3.2 Guideline for Energy Efficiency Improvement and Conservation for Iron and Steel-making Industry

3.2.1 Introduction

Iron and steel-making plants include the following five types: process flowchart of iron and steel production is shown in Figure 3.2.1-1.

(1) Integrated steel works where iron ores are processed to make pig iron by a blast furnace / COREX, which is processed into steel and further into steel products such as steel sheets, steel bars, etc.

(2) Steel works where DRI (Direct-reduced iron) is made by a direct-reduction method and processed into steel by an electric furnace and further into steel products.

(3) Electric furnace plants where DRI and steel scraps are molten by an electric furnace to make steel without using a blast furnace or a direct reducing furnace.

(4) Foundries where pig iron and iron scrap, etc. are melted in a cupola, an induction furnace of high frequency and low frequency, electric furnace, etc. to make cast iron/steel, then cast it into a mold and thereby produce castings.

(5) Simple rolling mills without any electric furnace, etc. when steel products such as slabs, blooms and billets, which are intermediate products, are purchased from the above-described plants (1), (2), or (3) to produce plate steels, steel bars and steel pipes.

An integrated steel works involves many processes, including a blast furnace where iron ores are reduced into pig iron, a sintering plant, a coke oven plant, etc. Although such a plant has a high energy utilization rate as a whole, it costs much in terms of equipment investment. Therefore, an integrated steel works is constructed at a place where the transportation cost of raw materials, iron ore and coal is low. And generally these steel plants are with an annual production capacity of some millions of ton. A direct-reducing steel works is constructed in a region where natural gas is available at a low price which directly influences the manufacturing costs.

On the other hand, although an electric furnace plant is not suitable for manufacturing high-quality products, it has such advantages as relatively low equipment and other capital costs, and the comparative ease in production and operation change, and processes suitable for manufacturing a variety of products in small quantities. Therefore, electric furnace plants are often located near the product consuming areas where product consumption is high and the production capacity is commensurate with the demand of that area.

In Indonesia, there are no integrated iron and steel works with blast furnace and converter system, but there are an integrated iron and steel works with direct reducing furnaces, electric furnace factories and foundries. This chapter describes mainly an electric arc furnace and billet reheating furnace of equipment consuming large amounts of energy in steel works. With regard to other factories, their specific types of equipment that consume large amount of energy will be explained later.

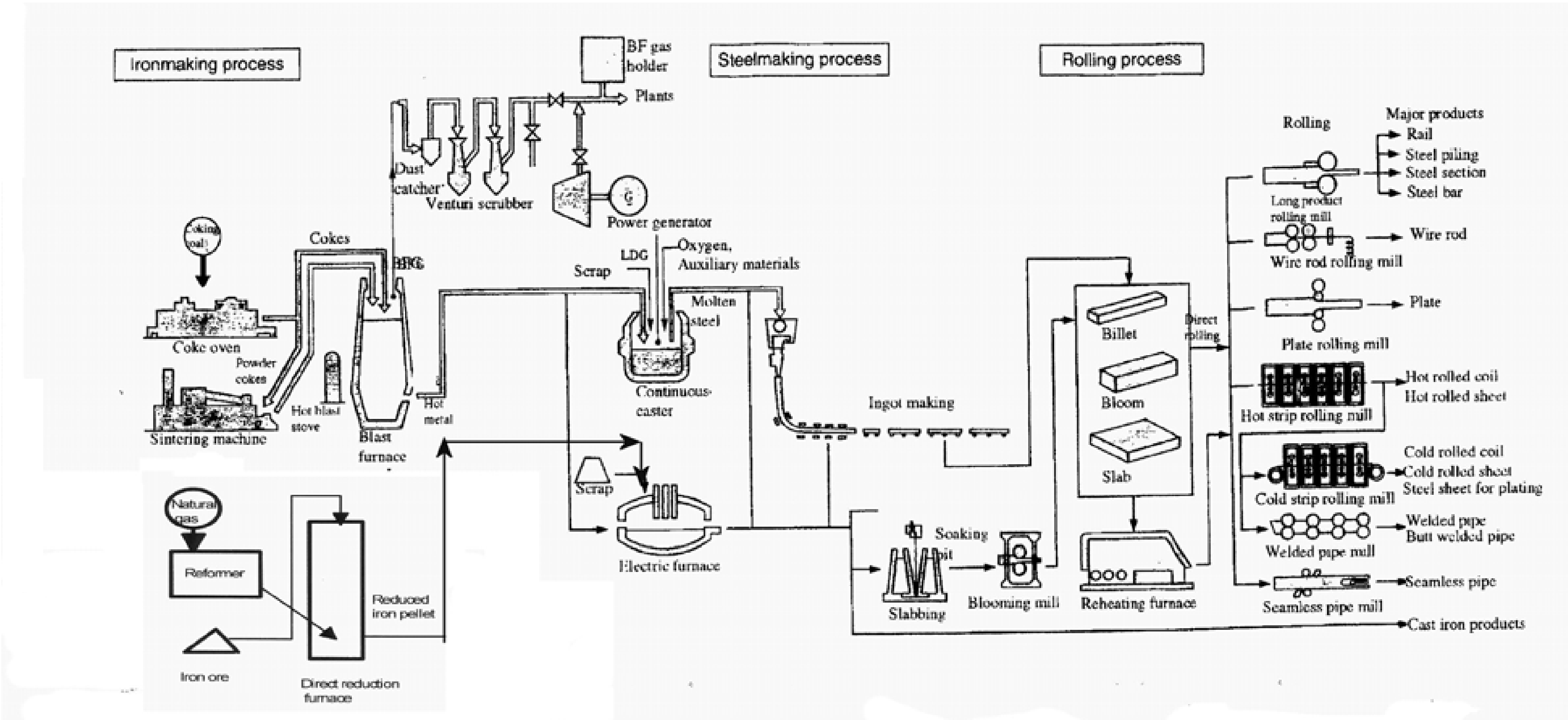

Figure 3.2.1-1 Process Flow of Iron and Steel Production

3.2.2 Process Overview of Electric Arc Furnace Plants and Energy Conservation Themes

An electric arc furnace offers favorable conditions for energy intensity per ton of steel produced, as well as low production costs, which is, however, largely influenced by price of scrap, because it principally uses scrap steel as raw materials and does not require the process of reducing iron ores as in the case with integrated steel works. The arc furnace is less suitable for producing high purity, high quality steel, since it cannot eliminate impurities contained in scrap such as Cu, Cr, Ni, etc. However, its market share is expected to expand in the future since it contributes to raising the recycle ratio of steel products, and enables lower product prices. This section picks up and explains typical types in equipment of an electric furnace factory, such as electric furnaces and billet reheating furnaces in rolling mill.

Figure 3.2.2-1 shows the flow of raw materials and products at an electric arc furnace plant.

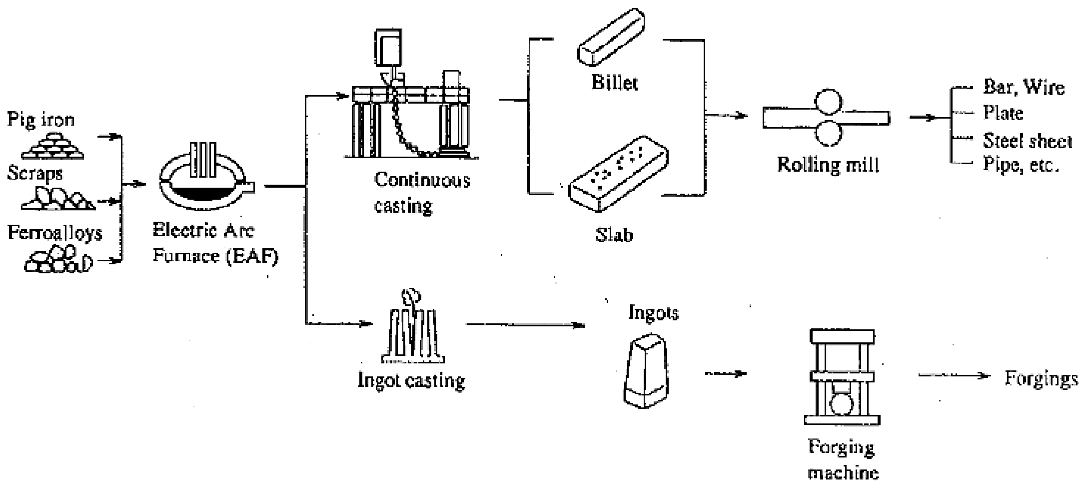

Figure 3.2.2-1 Flow of Raw Materials and Products of Arc Furnace Steel-making Method

(1) Themes of Energy Conservation Measures

Themes of energy conservation measures in electric furnace factories are shown in Table 3.2.2.1-1. The details of themes are described later.

Table 3.2.2-1 Themes of Energy Conservation Measures in Electric Furnace Factories

No.	Category	Energy conservation measures	Energy saving effects	Investment cost	Remarks
1	Electric arc furnace	Increase of transformer capacity	Reduction of melting time by high power supply	New installation revamping	
2	Electric arc furnace	Installation of supporting burner: Supply of diesel oil, heavy oil natural gas, coke and oxygen gas	Reduction of melting time of scrap Heavy oil volume : 5 liter/t ⇒ Power saving : 45kWh/ton	Installation cost of support burner	
3	Electric arc furnace	Reduction of melting time by injection of oxygen gas	Oxygen gas volume : 10 m^3N/t ⇒ 55kWh/ton	Installation cost of oxygen generator	
4	Electric arc furnace	Reduction of melting time by injection of carbon	Coke volume : 10kg/t ⇒ 50kWh/ton	Installation cost of carbon injection unit	
5	Electric arc furnace	Installation of scrap pre-heater	Improvement of power intensity : 20-40 kWh/ton	Installation cost of scrap pre-heater	
6	Electric arc furnace	Reduction of power-off time: - Scrap charging time, electrodes connection time, tap-to-tap time, furnace repairing time	Increase of production by reduction of power-off time	Modification cost of top covers lifter unit	
7	Electric arc furnace	Installation of secondary smelting plant: Products quality improvement and production increase by installation of ladle furnace	Productivity improvement by electric furnace for melting and ladle furnace for refining	Installation cost of ladle furnace	
8	Electric arc furnace	Reduction of tapping temperature	By reduction of 10 0C of tapping temperature, Improvement of electric intensity by 3kWh/ton	No investment cost	
9	Electric arc furnace	Optimum control of electric power input by computer control	Optimum control of electric power input	Installation cost of Computer control unit	
10	Electric arc furnace	Reduction of heat loss by cooling water of furnace body	Increase of refractory life of furnace	Installation cost of water cooling block of furnace	

No.	Category	Energy conservation measures	Energy saving effects	Investment cost	Remarks
11	Electric arc furnace	Reduction of tap-to-tap time	Reduction of tap-to-tap time by 30min ⇒ Improvement of power intensity by 50kWh/ton		
12	Reheating furnace	Improvement of air ratio	At exhaust gas temp.=500℃ and air ratio change =1.5 to 1.2; Fuel saving is 9%.	Installation cost of oxygen analyzer for exhaust gas	
13	Reheating furnace	Pre-heating of combustion air by waste heat recovery	At air ratio= 1.2, pre-heating air temp.= 400 ℃ and waste gas temp.= 800℃, fuel saving rate is 30%	Installation cost of air pre-heater	
14	Reheating furnace	Lower temperature of discharging billet	By lowering of discharging temperature of 10℃, fuel saving is 3 Mcal/ton	No investment cost	
15	Reheating furnace	Improvement of hot charge ratio	By increase of charging temperature of 100℃,fuel saving is 20Mcal/ton	Installation cost of Insulation box and cover	
16	Reheating furnace	Reduction of heat loss from furnace wall by ceramic fiber lining	Reduction ratio of dispersing heat loss :30%	Purchasing cost of ceramic fiber	
17	Reheating furnace	Prevention of heat loss from openings such as charging port and inspection port.	By close of openings, fuel saving ratio is 5%	No investment cost	
18	Reheating furnace	Reinforcement of insulation of water cooled skid pipe	By means of double insulation method for skid pipe, fuel saving ratio 5%	Insulation work cost	
19	Reheating furnace	Introduction of regenerative burner	By means of regenerative burner, fuel intensity improvement is 30 to 50%.	Installation cost of regenerative cost and modification cost of furnace body and piping	
20	Reheating furnace	Improvement of rolling yield: Reduction of scale loss, crop loss and miss roll	By improvement of rolling yield, fuel intensity of reheating furnace and power intensity in rolling mill are improved.	No investment cost	

(2) Electric Arc Furnace

I) Steel-making process by an electric furnace

In the steel making process, scrap is heated, melted, reduced in an electric arc furnace (if necessary, degassing and other processes can be carried out with a secondary smelter), and the molten steel is then transferred to a continuous caster (CC), or to a conventional caster to produce slabs or ingots.

The steel-making process uses approximately 75 % of the total amount of energy consumed at an electric arc furnace plant, and most of the energy in the steel-making process is consumed by the electric arc furnace.

Scrap is heated and melted inside the arc furnace by the arc heat generated between the scrap and the electrodes, and by the electric resistance generated within the scrap.

Normally, three-phase alternating currents ate the principal energy source for this process.

Figure 3.2.2-2 shows a flow diagram of the process of an electric arc furnace and energy conservation measures thereof.

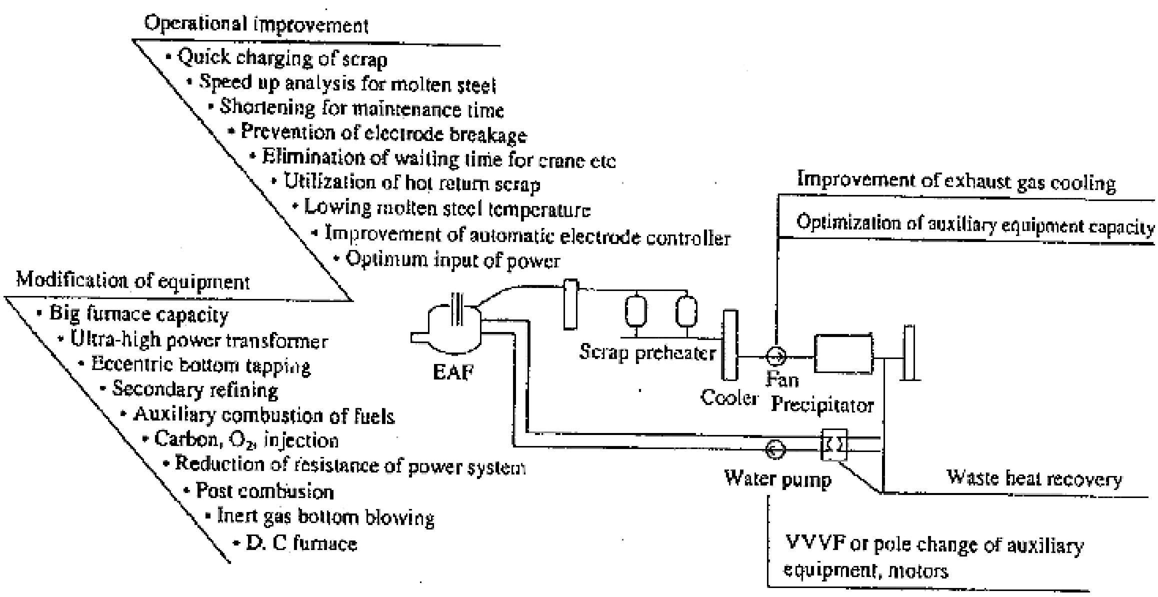

Figure 3.2.2-2 Flow and Energy Conservation Measures for Arc Furnaces

2) Energy conservation by improvement of the operation and equipment

The substantial effect of energy conservation achieved in the steel-making process is owed greatly to a rise in the continuous casting ratio, improved productivity of the electric arc furnace due to feeding of auxiliary fuels such as fuel oil and carbon, and injection of oxygen. An explanation of energy conservation measures for auxiliary machinery at electric arc furnaces, such as dust collectors and cooling water pumps, etc, will be omitted here since these technologies are common to other facilities as well. The main emphasis will he placed rather on how to improve the energy intensity of the electric arc furnace itself.

Electric arc furnaces consume a large amount of electricity. Assuming that fuel is converted into electricity by a power generation plant of PLN in Indonesia at a net thermal efficiency of 32.84 %, l kWh of that electric power should be equivalent to 10,965 kJ (2,619 kcal).

The measures for reduction of electricity intensity, as described below, are taken in order to decrease the cost for producing molten steel by an electric furnace. The effect evaluated based on I kWh = 10,965 kJ (2,619 kcal) shows that cost reduction measures constitutes energy conservation measures as well.

Generally, electric arc furnaces have fixed energy losses such as heat loss due to cooling water loss, radiated and dispersed heat losses of the furnace body. If the tap-to-tap time can be reduced by increasing the amount of energy input to the electric arc furnace; in other words, if productivity (tapping steel quantity per unit time) can be raised by increasing the amount of energy input, the rate of fixed losses will fall, and the energy intensity can be lowered. In view of the above, improving productivity has always been considered to be an effective energy conservation method. An example of a heat balance sheet for an electric arc furnace is shown in Table 3.2.2-2.

Here, however, I kWh of electricity should be treated as the equivalent of approx, 3600 kJ (860 kcal) in a theoretical analysis of the energy balance of an electric arc furnace.

Table 3.2.2-2 Heat Balance of Electric arc Furnace (Example)

Meal/t tapping

Heat input			Heat output		
	10^3 kcal/t	**%**		**10^3 kcal/t**	**%**
Heat by electric power	302	50.2	Sensible heat of molten steel	342	56.8
Combustion heat (Fuel)	41	6.8	Sensible heat of slag	52	8.6
Oxidation heat of electrode	20	3.3	Heat loss by exhaust gas	71	11.8
Oxidation heat of charged raw materials	197	32.7	Heat loss by cooling water	62	10.3
Heat of slag formation	12	2.0	Heat loss of transformer and secondary conductor	22	3.7
Heat recovered by preheated	15	2.5			
Other	15	2.5	Other	53	8.8
Heat input total	**602**	**100**	**Heat output total**	**602**	**100**

Heat input			Heat output		
	10^3 kcal/t	**%**		**10^3 kcal/t**	**%**
Heat by electric power	373	59.1	Sensible heat of molten steel	340	53.9
Combustion heat (Fuel)	25	4.0	Sensible heat of slag	47	7.4
Oxidation heat of electrode	26	4.1	Heat loss by exhaust gas	111	17.6
Oxidation heat of charged raw materials	192	30.4	Heat loss by cooling water	30	4.8
Heat of slag formation	11	1.8	Heat loss of transformer and secondary conductor	28	4.4
Heat recovered by preheated	−				
Other	4	0.6	Other	75	11.9
Heat input total	**631**	**100**	**Heat output total**	**631**	**100**

The following measures can he considered in order to improve the productivity of arc furnaces.

- Increasing the transformer capacity
- Improving the electricity intensity by utilizing a supporting burner, implementing oxygen injection, carbon injections, and preheating scrap
- Reducing the amount of power-off time
- Improving thermal efficiency
- Introducing secondary smelting equipment

Next, each of these measures is explained in further detail.

a) Increasing the transformer capacity

Transformer capacity of arc furnaces has exhibited a trend of steady growth in recent years, as the transition of RP (Regular Power) → HP (High Power) → UHP (Ultra High Power) has been carried out. Table 3.2.2-3 shows the relationship between arc furnace capacity and transformer capacity.

As shown in the table, it has become possible to increase the size of transformers and input a greater amount of electric power owing to 4 kinds of technologies:

- the technology to manufacture electrodes for UHP;
- technologies to water-cool furnace walls and ceiling, technology related to

refractory,
- slag forming technology,
- stabilization of electric arcs during the initial melting period using residual molten metal

Table 3.2.2-3 Relationship between Furnace Capacity, Required Size and Electrical Equipment

Nominal capacity of furnace [10^3 kg]	Outside diameter of furnace core [m]	Metal bath depth [mm]	Diameter of electrode [mm]	Capacity of transformer [MV·A] RP	HP	UHP	Secondary voltage (RP furnace) [V]
2	2.178	300	175	1.5	−	−	180 − 80
5	2.743	400	200 − 250	3	5	−	200 − 100
10	3.353	400	300 − 350	5	7.5	−	220 − 100
20	3.962	450	350 − 400	7.5	12	15	240 − 100
30	4.572	650	400 − 450	12	18	22	270 − 120
50	5.182	750	450 − 500	18	25	30	330 − 130
60	5.486	850	500	20	27	35	400 − 130
70	5.791	850	500	22	30	40	400 − 130
80	6.096	900	500	25	35	45	430 − 140
100	6.400	950	500 − 550	27	40	50	460 − 160
120	6.706	1,000	550 − 600	30	45	60	500 − 200
150	7.010	1,000	600	30	50	70	500 − 200
170	7.315	1,050	600	35	60	80	500 − 200
200	7.620	1,100	600	40	70	100	560 − 200
400	9.754	1,200	700	−	−	150	

Notes: RP: regular power, HP: high Power, UHP: ultra-high power
Source: Cast Product Handbook, 4th Edition, edited by Japan Cast Product Association

b) Reducing the electricity intensity

a. Supporting burner

The temperature rise and melting of scrap is facilitated by installing a supporting burner and utilizing kerosene, fuel oil, and natural gas, etc., while simultaneously supplying the necessary amount of oxygen. The burner is normally installed facing the cold spot.

An example of a supporting burner installation is shown in Figure 3.2.2-3, and the effect of reduction in electricity intensity by using a fuel oil burner is shown in Figure 3.2.2-4. The energy saving effect of support burner is 5 to 9 kWh/liter-oil

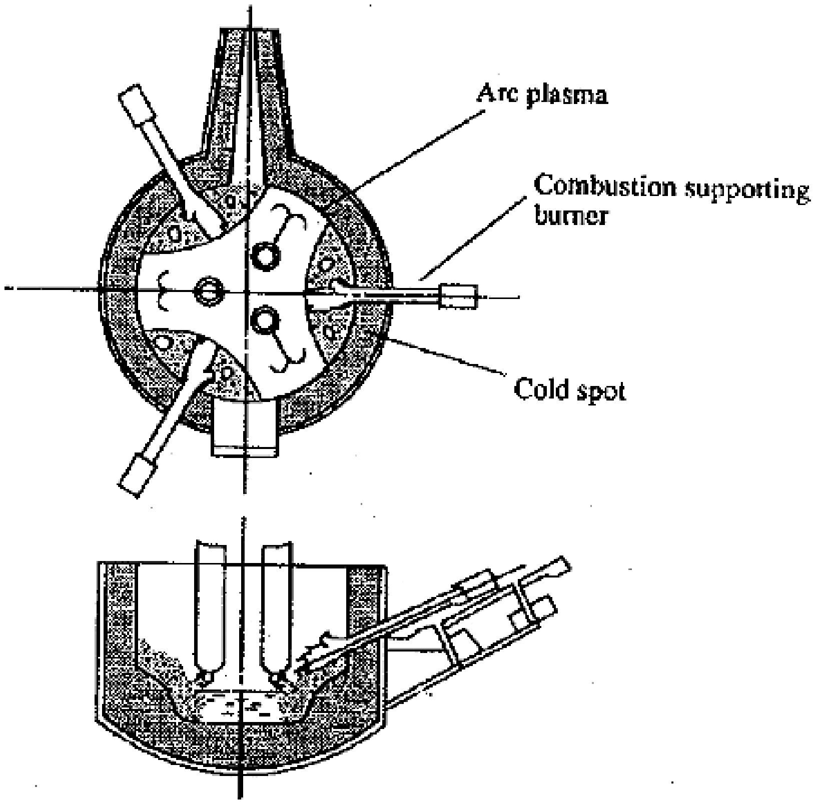

Figure 3.2.2-3 Example of Combustion Supporting Burner Installation

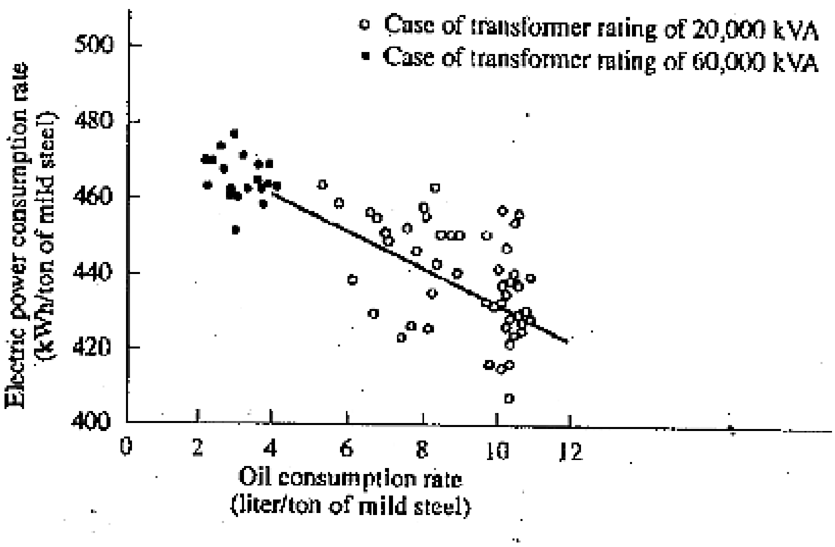

Figure 3.2.2-4 Effect of Combustion Burner

b. Oxygen injection operation

Oxygen injection operations, in which oxygen is directly blown against scrap and molten steel, has the effect of enhancing scrap cutting and Fe oxidation reactions as well as increasing heating and melting speed on the one hand, while on the other hand they exhibit a shortcoming in terms of decreased yield in the tapped steel. The carbon injection process was developed to solve this deficiency, and at present, the electricity intensity is reduced by effectively combining:

- the supporting burner,
- oxygen injection operations, and
- carbon injections.

While this has the effect of reducing the rate by 5.5 kWh of electric power per 1 m^3N/t of oxygen, the effect is halved for 20 m^3N/t, and further oxygen injection will increase oxidization loss, thus producing an adverse effect.

The effect of an oxygen injection operation is shown in Figure 3.2.2-5.

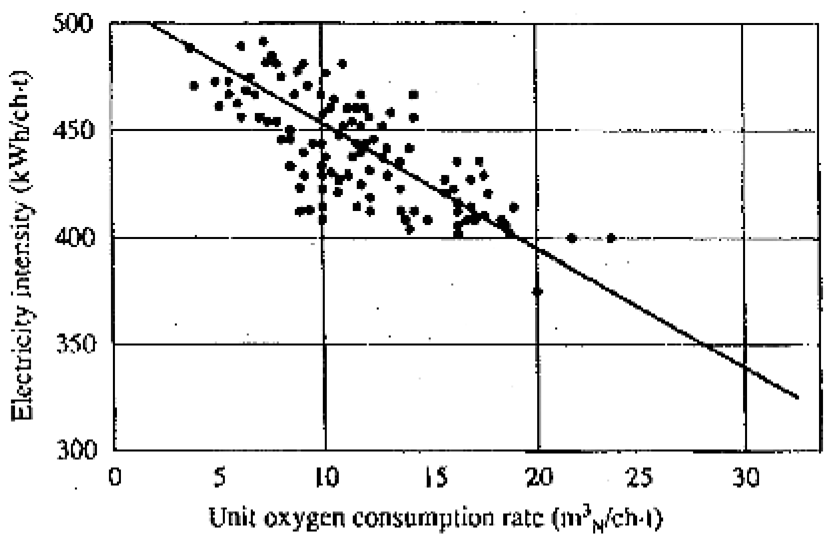

Figure 3.2.2-5 Effect of Oxygen Injection

c. Injection of carbon and aluminum dross

In addition to the melting of scrap by electric power, when oxygen and coke powder are blown into the furnace, the melting operation is further facilitated by the heat generation that accompanies oxidation of Fe and C, a slag forming phenomenon is triggered by the CO gas generated by the reaction between the FeO and C contained in the slag after meltdown, and radiation heat is prevented from being transmitted to the walls by the action of the resulting submerged arc. As a result, the electric power input efficiency is increased.

Due to this formation of a submerged arc, a high power factor operation and input of large amounts of electricity have become possible, and an improved electricity intensity, increased furnace wall life, and improved yield of steel output are achieved.

Aluminum dross has come into use as a part of combustion supporting materials. The metal aluminum content in aluminum dross is 30 to 40 %, and the effect of reduced electricity intensity due to the reaction heat of oxidizing aluminum dross is 4 to 6 kWh/kg of aluminum; also, addition of aluminum dross has the effect of preventing a sudden reaction between oxygen and carbon contained in the steel as well as preventing sudden boiling.

d. Preheating of scrap

A conceptional drawing of a device that recovers sensible heat from exhaust gas, which is the principle source of loss in arc furnaces and uses it to preheat scrap, is shown in Figure 3.2.2-6. Special emphasis is placed on the ease of operation in its design, in which the charging bucket that charges scrap is normally placed in one of a number of preheating baths installed in the exhaust gas system, subjected to drying/preheating and then can be taken out before the next charging of scrap. In order to prevent thermal deformation of the bucket, the pre-heating temperature of the exhaust gas used is limited to a maximum of 600°C.

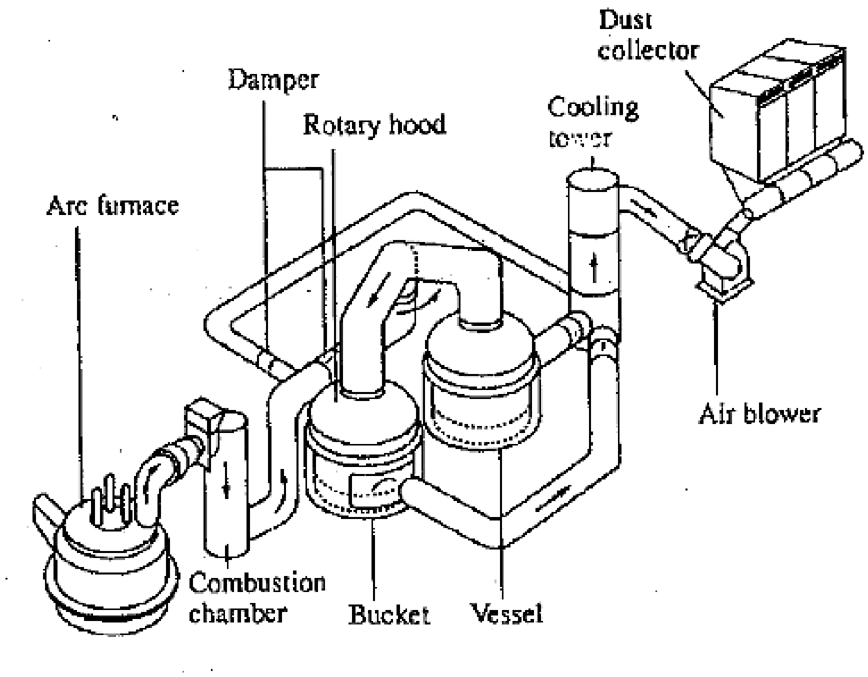

Figure 3.2.2-6 Conceptional Drawing of Scrap Preheating Equipment

These effects of improvement of electricity intensity are summarized in Table 3.2.2-4

Table 3.2.2-4 Effect of Alternative Energy on Electricity Conservation

Oxygen	0 to 20 m^3N/ton	5.5	kWh/m^3N
	>20m^3N/ton	2.7	kWh/m^3N
Oil	0 to 5 L/ton	9.0	kWh/L
Natural gas		8.5	kWh/m^3N
Coke		3.0 ~ 8.3	kWh/kg
Aluminum dross		5.0	kWh/kg-Aluminum
Scrap preheater		20 to 40	kWh//ton

e) Reduction of power-off time

In order to reduce the tap-to-tap time, it is also necessary to reduce power-off time as shown in the following items. An actual investigation conducted on the tap-to-tap time and power off time is shown in Figure 3.2.2-7.

a. Reduction of scrap charge time by accelerating the speed of raising, lowering, and rotating the furnace top cover, as well as raising and lowering the electrodes.
b. Reduction of the connection time for electrodes, etc.
c. Improvement of furnace heat resistance by introducing water cooling to the furnace walls
d. Reduction of tapping time by introducing eccentric bottom tapping (EBT) furnaces and a method of receiving steel in ladle cars

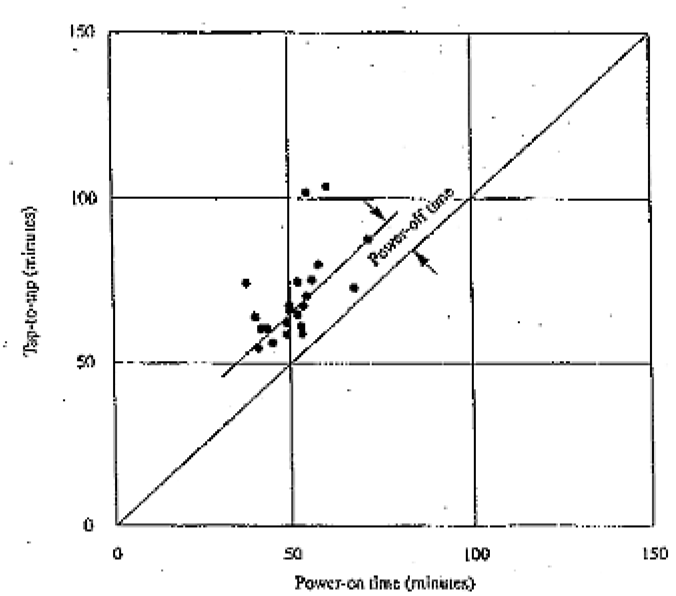

Figure 3.2.2-7 Relationship Between Tap-totap Time and Power-off Time in Arc Furnace Operation

d) Improvement of thermal efficiency

The adoption of EBT furnaces, computerized control of electric power inputs, slag forming technology, gas bottom blowing, and deploying the secondary combustion method inside the furnace, etc. are all said to contribute to improving thermal efficiency. The thermal efficiency of DC furnaces is raised by the molten steel made by a direct current arc and electromagnetic forces (the electricity intensity is better than that of alternating current arc furnaces).

e) Introduction of secondary smelting equipment

Adding facilities that smelt scrap inside the ladle, such as a ladle furnace (LF), not only improves targeting accuracy for temperature and composition, but also produces effects such as stabilization of CC operations, and improvements in the quality of slabs and steel ingots.

Especially when the functions of the electric arc furnace and ladle furnace are separated, a reduction in temperatures for tapping from the electric furnace, reduced tap-to-tap time, and improved CC ratio, etc. are observed. It should be noted, however, that the use of LF for the type of steel not requiring LF will bring about rather demerits.

f) Reductions in tapping temperature and the number of operating arc furnaces
By accelerating downstream processes (principally CC) and increasing the furnace size, the radiation heat from the ladle and the molten steel in the ladle will be relatively reduced. The tapping temperature equivalent to this radiation heat can be lowered, thus allowing the electricity intensity of an electric furnace to be reduced.

A 10 °C reduction in tapping temperature results in a 3 kWh/t reduction in the electricity intensity.

If the time between completion of tapping at the arc furnace and completion of CC casting can be shortened from 150 minutes to 100 minutes, the electricity intensity can decrease by 50 kWh/t; therefore accelerating CC casting speed should lead to both an increase in productivity and a reduction in the electricity intensity.

If the number of electric furnaces in operation can be reduced by one unit with the productivity kept unchanged, a substantial energy conservation effect will be achieved.

Hence, when a plural number of electric furnaces are used, the number of operating furnaces should always be kept in mind. In order to reduce the number of operating units, it is necessary to obtain the length of tap-to-tap time and implement various improvements for putting ii info practice. Since reducing the number of operating furnaces leads to a substantial cost reduction (energy saqving), the reduction of the number of operating units is one of the measures which are widely used for achieving energy conservation.

g) Computerized control of electric power input (Optimization of electric power input)
Needless to say, automatic control of voltage and current contributes to energy conservation, but it is also effective in reducing costs such as the consumption rate of electrodes, which is why almost all furnaces have adopted it.

h) Reduction of cooling water heat loss
Heat loss due to cooling water loss occupies over 10 % of the heat entering the arc furnace, making the reduction of this loss an important energy conservation goal for arc furnaces.

Introducing water cooling to the furnace body contributes greatly to the enlargement of the furnace size and to the promotion of UHP, thus serving as a more useful means for energy conservation than the water-cooling method for heat loss. However, there are examples in which water cooling loss was increased because the water cooling area was raised too much, resulting in a deterioration of the electricity intensity and making it impossible to reduce tap-to-tap time. Thus it is believed that review of the cooling water area will become an important energy conservation issue in the future.

i) Relationship between the tap-to-tap time and electricity intensity
The relationship between the tap-to-tap time of an arc furnace and electricity intensity exhibits a trend as shown in Table 3.2.2-5.

Table 3.2.2-5 Relationship between Tap-to-Tap Time and Electricity Intensity

Tap-to-tap time	Electricity intensity
180 minutes	550 to 600 kWh/t
120 minutes	480 to 520 kWh/t
90 minutes	430 to 470 kWh/t
70 minutes	380 to 420 kWh/t
60 minutes	360 to 400 kWh/t

3) Recovery of exhaust heat and modernization of process

a) Modified arc furnace
A few models using a new process which is aimed at preheating all scraps before heating and melting in order to improve electricity intensity by 20 %, such as the twin-shell furnace in which 2 electric furnaces are installed to perform alternate functions between heating/melting and soap preheating, and the shaft furnace which continuously heats scrap, have been proposed and already in operation at some plants.

b) Recovery of exhaust heat
Heat can be recovered from the cooling water and exhaust heat of arc furnaces. In electric arc furnace plants in Japan, the exhaust heat from a reheating furnace is recovered but the exhaust heat from an arc furnace is not yet recovered because of no necessity of steam demand.

(3) Reheating Furnace in Rolling Mill

1) Rolling process

In the rolling process, a semi-finished steel product (slab, bloom or billet) is heated to a specified temperature with a reheating furnace, rolled with a rolling mill, and then fabricated into the desired shape and size.

Usually, the main products that come out of the rolling mill at an arc furnace plant are almost all primary rolled products such as shape steels, bar steels, and wire rods. Energy conservation measures for the primary rolling process are described below.

The flow chart and energy conservation measures for primary rolling processes are shown in Figure 3.2.2-8.

Energy conservation measures for reheating furnaces consuming the largest amount of energy in the primary process will be described below.

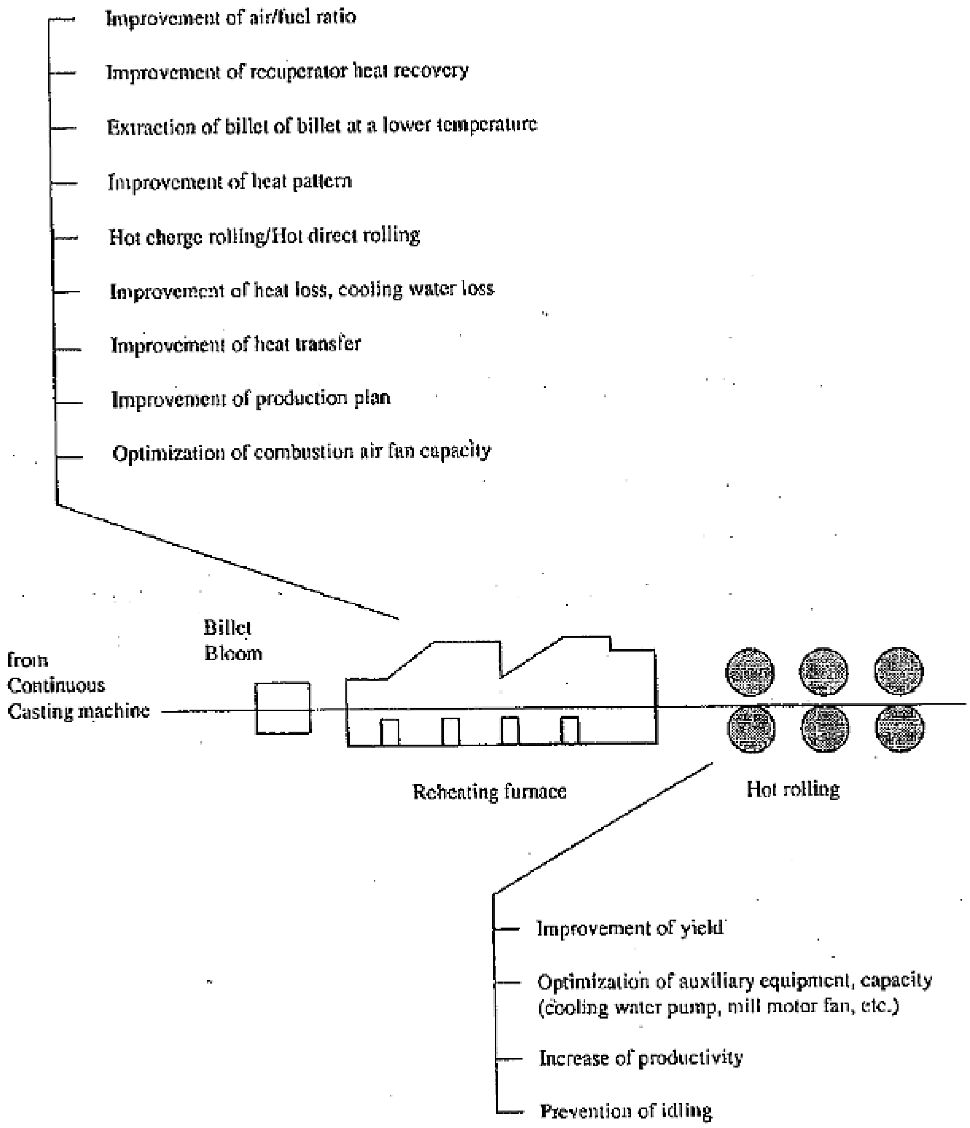

Figure 3.2.2-8 Flow and Energy Conservation Measures for Rolling Process

2) Energy conservation by improvement of operations and equipment

While fuel takes up 60 % of the energy used in the primary rolling process, and electricity and steam occupy the rest, it is the reduction in fuel intensity of reheating furnaces that has achieved outstanding energy conservation results. There were many reheating furnaces with a fuel intensity exceeding 450 Mcal/t before the oil crisis; today, however, furnaces with intensity levels of 200 Mcal/t or less are emerging.

An example of heat balance at a reheating furnace is shown in Table 3.2.2-6.

Table 3.2.2-6 Heat Balance of a Reheating Furnace

Charged slab temperature : cold Example 1
Charged billet temperature: hot Example 2
(Example 1)

Heat Input	Mcal/t	(%)	Heat Output	Mcal/t	(%)
Combustion heat of fuel	318.7	(97.6)	Heat content of extracted slab	194.8	(59.7)
Sensible heat of fuel	0	(0)	Sensible heat of scale	2.1	(0.6)
Heat content of charged slab	0	(0)	Sensible heat of exhaust gas	33.3	(10.2)
Scale formation heat	8.0	82.4)	Heat of cooling water	43.8	(13.4)
			Heat loss	52.7	(16.1)
Heat recovered by recuperator	(62.7)	((19.2))	Heat recovered by recuperator	(62.7)	((19.2))
Total	326.7	100	Total	326.7	100

Overall heat efficicncy ＝ ｛194.8 / (318.7 + 8.0)｝ × 100 ＝ 59.6 ％

(Example 2)

Heat Input	Mcal/t	(%)	Heat Output	Mcal/t	(%)
Combustion heat of fuel	168.8	(65.6)	Heat content of extracted slab	174.9	(67.9)
Sensible heat of fuel	0.3	(0.1)	Sensible heat of scale	3.1	(1.2)
Heat content of charged slab	73.9	(28.7)	Sensible heat of exhaust gas	30.7	(11.2)
Scale formation heat	13.2	(5.1)	Heat of cooling water	41.9	(16.3)
Sensible heat of atomizer	1.3	(0.5)	Heat loss	6.9	(2.7)
Heat recovered by recuperator	(16.7)	((6.5))	Heat recovered by recuperator	(16.7)	((6.5))
Total	326.7	100	Total	257.5	100

Overall heat efficiency ＝ {174.9 / {168.8 ＋ 0.3 ＋ 73.9 ＋ 13,2 + l.3}} × 100＝67.9%

Reheating furnaces are roughly categorized into batch type and continuous type, The batch type is principally a furnace for rehearing specially shaped items, while the continuous type is main stream for mass production. The pusher type, walking beam type, and walking hearth type are representative types of continuous repeating furnaces. The pusher type has a low construction cost and is adopted as small scale furnaces of 150 t/h or less, while the walking beam type is used as large scale furnaces. The walking hearth type is used for reheating and heat treating special shapes like round steel.

Besides the heat losses that occur during regular operations of a furnace, such as exhaust gas loss, other factors that reduce the thermal efficiency of a furnace, such as waiting time and rolling mill troubles, have unexpectedly large impacts. This is because a large amount of heat is required to hold and raise temperatures. This requires due consideration. Other factors not to be neglected include the effect that the rolling speed (load factor) of a reheating furnace, etc. have on the heat loss.

Next, energy conservation measures will be explained.

a) Improvement of the air ratio
While maintaining the air/fuel ratio at a proper level, the amount of air entering from outside is reduced by adjusting the furnace pressure controller. The relationship between air/fuel ratio and fuel intensity is shown in Figure 3.2.2-9. For example, lf the exhaust gas temperature is 500°C, and the air ratio is reduced from 1.5 to 1.2, the amount of fuel can be lowered by 9 %.

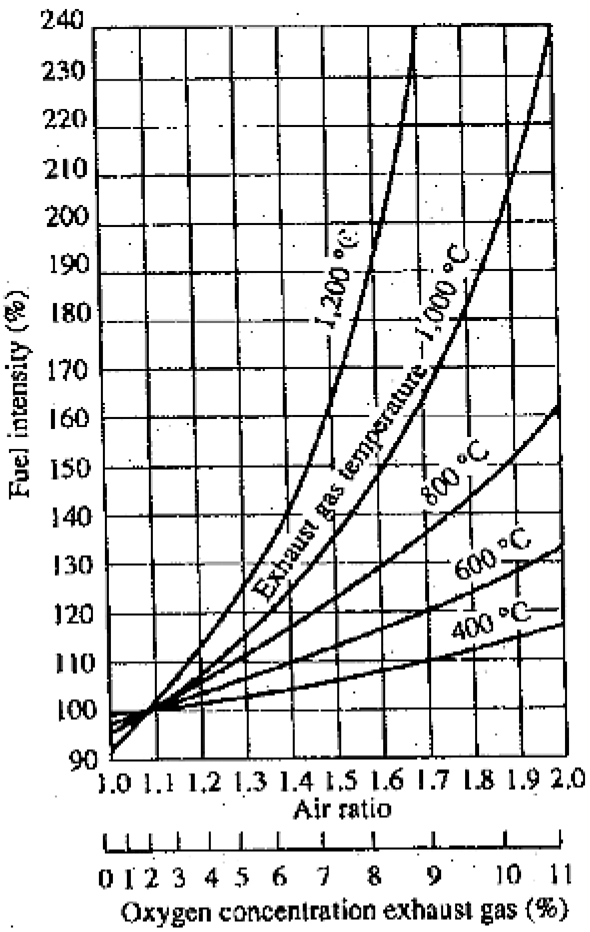

Figure 3.2.2-9 Relationship between Air/Fuel Ratio and Fuel Intensity

b) Reinforcing waste heat recovery
Since the performance of the air preheater (recuperator) deteriorates substantially and worsens fuel intensity when its heating surface gets dirty, the temperature efficiency it had when it was newly installed should be maintained by periodical simple heat balancing. If performance is not restored, the recuperator should be repaired, reinforced or replaced.

c) Law temperature discharge
When a slab, billet or bloom is discharged from the reheating furnace at lower temperatures, the fuel intensity goes down, but the electricity intensity tends to rise, and therefore these materials should be extracted as much as possible at low temperatures

with ample considerations to both (electricity and fuel) intensity conditions as well as to skid marks. If the extraction at low temperatures is possible, fuel intensity is expected to decrease by about 3 to 5 Mcal/t for every 10°C drop in discharge temperature.

d) Improvement of hot charge ratio

The design fuel intensity of reheating furnaces that reheat only cold slabs is 300 Mcal/t to 400 Mcal/t. There are many rolling reheating furnaces operating at fuel intensities of 200 Mcal/t or below at electric arc furnace plants that produce only deformed steel bars. High temperature slabs produced in continuous casting (CC) facilities are charged directly into rolling reheating furnaces (called Hot Charge Rolling (HCR)), or rolled directly with rolling mills (called Hot Direct Rolling (HDR)).

While it is obviously desirable to have the CC and reheating furnace slab charger close to each other for the conduction of hot charges, it is difficult to carry out a 100 % hot charge as there will be a discrepancy between the production capability of the CC and that of the rolling process. Therefore, a heat retaining box that temporarily stores hot continuous cast billets is normally installed as a buffer. The heat retaining box has a steel plate structure lined with insulating material, with a movable cover to allow billets to move in and out.

The amount of energy conservation achieved by hot charging is approximately 20 Meal/t per charge temperature of 100°C.

e) Prevention of heat loss due to radiation, and heat conduction, etc.

Furnaces installed recently have furnace walls made of ceramic fibers that are light weight and have small specific heat, giving them superior heat insulation as well as small accumlated heat losses. Heat loss through the furnace walls is thus improved.

Existing furnaces which have walls made of bricks can have both the amount of radiation heat and accumlated heat losses reduced by 30 to 40 % if 50 mm thick ceramic fiber is added on their inside walls.

f) Prevention of heat loss from openings

The presence of openings causes heat to escape outside as radiation heat, resulting in a leak of combustion gas and heat loss. Therefore, modifications should be made to minimize the size of any opening.

g) Prevention of heat loss from cooling water

Heat loss stemming from water cool skid pipes constituted 10 to 15 % of the fuel intensity in continuous reheating furnaces. In order to reduce the heat loss due to this cooling, methods to provide skid double insulation have been developed and adopted not only for newly installed furnaces, but also at existing ones, resulting in reduction of heat loss by half. An example of such an improvement is shown in Figure 3.2.2-10.

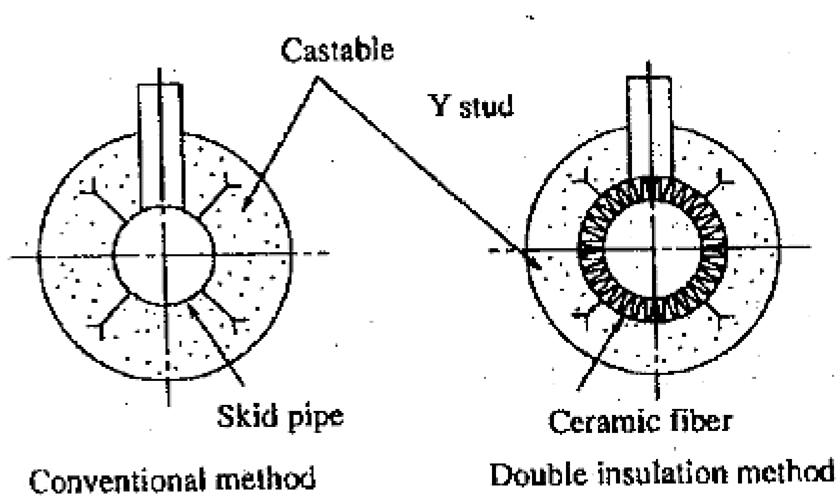

Figure 3.2.2-10 Double Insulation Method for Skid Pipe

h) More efficient heat conduction inside furnaces

The steel product inside a furnace is mainly (about in 95 % or more) heated by the heat radiated from combustion gas (gas radiation from CO_2 and H_2O, and solid radiation from hot carbon particle groups contained in the flame). 'Therefore, a sufficiently large furnace volume is required to obtain the so-called "optimal thickness of gas".

It is thus necessary to study whether or not the required furnace volume is obtained. If the volume is insufficient, innovations such as installing barrier walls to enhance heat-conduction inside the furnace and slightly changing the furnace configuration will be required. Also, if the hot gas is only flowing to the top end of the furnace and the gas temperature at its bottom end is lowered, there can be a drop in the amount of radiated heat conduction. Therefore, measures must be taken to make the temperature inside the furnace uniform in the direction of its height.

i) Prevention of heat loss due to external factors

If the air/fuel ratio of the rehearing furnace is managed properly, its fuel intensity can be kept at a level that is quite high, provided that continuous operations at a heating speed (t/h) within a given range is possible.

In actual operation, however, circumstances of the preceding or subsequent processes sometimes make the heating speed high or sometimes low, or there may be a need to hold heat for prolonged periods. These fluctuations lead to a noticeably unfavorable fuel intensity on an annual average.

When such situations occur, it becomes imperative to remove the factors involved, sometimes making it necessary to change or improve the production plan itself.

For example, if criteria for holding or raising the temperature in the rehearing furnace can be specified by adjusting the production speed to the preceding or subsequent process, and by resolving problems during the process that comes before or after the furnace, the fuel intensity can be improved substantially. Or, if there are multiple rolling lines (and therefore multiple rehearing furnaces as well) making various types of products, some rolling lines may have to stop at times because the production capacity of the continuous casting facility cannot keep up with that of the rolling line. If such a situation occurs on a regular basis and readjustment of production plan and work procedure alone cannot cope with such situation, it is indispensable to take measures for reducing the heat loss due to radiation and accumlated loss.

3) Energy conservation through waste heat recovery

a) Regenerative burner

When an air preheater is old and needs to be replaced, the installation of a regenerative burner should be studied.

By alternating combustion and heat recovery in intervals of a few tens of seconds by means of a "pair" of burners A and B that have a heat storage incorporated, a temperature efficiency of 85 % or more (preheated air temperature exceeds 1000°C) can be obtained despite the compact structure. This is because burner B becomes an exhaust outlet while burner A burns and exchanges heat with the heat storage of burner B. The heat storage and air exchange heat to supply clean hot air to burner A which is burning.

This system uses alumina-based refractory for the heat storage, its high temperature part consisting only of the burner and heat storage. Its exhaust gas system and air pipe system operate in low temperature, thus allowing the whole system to be compact. Because the switch valve for switching between heat recovery and combustion is set at a low temperature, there is little wear to the system, enabling a fuel saving of 30 to 50 %. This system has another excellent characteristic that NOx is 150 ppm or lower although the air preheating temperature is high. The flow diagram of this system is shown in Figure 3.2.2-11, and the effect of the increase in preheated air temperature is shown in Figure 3.2.2-12.

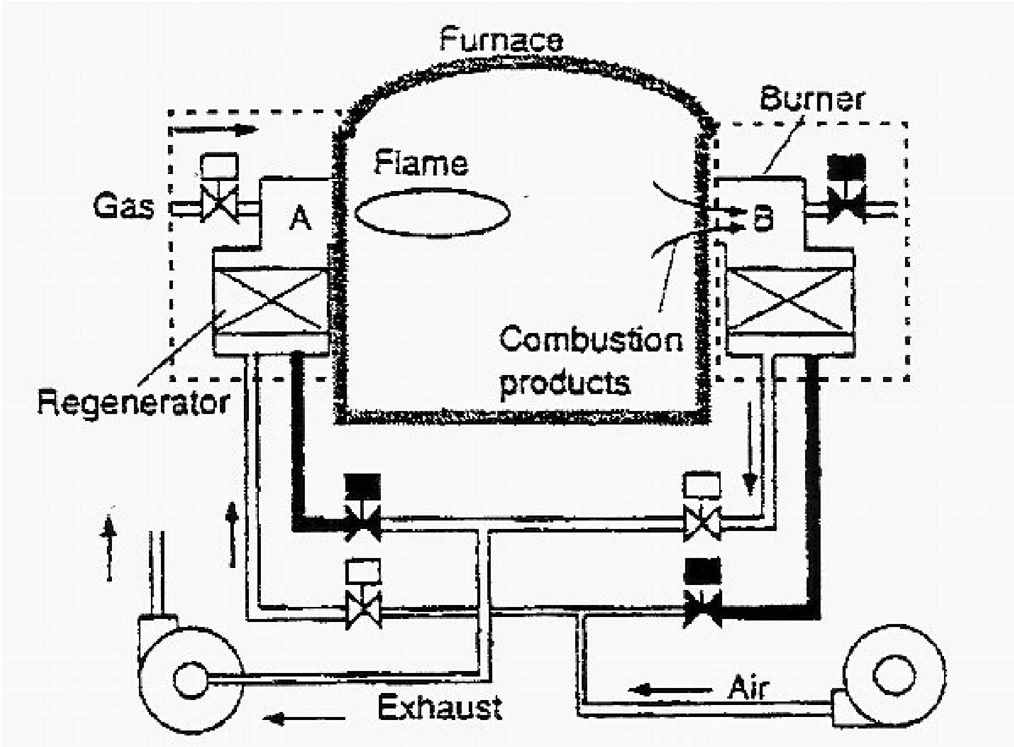

Figure 3.2.2-11 Conceptional Flow of Regenerative Burner in Reheating Furnace

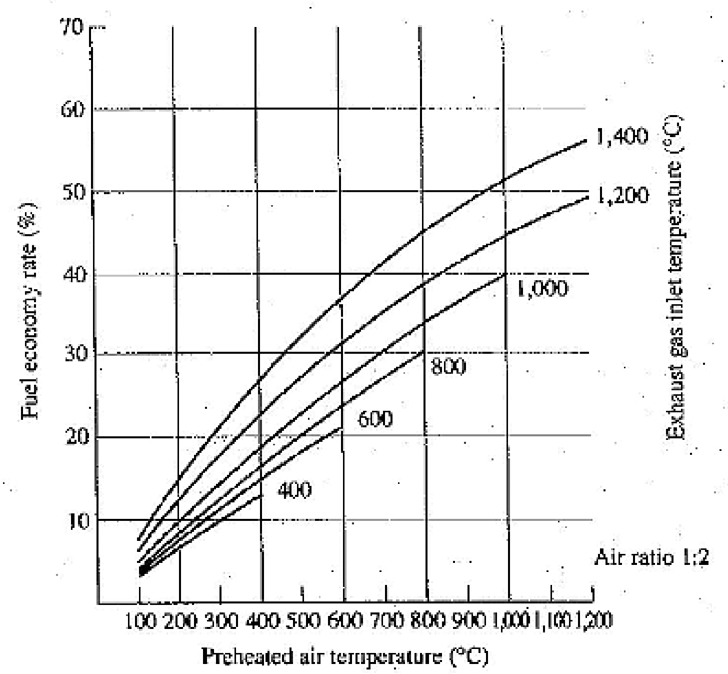

Figure 3.2.2-12 Effect of air Preheater

b) Recovery of skid cooling water sensible heat
This type of sensible heat can be recovered for a feed water preheater if a reheating furnace boiler is installed.

c) Rehearing furnace boiler

The boiler installation should be studied after considering ways to reduce the amount of exhaust gas through ways to reduce fuel intensity such as the hot charge method.

The exhaust gas temperature becomes 200 to 300°C when a regenerative burner is installed, reducing the benefits that can be derived from investing in the installation of a waste heat boiler.

4) Improvement of yield, and reduction of troubles

Improving yield not only results in energy conservation for the roll process, but also contributes to energy conservation in the processes that follow. It is thus important to improve the product yield by taking measures to reduce scale loss, crop loss, and miss roll. Troubles occurring at the roll line worsens the fuel intensity at the rehearing furnace, and the rate of miss roll increases, which in turn worsens yield. Reducing the frequency of facility troubles produces an immediate energy conservation effect.

5) Heat balance for continuous reheating furnace

In heat balancing for the reheating furnace, heat loss can be grasped quantitatively by obtaining details on the heat input and heat output to identify the important points in the countermeasures.

In Japan, heat balancing method is specified in the Japan Industrial Standard (JIS).

Figure 3.2.2-13 shows an example of heat balance for the steel product continuously reheating furnace to which the recent energy conservation measure has been applied.

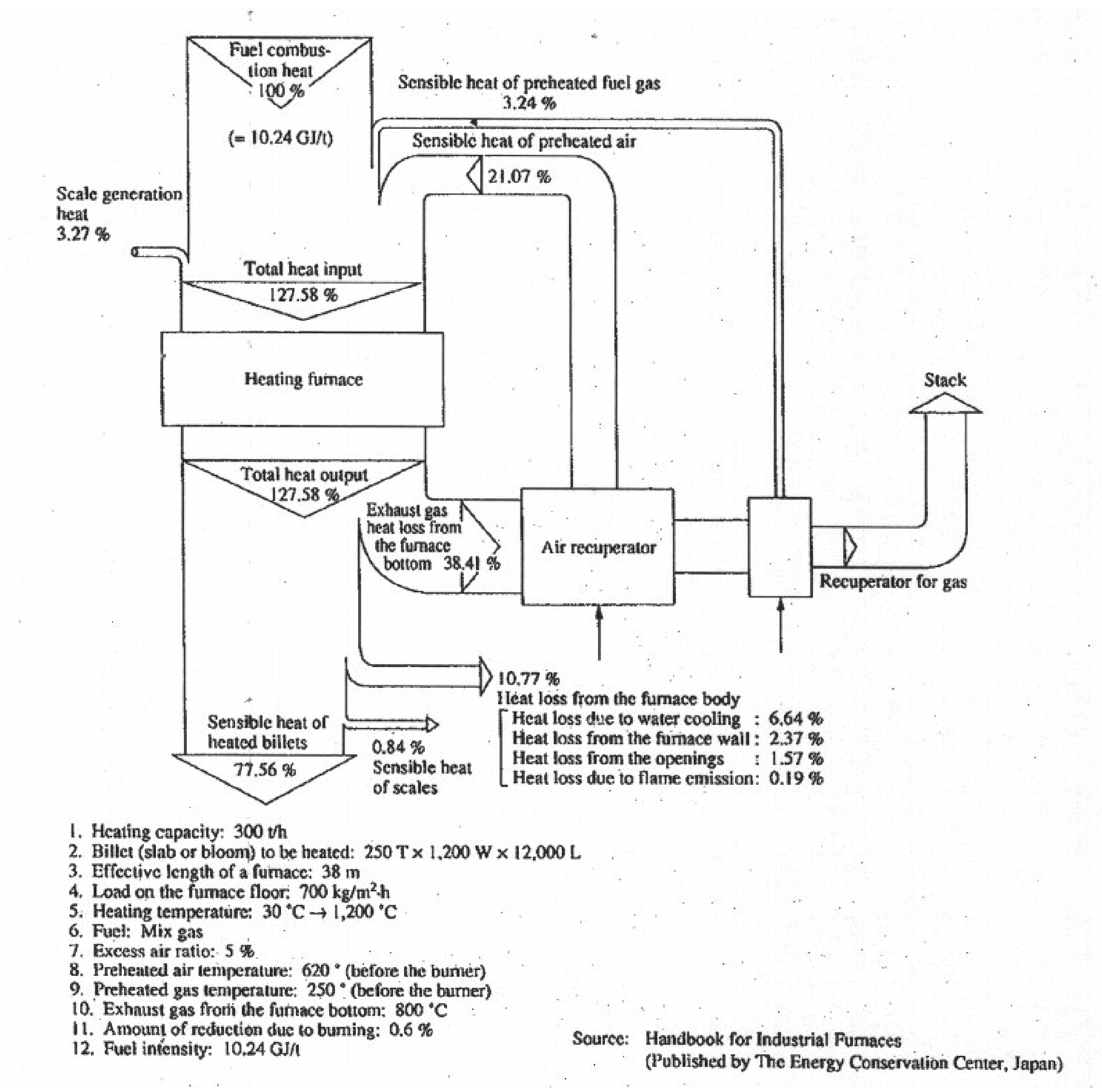

Figure 3.2.2-13 Heat Balance Drawing of Walking Beam Type Reheating Furnace

JIS also provides the calculation formula for the amount of heat loss for each of the following cases in addition to these tables. Calculation procedure of heat loss of exhaust gas is shown in "Energy conservation guideline in boiler".

- Heat emission from the outer wall
- Heat emission from the furnace floor
- Heat loss due to gas flame emission from the furnace opening
- Heat loss due to radiation from the furnace opening

a) Heat emitted from the Furnace body and the flue

a. Heat loss due to radiation from furnace wall and flue

Heat balancing time (h) x outer wall area (m^2) x [heat flux due to radiation (kJ/m^2h) + heat flux due to convection (kJ/m^2h)] / mass of steel product (t) [kJ/ton-steel]

Heat flux due to radiation is obtained from the following formula:

qr (kJ/m^2h) = $\varepsilon \times 20.428 \times [(Tw/100)^4] - [(Ta/100)^4]$

Heat flux due to natural convection for each of the following cases is obtained as follows:

- When the wall is horizontally upward:
  qc (kJ/m^{2}h) = 11.721 × $\Delta T^{1.25}$
- When the wall is vertically sideways :
  qc (kJ/m^{2}h) = 9.209 × $\Delta T^{1.25}$
- When the wall is horizontally downward:
  qc (kJ/m^{2}h) = 6.279 × $\Delta T^{1.25}$

where

ε: Emissivity of the furnace body surface

Tw: Outer wall temperature (K)

Ta: Ambient temperature (K)

ΔT: Tw - Ta (K)

b. Heat loss due to radiation from the furnace hearth

The heat emitted from the furnace hearth varies depending on the structure of the furnace hearth. Therefore, calculation matching the shape of the furnace hearth should be performed. For example, the heat radiation due to convection from the hearth of a walking beam type heating furnace can be obtained from the formula for the case when the wall is horizontally downward, which is described in the above item a.

The amount of heat emitted from the furnace hearth which is directly laid on the concrete base is obtained from the following formula:

Heat balancing measurement time (h) x furnace hearth area (m^2) x heat loss through the furnace hearth (kJ/m^{2}h) / mass of charged steel billet (t) [kJ/ton-steel]

Heat loss through the furnace hearth can be obtained from the following formula:

$Q = 3.599 \times S \times C \times (Th - Ta)/D$ [kJ/m^{2}h]

Where

S: Coefficient determined based on the shape of the furnace hearth: 4.1 for the circular floor, 4.5 for the square floor, and 3.8 for the long rectangular floor

C : Heat conductivity of the furnace hearth material (W/mK)

Th: Temperature of the furnace hearth surface (K)

Ta: Ambient temperature (K)

D: Furnace width between the inner walls (m)

b) Heat loss due to flame gas emitted from the furnace opening

Furnace opening time during heat balancing measurement (h) x Amount of emitted flame gas (m^{3}N/h) x [Average specific heat of emitted flame gas (kJ/m^{3}N K) x Temperature of emitted flame gas (K) - Average specific heat of emitted flame gas of reference temperature (kJ/m^{3}N K) x Reference temperature (K)] / mass of product steel

(t) [kJ/ton-steel]

The amount of emitted flame gas is obtained from the following formula:

$G = \alpha \times 4467 \times (273/Tg)^{0.5} \times (\Delta p)^{0.5} \times A$ [m^3N/h]

where

α: Coefficient determined by the shape of the outlet.
If the friction resistance coefficient is f, $\alpha = 1/(l+f)$

Δp: Furnace inside pressure at the opening (Pa)

Tg: Temperature of emitted flame gas (K)

A : Area of the opening (m^2)

c) Heat Balance Table formats

For reference, Tables 3.2.2-7 to 3.2.2-10 shows the heat balance table formats according to JIS.

Table 3.2.2-7 Equipment Overview List

1	Company and factory names			
2	Address			
3	Name of reheating furnace manufacturer			
4	Reheating furnace No.			
5	Rolling mill	Type		
6		Nominal capacity	t/year	
7		Major products		
8	Reheating furnace	Type		
9		Nominal capacity	t/h	
10		Effective length of furnace × furnace width	mm × mm	
11		Dimensions and material of furnace body brick and heat-insulating materials		
12		Kind of fuel used		
13		Type, capacity and quantity of combustion equipment		
14		Type and capacity of ventilation equipment		
15		Type and heating surface area of air preheater	m^2	
16		Material, dimensions, mass and heating temperature of standard steel products to be used as a basis for nominal capacity	Mm, kg, K	

Remark: With regard to the items 10, 11 and 15, a simplified diagram of the vertical and horizontal sections of the furnace (including the dimensions of major parts of the furnace and preheater, the kind of refractory materials and major measurement points) should be attached.

Table 3.2.2-8 Long-term Operation Data List

1	Operation date	**Date**				
2	Description of operation time		**Heating**	**Heating raising**	**Heat holding**	**Shutdown**
		h/month				
		%				
3	Heating ton	t/month				
4	Ton per heating hour	t/h				
5	Average mass of typical steel products (Maximum and minimum range)	kg				
6	Average temperature of hot charged steel	K				
7	Hot steel product ratio	%				
8	Fuel consumption	kL/month or m^3/month				
9	Lower calorific value of fuel	kJ/kg or kJ/m^3				
10	Heat intensity per ton of steel product	MJ/t				
11	Work shift status					

Remark: 1. Definitions of operating time shall be described as follows:
Heating time: Time during which a steel product is being extracted; that is, the operating time of a rolling mill.
Heat raising: Time required for the furnace to be heated up to the temperature when extraction can be conducted.
Holding time: Time during which extracting is stopped due to a failure of equipment other than the furnace, etc.
Shutdown time: Time during which no operation is performed (including the time for periodical repairs)
2. Definitions of steel products treated as hot-charge steels should be described.

Remarks 1. Definitions of operating time shall be described as follows:

Heating time: Time during which a steel product is being extracted; that is, the operating time of a rolling mill

Heat raising: Time required for the furnace to be heated up to the temperature when extraction can be conducted

Holding time: Time during which extracting is stopped one to a failure of equipment other than the furnace, etc.

Shutdown time: Time during which no operation is performed (including the time for periodical repairs)

2. Definitions of steel products treated as hot-charge steels shold be described.

Table 3.2.2-9 Measurement Data List

1	Measurement date and time (hours)					
2	Person who made measurements					
3	Weather	Atmospheric pressure		Outside temperature	Ambient temperature	Relative humidity
			MPa	K	K	%
4	Fuel	King				
5	Fuel	Soaking zone upper part	Consumption	kg/t or m^3/t		
6	Fuel	Soaking zone lower part	Consumption	kg/t or m^3/t		
7	Fuel	Heating zone upper part	Consumption	kg/t or m^3/t		
8	Fuel	Heating zone lopper part	Consumption	kg/t or m^3/t		
9	Fuel	Preheating zone upper part	Consumption	kg/t or m^3/t		
10	Fuel	Preheating zone lower part	Consumption	kg/t or m^3/t		
11	Fuel	Before the flowmeter	Pressure	Pa		
12	Fuel	Before the combustion equipment	Temperature	Pa		
13	Fuel	Inlet of the preheated	Temperature	K		
14	Fuel	Outlet of the preheater	Temperature	K		
15	Fuel	Before the flowmeter	Temperature	K		
16	Fuel	Before combustion equipment	Temperature	K		
17	Fuel	Mass or volumetric ratio of each component		kg/kg/ or m^3/m^3		
18	Fuel	Lower calorific value		kJ/kg or kJ/m^3		
19	Atomizer	Kind				
20	Atomizer	Soaking zone upper part	Consumption	kg/t or m^3/t		
21	Atomizer	Soaking zone lower part	Consumption	kg/t or m^3/t		
22	Atomizer	Heating zone upper part	Consumption	kg/t or m^3/t		
23	Atomizer	Heating zone lower part	Consumption	kg/t or m^3/t		
24	Atomizer	Preheating zone upper part	Consumption	kg/t or m^3/t		
25	Atomizer	Preheating zone lower part	Consumption	kg/t or m^3/t		
26	Atomizer	Before the flowmeter	Pressure	Pa		
27	Atomizer	Before the combustion equipment	Pressure	Pa		
28	Atomizer	Before the flowmeter	Temperature	K		
29	Atomizer	Before combustion equipment	Temperature	K		
30	Combustion air	Soaking zone upper part	Consumption	m^3/t		
31	Combustion air	Soaking zone lower part	Consumption	m^3/t		
32	Combustion air	Heating zone upper part	Consumption	m^3/t		
33	Combustion air	Heating zone lower part	Consumption	m^3/t		
34	Combustion air	Preheating zone upper part	Consumption	m^3/t		
35	Combustion air	Preheating zone lower part	Consumption	m^3/t		
36	Combustion air	Hot air blow-off amount		m^3/t		
37	Combustion air	Before the flowmeter	Pressure	Pa		
38	Combustion air	Before the combustion equipment	Pressure	Pa		
39	Combustion air	Inlet of the preheater	Temperature	K		
40	Combustion air	Outlet of the precheater	Temperature	K		
41	Combustion air	Before the flowmeter	Temperature	K		
42	Combustion air	Before combustion equipment	Temperature	K		
43	Oxygen	Consumption		m^3/t		
44	Oxygen	Temperature		K		
45	Oxygen	Pressure		Pa		
46	Oxygen	Oxygen purity		m^3/m^3		
47	Cooling water	Consumption		t/t		
48	Cooling water	Temperature at the inlet		K		
49	Cooling water	Temperature at the outlet		K		
50	Cooling water	Pressure		MPa		
51	Combustion gas	Furnace bottom temperature		K		
52	Combustion gas	Temperature at the preheater inlet		K		
53	Combustion gas	Temperature at the preheater outlet		K		
54	Combustion gas	Volumetric ratio of each component		m^3/m^3		
55	Steel product	Average dimensions (Thickness × width × length)		mm × mm × mm		
56	Steel product	Average mass		kg		
57	Steel product	Mass meter for charged steel		t		
58	Steel product	Mass meter for extracted steel		t		
59	Steel product	Mass meter for steel products in a furnace at the start of measurement		t		
60	Steel product	Mass meter for steel products in a furnace at the end of measurement		t		
61	Steel product	Average charge temperature		K		
62	Steel product	Average extraction temperature		K		
63	Steel product	Amount of reduction due to burning		kg/t		
64	Steel product	Average in-furnace time		h		
65	Furnace Internal pressure			Pa		
66	Surface temperature of each part of the furnace body			K		

Remarks: For the measurement method for item No.66, a simple sketch of the furnace body should be attached.

Table 3.2.2-10 Heat Balance Table

Heat input			**Heat output**		
Item	**MJ/t**	**%**	**Item**	**MJ/t**	**%**
(1) Fuel combustion heat			(8) Heat content of the extracted steel product		
(2) Sensible heat of fuel			(9) Sensible heat of scale		
(3) Sensible heat of combustion air			(10) Sensible heat of exhaust gas		
(4) Sensible heat of atomizer			(11) Heat loss due to incomplete combustion gas		
(5) heat content of a charged steel product			(12) Heat carried away by cooling water		
(6) Heat generated by scale formation					
(7) Heat recovered by the preheated	( )	( )	(13) Other heat output		
			• Heat loss due to radiation from the furnace body and the flue		
			• Heat loss due to gas flame emission from the furnace opening		
			• Heat loss due to emission from the furnace opening		
			• Heat loss from the piping for preheated fluid		
			• Heat loss due to hot air blow-off		
			• Other heat losses		
			(14) Heat recovered by the preheater	( )	( )
Total **(1) + (2) + (3) + (4) + (5) + (6)**			**Total** **(8) + (9) + (10) + (11) + (12) + (13)**		

Remarks
1. For entry of heating values, MJ/t should be used as the unit, and the fractional portion of the number should be rounded off to the first decimal place.
2. The percentage should be rounded off to the first decimal place.
3. "Heat recovered by a preheater" means the circulating heat based on the temperature and the flow rate before the combustion equipment.
4. Other heal losses should be analyzed in as much detail as possible.