Development of Slab Reheating Furnace with Waste Gas Jet Preheating Equipment*

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Synopsis

A slab reheating furnace with waste gas jet preheating equipment is aimed for the reduction of energy consumption and the improvement of productivity. This paper describes the utilization of this equipment with special reference to the reduction of energy consumption.

The high heat transfer coefficient is obtained by gas jet. The waste gas of furnace is blown at a high speed on the charged slabs to preheat them. As a result, more heat of waste gas is utilized by the new equipment than by the conventional furnace. Kawasaki Heavy Industries, Ltd. has studied the heat transfer of gas jet in a commercial furnace.

This equipment has been applied to No. 1 reheating furnace of the new plate mill of Oita Works, Nippon Steel Corp. Since January, 1977, the reheating furnace has been operated without any equipment trouble and has improved energy consumption.

I. Preface

Remarkable energy saving of a reheating furnace has been achieved by reducing the radiation heat loss, improving the combustion control, improving the gas temperature distribution in the furnace, and other methods.¹⁾ Above all, reduction of the waste gas heat loss, a majority of the total heat loss, is very effective to improve thermal efficiency of the reheating furnace. There are two possible ways in order to reduce the waste gas heat loss. One is to recover waste heat in the flue and the other is to reduce the wasted energy at the waste gas outlet of the furnace. The former can be achieved by preheating slabs, preheating combustion air, installing a waste-heat boiler, and others.²⁾ The latter is achieved by controlling the fuel/air ratio for adjustment of the O_2 density and by reducing the waste gas temperature, as commonly carried out. The reduction of waste gas temperature depends upon the degree of the heat transfer improvement at each stage of the furnace.

When the furnace length is extended, the effect of heat radiation, a key factor of heat transfer, rapidly reduces with reduction of furnace temperature from the viewpoint of heat transfer characteristics of the furnace.³⁾ The effect is thus limited and other means for obtaining heat transfer are needed.

One of the means is the impinging jet heat transfer. A few years ago, Kawasaki Heavy Industries, Ltd. noticed that high heat transfer is obtained by impinging jet and initiated research for a new system of preheating slabs by gas jet. A reheating furnace with a waste gas jet preheating equipment has been developed jointly by Nippon Steel Corp. and Kawasaki Heavy Industries, Ltd. and has been built in an eco-

nomical low-heat intensity furnace, No. 1 slab reheating furnace (280 t/h) in Oita Works, Nippon Steel Corp. This is intended to obtain more heat transfer to slabs by utilizing the high-speed impinging gas jet obtaining than by radiation in the furnace.

Another system utilizes the waste gas discharged from an established furnace for preheating steels, recovers waste heat, and increases the furnace capacity. This system has been adapted to the round billet reheating furnace in Wakayama Steel Works, Sumitomo Metal Industries, Ltd.⁴⁾ The jet preheating method and the reheating furnace with a waste gas jet preheating equipment primarily developed to save energy by improved heat transfer in the furnace are outlined in this report.

II. Principle of Jet Preheating Equipment

The equipment is intended to preheat steels by jetting high-temperature, high speed waste gas from nozzles on the surface. The high speed impinging gas jet performs effective heat exchange between the steel and the high-temperature waste gas. The heat transfer is greatly influenced by the flow pattern from nozzles, by distance between nozzle and steel, nozzle pitches, jet speed at nozzle and other minor factors.⁵⁾ The coefficient of heat transfer at stagnation point just underneath the nozzle in Fig. 1 is very high. The coefficient of heat transfer in the impinging and wall jet regions is lower, but the experiment proves that the mean coefficient of heat transfer in these regions is considerably higher value than in a uniform flow.⁶⁻⁸⁾

In the air single-jet experiment by Nishiwaki and his group,⁹⁾ the coefficient of heat transfer α_0 at stagnation point became as high as 210 kcal/m²h°C at jet

Fig. 1. Flow of impinging jet.

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Fig. 2. Model of jet nozzles.

speed $W_0=42$ m/s when the ratio of distance H between nozzle and plate to the nozzle diameter D is 8, and the coefficients of heat transfer in the impinging and wall jet regions were reduced in proportion to $(r/D)^{-1/3}$, where r is the distance from stagnation point. The experimental result by R. Gardon and J. Cobonpue¹⁰⁾ gives the following experimental formula for the mean coefficient of heat transfer α_m (kcal/m²h°C):

$$Nu = 0.286Re^{0.625} \dots\dots\dots(1-1)$$

for the range $2.5 \times 10^4 < Re < 2.5 \times 10^5$,
 $1 < H/D, 24 < X_n/D < 32$ (see Fig. 2)

- where, Nu : Nusselt number $= \alpha_m \cdot X_n / \lambda$ (1-2)
 Re : Reynolds number $= U_a \cdot X_n / \nu$ (1-3)
 X_n : Nozzle pitch (m)
 U_a : Max. speed of free jet at plate position (m/s)
 λ : Heat conductivity of fluid (kcal/mh°C)
 ν : Dynamic viscosity coefficient of fluid (m²/s).

III. Heat Transfer of Impinging Gas Jet

In measurements for the heat transfer of impinging gas jet, air was used as fluid in a small-sized test furnace. It is questionable whether the experimental result can be applied to large-sized slab reheating furnace. The test furnace was manufactured as shown in Photo. 1 and the test was conducted with high temperature waste gas and commercial slabs.

1. Test Furnace

The steel plate casing of the test furnace is fixed with shaped steel, and the internal surface of the casing is coated with heat resisting ceramic fiber. The inner surface of gas headers on the ceiling is coated with castable refractory, and both the nozzle diameter and the slab/nozzle distance were changeable. Test slabs were 130 mm thick. The upper surface of a slab was preheated, while the lower surface was thoroughly insulated from heat by ceramic fiber coating. Hot combustion gas generated in the combustion chamber is blown from nozzles onto the slab at a high speed. Figure 3 is a schematic diagram of the test furnace. Figure 4 shows points on a slab for temperature measurements and nozzle arrangement.

2. Test Results

The mean value of the heat transfer coefficient α_m

Photo. 1. General view of test furnace.

on the slab surface was obtained by calculating the amount of absorbed heat at preheating temperature, taking into account the radiation heat transfer. The heat conductivity of combustion gas λ_g and the coefficient of dynamic viscosity ν_g are substituted in the following experimental formula of heat transfer for impinging jet.

$$Nu = \alpha_m \cdot X_n / \lambda_g = K_0 (U_g \cdot X_n / \nu_g)^m \dots\dots\dots(2-1)$$

Coefficients K_0 and m in this formula were obtained from the relation between Reynolds and Nusselt numbers shown in Fig. 5.

X_n is the same symbol as in Eq. (1-2). U_g is the maximum jet speed at the nozzle. λ_g and ν_g are defined by the mean values of gas temperature and slab surface temperature, respectively.

1. Mean Heat Transfer Characteristics on Slab Surface

Figure 5 shows the mean heat transfer characteristics for the impinging gas jet obtained in this test. The value of m was 0.625, very close to the test result in a previous report, but K_0 was very dependent upon the jet conditions. The jet gas temperature ranged from 450°C to 550°C.

2. Factor Affecting the Mean Heat Transfer Characteristic

(1) Distance H between Nozzle and Slab Surface

Figure 6 shows the result when the distance H was changed at a jet gas temperature of 550°C and a nozzle diameter of 90 mm. As can be seen in this diagram, the mean coefficient of heat transfer α_m reaches the maximum value at $H=200$ mm.

Fig. 3. Diagram of test furnace.

Fig. 4. Measuring points of slab temperature. (Nozzle pitch 480 mm)

Fig. 5. Relation between Reynolds and Nusselt numbers.

Fig. 6. Effect of distance between nozzle and slab on the heat transfer coefficient.

Fig. 7. Effect of nozzle diameter and nozzle pitch on the heat transfer coefficient.

(2) Influence of Nozzle Diameter D and Nozzle Pitch X_n

Figure 7 shows the effects of the nozzle size and the nozzle pitch on the heat transfer coefficient. For fixed flow rate of gas jet on unit slab surface, α_m becomes larger with decreasing nozzle diameter at $X_n/D=8$. However, the number of nozzles is increased with reduction of the nozzle pitch, and hence, this is not very practical in consideration of maintenance of a reheating furnace.

IV. Application to Reheating Furnace

To install a jet preheating equipment, high temperature booster fans, waste gas circulation duct, jet preheating chamber, and other equipments are required to the conventional reheating furnace when applying the jet preheating equipment to the conventional reheating furnace. There are two ways of application: to an existing furnace and to a new furnace.

1. Application to an Existing Furnace

In application to an existing furnace, strengthening the furnace capacity and more heat recovery of waste gas are required. For installation place, the space of the entry skid part may be utilized, or another independent place may be taken. However, existing furnaces have various designs, operating situations, and layouts, which should be investigated in accordance with cases. Calculation is herein made of the heat recovery of waste gas discharged from a high heat intensity furnace having a hearth load of 800 to 900 kg/m²h.

The common waste gas temperature is about 1 150°C for a furnace with a jet preheating equipment, and the slab temperature is preheated from 20°C to approx. 240°C before slabs are charged in the furnace. When the preheated steel of approx. 240°C is heated to about 1 250°C in the furnace, the waste gas temperature of this furnace goes down to about 940°C.

As a consequence, the waste gas loss and the heat given to steel in the furnace are reduced. Besides, the radiation heat loss of the furnace body due to the reduction of waste gas temperature of the furnace from 1 150°C to 940°C, the heat absorbed by skid cooling water, the heat loss from the charging door are reduced. Thereby, a large amount of fuel can be saved. The results so far attained show that the fuel consumption rate of the high heat intensity furnace is usually 400 to 450 kcal/kg. The use of this equipment makes possible the reduction of the fuel consumption rate by 20~30% to about 300 to 350 kcal/kg, ensuring considerable energy saving.

2. Application to New Furnaces

Description herein is provided of application as reheating furnace with jet preheating equipment. As shown in Fig. 8, the reheating furnace with jet preheating equipment comprises a conventional reheating furnace, recuperator, high temperature booster fan, waste gas circulation duct, jet preheating chamber, and others. However, to combine these equipments, a differential pressure control device in the throat is required.

In general, if the furnace length is extended, heat exchange is affected between combustion gas and steel so that waste gas temperature of the furnace is reduced, and the waste gas heat loss is reduced. However, as the amount of radiation heat is rapidly reduced with reduction of furnace temperature, the amount of heat transferred to steel is also reduced by extension of the furnace length. Besides, with extension of the furnace length, heat loss increases with increase of the water-cooling skid pipe length and of surface area of the furnace body. Accordingly, even with extension of the furnace length, there is a limit to reducing the fuel consumption rate.¹¹⁾

On the other hand, the facility cost increases with extension of the furnace length. Optimum furnace length must exist somewhere in view of economy. A calculation shows that favorable economical investment is obtained when the furnace length is extended to about 1.3~1.4 times of the conventional high heat intensity furnace. Reheating furnaces having such furnace length are called low heat intensity furnaces.

In Fig. 9, the broken lines show the longitudinal distribution of the temperature in a low heat intensity

Fig. 9. Temperature profile in preheating zone.

Fig. 8. Diagram of furnace pressure control.

furnace, and the full lines show the temperature distribution of reheating furnace with jet preheating equipment of the same furnace length. At position of a (m), the steel temperature is 130°C in the low heat intensity furnace and about 190°C in the furnace with jet preheating equipment. Waste gas temperature is about 990°C in the low heat intensity furnace and about 890°C in the furnace with jet preheating equipment. Obviously the furnace with jet preheating furnace is superior.

The specification of the new furnace is as follows:

Furnace type:	Walking beam
Furnace capacity:	280 t/h
Furnace dimensions	
Low heat intensity:	11.4 m wide×46 m long
Furnace with jet preheating equipment:	
	Reheating furnace length 40 m
	Jet zone length 6 m
Standard slab:	250 mm thick×1 900 mm wide×4 800 mm long
Charging row:	2 rows
Heating time:	180 min

Fuel: Coke oven gas
Calorific value: 4 430 kcal/Nm³

Table 1 shows the heat balance of the two furnace capacities of 280 t/h and 140 t/h (1/2 load). The fuel consumption rate 340 kcal/kg of the low heat intensity furnace was obtained for the reheating furnace in which slabs are discharged at 1 250°C and preheating combustion air temperature is 450°C.

The radiation heat losses were minimized by double-insulation of the skid pipes for the best thermal efficiency. The fuel consumption rate of the furnace with jet preheating equipment is 290 kcal/kg, about 15% reduction as compared with the low heat intensity furnace. The same condition was achieved in case of 1/2 load as well, and the reheating furnace had high thermal efficiency over a wide load range. Table 2 shows the running cost of the two furnaces for annual operating time of 6 000 h. For the furnace with jet preheating equipment, the electric power of the high temperature booster fan increases a little, reducing the fuel cost by 10%.

On the other hand, the facility investment for the

Table 1. Calculation of heat balance of 280 t/h walking beam furnace.

		Full capacity (280 t/h)		Half capacity (140 t/h)	
		Low heat intensity furnace	With preheating equipment	Low heat intensity furnace	With preheating equipment
Heat input	Combustion heat	95.2	81.2	53.1	44.2
	Sensible heat of fuel	0.1	0.1	—	—
	Sensible heat of hot air	16.0	13.7	7.9	6.6
	Oxidation heat of scale	2.6	2.6	1.3	1.3
	Total	113.9	97.6	62.3	52.1
Heat output	Latent heat of slab	56.1	50.5	28.0	25.6
	Sensible heat of scale	0.7	0.7	0.4	0.4
	Sensible heat of waste gas	41.1	34.6	19.6	15.8
	Total heat losses	16.0	11.8	14.3	10.3
Total consumption (kcal/kg)		340	290	379	316
Waste gas temperature (°C)		900	890	780	760
Preheating air temperature (°C)		450	450	400	400

Unit: Gcal/h

Table 2. Capital cost comparison.

Heating capacity Fuel consumption		Low heat intensity furnace		With preheating equipment	
		280 t/h 340 kcal/kg		280 t/h 290 kcal/kg	
	Yen	Consumption	Running cost (million yen)	Consumption	Running cost (million yen)
Fuel	13.3/Nm ³	21 500 Nm ³ /h	1 716	18 300 Nm ³ /h	1 460
Compressed air	1.7/Nm ³	105 Nm ³ /h	1	105 Nm ³ /h	1
Recirculating water	18/m ³	680 m ³ /h	112	680 m ³ /h	112
Fresh water	52/m ³	0.5 m ³ /h	—	1.5 m ³ /h	—
Electric power	10/kWh	800 kWh	48	1 540 kWh	92
Total running cost			1 877		1 665
Differential running cost			212 million yen/y

Fig. 10. Optimum length of waste gas jet preheating equipment.

furnace with jet preheating equipment becomes larger than that for the low heat intensity furnace, but this can be depreciated in a short term by large saving of fuel cost.

1. Length of Jet Preheating Chamber

There should exist the optimum length of the jet preheating chamber which minimizes the fuel consumption rate. The jet gas temperature is restricted by the heat resisting property of the high temperature booster fan, but the temperature should be 550°C. In excess of 550°C, air dilution should be made to keep constant the gas temperature at 550°C. Figure 10 shows the dependences of the slab preheating temperature t_{ve} , the waste gas temperature at outlet of furnace t_g , and the fuel consumption rate W_f on the ratio of the jet preheating chamber length to the total furnace length. Obviously, to obtain the minimum value of the fuel consumption rate, the jet preheating chamber should be about 13% of the overall effective furnace length.

2. Control of Furnace Pressure¹²⁾

In the reheating furnace with jet preheating equipment, a furnace pressure control device should be newly attached. Figure 8 shows a schematic diagram of furnace pressure control for the reheating furnace. The control device is used for the following purposes:

- 1) Preventing the exhaust gas from flowing out of the furnace, or the atmospheric air from flowing into the furnace
- 2) Keeping constant the flow rate of gas which passes through the throat part combining the jet zone and the combustion zone.

As controlled variables, ① the combustion zone pressure and ② the pressure difference between the jet zone and the combustion zone are selected for the above mentioned purposes. All the gas generated on the combustion zone goes through the jet zone and is drained to the stack.

Therefore, the followings are determined as manipulated variables:

- ① the duct damper at the jet zone outlet (the main damper)
- ② the duct damper at the booster fan suction side (the sub damper).

Then, the following five items are considered as key disturbances:

- a) Fluctuation of furnace load (change of the slab dimension, the extraction pitch, and others)
- b) Change of charging rate of fuel
- c) Opening and closing of the discharging door
- d) Opening and closing of the charging door
- e) Fluctuation of dilution air blow rate for the booster fan protection.

a, b and c represent the changes of gas blow rate in the combustion zone, while d and e cause a change of gas blow rate in the jet zone.

The favorable combinations of the controlled variables and the manipulated variables for disturbances

a, b and c are as follows:

Controlled variable ①—Manipulated variable ①

Controlled variable ②—Manipulated variable ②

The favorable combinations for disturbances d and e are as follows:

Controlled variable ①—Manipulated variable ②

Controlled variable ②—Manipulated variable ①

Here, disturbances c and d are larger than a, b or e. It is accordingly desirable to control for the larger disturbances c and d, but the combination of the controlled variable and the manipulated variables for c is different from that for d. That is why either should be selected. Taking into full consideration that disturbance e results from b and that the atmosphere in the combustion zone should not be disturbed, it is profitable to take the combination of the controlled variables—the manipulated variables for disturbances a, b and c. To evaluate the control system mentioned above and to determine the parameter values of each P-I controller, dynamic simulation was carried out using a mathematical model.

The results are shown in Figs. 11 and 12. Figure 11 is the result for 5% increase of the fuel charging rate from that for steady running. Figure 12 is the result when the discharging door was opened or closed. From these results, it is concluded that the furnace pressure control system of the reheating furnace shown in Fig. 8 was very effective.

V. No. 1 Slab Reheating Furnace at Oita Works, NSC

The world's largest new plate mill with a width of 5 500 mm started to work in January, 1977, at Oita Works. No. 1 reheating furnace of the new plate mill is the first one in which the jet preheating equipment so far mentioned was applied. Photograph 2 shows charging part of the furnace. The construction and operation of the furnace are introduced in the following.

1. Construction

1. Reheating Furnace

The furnace is of the walking beam with an end burner installed in the lower part of each of the six zones. Waste gas flows upward from the outlet of the furnace and exchanges heat with combustion air by means of a metallic recuperator in the flue. Then, the waste gas is sucked from the flue after the recuperator by high temperature booster fans, and is led to the jet preheating chamber, brown from the jet nozzles and exchanging heat with slabs (see Fig. 13).

Waste gas from the jet preheating chamber is discharged from a chimney. When the jet preheating chamber is not used (for example, failure of high

temperature fan *etc.*), the switchover damper enables the waste gas to flow out to the chimney directly from behind the recuperator. Up to now, there has been no trouble, requiring no need for the damper. Main specifications of the furnace are described in Table 3.

2. Jet Preheating Equipment

The facilities comprising the jet preheating equipment are a waste gas circulation duct, high temperature booster fans, jet nozzles, a jet preheating chamber, furnace pressure control device, and others. Main specifications are given in Table 4.

(1) Circulation Duct

The waste gas pipe leading to the jet nozzle header from high temperature booster fans *via* recuperator is called the circulation duct. The lining of the duct is made by heat resisting refractory blocks of 230 mm thickness to lessen heat radiation. Two high temperature booster fans have been arranged in both sides of the furnace body from capacity restriction. Besides, a diluting air inlet has been established at the suction side to protect the high temperature booster fans.

(2) High Temperature Booster Fan

The specifications of the high temperature booster fan have been determined without any empirical knowledge, and are given in Table 5.

Fig. 11. Simulation results (in response to fuel flow).

Fig. 12. Simulation results (in response to opening and closing of discharging door).

Photo. 2. Reheating furnace with waste gas jet preheating equipment in plate mill at Oita Works.

Fig. 13. Longitudinal sections of reheating furnace with waste gas jet preheating equipment.

Table 3. Specifications of reheating furnace.

Item	Specifications
Furnace type	Walking beam
Heating capacity	280 t/h
Heating rate	650 kg/m ² h
Furnace size	11 400 mm width × 47 500 mm length
Fuel	Coke oven gas
Fuel consumption	290 kcal/kg
Slab thickness	100~300 mm
Slab width	1 500~3 000 mm
Slab length	2 600~5 200 mm × 2 rows
Slab heating temp.	1 250°C

Table 4. Specifications of jet preheating equipment.

Item	Specifications
Slab size and rows	250 mm × 1 900 mm × 4 800 mm × 2 rows
Nozzle dia. and pitch	60 mm × 480 p
Jet speed and temp.	75 m/s, 550°C
Preheating time	24 min
Slab temperature	200 ± 20°C
Zone length	6 200 mm

Table 5. Specifications of booster fan.

Item	Specifications
Type	Paddle type
Flow rate	3 700 m ³ /min
Total pressure	300 mmAq
Waste gas temperature	550°C
Motor	420 kW (6 600 V, 60 Hz, 6 p)

(i) Type

The paddle type is of simple construction having no clear surging zone and is most suitable to the reheating furnace having large fluctuation of waste gas volume.

(ii) Vane Material

Austenitic alloy steel having high temperature strength is excellent but has defects such as small thermal conductivity and large thermal expansion ratio liable to cause thermal distortion. Therefore, martensitic alloy steel has been selected.

(3) Jet Nozzle and Nozzle Headers

Nozzle headers have been arranged in the direction of furnace length and constructed so that some of them can be withdrawn by the control valve. To take out lower nozzle headers, piping has been performed under the entry skids at the charging port and the driving mechanism of the walking beam has been working perfectly. Jet nozzles have been placed every 480 mm so that there was a wide space in the furnace for maintenance.

Jet nozzles in the lower part has been arranged so as to go away from the skid pipes and riser pipes. The longitudinal section of jet preheating equipment is shown in Fig. 14 and the cross section in Fig. 15. Jet nozzles and nozzle headers were made of heat resisting steel, thermal expansion having been taken

Fig. 14. Longitudinal sections of preheating equipment.

Fig. 15. Cross sections of preheating equipment.

into consideration regarding their mounting method. The inside diameter of a nozzle is 53.5 mm.

(4) Jet Preheating Chamber

The chamber body temperature does not exceed 550°C and the body is of the simplest steel construction having the lining build up with Y-shape studs and heat-resisting castable material of 150 mm thickness. Insulation of skid pipes, 50 mm thickness, is castable and less expensive than the low-heat intensity furnace.

(5) Furnace Pressure Control Device

The construction comprises heat-resisting dampers and furnace pressure detecting ends. The control system is described in IV.2.2.

3. Others

(1) Flue and Chimney

Installation of the jet preheating equipment allows for reductions of the fuel consumption rate and the waste gas volume. Reduced waste gas temperature permits reducing the cross section area of flue and chimney in design, leading to inexpensive facility.

(2) Combustion Zone

In case of a low-heat intensity furnace with a length of 46 m, eight combustion zones are required. However, the jet preheating equipment necessitates only six zones.

(3) Combustion Air Blower

Reduced fuel consumption rate accounts for the lowering of blower capacity and pipe size.

2. Operation

In three months after the new Works was put in operation, a performance test was conducted under the conditions shown in Table 6. The result is reported in the following.

1. Slab Temperature in Jet Preheating Equipment

3.2 mm ϕ CA thermocouple was embedded in a normal steel slab 250 mm thick $\times$ 1 895 mm wide $\times$ 3 725 mm long to measure the temperature. The result is shown in Fig. 16. As shown in Fig. 16, temperatures were measured at 6 points, *i.e.*, 25 mm from the surface between nozzles, center of thickness and 25 mm from the surface of the other side. The mean jet gas temperature $T_{gn}=400^{\circ}\text{C}$, and the mean jet gas speed from nozzles $U_{gn}=80$ m/s.

The distance between jet nozzle and slab was varied by vertical movement of the walking beam, and the temperature increased almost linearly to about 160°C. The data point in Fig. 5 is within the experimental range. Slabs were preheated to 40°C, because jet gas flowed on the slab on the entry skid through the charging door. In some cases, water dew formed on the cooled slab on the entry skids.

2. Heat Balance

The operating conditions for the 8 h measurement are shown in Table 6, and the results for actual heat balance are shown in Table 7. The fuel consumption rate was 293 kcal/kg. The power of high temperature booster fan was estimated to be 1.8 kwh/t from the measured value, corresponding to 4 400 kcal/t when converted into primary energy for 35% generation efficiency.

3. Summary

Problems with the jet preheating equipment have

Table 6. Operating conditions of heat balance.

Item	Conditions
Measuring time	480 min
Rolling time	347 min (72.3%)
Heating capacity	167 t/h
Slab thickness	247 mm
Slab length and rows	3 631 mm $\times$ 2 rows
Slab temperature	1 150°C

been related to failure of high temperature booster fan, jet nozzles, and others, to analysis of furnace performance depending on heat transfer characteristics, and to economy including investments. After the passage of about one year, there is no failure on the facility and satisfactory production is being continued.

VI. Conclusion

Outlined was the reheating furnace with jet preheating equipment joint-developed and utilized by Nippon Steel Corp. and Kawasaki Heavy Industries, Ltd.

As for the heat transfer characteristics depending upon impinging jet, almost the same value was obtained in the test and in the commercial furnace. As the whole commercial furnace is not fully adjusted, the optimum operational state is not yet achieved. However, the monthly mean fuel consumption rate has been reduced to 270 kcal/kg.

In the initial designing, facility maintenance as well as performance was considered. There has been no problem on facility maintenance. In the future, the operational references and facilities for improving the performance further will be investigated.

This method has been developed as a heat recovery method of waste gas to increase heat transfer to steel in the low temperature region. This must be the technology to be expected in the future as well and will greatly contribute to energy saving.

Finally, we express our thanks for cooperation of the persons concerning the development of the new furnace.

Fig. 16. Measured slab temperatures.

Table 7. Actual heat balance at Oita Works, NSC.

Heat input					Heat output				
		(Mcal/h)	(kcal/kg)	(%)			(Mcal/h)	(kcal/kg)	(%)
①	Combustion heat	48 884	293	83.0	⑥	Latent heat of discharging slab	31 196	187	53.0
②	Sensible heat of fuel	85	—	—	⑦	Sensible heat of scale	200	1	0.3
③	Sensible heat of air	6 022	36	10.2	⑧	Sensible heat of waste gas	20 225	121	34.3
④	Latent heat of charging slab	3 139	19	5.4	⑨	Heat loss for cooling water	4 336	26	7.3
⑤	Oxidation heat of scale	809	5	1.4	⑩	Radiation heat losses	1 356	8	2.3
					⑪	Other heat losses	1 626	10	2.8
Total		58 939	353	100	Total		58 939	353	100

$$\text{Heat efficiency} = \frac{\textcircled{6}}{\textcircled{1}} \times 100 = 63.8\%$$

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