Activities for Carbon Neutrality in Heat Treatment Furnaces

Y. HIRADE M. OGURI A. MATSUBARA K. MATSUMOTO K. SAIGUSA

To achieve carbon neutrality by 2050, it is essential to take energy-saving measures in the heat treatment furnace process, which makes up a large portion of the CO_2 emitted in all processes. In a heat treatment furnace, only about 20% of the energy input is effectively used to heat the work, and the remaining 80% is lost. Losses caused by Endothermic gas, heat dissipation from the furnace body, and temperature control of quenching oil are particularly significant. Focusing on these energy losses, we developed energy-saving technology and conducted demonstration tests to confirm its effectiveness.

***Key Words**: Carbon neutrality, Carbon-free society, Energy conservation, Curburizing furnace*

1. Introduction

Aiming to achieve carbon neutrality in 2050, the Japanese government has established the extremely high target for 2030 of a 46% reduction in CO_2 emissions from 2013 levels[1]. In order to meet the needs of this government policy, the JTEKT Group has established the targets of a 60% reduction in CO_2 emissions in 2030 relative to 2013 levels, and achieving carbon neutrality in 2035.

As shown in **Fig. 1**, out of all processes, heat treatment processes account for 22% of CO_2 emissions from JTEKT plants in Japan, an extremely high level. When we limit the plants to just those that have heat treatment furnaces, CO_2 emissions from heat treatment processes account for 40% or more of all process emissions. For these reasons, energy-saving measures for heat treatment furnaces are an urgent issue for achieving CO_2 emission reduction targets.

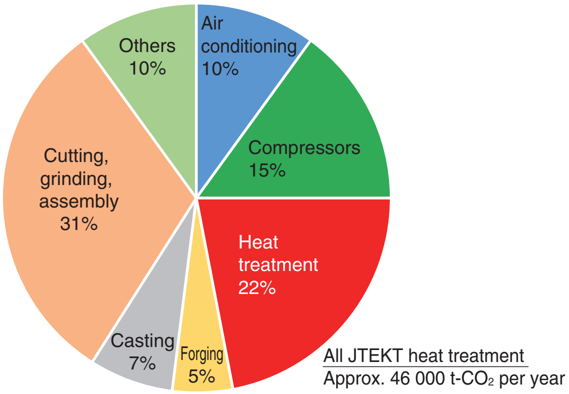


Fig. 1 CO_2 emissions at JTEKT's domestic plants

2. Breakdown of Energy Consumption at Heat Treatment Furnaces

A breakdown of energy consumption in a batch furnace is shown in **Fig. 2**. Only about 20% of the energy input is used as the necessary heating energy for product heat treatment, and for product transport and other drive energy. The remaining 80% of the energy is lost, consisting of heat dissipation from the furnace body, temperature control of quenching oil, generation and heating of endothermic gas, and heat dissipation from doors, fans, hearth rollers, and other parts connecting to the inside and outside of the furnace.

This report focuses on energy loss resulting from heat dissipation from the furnace body, temperature control of quenching oil, and the energy required for generation and heating of endothermic gas, which account for a

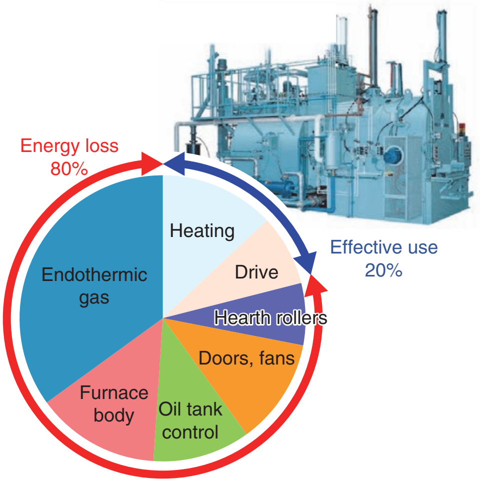


Fig. 2 Batch furnace energy consumption

large percentage of the total energy loss. It describes the development of energy-saving technologies to address these energy losses. It also reports the results of demonstration tests using actual equipment.

3. Energy-saving Technologies for Achieving Carbon Neutrality

3. 1 Improving Furnace Heat Insulation Performance[2)]

First, we reviewed the insulation structure of the furnace in order to reduce the amount of heat dissipated from the furnace body. A conventional gas carburizing furnace is shown in **Fig. 3**. Moving from the inside of the furnace to the outside, the structure consists of insulating bricks, high-temperature insulation boards, and low-temperature insulation boards. However in order to improve heat insulation performance in newly developed energy-saving furnaces, Super Moldatherm[2)] (hereafter "SMT") that has high insulation performance and was developed by JTEKT Thermo Systems Corporation is placed on the top surface inside the furnace, which is the high-temperature side, and porous insulation boards are placed on the low-temperature top surface on the outside of the furnace. SMT is a heat insulation material composed primarily of ceramic fibers, with minute particles arranged, dispersed, and adhered to it. Because it has superior insulation performance in high-temperature ranges, placing it on the top surface inside the furnace can result in a large reduction in the amount of heat dissipated from the furnace body. This can also lower the temperature inside the heat treatment plant, improving the work environment.

3. 2 Optimization of the Quenching Oil Temperature Control Method[2)]

The series of processes in a heat treatment furnace and the control method for quenching oil temperature are shown in **Fig. 4**. At the heat treatment oil-cooling process, products heated to approximately 850℃ are quenched, and the quenching oil temperature rises by around 10 to 20℃. For this reason, it is necessary to cool the heated oil to the setting temperature before the next quenching process. Conventional quenching oil temperature control performs forced cooling using a heat exchanger in order to quickly cool the oil that was heated during quenching to the setting temperature. Once the temperature of the quenching oil reaches the setting temperature, the heater is repeatedly turned on/off in order to maintain the setting temperature. This consumes a large amount of electric power. For this reason, the method of forced cooling for the quenching oil was reviewed, and the control method was optimized so that the quenching oil temperature gradually cools to the setting temperature before the timing of the next quenching. This method reduces the amount of electric power consumed by the heater which was previously used to maintain the temperature.

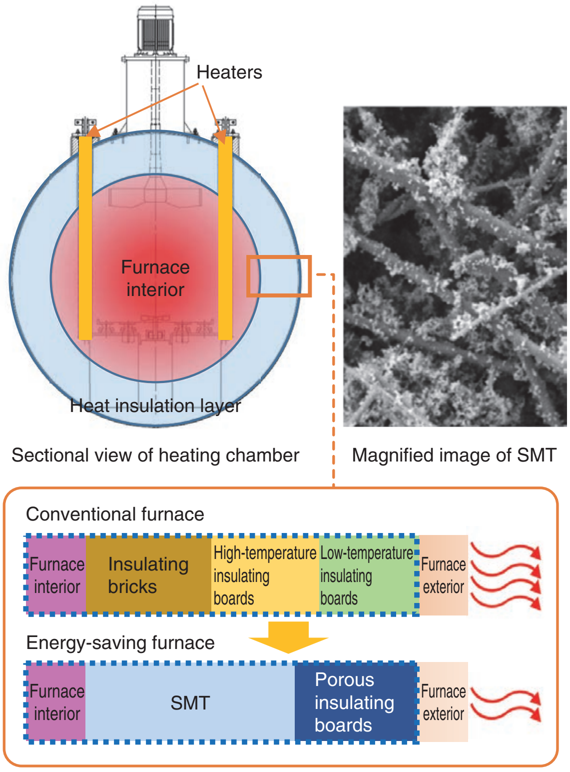


Fig. 3 Energy-saving furnace insulation structure

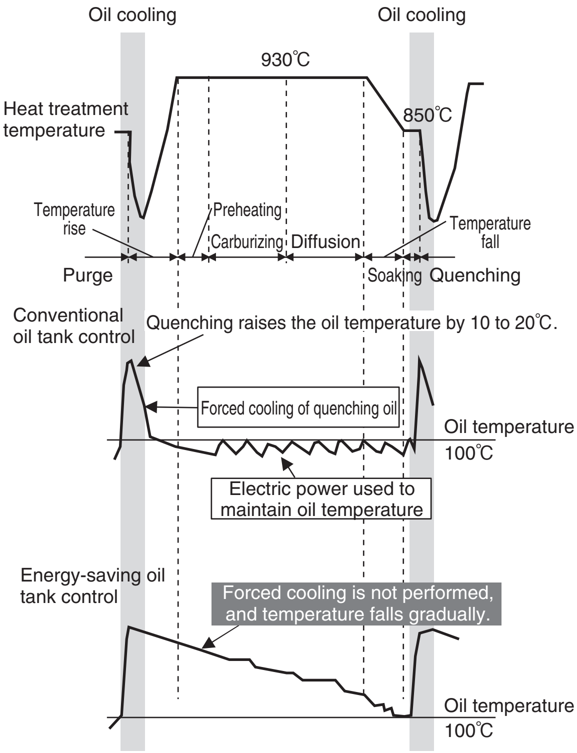
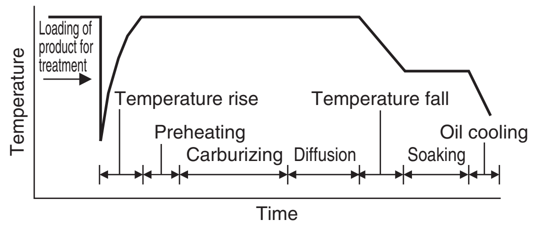


Fig. 4 Overview of quenching oil temperature control method

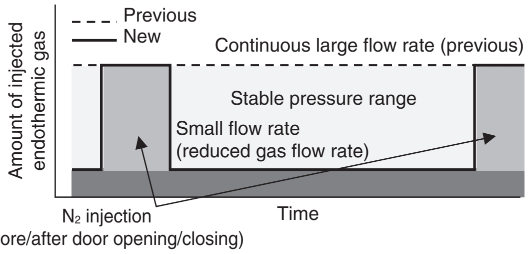
3. 3 Reduction of Endothermic Gas[2)]

The relationship between the heat treatment pattern and amount of endothermic gas is shown in **Fig. 5**. At the carburizing process, generally endothermic gas consisting primarily of CO, N_2, and H_2 is generated in a conversion furnace while consuming large amounts of energy, and this endothermic gas is continuously injected at a fixed flow rate into the heat treatment furnace. In the heat treatment furnace, the door inside the furnace is opened and closed at times such as when products are loaded and unloaded, resulting in large changes in pressure in the heating furnace and inside the quenching oil tank. If negative pressure occurs in the furnace or oil tank at this time, there is the risk that unreacted air may be sucked in, causing an explosion. For this reason, a large flow of endothermic gas is continually injected into the heating furnace in order to prevent negative pressure from occurring. However this means that an excessive amount of endothermic gas is injected at other times when the pressure is stable. In the furnace that was developed here, a continuous small flow of endothermic gas is injected as shown in **Fig. 5**, and additional N_2 gas is injected (N_2 shot) when the pressure inside the furnace becomes negative, reducing the amount of endothermic gas.

As another measure, there is the method of automatically adjusting the amount of gas generated in the conversion furnace as needed. With this system, in the stable pressure range shown in **Fig. 5**, a small flow of endothermic gas is injected. When the pressure inside the furnace becomes negative, a large flow of endothermic gas is injected instead of N_2. In the same manner as the N_2 shot, a large reduction in endothermic gas can be achieved.



<Heat treatment pattern>



<Amount of injected endothermic gas>

Fig. 5 Relationship between heat treatment pattern and amount of Endothermic gas

4. Results of Verification with Actual Equipment

4. 1 Improving Furnace Heat Insulation Performance

When performing an overhaul of an electrical heating-type batch furnace, the furnace insulation structure was changed from conventional bricks to energy-saving SMT and porous insulation boards, and a catalyst was added to stabilize the atmosphere. In order to check the insulation performance of this structure, the results from a comparison of the amount of electric power consumed when maintaining a temperature of 930℃ inside the furnace before and after the changes are shown in **Fig. 6**. While 21.7 kW of electric power was consumed before the changes, consumption after the changes was 16.9 kW, a reduction in electric power of 4.8 kW (–22%).

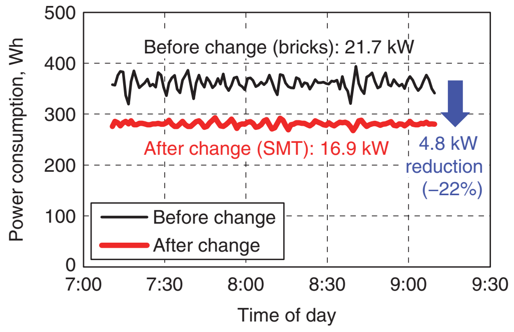


Fig. 6 Comparison of power consumption by empty furnace at 930℃

Next when we compared the effective case depth of products following carburizing treatment before and after the heat insulation material changes, we found that the effective case depth was approximately 12% deeper as shown in **Fig. 7**. To investigate the cause, we compared the gas components inside the furnace. The concentration of CO that contributes to the carburizing reaction had increased from 23% to 25%, confirming that the gas components better facilitated carburizing. Based on the above, because the same effective case depth as before can be obtained even when the treatment time is shortened by 40 minutes, the shorter treatment time can be expected to improve productivity. However further investigation is necessary to determine the sustainability of this effect.

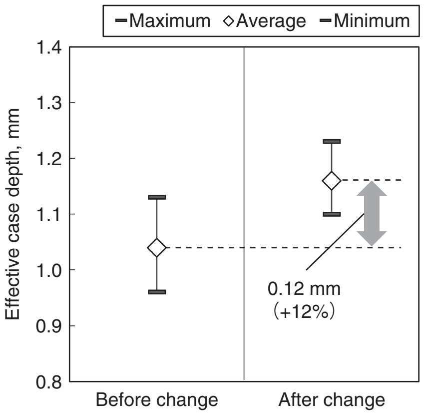


Fig. 7 Comparison of effective case depth

4. 2 Optimization of the Quenching Oil Temperature Control Method

For a furnace where temperature control of the oil tank was performed using a heater, the temperature control method was optimized so that cooling of the quenching oil is completed just before quenching is performed as described before. Specifically, forced cooling after quenching is not performed, and the oil cools gradually. This minimizes the electric power consumed by the heat source heater, the quenching oil circulation pump, and the mixer. It was confirmed that this optimization of quenching oil temperature control reduced electric power by 37.4 kWh per treatment as shown in **Fig. 8**. The oil type in the modified furnace was semi-hot oil that can balance both heat treatment strain and hardenability, and the oil temperature is controlled to 90℃. However in a furnace that uses hot oil where the quenching oil temperature is higher, more energy is required in order to maintain the temperature, and therefore greater reduction effects can be expected. Because quenching is an important factor that decides product heat treatment quality, we also investigated the heat treatment quality before and after the modifications. No significant difference was found between the two, and it was confirmed that the same level of quality as before was also obtained after the modifications.

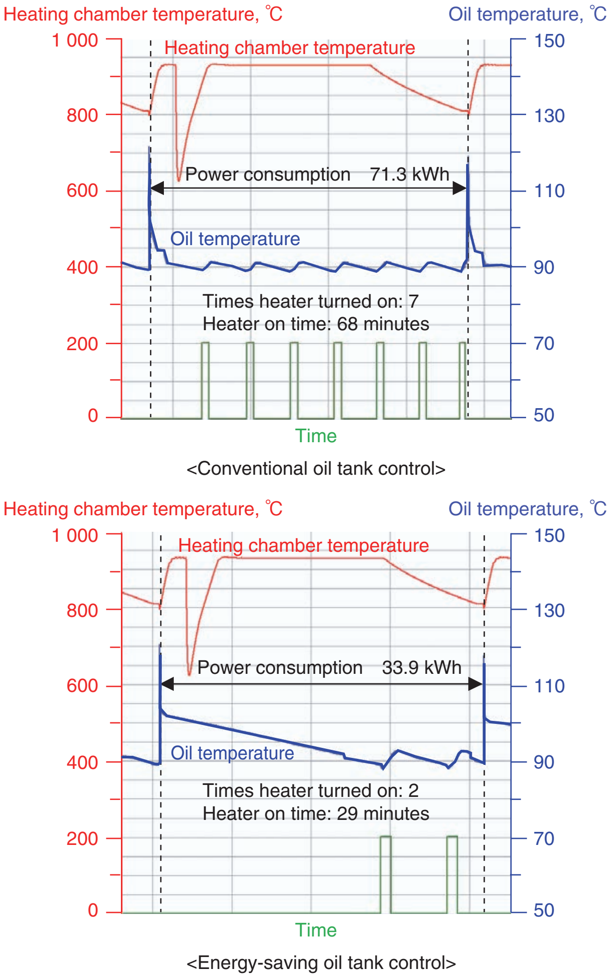


Fig. 8 Energy saving effect of optimization of quenching oil temperature control

4. 3 Reduction of Endothermic Gas

As a basic evaluation of the N_2 shots, the gas components inside the furnace (H_2 concentration, CO concentration) and heat treatment quality were evaluated when the amount of endothermic gas injected during carburizing treatment was reduced to 2/3 of the previous amount and when it was reduced to 1/3 of the previous amount. When the amount of endothermic gas injected was reduced, the concentration of the gases which contribute to the carburizing reaction changed as shown in **Fig. 9**: H_2 concentration increased by a maximum of approximately 2% and CO concentration decreased by a maximum of approximately 1%. At the same time, it was confirmed that the effective case depth shown in **Fig. 10** and other heat treatment quality can be ensured at the same level as before when the amount of injected endothermic gas is reduced to 1/3. In the future, in order to ensure the safety of heat treatment furnaces, we will optimize the amount of N_2 that is injected when there are large changes in the pressure inside the furnace and oil tank, such as when the door opens and closes, and will identify the ideal N_2 injection positions, as we aim for mass production deployment of this technology.

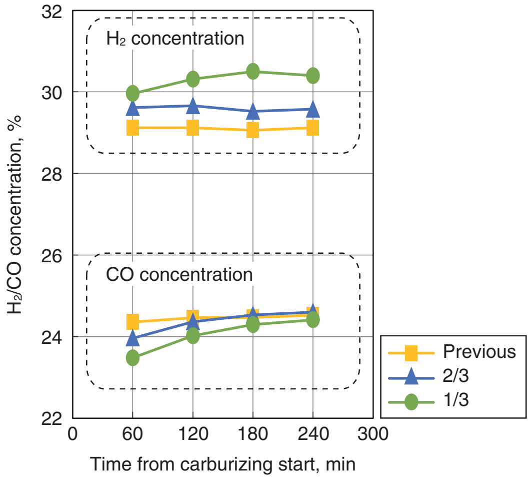


Fig. 9 Furnace gas composition during Endothermic gas reduction

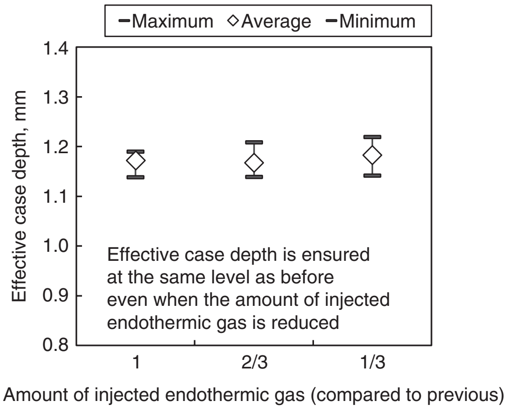


Fig. 10 Heat treatment quality during endothermic gas reduction

5. Carbon Neutral Heat Source Using Hydrogen Burners

As an additional measure for achieving carbon neutrality, we evaluated the possibility of using hydrogen burners in heat treatment furnaces. Because hydrogen fuel is a clean fuel that does not emit CO_2 when burned, it can reduce CO_2 produced from the heat source to zero. On the other hand, it leaks easily and burns easily, and the calorific value is approximately one quarter that of city gas. For these reasons, we actually installed hydrogen burners in a batch furnace in order to check safety, temperature rise capacity, emissions gas characteristics, and cost.

With the installation of hydrogen detectors and other leakage countermeasures, and backfire countermeasures consisting of flame-extinguishing elements and check valves, it was confirmed that there are no problems with safety. For temperature rise capacity, the temperature distributions inside the furnace were compared when using city gas and hydrogen. It was confirmed that there is no difference in the temperature characteristics resulting from the different fuels. However with the emission gas characteristics, as shown in **Table 1**, while the converted NOx value was at or below the standard, it was higher than with city gas. Therefore it will be necessary to enact measures to reduce NOx emissions in the future. In addition, the results showed that the amount of hydrogen fuel consumed was four times the amount of city gas.

Based on the above, we can conclude that it is technically possible to use hydrogen burners in a heat treatment furnace. However because hydrogen gas is expensive, heat treatment costs are higher, and at present this unavoidably results in a worsening of manufacturing cost. Therefore it will be necessary to identify a suitable time for introduction, focusing on the price of hydrogen.

Table 1 Comparison of exhaust gas characteristics between town gas and H_2 gas

	Converted NOx (ppm)		CO (ppm)		Dew point (℃)	
Judgment standard	≤ 180		≤ 0		≤ 500	
City gas	70 to 97	○	0	○	54.3	○
Hydrogen	114 to 143	○	0	○	65.0	○

6. Conclusion

The heat treatment process emits more CO_2 than other processes. In particular, the CO_2 emissions per heat treatment furnace are extremely large, and the adoption of energy-saving measures for heat treatment furnaces is an urgent issue. Moreover, because most heat treatment furnaces are used for 30 years or more after installation, technologies to reduce CO_2 emissions from existing furnaces are also necessary. The energy-saving technologies described in this report can be used to modify existing furnaces, and therefore they can achieve a large reduction in CO_2 emissions without requiring a large investment. By applying the three energy-saving technologies of improving furnace insulation performance using Super Moldatherm, optimizing the quenching oil temperature control method, and reducing endothermic gas, it is possible to reduce energy loss in existing furnaces by approximately 35%. The installation of hydrogen burners as a heat source with zero CO_2 emissions can reduce energy consumption in a batch furnace, including product heating, by approximately 65%. While the level of technical difficulty is high, active studies will also be conducted for future improvements such as utilizing waste heat to achieve waste-free use of input energy. We will continue with future development that can contribute to achieving carbon neutrality in the heat treatment process.

References

1) Ministry of Economy, Trade and Industry: Plan for Global Warming Countermeasures (10-22-2021), https://www.meti.go.jp/policy/energy_environment/global_warming/ontaikeikaku/keikaku_honbun.pdf (2021) (in Japanese).
2) R. YAMAMOTO: Trend and Practical Application of Heat Treatment Equipment for Decarbonized Society, NETSU SHORI, Vol. 63 No. 3 (2023) 116-119 (in Japanese).

Y. HIRADE[*] M. OGURI[*] A. MATSUBARA[**]

K. MATSUMOTO[**] K. SAIGUSA[**]

* *Heat Treatment Production Engineering Dept., Production Engineering Division*
** *Industrial Furnace Equipment Dept., JTEKT THERMO SYSTEMS CORPORATION*