DEVELOPMENT OF REGENERATIVE RADIANT TUBE BURNERS FOR HEAT TREATMENT FURNACES

Main author

Masataka Yabushita

Commercial Combustion Application Group,

Technical Research Institute, Toho gas Co., Ltd.

Japan

Co-authors

Shinpei Miura

Minoru Ito

Yoshihiro Nakamura

1. ABSTRACT

The quenching process, as a representative thermal process in the manufacture of automotive components, is conducted at temperatures ranging from 750° to 1000ºC. Because we targeted these types of high-temperature thermal processes and have developed an environmentally compatible regenerative radiant tube burner (RRTB) offering high thermal efficiency, we hereby present a summary of that work along with some actual customer operation results.

TABLE OF CONTENTS

2. BODY OF PAPER

2.1 Introduction

2.1.1 Our approach to the development of industrial burners

Toho gas Co., Ltd., as a business in the Tokai region (whose center is Aichi Prefecture of central Japan), supplies customers with natural gas. There is a heavy concentration of automotive businesses in the region, making this the key industry. The automotive industry thus presents considerable demand for the heat treatment of metal parts, and from the perspective of worldwide environmental preservation it is now essential to use the most environmentally friendly energy sources in a highly efficient manner. Therefore, in order to respond to that demand, our company has worked on the development of a high-efficiency burner that uses environmentally friendly natural gas as its energy source.

2.1.2 Burners for heat-treating furnaces (radiant tube burners)

A quenching furnace is a heat-treating furnace used for the treatment of metallic components such as automotive parts. Quenching is a process in which a metallic part is heated at high temperature and is then cooled (quenched), giving the metallic part increased strength. In order to prevent surface oxidation or a change in surface composition when a metal is heated to a high temperature, a special gas atmosphere is introduced. Consequently, it is not possible to heat with a direct flame, and radiant tube burners are widely used to indirectly heat the target material with radiant heat. Flames are generated within the tubes of a radiant tube burner, and the burner works by heating the unheated material with radiant heat from the outer surfaces of the heated tubes. Because of this heating mechanism it is also possible to heat without disturbing the gas atmosphere inside the heat-treating furnace that requires a special atmosphere for processes such as carburizing, nitriding and non-oxidizing heating.

2.1.3 Thermal storage burners (regenerative burners)

In the realm of large-scale, high-temperature heating ovens, such as glass melting ovens and coke ovens, regenerative combustion systems (RCS)*[1] have conventionally been used. In an RCS there are two burners having embedded heat storage elements that are used as a pair by switching between them and firing in an alternating manner at intervals of several tens of seconds. While one of the burners is being fired, the exhaust gas is discharged through the heat storage elements within the other burner. During this process the sensible heat of the exhaust gas is stored in the heat storage elements. Once the combustion is switched over, the combustion air is preheated by the hot storage elements and is then available for combustion. Because it is possible with this technique to recover nearly twice as much exhaust heat as that from a typical heat exchanger (recuperator), it is widely used in the field of high-temperature heating as an ultrahigh-efficiency heating method.

However, because the preheated air reaches high temperatures, there is a tendency for more NOx to be produced. Particularly in the case where narrow spaces are used, such as in radiant tubes, the attainment of low NOx becomes a challenge.

2.1.4 NOx reduction technologies *[1]

As indicated above, NOx reduction is essential when high-efficiency regenerative burner technology is employed.

Normally, for gas combustion with an air ratio greater than 1, thermal NOx comprises nearly 100% of the exhaust NOx. It is known that the production of thermal NOx usually depends on the flame temperature, oxygen concentration and residence time. Therefore, some effective NOx reduction measures include:

- Reducing the flame temperature;
- Reducing the O_2 concentration; and
- Shortening the residence time of the exhaust gas in the high-temperature zone.

Specific NOx reduction technologies that correspond to these measures include exhaust gas recirculation (EGR), air or fuel staged combustion, and slow combustion. Among these methods, EGR is widely used because it is easy to reduce the NOx value, given the reduced O2 concentration. In addition to regenerative burners, this method is commonly used in industrial burners for the purpose of reducing NOx emissions. However, there have been concerns about equipment corrosion in the recirculating external gas method, where the exhaust gas passes through the combustion blower and the combustion air pipework. An acid drain is the source of the corrosive material. Furthermore, for burners of the type used in fuel direct injection (FDI) systems that use recirculating combustion exhaust gas in the furnace, there is the concern that the narrow space within the radiant tubes makes successful operation difficult to achieve.

2.2 Development of Regenerative Radiant Tube Burners (RRTB)

2.2.1 Development Concepts

(1) Indirect heating burners

We developed the RRTB as radiant tube burners for application to heat-treating furnaces, which are in high demand within areas under the serving area of our company. They are indirect heating burners used for applications such as hardening and case hardening, which are conducted in furnace atmospheres in the range of 750^{o} to 950^{o}C.

(2) High efficiency, low NOx

Starting from the initial RRTB development, in order to reach the goals of energy conservation and CO_2 reduction, we adopted thermal storage burners with the potential for greater than 85% thermal efficiencies (based on exhaust-gas losses). With the choice of an indirect heating regenerative burner, we envisioned that the amount of NOx discharged would increase, as described above, and consequently we adopted a two-stage combustion method for the reduction of NOx in the RRTB.

(3) Improved maintenance

From maintenance considerations, durable ceramic balls were selected for use as the heat storage elements. Furthermore, for the combustion air changeover valve, we selected a three-way valve (DV-80) made by the Yokoi Kikai Kosakusyo Co., Ltd. This valve had been used in our company's other regenerative burners and thus demonstrated the desired performance results.

(4) Flexibility of installation orientation

From a structural standpoint, there have been cases where previously commercialized regenerative radiant tube burners from other suppliers could only be oriented horizontally. Based on our new design of the internal structure, the burners of our RRTB can be installed in either the horizontal direction or the vertical direction. As a result, they cannot only be used in mesh-belt furnaces but there are also possible applications in tray pusher furnaces to heat non-preheated materials from the side.

2.2.2 Burner structure

A photograph of the exterior of the RRTB is shown in Figure 1, and a schematic diagram of the structure is provided in Figure 2.

As shown in Figure 2, the RRTB is comprised of the following main parts: a) burner body; b) thermal storage elements; c) burner gun; d) combustion tube; and e) radiant tube. Of these, the combustion tube (d) is the most important RRTB component with respect to the reduction of NOx. The combustion tube (d) is the structure that distributes the preheated combustion air from the thermal storage elements to two stages, where the preheated air distributed in the vicinity of the burner gun constitutes the first flame stage. The preheated air that is distributed between the combustion tube and the radiant tube contacts the first stage flame at the end of the burner tube, forming the second stage flame. By dividing the supply of combustion air into two stages, rapid combustion is suppressed and the flame temperature is limited, resulting in the reduction of NOx.

Additionally, the combustion tube has a special flange construction such that a burner, which previously could only be mounted horizontally, can now be mounted in a vertical position from the top portion of the furnace body.

2.2.3 Three-way valve (DV-80) structure

The DV-80 is depicted in Figure 3.

As shown in Figure 3, the DV-80 is comprised of the following main parts: a) body; b) cylinder; c) shaft; and d) auto switch.

In the DV-80 the cylinder is driven by compressed air, and the airflow is switched over by means of the shaft tip valve element, which moves up and down. Because the valve seat is permanently exposed to the temperature of the regenerative burner exhaust gas, a metal packing is used.

2.2.4 RRTB and DV-80 specifications

The specifications for the RRTB and the DV-80 are given in the tables 1 and 2.

2.2.5 RRTB basic performance

(1) Efficiency

The relationship between the respective furnace temperatures and thermal efficiencies of the RRTB-125 and the RRTB-150 are presented in Figure 4. For either type, it is verified that the thermal efficiency is greater than 85% (based on exhaust-gas losses) over all temperatures in the operating range.

(2) NOx

The relationship between the respective combustion capacities and NOx discharges at an oven temperature of 950^{o}C for the RRTB-125 and RRTB-150 is shown in Figure 5. At the rated combustion capacities, NOx values were kept below 200 ppm (11% O_2 basis value). When compared to prior regenerative radiant tube burners that did not employ NOx reduction technologies, this represents a reduction of approximately 50%. A significant reduction in NOx is ensured when using our burner, which incorporates two-stage combustion technology.

2.3 Field installation cases

2.3.1 RRTB-125

A particular customer has used an RRTB-125 in an actual factory operation since April 2010. There are 12 burners (six sets) installed in the heating zone of a continuous quenching furnace, and they are operated continuously 24 hours a day at temperatures in the range 830^{o} - 880^{o}C.
Under actual operating conditions, the thermal efficiency is approximately 90% (based on exhaust-gas losses; maximum gas temperature = 250^{o}C), and the NOx level is less than 180 ppm (11% O_2 basis). This operation thus verifies the high efficiency and low NOx emissions of the burner.

2.3.2 RRTB-150

A customer plans to start using an RRTB-150 at its site in September 2011. Details of the operating conditions and performance will be reported at IGRC2011.

2.4 Remote monitoring equipment

A diagram of the remote monitoring equipment is shown in Figure 6.
Remote monitoring equipment was set up at the customer's RRTB-125 installation. The system was configured to monitor the furnace temperature, exhaust temperature, airflow rate, gas flow rate and flame voltage.

In regenerative burners, the balance of thermal storage between a pair of burners degrades and the exhaust temperature rises, and there are also related breakdowns in the ancillary equipment (such as the changeover valve). The following are among the main causes of the degradation of the thermal storage balance:

Reduction of thermal storage due to clogging or breakage of the thermal storage elements;
Changes of thermal storage due to deviations of the gas flow rate from the setpoint;
Changes of extracted heat due to deviations of the airflow rate from the setpoint;
Changes of extracted heat accompanying reduced airflow due to changeover valve leakage.
Therefore, by constantly monitoring the exhaust gas temperature and the air and gas flow rates, any unusual conditions will be detected before the exhaust gas temperature becomes abnormally high, meaning it is possible to take corrective action.

Additionally, the monitoring of the Ultravision flame voltage enables one to not only monitor the presence, absence or timing of an accidental fire but also to detect the Ultravision self-discharge, making it possible to deal with problems quickly.

2.5 Summary

(a) A high-efficiency, low NOx RRTB was developed, incorporating a two-stage combustion process;
(b) A special combustion tube design permits installation in horizontal or vertical orientation;
(c) Based on actual operating conditions, it has been confirmed that thermal efficiencies are approximately 90% and that NOx levels are less than 180 ppm (11% O_2 basis value).
(d) Through the use of the remote monitoring system, abnormal conditions can be detected before a breakdown occurs, thus allowing prompt corrective measures to be taken.

3. REFERENCES

*1 Ichiro Nakamachi, Fujio Shoji, "Gas combustion theory and practice".

4. LIST OF PAPER

Type	RRTB-125	RRTB-150
Tube diameter	5 inch	6 inch
Rated combustion capacity	64 kW	93 kW
Maximum operating temperature	950°C (furnace temperature)	
Suitable air ratio	1.25	1.20
Gas supply pressure	> 10 kPa	
Gas type	13A	

Table 1 Newly developed burner (RRTB) specifications

Type	DV-80
Diameter	3 inch
Airflow rate	360 m3/h
Valve actuation pressure	0.2 to 0.5 MPa
Maximum operating temperature	400°C (exhaust gas)

Table 2 Three-way valve (DV-80) specifications

5. LIST OF FIGURES

Figure 1 Photograph of the newly developed burner (RRTB)

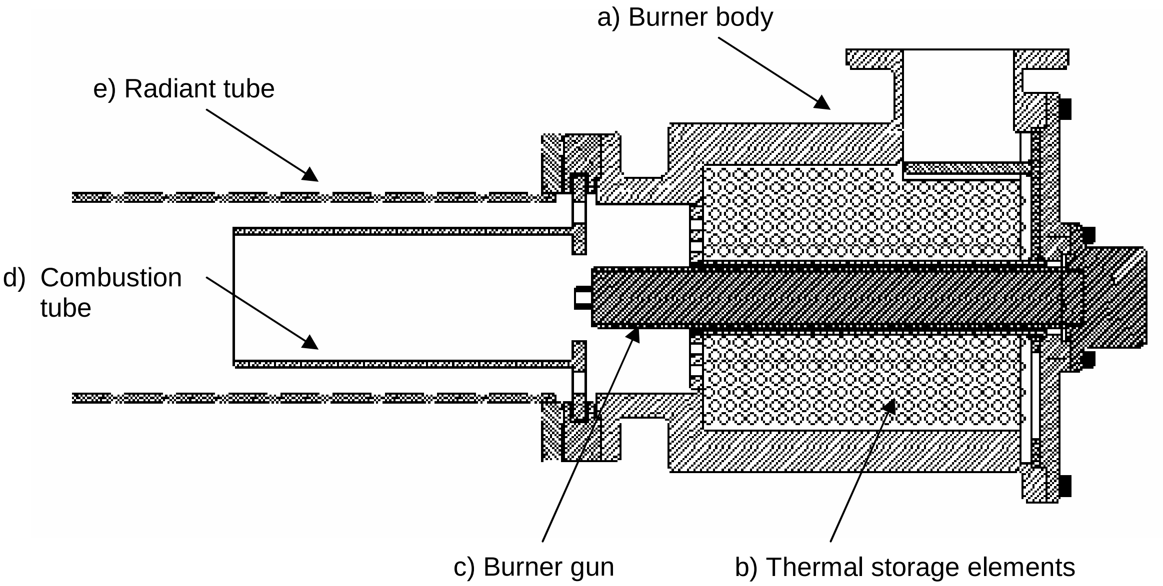


Figure 2 Schematic diagram of the newly developed burner (RRTB)

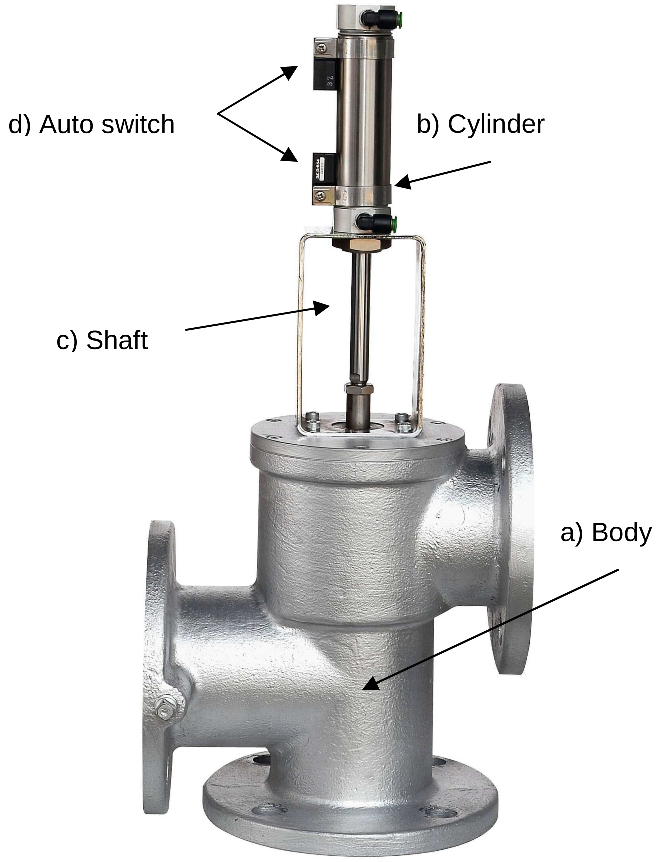
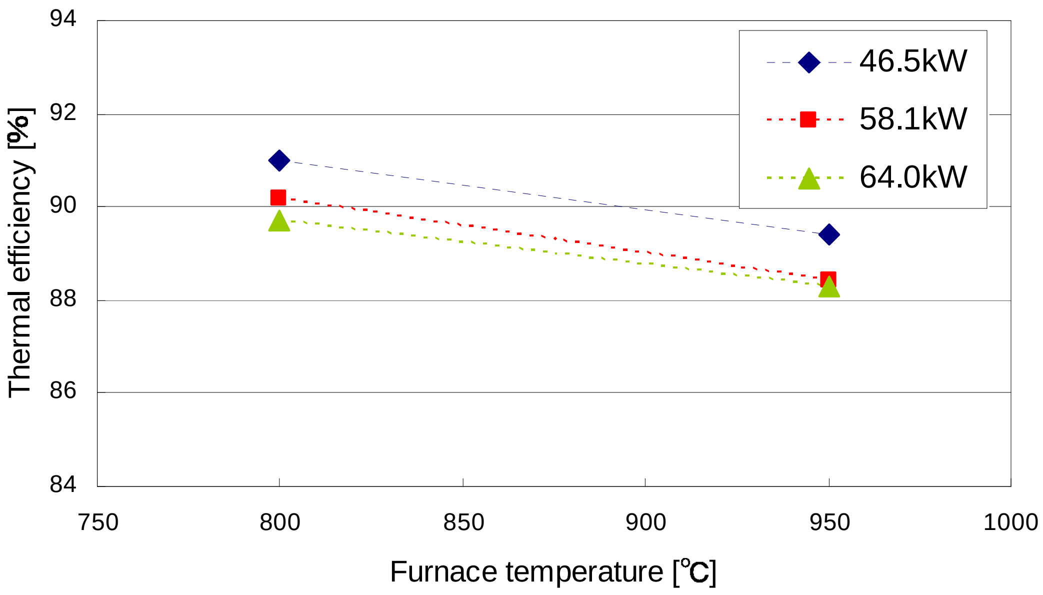


Figure 3 Photograph of the three-way valve (DV-80)

(a) RRTB-125



(b) RRTB-150

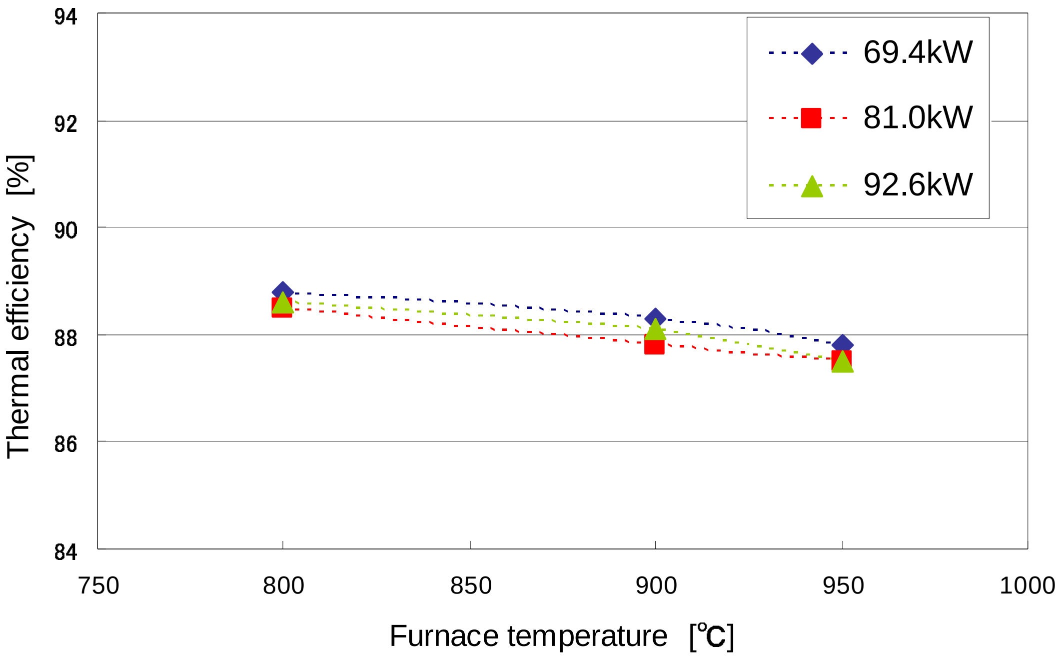
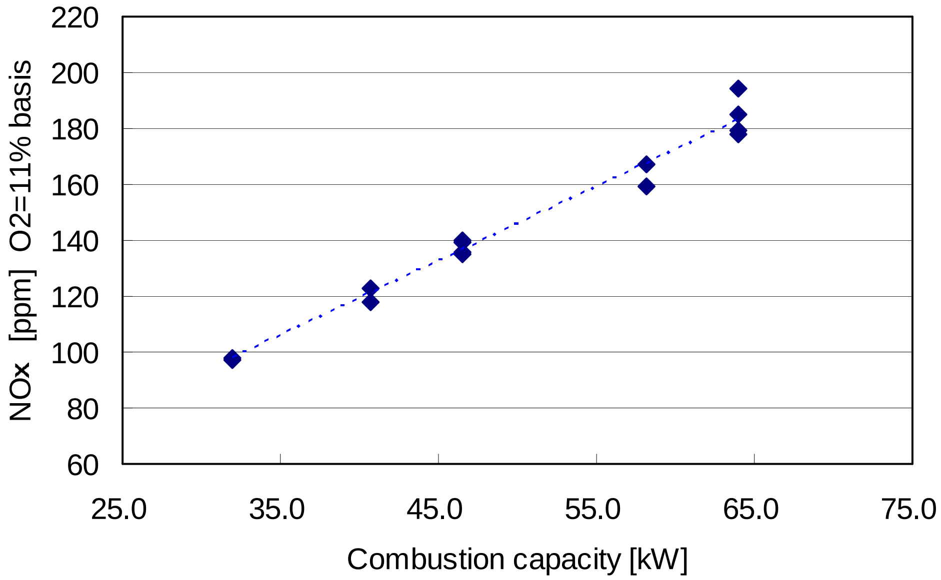


Figure 4 Relationship between furnace temperature and thermal efficiency for the (a) RRTB-125 and (b) RRTB-150.

(a) RRTB-125



(b) RRTB-150

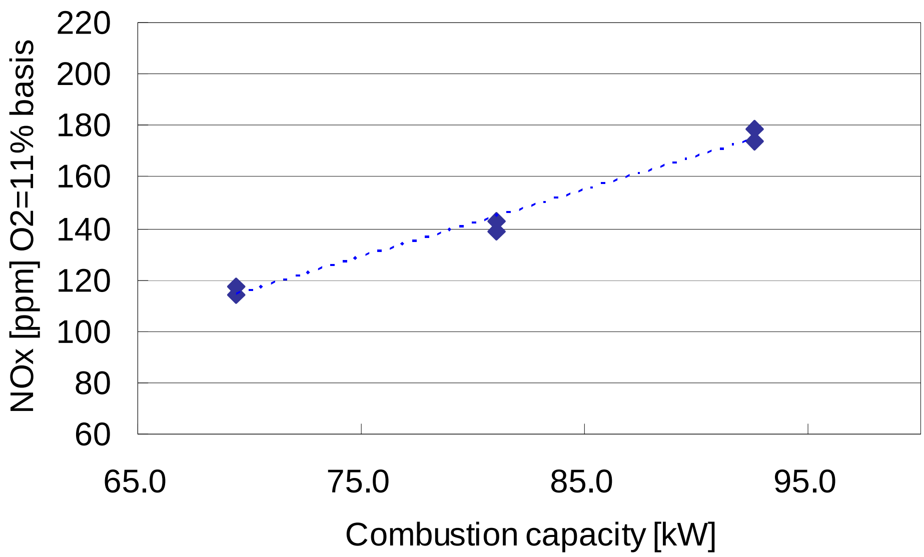


Figure 5 Relationship between combustion capacity and NOx emissions at 950 ℃ for the RRTB-125 and RRTB-150 .

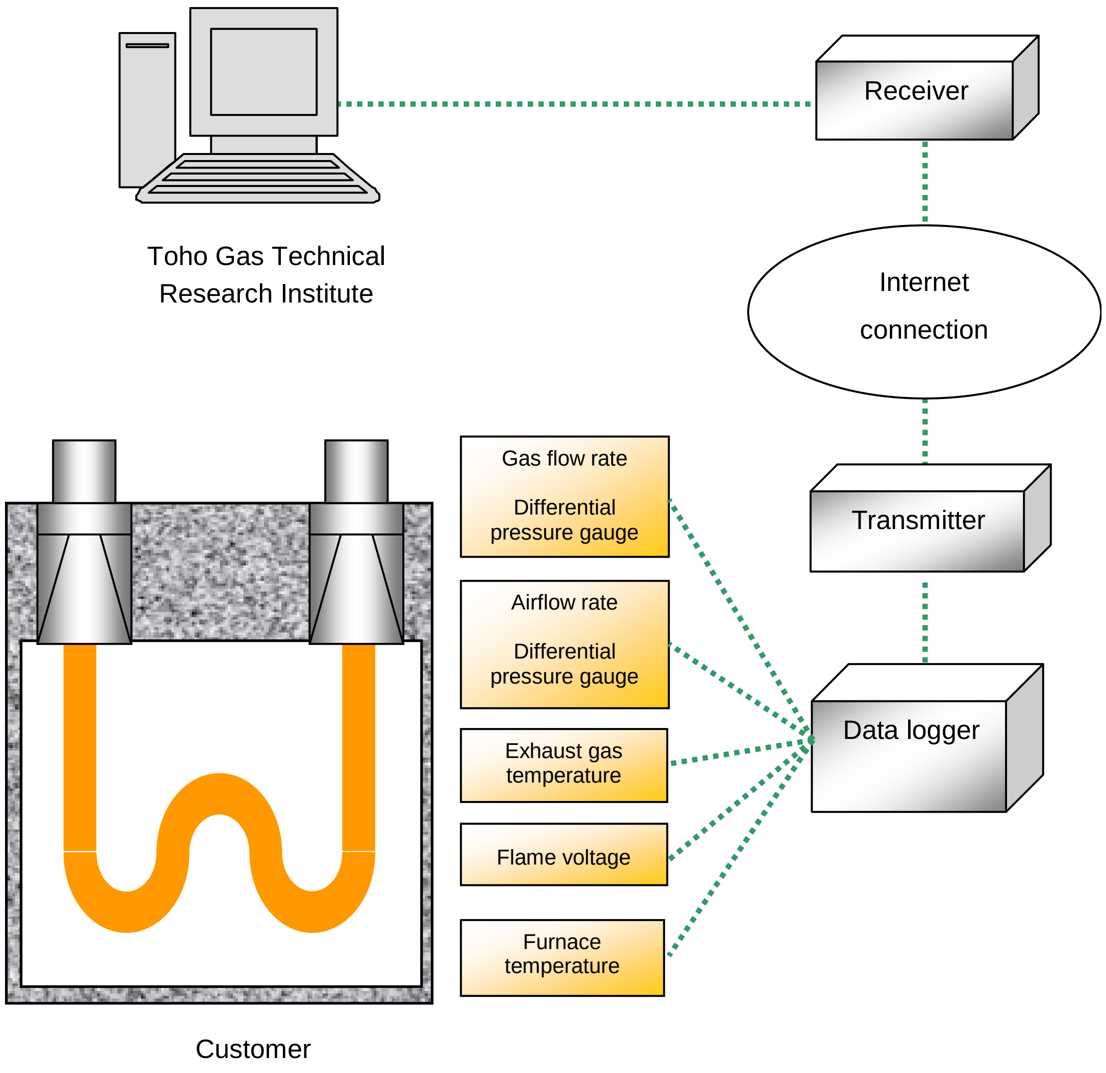


Figure 6 Diagram of the remote monitoring equipment