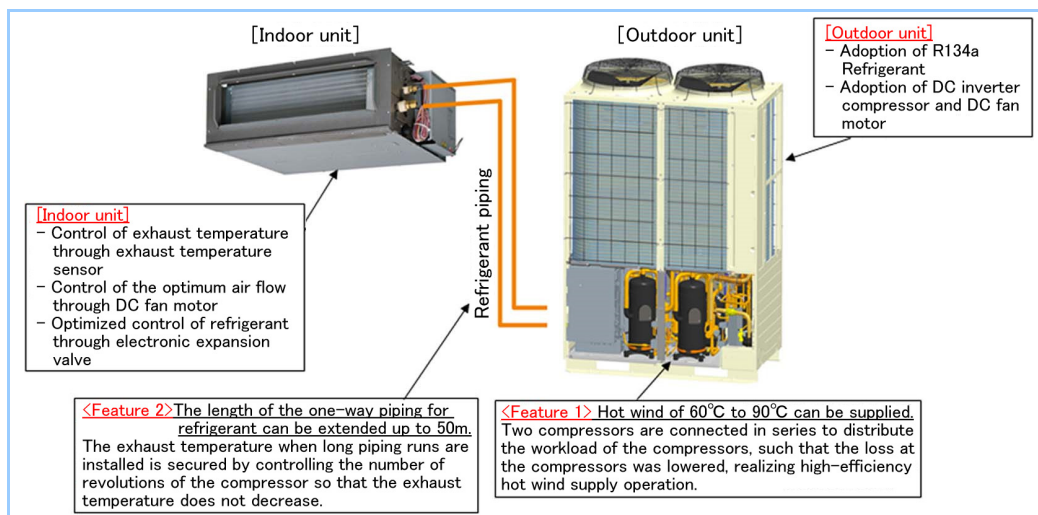
(note 4) Since the legal refrigerant ton is less than 5 tons, notification under the High Pressure Gas Safety Act is not required.

(note 5) Size of the control box on the side of the indoor unit

## 2. Points on development of "Neppu-ton" and features

### 2.1 Realization of hot wind supply and higher COP

**Figure 1** shows the application technology that achieved the supply of hot wind of 60°C to 90°C and a COP of 3.5 by "Neppu-ton," and the details are described below.



**Figure 1 Points on development of "Neppu-ton" and features**

#### (1) Adoption of R134a Refrigerant for supply of hot wind

A heat pump is a system for drawing up heat from heat sources such as air and water using a refrigerant that circulates inside and supplying the heat to the user side. In order to realize the supply of hot wind of 90°C, the pressure and temperature of the refrigerant need to increase. Although general air conditioners are also heat pumps, the refrigerant used in them is R410A, the temperature of which can be increased only up to about 60°C, which corresponds to the saturation pressure. With the aim of commercializing "Neppu-ton" by using the technologies of air conditioners, R134a Refrigerant was adopted, because the refrigerant of "Neppu-ton" needs to be heated to higher temperature than that of an air conditioner. The temperature of R134a can become 90°C or higher corresponding to the saturation pressure. The adoption of R134a Refrigerant enabled the supply of hot wind of 90°C.

#### (2) Adoption of two-stage compression cycle

By the adoption of R134a, hot wind of 90°C can be supplied. On the other hand, since the refrigerant temperature and pressure are increased, the compressor which is a main component needs to be operated at a high pressure ratio<sup>(note 6)</sup>. Therefore, the loss at the compressor increases, resulting in the degradation of performance. In addition, when the outside

temperature is low ( $-5^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ ), the refrigerant pressure on the low-pressure side is specifically reduced, and the pressure ratio exceeds the operational limit of the compressor, making it impossible to continue operation. In order to solve this problem, a two-stage compression cycle was adopted in which two compressors are arranged in series. Thus, the workload of one compressor was reduced, such that the loss at the compressor was lowered, realizing high-efficiency operation and enabling continuous operation at low outside temperatures.

(note 6) The heat pump compresses the refrigerant using a compressor to increase the refrigerant temperature and pressure. The refrigerant is separated into a high-pressure state (high pressure) and a low-pressure state (low pressure). The value obtained by dividing the pressure value on the high-pressure side by the pressure value on the low-pressure side is called the "pressure ratio." When the pressure ratio is high, the loss of the refrigerant in the compression process becomes large, resulting in a reduction of efficiency.

(3) **Optimizing control of refrigerant by electronic expansion valve of indoor unit**

For the indoor unit, an electronic expansion valve that can change the throttling amount to the desired level was adopted. The throttling amount is controlled while observing the refrigerant temperature and the temperature of hot wind being supplied so that refrigerant with an increased pressure and temperature enters an optimal state, thereby achieving a higher COP.

(4) **Adoption of compressor and air blower equipped with high-efficiency DC motor**

For the compressor and the air blower, a high-efficiency DC (direct current inverter) motor was adopted, resulting in a substantial improvement in the motor efficiency compared to the conventional AC (alternating current) motor.

## 2.2 Securing flexibility in installation work

"Neppu-ton" is a product with a higher flexibility in installation due to its separate-type configuration comprised of an outdoor unit which takes in heat from the atmosphere and an indoor unit which supplies hot wind. The outdoor unit has the same external form as that of multi-split air conditioners for buildings, and a high-static pressure duct type indoor unit is used so that it can be easily connected to an existing supply air duct in a factory. The outdoor unit and the indoor unit are connected by the refrigerant copper pipe, the same as with air conditioners. The length of the one-way piping can be extended up to 50m, which enables flexible installation and inexpensive installation work.

In addition, if the connection piping run is long, the hot wind supply temperature may be decreased due to heat radiation loss at the piping. To prevent the exhaust temperature from decreasing when long piping runs are installed, a temperature sensor is used as standard at the hot wind supply part of the indoor unit, and the number of revolutions of the compressor is controlled according to the temperature detected by the sensor.

## 3. Application to existing drying device (measure at defrosting)

"Neppu-ton" uses an air-source heat pump. Therefore, when the outside temperature is low, the moisture in the air freezes and frost is formed on the air heat exchanger of the outdoor unit. When frost is formed on the heat exchanger, the supply of hot wind cannot be continued and defrosting is needed. During defrosting, hot wind cannot be supplied. Taking any countermeasure against it is the largest issue for air-source heat pumps.

Therefore, it is recommended to adopt a hybrid method where the existing drying device such as a steam boiler or a hot wind generator is used and "Neppu-ton" is used as a backup heating for the air supply by the existing drying device. Through this method, hot wind can be supplied by the existing drying device during defrosting, allowing the drying process to be continued. However, if the supply of hot wind from "Neppu-ton" is stopped suddenly during defrosting, the temperature control on the existing drying device cannot keep up and the drying temperature will change significantly, resulting in an adverse effect on the drying quality.

In order to solve this problem, the following control method was adopted for "Neppu-ton." Before defrosting is performed, the number of revolutions of the compressor is reduced in steps to gradually decrease the hot wind supply temperature, so that the drying temperature of the existing drying device does not change significantly. The details of this method will be described later in Chapter 4. It has been confirmed that with this method, the drying quality is not adversely affected.

Furthermore, a change in the amount of air supplied to the whole drying device may adversely affect the drying quality. Therefore, in general air conditioners, the air blower of the indoor unit is stopped during defrosting to prevent cold drafts (unpleasant cold sensation). "Neppu-ton" is designed so that the air blower inside the indoor unit can be continuously operated during defrosting.

## 4. Demonstration test in the field

### 4.1 Outline of the demonstration test in the field

With "Neppu-ton" applied to two existing drying devices in the field, the verification was conducted in order to demonstrate "the energy-saving performance under actual use" and that "application to the existing drying device does not adversely affect the drying quality" as follows:

- (1) "Neppu-ton" was applied to a dry laminator<sup>(note 7)</sup> and the reduction in energy usage, CO<sub>2</sub> emissions and running cost were measured. As a result, we confirmed roughly a 50% reduction in all the items.
- (2) "Neppu-ton" was applied to a spray drying device (spray drier<sup>(note 8)</sup>), and it was confirmed that there was no problem in terms of the drying quality of ceramics (products to be dried) in a series of operations including the defrosting of "Neppu-ton."

The contents of the verifications are described below.

(note 7) Device for laminating two or more films. After an adhesive is applied to one of the films, the adhesive is cured by hot wind, etc., for adhesion.

(note 8) Device for continuously manufacturing powdered products in one process by atomizing liquid material and bringing it in contact with hot wind to dry. Used in the manufacturing of powdered beverages, powder seasonings, Chinese medicines, powdered detergents, ceramics, etc.

### 4.2 Application to dry laminator

Figure 2 shows the system diagram of the dry laminator, and Figure 3 shows the state of the indoor unit of "Neppu-ton" installed.

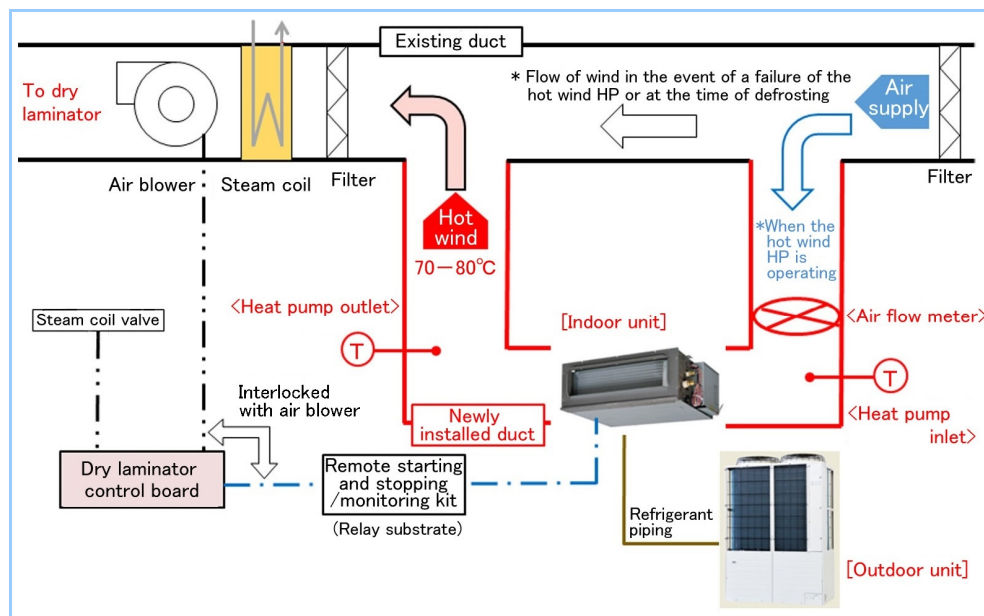


Figure 2 Overview of the system with "Neppu-ton" applied to the dry laminator

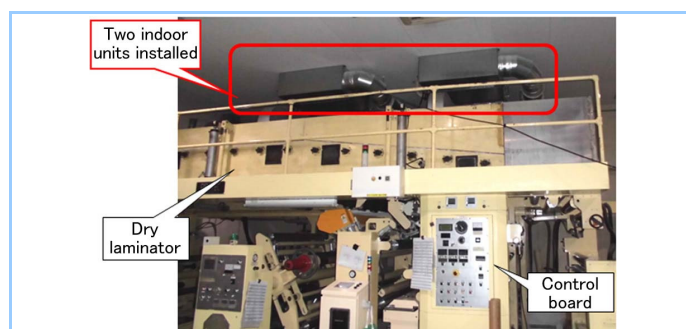


Figure 3 State of the indoor unit of "Neppu-ton" installed

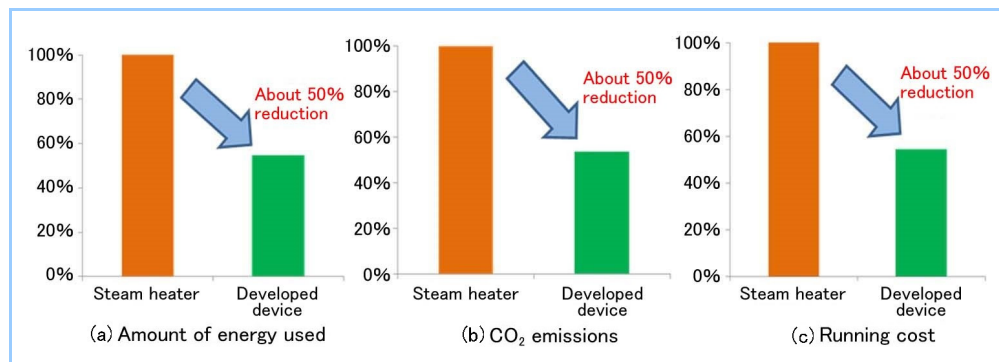
The heat source unit of the existing drying device was a steam boiler, in which the steam heater was used to generate hot wind of 70°C to 80°C to dry film. "Neppu-ton" was applied here for air supply heating.

In this demonstration test, thermocouples were installed at the hot wind supplying (exhaust) part and the intake duct of the indoor unit of "Neppu-ton," and additionally, an air flow meter was installed on the intake side to measure the heating capacity of "Neppu-ton" based on the change in the air sensible heat amount. Furthermore, in "Neppu-ton," a wattmeter was installed to measure the power consumption during operation. The reduced amount of utility gas, which is the fuel of the steam boiler, was calculated backward from the heating amount of "Neppu-ton" and was compared with the amount of consumed power to evaluate the economic efficiency.

**Figure 4** shows a summary of the measurement results from November 27 to December 28, 2016. The results show that the amount of energy used, CO<sub>2</sub> emissions and the running cost were reduced by about 50%, and the high energy-saving performance of "Neppu-ton" was confirmed.

This demonstration test was conducted in winter, and "Neppu-ton" was defrosting. The drying temperature fluctuated in the range of  $\pm 5^{\circ}\text{C}$ , which was within the allowable drying temperature fluctuations of the dry laminator.

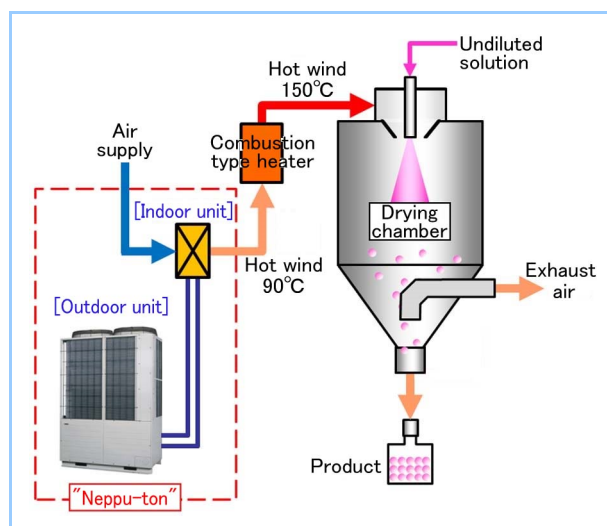
This demonstration test is planned to be continued until October 2017.



**Figure 4** Summary of the dry laminator measurement results

### 4.3 Application to spray-drying device (spray drier)

**Figure 5** shows the system diagram of the spray drying device.



**Figure 5** Overview of the system with "Neppu-ton" applied to the spray drying device

The heat source unit of the existing drying device was an LPG combustion type heater, which was a device for producing fine-particulate powdered ceramics by spray-drying the liquefied ceramics using hot wind of 150°C. Using a system where the supply air is preheated to 90°C by "Neppu-ton," the drying quality was evaluated.

The check items for drying quality are the mean particle size of the powdered ceramics (median size) and the amount of water content. In this demonstration test, the ceramics that were

dried while "Neppu-ton" was in operation and the ceramics that were dried with "Neppu-ton" not in operation were sampled individually, and the difference between both samples was verified. Furthermore, while "Neppu-ton" was operating in defrosting mode, ceramics were continuously sampled, and the change in the mean particle diameter and the amount of water content was observed.

The test results are shown in **Tables 2** and **3**.

**Table 2 Evaluation of the drying quality of "Neppu-ton" during continuous operation**

	Water content	Mean particle diameter (Median diameter)
No operation of "Neppu-ton" (Drying only with the existing device)	0.2wt %	48.4 $\mu$ m
During operation of "Neppu-ton"	0.2wt %	47.1 $\mu$ m

**Table 3 Evaluation of the drying quality of "Neppu-ton" during defrosting operation**

	Water content	Mean particle diameter (Median diameter)
Immediately before defrosting	0.1wt %	47.7 $\mu$ m
While the hot wind temperature is decreasing	0.3wt %	47.1 $\mu$ m
At the time when defrosting ends	0.1wt %	47.3 $\mu$ m

The range of changes in the water content is less than 1wt%, indicating no problems.

There was no difference in the measured values between "Neppu-ton" in operation and "Neppu-ton" not in operation. In addition, the range of changes in the amount of water content immediately before, during and after defrosting is 1wt% or less, which is insignificant. It was confirmed that there was no problem in terms of the drying quality.

**Figure 6** shows a photo of the ceramics that were dried in this test.



**Figure 6 Ceramics after drying**

1. Ceramic powder with a mean particle diameter of 47 $\mu$ m that was dried
2. After "Neppu-ton" was introduced in the spray drying device, drying was conducted. As a result, it was confirmed that the ceramic after drying had no problems as a product.

## 5. Conclusion

Mitsubishi Heavy Industries Thermal Systems, Ltd. developed "Neppu-ton," which is a high-efficiency hot wind generator that uses an air-source heat pump, for the first time in Japan. We verified the operation of "Neppu-ton" in the field, which is impossible with the company's in-house test equipment, and confirmed that there was no problem in terms of the high energy-saving performance and the drying quality. This made it clear that a major contribution by "Neppu-ton" to energy saving in industrial fields can be expected. It is considered that various drying devices other than those used in this demonstration test will be put on the market, and we are going to continue to improve the product so that it can be applied to such devices without issue. Furthermore, we will study application to hot-water heat pumps using this technology.