DEVELOPMENT AND APPLICATION OF HIGH-EFFICIENCY INDIRECT HEATING BURNER USED IN METAL HEAT TREATMENT FIELD

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1. INTRODUCTION

In metal heat treatment field, atmosphere heat treatment for which the inside of the furnace is filled special atmosphere gas is performed in many cases. Also, High quality treatment, such as oxidation prevention of a product, are performed in many cases. These heat treatment furnaces are constructed to intercept invasion of the outside air in order to preserve the atmosphere in the furnace. When a gas burner is used for heating, therefore, indirect heating using a radiant tube burner must be used to keep an atmosphere free from combustion gas.

Conventionally electric heaters were widely employed as the heat source due to the easy controllability of temperature and the good temperature distribution. But interest to natural gas burning radiant tube burners for heat treatment is still more increasing from the standpoint of environmental protection through energy saving, reduction of CO2 emissions and reduction of treatment costs.

To date, Toho Gas has developed and marketed various types of burners, including single-ended radiant tube burners and regenerative radiant tube burners, which are being applied a large number of gas burning furnaces primarily designed for atmosphere heat treatment. Recently, moreover, the treatment under high temperature and high vacuum, such as vacuum carburizing treatment, have been attracting a lot of attention. Against this backdrop, Toho Gas have been developing radiant tube burner systems which are applied for new heat treatment technologies and even greater energy savings.

In this paper, the development of these radiant tube burner systems for the metal heat treatment is described.

2. PROBLEMS TACKLED TO DATE

2.1 Single-Ended Radiant Tube Burner (SRTB)

2.1.1 Overview

Electric heaters have been widely used as the heat source for indirect heating furnaces, such as atmosphere heat treatment furnaces. The electric heaters used in indirect heating furnaces are sheathed in a protective tube to prevent them from high temperatures and the atmosphere. We developed a single-ended radiant tube burner (SRTB) as an alternate heat source for such an electric heater with protective tube. The SRTBs we developed have small outer tube sizes (dia 90 - 140), which are ideal for application in box type furnaces and small-scale continuous furnaces, especially for high-mix low-volume production lines and more than 1000 sets have been introduced.

2.1.2 Structure and Specifications of SRTB System

As shown in Figure 2-1, the SRTB is made up of a burner unit and inner and outer tube. The SRTB has a double-tube structure consisting of an inner tube and an outer tube. The burner nozzle is installed inside the inner tube, so the burner burns inside the inner tube. The combustion gas flows to the tip of the inner tube and then reverses its course and flows between the inner and outer tubes, setting up a heat exchange with the outer tube. After passing through the burner body, the combustion gas is then exhausted through the exhaust gas outlet. At this time, exhaust heat is recovered through a heat exchange with the combustion air. The inner and outer tubes are made of heat resistant cast steel, so they can be used in furnaces whose interior temperature reaches 1000°C.

The SRTB specifications are shown in Table 2-1. The SRTB outer tube is available in three sizes: 90, 114, and 140 in diameter (3, 4, and 5 inches).
Outer tube size | dia90 | dia114 | dia140
---|---|---|---
Inner tube size  | dia61 | dia77 | dia90
Effective length of tube (mm) | 800~1400 | 1000~1600 | 1200~1800
Combustion capacity (kW/unit) | 8.4~15.1 | 13.4~21.5 | 19.8~29.7

Table 2-1 SRTB Specifications

The SRTB performance data are shown in Table 2-2.

| Outer tube size | dia90 |
| Effective length of tube | 1000mm |
| Combustion capacity | 11.5kW |
| Air ratio | 1.4 |
| Combustion capacity range | 3.3~11.6 |
| Thermal efficiency | 72% |
| Preheated air temperature | 480 |
| NOx (O₂ concentration = 11% equivalent) | 180ppm |

Table 2-2 SRTB Performance Data

The above data were measured under the following conditions.

Test furnace dimensions: 400D × 400W × 1400H
Furnace temperature: 900°C

2.1.3 Application of SRTB in Heat Treatment Furnaces

(i) Application in a continuous carburizing furnace

Described herein is a typical SRTB installation in a continuous carburizing furnace, in which SRTBs are installed in all the zones of the furnace. The continuous carburizing furnace has a treatment capacity of 500kg/h and is separated in a degreasing zone, preheat zone, carburizing zone, diffusion zone, and quenching zone. The temperature in the carburizing zone was set at 950°C approximately.

Forty-six dia114 SRTBs were arranged from the ceiling along the sides of the continuous carburizing furnace. The SRTB input was set at 12.8kW for each unit. The installation interval of each SRTB was varied to suit the load in each zone.

As compared with the furnace with electric heaters of the same capacity, this furnace had practically the same warm-up characteristics and uniform temperature distribution. The average thermal efficiency of all burners is 65%. Based on a comparison of the primary energy calculations, a 40% energy saving and a 26% reduction in CO₂ emissions were obtained with this system, compared with an electric heater.

The following describes how electric power consumption was compared and assessed using primary energy calculations.

(ii) Application in a batch type nitriding furnace

Described herein is a typical SRTB installation in a batch type nitriding furnace. The batch type nitriding furnace had a treatment capacity of 600kg/charge, and the treatment temperature was set at 500°C approximately. Since the nitriding treatment requires the introduction of ammonia gas in the furnace, the tubes may corrode; hence, the outer tubes were made of a heat-resistant metal with a surface coating.
Ten dia114 SRTBs were arranged from the ceiling along the sides of the nitriding furnace. The SRTB input was set at 11.6kW for each unit. Practically the same energy saving and reduction of CO₂ emissions were obtained with this furnace as with the continuous carburizing furnace described in the previous case.

2.2 Wide Turndown ratio Radiant Tube Burner (WRTB)

2.2.1 Overview

As mentioned previously, the SRTB was developed as a heat source for high temperature indirect heating furnaces, such as atmosphere heat treatment furnaces. In applying the SRTB in relatively low-temperature indirect heating furnaces, such as tempering furnaces, however, we encountered problems such as increased costs due to increased number of burners for precise temperature controllability.

To apply gas burners to low-temperature indirect heating furnaces, therefore, we had to develop a burner with a large capacity and wide turndown ratio.

We developed a wide turndown ratio radiant tube burner (hereafter referred to as WRTB) and to date more than 50 sets have been introduced.

2.2.2 Structure and Specifications of WRTB System

As shown in Figure 2-2, the WRTB consists of a burner unit and a radiant tube, which can be either U-shaped or W-shaped.

Each WRTB unit has a built-in main burner and sub burner. The sub burner is installed inside the main burner on the same axis as that of the main burner. The main burner has a variable combustion capacity, whereas that of the sub burner is fixed. The combustion capacity of the sub burner is approximately 1/23 - 1/53 that of the main burner. The sub burner was designed to have a larger turndown ratio than a conventional burner so that favorable combustion conditions could be maintained regardless of the main burner combustion conditions.

A heat exchanger was installed on the exhaust side of the radiant tube to enable a heat exchange between the exhaust gas and the combustion air.

The specifications of the WRTB are shown in Table 2-3. The WRTB outer tube is available in two sizes: 114 and 165 In diameter(4 and 6 inches).

<table>
<thead>
<tr>
<th>Outer tube size</th>
<th>dia114</th>
<th>dia165</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard length of tube (mm)</td>
<td>4000</td>
<td>6000</td>
</tr>
<tr>
<td>Maximum combustion capacity (kW)</td>
<td>58.1</td>
<td>93.0</td>
</tr>
<tr>
<td>Minimum combustion capacity (kW)</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Turndown ratio</td>
<td>1:33</td>
<td>1:53</td>
</tr>
</tbody>
</table>

Table 2-3 WRTB Specifications

2.2.3 Application of WRTB in Heat Treatment Furnaces

(i) Application in a batch type tempering furnace

Described herein is a typical WRTB installation in a batch type tempering furnace. The batch type tempering furnace has a treatment capacity of 600kg/charge, and the treatment temperature can be varied from 200 - 600°C.

Two dia114 W-shaped tubes were arranged from the ceiling along the sides of the tempering furnace. The WRTB input was set at 58.1kW for each unit. The temperature distribution inside the furnace was within ±10°C at both the minimum operating temperature of 200°C and the maximum operating temperature of 600°C. As compared with the furnace with electric heaters of the same capacity, the furnace had practically the same warm-up characteristics. Moreover, we were able to reduce the treated product cooling time by almost half, by introducing air into the tube interior while the furnace was cooling down.
3. THE PRESENT MEASURE

3.1 Compact Type Regenerative Radiant Tube Burner (RRTB)

3.1.1 Overview
The technical development of the SRTB and WRTB was advanced for the conversion of electric heaters to gas burning furnaces from the standpoint of energy saving and reduction of CO₂ emissions. The pursuit of further energy savings, however, is a huge problem.

Regenerative burner systems are attracting much attention in the industrial heating field as the leading energy-saving techniques.

Regenerative burner systems were predominantly developed for applications in large-capacity direct heating systems such as iron and steel-related systems and light alloy melting systems. The development of technologies that can be applied to heat treatment furnaces and other small-and medium-scale indirect heating systems has been particularly problematic.

We therefore developed a compact regenerative radiant tube burner (hereafter referred to as RRTB) for use in heat treatment furnace and other small-and medium-scale indirect heating furnaces. To date, we have developed RRTBs with radiant tube sizes of dia90 - 140, as well as system applications that suit various furnace shapes and operating conditions.

Since 1994, when the first RRTB was developed, more than 1000 sets have been introduced, mainly for heat treatment furnaces.

3.1.2 Structure and Specifications of RRTB System
As shown in Figure 3-1, the RRTB is comprised of a pair of burner units, a radiant tube, and a 4-way selector valve.

![Figure 3-1. Structure of RRTB](image)

The tube can be either U-shaped or W-shaped. A regenerator is built in either the burner body or the radiant tube. The regenerator is made of a ceramic material similar to that of the catalyst carrier used in automobiles to clean the exhaust gas.

In this system, two burners equipped on each end of the radiant tube operate alternately in 30-second cycles. The exhaust gas and combustion air flow through the same hole in the burner body, and a 4-way selector valve is installed between the two burners and between the combustion air blower and the exhaust pipe.

The burners burn in alternate cycles as the selector valve switches between burn mode and exhaust mode for each burner.

When one of the burners is burning, the combustion gas is carried to the opposite-side burner, passing through the tube interior. A heat exchange then occurs with the opposite-side regenerator. When the selector valve switches to the other burner, combustion air passes through the regenerator, which is now hot, causing a heat exchange. Thus, as the exhaust gas and combustion air alternately pass through the regenerator, the heat of the exhaust gas is used to preheat the combustion air.

The burner nozzle consists of a gas nozzle, primary air nozzle, and a secondary air nozzle. The air preheated in the regenerator is fed into the secondary air nozzle.

Functioning also to cool the burner nozzle, the primary air flows through the system all the time.

The RRTB specifications are shown in Table 2-1. The RRTB radiant tube is available in three sizes: 90, 120, and 140 in diameter (3, 4, and 5 inches).

<table>
<thead>
<tr>
<th>Outer tube size</th>
<th>dia90</th>
<th>dia120</th>
<th>dia140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard length of tube (mm)</td>
<td>2600</td>
<td>3100</td>
<td>3900</td>
</tr>
<tr>
<td>Maximum combustion capacity (kW)</td>
<td>23.2</td>
<td>40.7</td>
<td>64.0</td>
</tr>
</tbody>
</table>

Table 2-1 RRTB Specifications
3.1.3 Energy Saving

The RRTB has a regenerative heat exchange system with a high exhaust heat recovery rate. In the regenerative system, a hot fluid and cold fluid are alternately passed through the regenerator in short intervals. This makes it possible to obtain a highly efficient heat exchange through the regenerator.

The large capacity regenerative burners currently installed in metal melting furnaces have ball-shaped or saddle-shaped ceramic regenerators. These are widely used as filler of industrial catalysts. These regenerators, though, have relatively a small surface area per unit volume. In order to secure the required amount of regenerative heat, therefore, the burner body that accommodates the regenerator has to be large, and hence cannot be easily used in small-and medium-scale radiant tube burners.

In the RRTB, a honeycomb-shaped ceramic regenerator is used that not only has a large surface area per unit volume but superior heat resistance characteristics as well. This regenerator, which is also used in the catalyst carrier used in automobiles to clean the exhaust gas, has high heat resistance and durability against thermal expansion. In addition, the burner is constructed with the regenerator built into the burner tube.

These measures made it possible to produce a compact burner body and recover exhaust heat with a high efficiency and in a short time.

The results of performance evaluation tests conducted using a test furnace are described in the following.

The test furnace used in the RRTB performance evaluation tests is a furnace with the following specifications (referred to as the test furnace), unless otherwise noted.
- Radiant tube size and shape: 120mm (4 inches); W-shape
- Effective length of tube: 3200mm
- Internal dimensions: 900D × 600W × 600H

The thermal efficiency of the test furnace was calculated under the following operating conditions.
- Furnace temperature: 900°C
- Input: 40.7kW
- Air ratio: 1:4

The thermal efficiency during combustion was at least 80% at 900°C, which was the treatment temperature during the carburizing treatment. This represents a 15% improvement as compared with a conventional burner with built-in heat exchanger, and 50% of large energy saving as compared with an electric heater. Also, the reduction in CO₂ emissions, compared with an electric heater, was as much as 40%.

3.1.4 Reduction of NOx Emission

Since the regenerative burner system has a high exhaust heat recovery rate, it follows by necessity that the combustion air temperature is high. Generally, when the combustion air temperature is high, the flame temperature is also high and the amount of NOx produced increases. The NOx emission is particularly large with a small diameter radiant tube burner, because combustion takes place in a limited narrow space, so the combustion chamber load is high. For a regenerative radiant tube burner, therefore, reduction of NOx emission is a key problem.

The RRTB has a nozzle structure that makes self exhaust gas re-circulation inside the tube. A schematic view of the nozzle is shown in Figure 3-2.

The secondary air nozzle is a disk-shaped plate with an arc-shaped notch in one part of it. Air is injected through the clearance between the plate and the inner wall of the radiant tube. The flow of combustion air is deflected inside the tube downstream of the air nozzle, on the side of the plate that has notch, causing the exhaust gas to automatically get mixed into the combustion air. The amount of exhaust gas that gets mixed into the combustion air can be increased by increasing the speed of the combustion air through the nozzle (70 - 100m/s at 900°C).

This structure reduces the NOx concentration to about 1/4 that produced with a burner that has no NOx-reducing measure.
We confirmed that an external exhaust gas re-circulation (EGR) function, in which a portion of the exhaust gas is forcefully fed into the combustion air, is effective in further reducing the NOx emission. The exhaust gas properties were measured under the following test furnace operating conditions.

- Furnace temperature: 1050°C
- Input: 34.9, 40.7kW
- Air ratio: 1:4

The NOx concentration measured under the above conditions are shown in Figure 3-3. It was confirmed that at a furnace temperature of 1050°C, the NOx content was approximately 280ppm with a 0% EGR rate (normal combustion conditions) and approximately 150ppm with a 15% EGR rate.

### 3.1.5 Achieving a Uniform RT Surface Temperature

Most electric furnaces consist of a large number of heater units packed closely together, owing to the fact that the heating capacity of each heater is small. Consequently, when a radiant tube burner is used in an application that requires a uniform temperature distribution inside the furnace, an arrangement of many small-capacity compact burners is designed, similar to the electric heater configuration. The use of a large number of burners raises costs, offsetting any running cost benefits, and becomes a huge impediment to the introduction of gas burning indirect heating furnaces.

As mentioned previously, the RRTB has a pair of burners installed at both ends of the tube that operate in alternating burning cycles. This configuration produces a more uniform tube surface temperature distribution than that of a normal radiant tube burner at one end of the tube.

The tube surface temperature distribution was measured with the following test furnace operating conditions.

- Furnace temperature: 950°C
- Input: 40.7kW
- Air ratio: 1:4

The temperature distribution values measured under the above conditions are shown in Figure 3-4. The temperature differential $\Delta T$ was no greater than 30°C with the furnace temperature controlled at 950°C.

### 3.1.6 Application of RRTB in Heat Treatment Furnaces

#### (i) Application in a batch type carburizing furnace

The most common RRTB application is in batch type carburizing furnaces. Described herein is a typical RRTB installation in a batch type carburizing furnace. A schematic view of the system is shown in Figure 3-5. This batch type carburizing furnace has a treatment capacity of 600kg/charge, and the treatment temperature is set at 930°C approximately.

Two sets of dia140 (5-inch) RRTBs were arranged from the ceiling along the sides of the carburizing furnace, and the RRTB input was 48.8kW per set.
The equivalent electric capacity of an electric heater is 80kW. The furnace had practically the same warm-up characteristics and uniform temperature distribution as compared with an electric heater of the same capacity.

The burner average thermal efficiency during operation was 80%.

Compared with an electric heater, a substantial 50% energy saving and about a 40% reduction in CO₂ emissions were obtained. It was also confirmed that the system could operate at practically the same level of performance demonstrated in the evaluation tests.

(ii) Copper brazing furnace

In the past, most mesh-belt type brazing furnaces for copper (maximum furnace operating temperature of 1150°C) used electric heaters. We therefore started this development with the aim of applying RRTBs in copper brazing furnaces. A typical RRTB installation in a copper brazing furnace is described in the following.

The furnace specifications are shown in Table 3-2.

<table>
<thead>
<tr>
<th>Furnace specifications</th>
<th>Treatment capacity</th>
<th>100kg/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum operating temperature</td>
<td>1,150°C</td>
<td></td>
</tr>
<tr>
<td>Internal dimensions</td>
<td>W450, H160mm</td>
<td></td>
</tr>
<tr>
<td>Burner specifications</td>
<td>Combustion capacity</td>
<td>27kW, 4 sets</td>
</tr>
<tr>
<td>RT shape</td>
<td>dia90, L3000mm (straight type)</td>
<td></td>
</tr>
<tr>
<td>RT material</td>
<td>SiC impregnated with silicon</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-2 Copper Brazing Furnace Specifications

Since the maximum operating temperature of the copper brazing furnace is 1150°C, as is shown in the above table, a conventional radiant tube made of heat-resistant cast steel cannot be used; hence, a straight type ceramic tube was adopted. SiC impregnated with silicon was selected as the tube material. The straight tubes were installed parallel to the moving direction of the mesh belt, and a burner was equipped at each tube end. A total of 4 tubes were installed, two above and two below the mesh belt.

A reducing atmospheric gas was fed into the furnace interior to prevent product oxidation. This made it necessary to seal between the burner body and the tubes. In addition, since the straight tubes repeatedly expand and contract as the furnace warms up and cools down, we developed a sealing method that could absorb the tube thermal contraction and prevent combustion gas from leaking into the furnace interior.

The furnace had practically the same warm-up characteristics and uniform temperature distribution as compared with the furnace with electric heaters of the same capacity operating under normal conditions.

The average thermal efficiency of the burner under normal operating conditions was 70%. This is lower than the thermal efficiency obtained in the evaluation tests due to the cooling loss of the seal area. But a substantial energy saving of 43% and a dramatic reduction in CO₂ emissions of approximately 28% were obtained with this furnace, compared with an electric heater.

3.2 High-Temperature/Vacuum Single-Ended Radiant Tube Burner (VSRTB)

3.2.1 Overview

In the vacuum carburizing treatment, a small quantity of hydrocarbons is introduced into the furnace interior under reduced pressure conditions. The vacuum carburizing treatment has advantages over the conventional carburizing treatment, such as reduced treatment time, energy saving, cost saving, and improved product quality. Because of this, vacuum carburizing is attracting much attention as the next-generation heat treatment technology.

But because vacuum carburizing is performed under reduced pressure conditions with the furnace temperature above 1000°C, an SRTB that uses conventional cast steel tubes cannot be used in this treatment because of durability problems.

We therefore developed a high-temperature/vacuum single-ended radiant tube burner (hereafter referred to as VSRTB) for vacuum carburizing furnaces and other high-vacuum high-temperature furnace applications.
3.2.2 VSRTB System Structure and Specifications

The VSRTB is comprised of a burner unit and inner and outer tubes, similar to the SRTB, and it has the same working principle as the SRTB. A description of its basic structure is therefore omitted herein.

Three greatly different points from SRTB exists in VSRTB. Firstly, the inner and outer tubes are made of ceramic. Secondly, it has a vacuum-sealed construction between the burner body and the tube and between the tube and the vacuum furnace. And thirdly, incorporated in the burner body is an improved heat exchange function, which is described after the next section.

These improvements make the VSRTB capable of being applied in vacuum carburizing furnaces and other furnaces whose temperature reaches up to 1100°C, under reduced pressure conditions.

The VSRTB specifications are shown in Table 3-3.

<table>
<thead>
<tr>
<th>Type</th>
<th>VSRT-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum combustion capacity</td>
<td>20kW</td>
</tr>
<tr>
<td>Minimum combustion capacity</td>
<td>6kW</td>
</tr>
<tr>
<td>Tube outer size</td>
<td>dia116 (4 inches)</td>
</tr>
<tr>
<td>Tube material</td>
<td>Ceramic (atmospheric pressure sintered silicon carbide)</td>
</tr>
<tr>
<td>Maximum operating temperature inside furnace</td>
<td>1000°C</td>
</tr>
<tr>
<td>Minimum operating vacuum</td>
<td>0.4Pa</td>
</tr>
</tbody>
</table>

Table 3-3 VSRTB Specifications

3.2.3 About the Tube Material

The VSRTB inner and outer tubes are made of atmospheric pressure sintered SiC. This material was chosen because, of all the ceramic materials, it has the following particular features.

* High operating temperature
* High strength and little deformation at high temperatures
* Chemically stable and highly resistant to corrosion

The properties of atmospheric pressure sintered SiC are shown in Table 3-4.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>170W/mK</td>
</tr>
<tr>
<td>modulus of elasticity</td>
<td>420GPa</td>
</tr>
<tr>
<td>coefficient of linear expansion</td>
<td>4.5*10^-6/K</td>
</tr>
<tr>
<td>bulk density</td>
<td>3.15g/cm³</td>
</tr>
</tbody>
</table>

Table 3-4 Properties of Atmospheric Pressure Sintered SiC

The values for thermal conductivity, modulus of elasticity, and coefficient of linear expansion are room-temperature values. The material was sintered close to its true density, and there was no deterioration in material strength from room temperature to high temperature.

Up until then, however, there had been no record of atmospheric pressure sintered SiC used regularly in a high-temperature and high-vacuum environment. We therefore executed a material evaluation as follows.

First, we evaluated the conditions of a test piece that was first heated and then cooled under high-temperature and high-vacuum conditions. The evaluation items were bulk density, bending strength, and structural check. The test conditions were as follows.

- **Test piece material:** atmospheric pressure sintered SiC
- **Test piece dimensions:** 3mm × 4mm × 40mm
- **Heating pattern 1:** Pressurize to 1000Pa, raise furnace internal temperature to 1,250°C, introduce nitrogen gas (pressure: 0.29MpaG, temperature: 25°C), and then quench.
- **Heating pattern 2:** Raise furnace internal temperature to 1,250°C and then slow-cool in furnace by dissipation of furnace body heat.

The evaluation results are shown in Table 3-5.
Since none of the test items showed any change before and after the test, the test confirmed that there was no rapid deterioration of atmospheric pressure sintered SiC under high-temperature and high-vacuum conditions.

We then evaluated the conditions of a test piece that was first heated and then cooled under high-temperature and high-vacuum conditions, using a test piece (dia116mm, L600mm, closed end) that had been manufactured using the same process as that of a radiant tube. The evaluation items were bending strength and structural check. The test results are described in the following.

Test piece material: atmospheric pressure sintered SiC
Test piece dimensions: tube shape (dia116mm × L600mm, closed end)
Heating pattern: Pressurize to 1000Pa, raise furnace internal temperature to 1,250°C, introduce nitrogen gas (pressure: 0.51MPaG, temperature: 25°C), and then quench.

The test results are shown in Table 3-6.

Since none of the test items showed any change before and after the test, the test confirmed that a radiant tube made of atmospheric pressure sintered SiC could be used under high-temperature and high-vacuum conditions.

### 3.2.4 About the Vacuum-Sealed Structure

In a vacuum carburizing furnace, a high vacuum below 1000Pa is formed in the furnace interior. The furnace must therefore have a structure that seals out the atmospheric pressure outside the furnace. As mentioned previously, we used atmospheric pressure sintered SiC as the radiant tube material. But ceramic materials, including atmospheric pressure sintered SiC, have the following drawbacks.

* Lack toughness and tend to break if deformed even slightly.
* Cannot be manufactured to the same dimensional accuracy as metal.
* Cannot be easily joined to metal directly (bonding, welding).

Instead of directly sealing between the furnace body and the outer tube, therefore, we used a structure in which the outer tube had a tube flange sandwiched between metal flanges.

The outer tube was integrated with a disc-shaped tube flange, which was sandwiched between two metal flanges (hereafter referred to as sealing flanges). The sealing flanges sealed the area between the furnace body and the burner body.

A resinous O-ring was used to seal between the sealing flange and the tube. This sealed structure was able to absorb deformation due to tube heat and maintain a secure vacuum seal.

But since the O-ring was made of resins and had a temperature resistance of only 220°C, it was necessary to prevent the tube heat from being conducted to the O-ring. A water cooling function was therefore incorporated with the top and bottom sealing flanges, and a maximum temperature of 150°C was targeted as the side-surface temperature of tube flange in order to prevent O-ring deterioration.

Packing was inserted between the top and bottom sealing flanges and the tube flange in order to boost the cooling effect. We used carbon graphite as the packing material because it can absorb the tube machining accuracy and thermal expansion, and because of its good thermal conductivity characteristics.

To execute a detailed design, we carried out a numerical analysis of heat distribution and stress distribution in the flange area. Based on this numerical analysis, we determined the dimensions of each part of the sealing structure and the cooling capacity, and conducted warm-up/cool-down tests using a test furnace. The evaluation items consisted of the temperature at all parts of the tube, leak check at all flanges, and an external appearance check. The tests were performed under the following conditions.
Tube size: dia116 (4 inches)
Effective length of tube: 900mm
Heating pattern: Maintain normal pressure, raise furnace internal temperature to 1,100°C, and slow-cool in furnace by allowing heat to dissipate naturally.

The test results are shown in Table 3-7.

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube flange side-surface temperature</td>
<td>100~110°C</td>
<td>Target: 150°C</td>
</tr>
<tr>
<td>leakage</td>
<td>No problems</td>
<td></td>
</tr>
<tr>
<td>Tube external appearance</td>
<td>Same as before test</td>
<td></td>
</tr>
<tr>
<td>O-ring external appearance</td>
<td>Same as before test</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-7 Sealed Parts Evaluation Results

As is evident from Table 3-7, all items were confirmed to be satisfactory. Furthermore, the temperature distribution was close to the numerical analysis results, and the tube was presumed to be able to withstand the expected thermal stresses.

3.2.5 Improving the Built-in Heat Exchanger

In a conventional SRTB, the furnace internal temperature is 1,000°C, the maximum combustion capacity is 16kW, and the thermal efficiency is approximately 70%. In the VSRTB, since the maximum operating temperature was 1,100°C, we figured that the efficiency would drop to approximately 65% if we tried to get the same heat exchange performance as the SRTB. We therefore modified the heat exchanger design for the VSRTB, setting a thermal efficiency target of 80% with the same burner head outer dimensions.

The SRTB has a one-pass counter-flow type heat exchanger built into the burner body. For the VSRTB we adopted a two-pass counter-flow type heat exchanger in order to obtain a larger heat transfer area. By increasing the heat transfer area and improving the flow velocity, we improved the heat transfer coefficient and thereby achieved a thermal efficiency of approximately 80%.

3.2.6 Application of VSRTB in Vacuum Heating Furnaces

Described herein is a typical VSRTB installation in a batch type vacuum heating furnace. The furnace treatment capacity is 400kg/charge. A schematic view of the system is shown in Figure 3-6. The furnace internal dimensions are 900D × 600W × 600H, and the maximum operating temperature is 1100°C. The furnace is a multi-purpose furnace such as vacuum annealing and vacuum gas hardening.

Eight dia116 (4 inches) VSRTBs were arranged from the ceiling along the sides of the furnace, and the VSRTB input was set at 20kW per unit.

The equivalent electric capacity of an electric heater is 60kW. The furnace had practically the same warm-up characteristics and uniform temperature distribution as compared with the furnace with electric heaters of the same capacity.

The burner average thermal efficiency during operation was 70%.

Compared with an electric heater, a substantial 43% energy saving and about a 28% reduction in CO2 emissions were obtained. It was also confirmed that the system could operate at practically the same level of performance demonstrated in the evaluation tests, except for the heat dissipation loss due to the water-cooled flanges.

The application of a VSRTB in a vacuum carburizing furnace is currently at the basic design stage.

4. CONCLUSION

This paper introduced our development of radiant tube burners used in metal heat treatment. To date, we at Toho Gas have developed SRTBs, WRTBs, RRTBs, and VSRTBs that can be used in a wide range of applications from tempering furnaces with an internal temperature of 100°C to vacuum carburizing furnaces with an internal temperature of 1000°C or higher. In the future we intend to pursue ongoing technical innovation in the metal heat treatment field, and we will continue to tackle the development of heating systems that will serve as the driving force behind this technical innovation.