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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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HANDY MANUAL

IRON & STEEL INDUSTRY

Output of a Seminar on Energy Conservation in Iron and Steel Industry

Sponsored by

United Nations Industrial Development Organization (UNIDO)

and

Ministry of International Trade and Industry (MITI), Japan

Hosted by

Ministry of Energy, Telecommunications and Post, Malaysia

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The Energy Conservation Center (ECC), Japan

1992

Malaysia **Indonesia**

Preface

The conservation of energy is an essential step we can all take towards overcoming the mounting problems of the worldwide energy crisis and environmental degradation. In particular, developing countries are interested to increase their awareness on the inefficient power generation and energy usage in their countries. However, usually only limited information sources on the rational use of energy are available.

The know-how on modern energy saving and conservation technologies should, therefore, be disseminated to governments and industrial managers, as well as to engineers and operators at the plant level in developing countries. It is particularly important that they acquire practical knowledge of the currently available energy conservation technologies and techniques.

In December 1983, UNIDO organized a Regional Meeting on Energy Consumption as well as an Expert Group Meeting on Energy Conservation in small- and medium-scale industries for Asian countries. During these meetings, it was brought out that, for some energy intensive industries, savings up to 10% could be achieved through basic housekeeping improvements, such as auditing and energy management.

The rational use of energy calls for a broad application of energy conservation technologies in the various industrial sectors where energy is wasted. One of these energy intensive industrial sectors to be considered to improve efficiency through the introduction of modern energy conservation technologies is the steel industry.

In the steel industry, significant improvements in the level of energy efficiency could be achieved by utilizing waste heat from furnaces, adjusting air/fuel ratio in furnace and boiler burners and using drain water, as well as by eliminating and linking production processes.

Currently, UNIDO, with the financial support of the Japanese Government, is carrying out a Regional Programme on the promotion and application of energy saving technologies in selected Asian developing countries. This programme aims at adopting these innovative energy conservation technologies, developed in Japan, to the conditions of developing countries.

In this programme, we are considering that the transfer of these technologies could be achieved through:

(i) Conducting surveys of energy usage and efficiency at the plant level;

(ii) Preparing manuals on energy management and energy conservation/saving technologies, based on the findings of the above surveys;

(iii) Presenting and discussing the manuals at seminars held for government officials, representatives of industries, plant managers and engineers;

(iv) Disseminating the manuals to other developing countries for their proper utilization and application by the industrial sector.

The experience obtained through this programme will be applied to other programmes/projects which involve other industrial sectors as well as other developing countries and regions.

UNIDO has started this programme with the project US/RAS/90/075 - Rational Use of Energy Resources in Steel and Textile Industry in Malaysia and Indonesia.

The present Handy Manual on Iron and Steel Industry was prepared by UNIDO, with the cooperation of experts from the Energy Conservation Center (ECC) of Japan, on energy saving technologies in the framework of the above mentioned UNIDO project. It is based on the results of the surveys carried out, the plant observations and the recommendations and suggestions emanating from the Seminars on Energy Conservation in the Steel and Textile Industries, held under the same project in January 1992 in Jakarta, Indonesia, and Kuala Lumpur, Malaysia. The manual will not only be interesting for government and representatives from industry, but it is, in particular, designed for plant-level engineers and operators in developing countries as a help to improve energy efficiency in the production process.

Appreciation is expressed for the valuable contribution made by the following institutions to the successful preparation and publication of the manual mentioned above:

Ministry of Mines and Energy, Indonesia

Ministry of Energy, Telecommunications and Posts, Malaysia

Ministry of International Trade and Industry (MITI), Japan

The Energy Conservation Center (ECC), Japan

June 1992

CONTENTS

1. Characteristics of the Manual

With the aim to promote energy conservation in the iron and steel industry, this manual summarizes a number of measures which can be taken for an effective energy conservation and describes how to apply them.

It focuses on arc furnaces and reheating furnaces, which consume a particularly large amount of energy and for which further energy conservation measures have to be applied.

The manual describes general methods for energy conservation as well as practical examples and results that can serve as reference for the engineers who deal with the operation of mills. It will help them adopt suitable energy conservation measures for their particular mills.

We hope that his manual will be used as a guide to better energy efficiency and to more effective management practices in the iron and steel industry.

2. Production Process of Iron and Steel Industry

Arc furnace steel-making method effectively utilizes a waste resource by using scrap as its raw material. This method also saves energy, because it requires less energy than the blast furnace-converter method to produce one ton of crude steel. Figure 1 shows the production process by the arc furnace steel-making method.

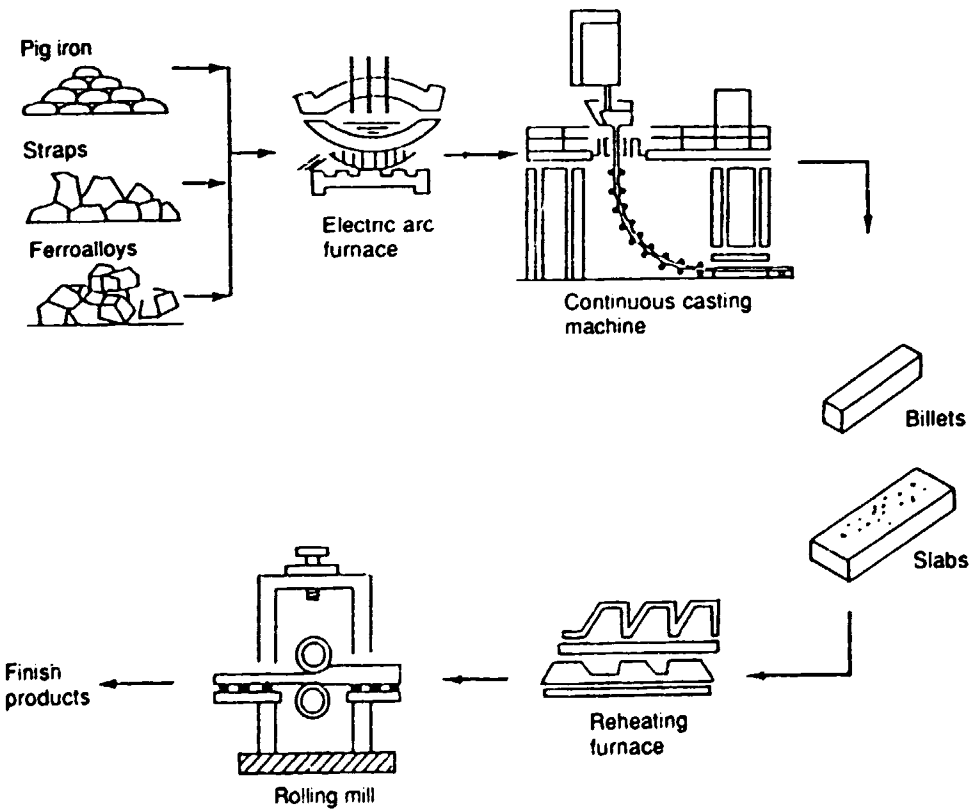


Figure 1 Production process by arc furnace steel-making method

3. Promotion of Energy Conservation Technologies

3.1 Arc Furnace

3.1.1 Correspondence of Heat Energy from Steel melting in Arc Furnace

Electric power is the major source of heat energy used for arc furnaces.

In the steel industry, the arc furnace is mainly used to melt steel material by means of the arc and electric resistance heating and remove undesirable components such as phosphorus, sulfur, hydrogen and oxygen from the material through different chemical reactions including decarburization, dephosphorization, desulfurization and deoxidation in order to impart it with required physical and mechanical characteristics while adjusting the contents of major components such as carbon so that steel with good properties can be obtained.

To achieve these objectives, it is essential to perform the whole process as quickly as possible because the above reactions may proceed reversibly as the material stays under the melting conditions in an arc furnace for a lengthy period of time.

Major methods currently used to accelerate the melting process and to save electric power required for the process include the use of an oil burner for auxiliary melting of the material in the furnace, use of a lance pipe to stop the supply of oxygen, blowing of oxygen into the metal bath and, in some cases, use of a heavy weight to compress bulky feed material in the furnace.

Energy-Saving Measures through the Operation of Arc Furnaces

In order to save energy one should:

(1) Reduce operating hours

(2) Raise the resistance welding time in order to eliminate wasteful power consumption. Consequently, the use of excessively bulky materials should be avoided as much as possible, and they should be pressed and massed together.

(3) Effectively use oxygen blow to quickly raise the temperature to over 1,600°C. The use of essentials, such as a poker, is desirable.

(4) As a charge will come two or three times, it is necessary, in order to secure operation speed, to have close contact between the crane operator and other related operators so that there is no waiting for the crane.

(5) Install high-powered transformers and carry out rapid dissolution.

3.1.2 Capacity, Required Size and Electrical Equipment for Arc Furnace

Table 1 shows relations among capacity, required size and electrical equipment.

The melting rate depends largely on the capacity of the transformer as seen from Table 2.

Table 1 Relations among furnace capacity, requir~d size and electrical equipment

Nominal capacity of furnace [10³kg]	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	1000	550~600	30	45	60	500/200
150	7.010	1000	600	30	50	70	500/200
170	7.315	1050	600	35	60	80	500/200
200	7.620	1100	600	40	70	100	560/200
400	9.754	1200	700	-	–	150	

Notes RP: regular power, HP: high power, UHP: ultra-high power
Source: Cast Product Handbook, 4th Ed., ed. Japan Cast Product Association

Table 2 Theoretical production rate at different electric power level (70-ton furnace)

	Melting time [min]	Theoretical production rate [t/m]	Ratio of efficiency [%]
RP	159	100	100
HP	105	150	150
UHP	70	230	230

Source: same as in Table 1

3.1.3 Arc Furnace Melting Process

(i) Feed Material and Feeding Process

a) Feed Material

The type of feed material used in the arc furnace melting process depends on the product to be produced. Machine chips, pressed steel scraps, light steel scraps and steel casting scraps are generally used for producing bars and sections, while steel casting scraps, light steel scraps, machine chip scraps and steel casting scraps are employed for producing steel castings.

In the former case, feed materials are bulky, and cannot be fed to the furnace in one step, generally requiring three or more steps instead. In any case, it is essential to prevent non-ferrous metals, including copper and aluminum, and non-metallic substances, including rust and oil, from getting into the feed material.

b) Feeding of Material

Bulky feed materials are normally used for the production of general steel products, as stated above. In general, the canopy is opened and a charging basket is employed to feed them in several steps.

Figures 2-a, 2-b and 2-c show a typical sequence of charging operations where a charge (10 tons) is fed in three steps.

In the first step, machine chips are laid on the floor of the furnace, followed by the feeding of limestone, light steel scraps, returned scraps, pressed steel plate scraps, light steel scraps and machine chips in this order. Secondly, pressed steel scraps, light steel scraps and machine chips are fed onto the metal bath at the bottom. In the third process, returned scraps, steel casting scraps, pressed steel plate scraps, light steel scraps and machine chips, carried in a charging basket, are fed in this order from the top of the furnace onto the metal bath.

In feeding one charge, bulky materials should be at the bottom while lighter ones should be at the top. This permits the efficient use of electric power while preventing damage to the rod electrodes.

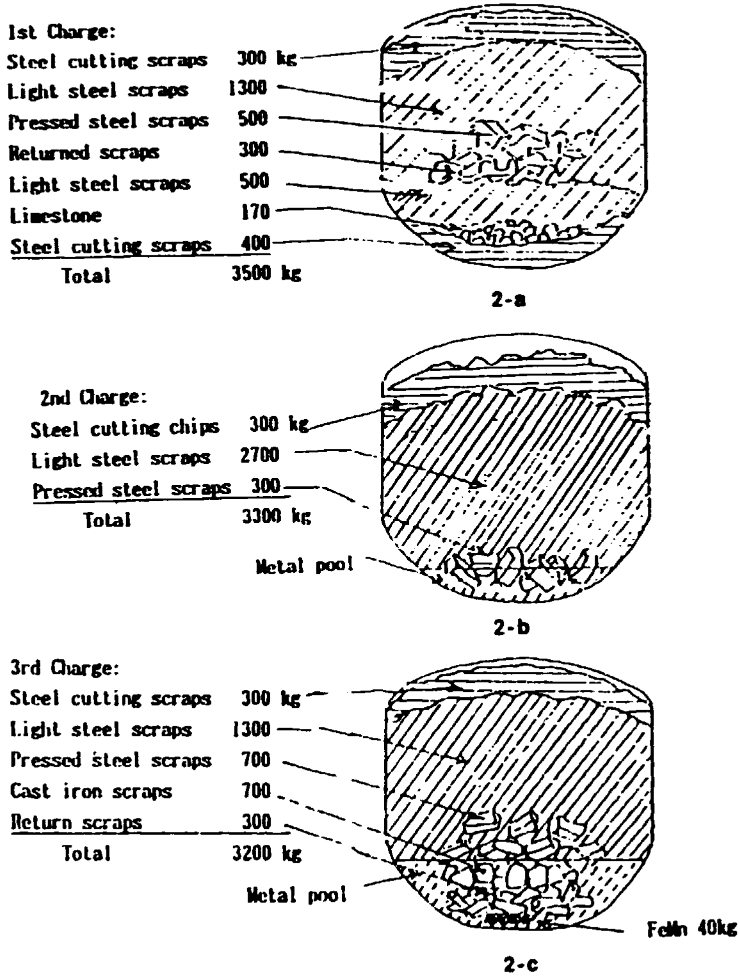


Figure 2 Method and sequence of feeding material to arc furnace (fed in three steps)

A bypass may be provided between the dust collector and the arc furnace, with a charging basket placed there for pre-heating in waste gas. This can reduce the power consumption by 20–50 kWh/t.

(ii) Operation of Arc Furnace

After charging the arc furnace with materials, electric power is supplied and then melting operations are performed as described in the following example, where a furnace with a capacity of eight tons (10-ton charge) is used.

a) Melting Period

The melting period accounts for more than 50% of the total power consumption used in the entire arc furnace melting process. The operations, therefore, require skilled workers.

a. Blending of feed Material

The following material composition and charging sequence are recommended.

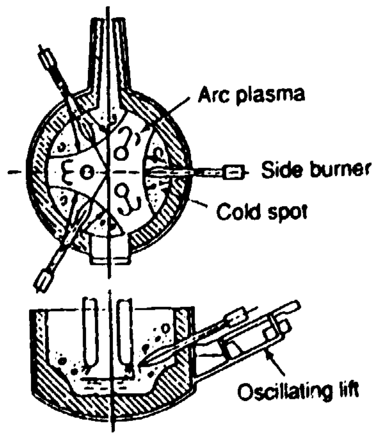
Desired composition

Light steel scraps:	approx. 60%
Steel cutting scraps:	15%
Pressed steel scraps:	15%
Pressed steel plate scraps:	5%
Returned steel scraps:	5%

Where charging is performed in three steps, it is recommended to adjust their weight ratio to 45%, 30% and 25%.

b. Oil Burner

For the saving of electric power, an oil burner is used to accelerate the melting of the fed material. In this case, the burner is fixed at a cold spot in the furnace as shown in Figure 3 so as to avoid the burning of the electrodes.



Source: Cast Product Handbook, 4th Ed., ed. Japan Cast Product Association

Figure 3 Swing side oil burner

c. Specification and Use of Oxygen Lance Pipe

Desirable specifications are as follows : a diameter of 20–40 mm, a pressure of 5–10 kgf/cm^2, a flow rate of 20–60 m^3/min, and a consumption of 5–15 m^3/t.

Oxygen lance cutting should be performed along the side wall of the furnace in a way that will not cause damage to the wall (Figure 4).

Lance cutting, if required, should be conduc.ed as early as possible. Thus, it should be started in about 15 min after the first charging, about 5 min after the second charging, and about 5 min after the third charging (time measured after the start of electric power supply).

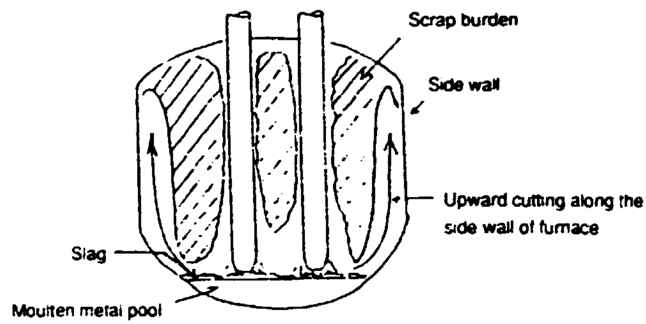
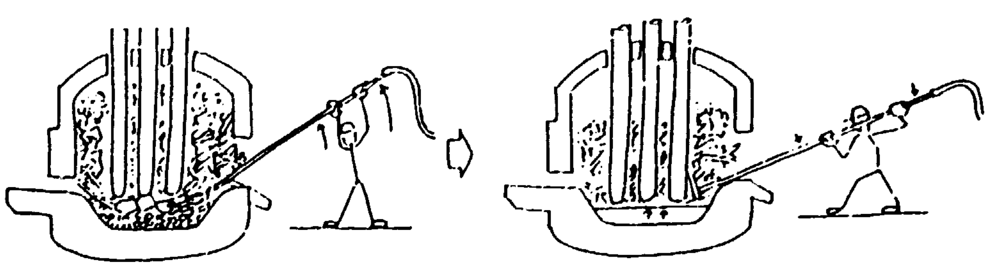
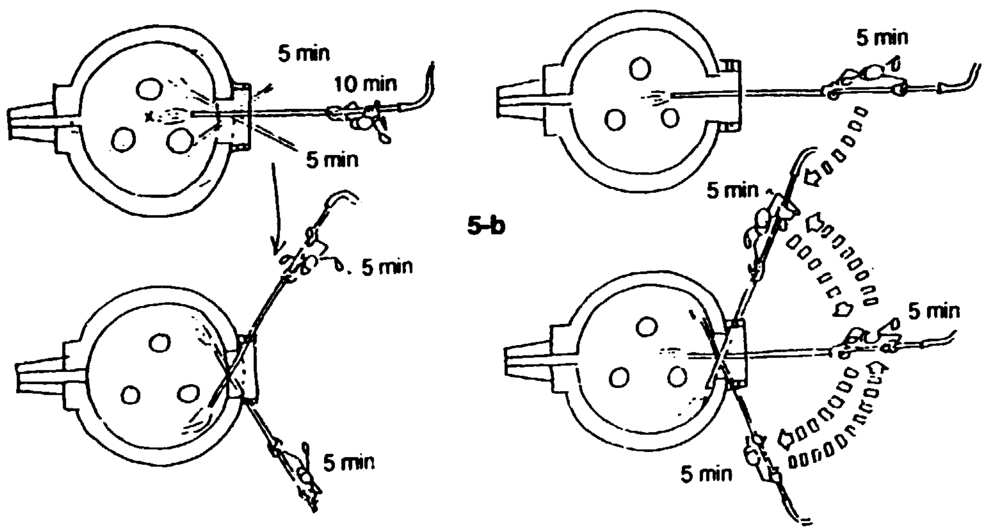


Figure 4 Cutting of oxygen lance

During heating, the oxygen lance should be inserted deep (50 mm or more depending on the furnace capacity) into the metal pool in the furnace so as to avoid damage to the electrodes, as illustrated in Figure 5-a, 5-b and 5-c.



5-a



5-c

Figure 5 Oxygen blowing process in oxidizing period

d. Compression of Fed Material under Weight

When bulky material becomes slightly red hot in the furnace, the canopy is removed and the material is compressed under an appropriate weight suspended from a crane, with power supply stopped for saving electric energy. Power supply is resumed immediately after completing the compression.

The duration of compression under the weight should generally be in the range of 15 to 25 min after the start of power supply depending on the total weight of the material. This operation should be carried out quickly and therefore should be performed in close coordination with the crane.

e. Removal of Slag after Meltdown

Steel scraps fed in the furnace often contain many undesirable components including soil, stones, scraped bricks, and concrete debris, leaving large amounts of slag after the meltdown and reducing the fluidity. Slag should be removed as early as possible.

b) Oxidizing Period

Samples are taken from the molten metal bath and subjected to analysis of the contents of carbon, silicon, manganese and sulfur to allow composition adjustment immediately before the start of the oxidizing period.

The oxidizing period is important in accelerating major processes including dephosphorization, desulfurization, decarburization and deoxidation. This requires a metal bath temperature of above 1,600°C. To achieve this, the voltage is decreased to increase the current. Oxygen blowing through the lance pipe is performed during this period. The description on temperature raise in Paragraph c. "Specification and Use of Oxygen Lance Pipe" should be referred to for details of this operation. The metal bath temperature should generally be above 1,620°C at the end of the oxidizing period.

Slag in the surface of molten metal bath should be removed completely at the end of the oxidizing period.

c) Reducing Period

During the reducing period, scouring is performed in the presence of basic slag to remove oxygen in the bath, whose content is increased during the oxidizing period. At the same time, desulfurization is carried out while adjusting the composition and temperature of the bath.

The deoxidation process consists of diffused deoxidation, which uses reducing slag, and forced deoxidation. Steel is taken out when the reducing slag has become stable after the raise of the bath temperature showing the completion of the scouring. The operations are illustrated in Figures 6-a, 6-b, 6-c, 6-d, 6-e, 6-f, 6-g and 6-h.

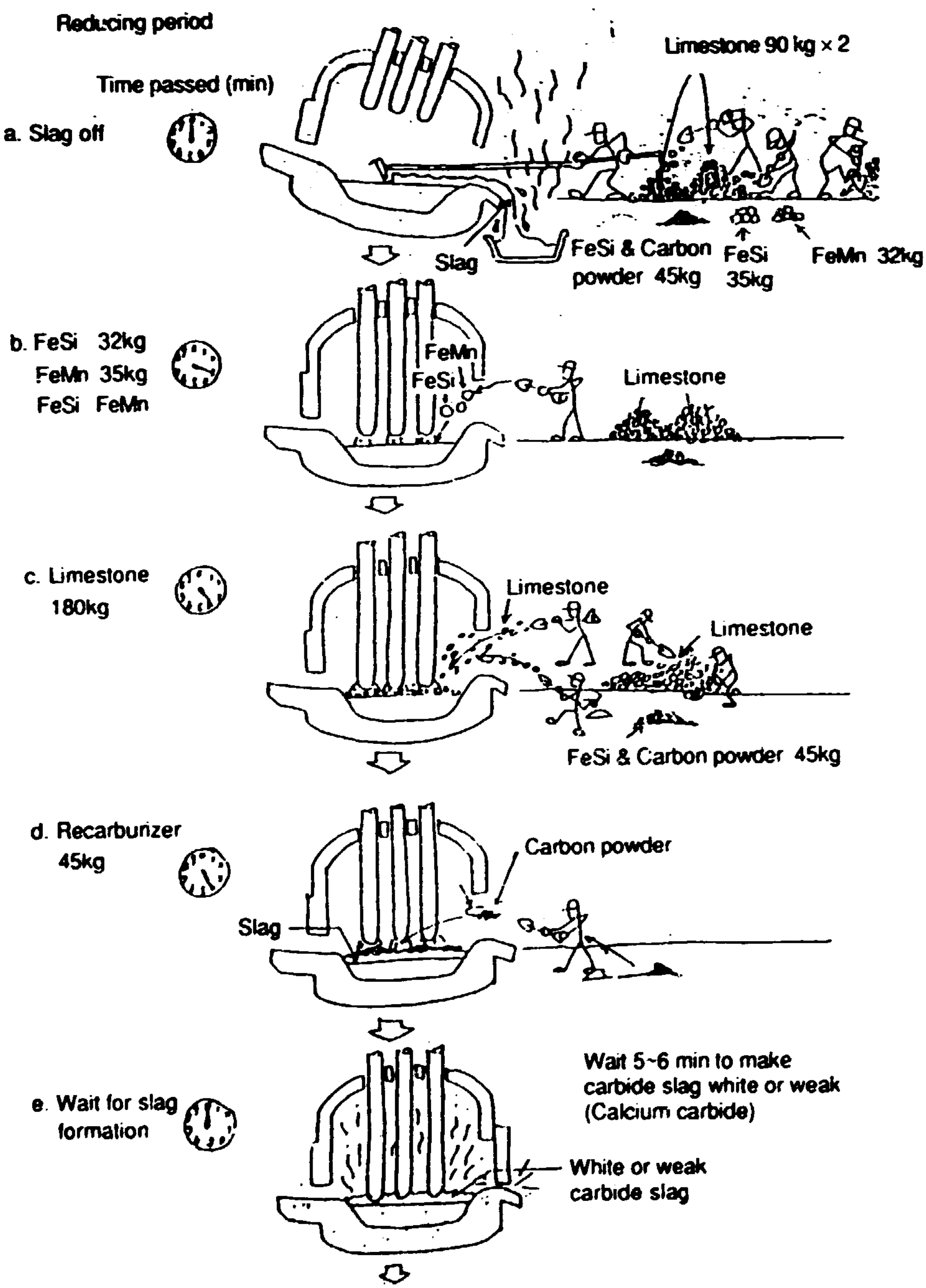


Figure 6 Operation of steel making in basic arc furnace reducing period (1)

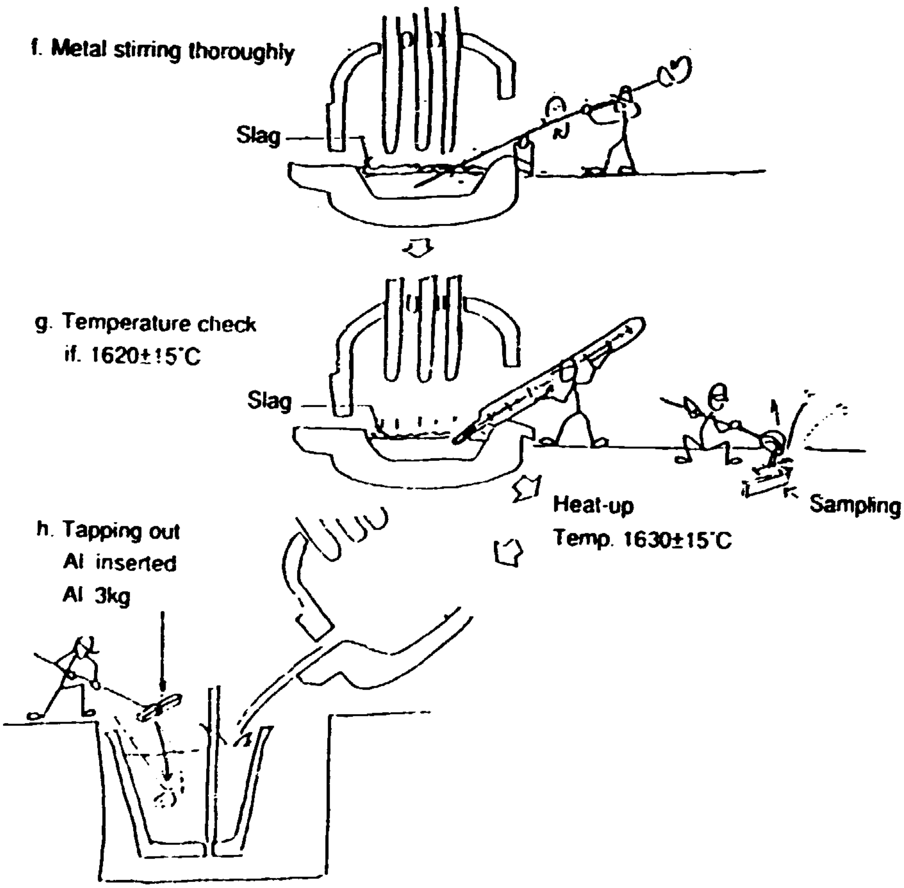


Figure 6 Operation of steel making in basic arc furnace reducing period (2)

d) Cautions for Arc Furnace Operation

As stated at the beginning, the steel making process through arc furnace melting is aimed mainly at the removal of undesirable elements such as phosphorus, sulfur, hydrogen and oxygen, and the adjustment of the composition for various components including carbon. These steel-making reactions are very sensitive when performed in the presence of high-temperature slag. What is most important, therefore, is to avoid the diffusion of heat out of the furnace and the inflow of air into the furnace. It is also essential to prevent the furnace from coming into a state which is undesirable for the slag formation. In addition, the operations should be carried out quickly because their duration can affect the quality of the product.

e) Operations after Removal of Steel and Reduction in Duration

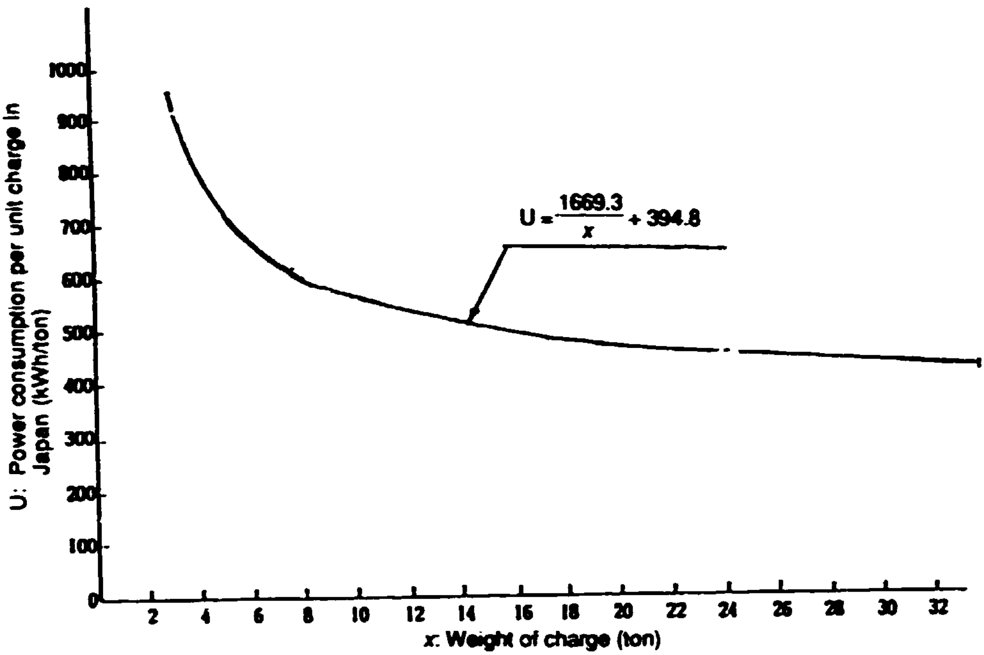
To reduce the time period until the start of the next melting process after the removal of steel is important in improving the steel removal efficiency and decreasing the power consumption.

Furnace repair materials, limestone, feed steel materials, etc., should always be kept ready to permit quick repair and charging of the furnace. Coordinated operations with the crane, etc., should also be performed quickly and systematically. Adequate training of workers is essential to ensure these.

f) Unit Power Consumption by Basic Arc Furnace and Standard Method for Melting

The process for arc furnace melting is described in the previous section. Illustrated below is the standard method for basic arc furnace melting used in Japan and typical power consumption per unit production in the country.

Table 3 and Figure 7 show the operation and typical power consumption per unit charge, respectively.



Source: 1977 Japan Cast and Forged Steel Association Report of Analysis Results on Unit Steel Production in Different Electric Arc Furnaces

Figure 7 Typical power consumption per unit charge in Japan (kWh/ton)

Table 3 Standard operation of steel making in basic furnace

Charging materials and additives	Process	Required time [min]	Operations	Chemical composition [%] C	Si	Mn	P, S	Steel melting temperature [°C]
Dolomite → Magnesia	Maintenance	10~20	Power supply					
Scrapped steel → $CaCO_3$ 10~40 kg/ton → (CaO 5~20 kg/ton) Recarburizer (as required)	Charging	5~10						
	Melting period	40~60	Oxygen cutting					
Fe-Ore (scale) →	Oxidizing period	20~40	Complete meltdown	0.40/ 0.60		0.20/ 0.40	≤0.070	Temperature raise
$CaCO_3$ → CaF_2			Oxidative boiling refining					
O_2 →			Oxygen pressure 5~10 kgf/cm^2 Decarburization rate 0.04~0.09%C/min					≥1600
	Skimming	5~8	Complete skimming	0.10/ 0.15		0.20/ 0.30	P ≤0.020	≥1650
Si-Mn, Fe-Mn, Fe-Si → $CaCO_3$ 20~30 kg/ton (CaO 10~15 kg/ton) CaF_2 4~6 kg/ton C-P, Si-P 1.5~2.5 kg/ton	Reducing period	20~50	White slag, weak carbide slag (basicity 2.5~3.0) Determination of degree of deoxidation				S ≤0.020	
Ferroalloy → Al 0.3 kg/ton →	Removal of steel	3~5	Removal of steel (preheating of ladle)	0.20/ 0.30	0.30/ 0.50	0.50/ 0.80		1600 ~ 1640

Source: Cast Product Handbook, 4th Ed., ed. Japan Cast Product Association

3.2 Reheating Furnace

3.2.1 Specification

After billets are roughly rolled at a blooming mill or made by continuous casting, a reheating furnace reheats them at a given temperature according to its purpose before they are sent to the hot rolling process to make finished products.

Reheating furnaces can be divided into batch-type furnaces and continuous furnaces. Batch-type furnaces are mainly used as auxiliary equipment to reheat something of a special form. For mass production, continuous furnaces are used in general.

The types of continuous furnaces include pusher-type furnace, walking hearth-type furnace, and walking beam-type furnace. In the past, pusher-type furnaces were used most widely, and walking hearth-type furnaces were used for special treatments. With increased heating capacity, walking beam-type furnaces are getting adopted widely. Figures 8 and 9 show examples of a pusher-type furnace and a walking beam-type furnace. Table 4 compares these furnace types, and Table 5 shows layouts of reheating furnaces.

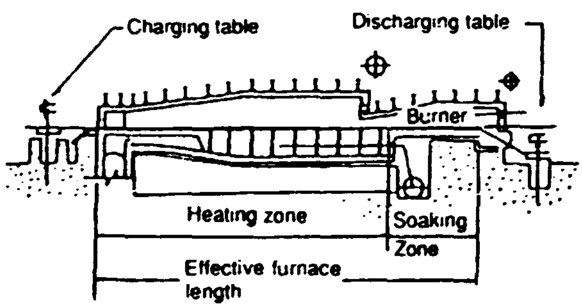


Figure 8 Pusher-type 3-zone reheating furnace

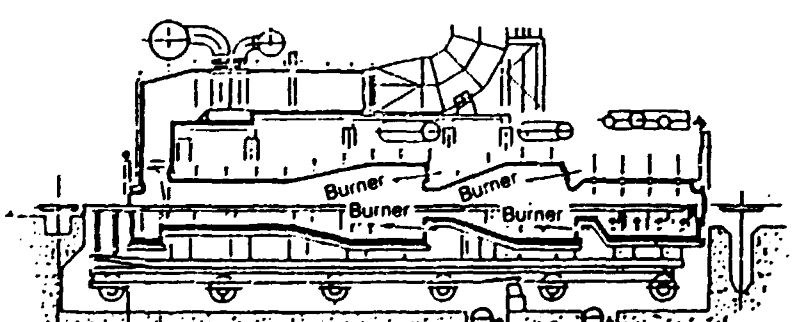
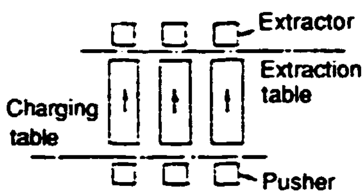
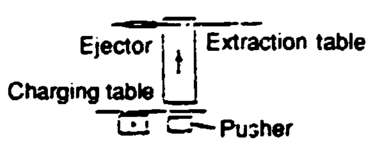
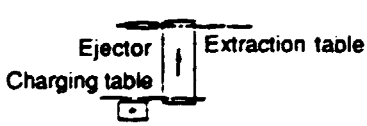


Figure 9 Walking beam-type reheating furnace

Table 4 Comparison of furnace types

Furnace type	Advantages	Disadvantages	Applications
Pusher-type furnace	1. Installation cost is slightly lower than other types. 2. Double-side heating is possible. 3. High efficiency.	1. Skid marks and scratches are easily made. 2. There is a limit to the length of furnace. 3. The thickness of steel materials cannot be changed quickly.	1. Mass production 2. Widely used in many mills. Being replaced by walking beam-type.
Walking hearth-type furnace	1. No skid mark is made. 2. No scratch is made. 3. Furnace can be emptied by itself.	1. The length of furnace is long because of one-side heating. 2. The scale disposal on the hearth is complicated.	1. Applied to heating and heat treatment of thin material, round billet, steel pipe.
Walking beam-type furnace	1. There is no limit to the length of furnace. 2. Skid marks are small, and no scratch is made. 3. High efficiency. 4. Furnace can be emptied by itself.	1. Installation cost is slightly higher. 2. The number of skids is large, and the loss by cooling water is rather high.	1. Mass production 2. Applied to roughly shaped billet which cannot be pushed by pusher-type furnace, especially thick slab, and when products of very high quality are required.

Table 5 Layout of heating furnace

Charging/ extraction method	Furnace layout	Characteristics
Back charging, front extraction		1. It is easy to charge and extract large billets. 2. The layout is easy when two or more furnaces are installed. Thus, this method is suitable for large-capacity facilities such as hot strip mills and slab mills. 3. The area of openings for charging and extracting is large. As a result, heat loss by thermal radiation or air intrusion is large. 4. Extraction is done by pushing or extractors.
Back charging, side extraction		1. Billets can be kept hot during the rolling, thanks to the closeness of the rolling mill and the reheating furnace. 2. Heat loss by thermal radiation from the extraction outlet is small. 3. Extraction is done by ejectors or rollers. However, when rollers are used, heat loss is large through cooling water for the rollers.
Side charging, side extraction		1. Heat loss is small at both the charging inlet and the extraction outlet. This method is most suitable to a reheating furnace for long billets.

The arrangement of burners to a furnace is very important for heating characteristics of the furnace. According to the positions of burners to furnace, arrangements are classified into three methods; axial-flow burning, side burning, and roof burning. Each method has its own characteristics. A particular method is adopted for a furnace to take advantage of its characteristics. In some furnaces, combinations of these burning methods are applied. Table 6 shows a comparison among various burning methods.

Table 6 Comparison of burning methods for reheating furnaces

Item	Axial-flow burning	Side burning	Roof burning
1. Position of burners to furnace			
2. Fuel	2. Heavy oil, C gas, M gas etc.	2. Heavy oil, C gas, M gas etc.	2. Kerosine, C gas, M gas etc.
3. Type of burner flame	3. Long flame type	3. Short flame type (variable type)	3. High load burning radiation type
4. Control ability of fuel amount	4. Wide range of adjustment	4. Narrow range of adjustment. A thinned-out control is necessary, responding to burning amount.	4. Relatively wide range of adjustment
5. Heating load	5. Can be large with large-capacity burners	5. Can be large with large-capacity burners	5. Not so large with small burners
6. Limitation due to furnace size	6. Limitation on the length per zone in the direction of furnace length	6. Limitation in the direction of furnace width	6. Not particularly. Under-burning is impossible.
7. Flow of burning gas inside the furnace	7. The flow is smooth along the length of furnace.	7. Drift tends to occur, because the direction of burners and the direction of furnace length make the right angle.	7. Flow is smooth in the furnace, because most of burning is done in burner tiles.
8. Setting structure of burners to furnace body	8. Nose parts are necessary, and the structure of furnace body gets complicated.	8. There is no nose part, and the structure is simple.	8. The structure of furnace is simple, but the pipe arrangement is complicated due to the large number of burners.
9. Uniformity of heating (heat pattern)	9 Uniformity is easily gained for the direction of furnace width. The temperature tends to fall at nose parts in the direction of furnace length.	9. Uniformity is poor in the direction of furnace width. Uniformity in the direction of furnace length is easy to gain.	9. Uniformity is easily gained in both directions of furnace width and furnace length.
10. Workability	10. Relatively good except around burners at lower area where the temperature is high.	10. Workability is good.	10. Rather poor with relatively high temperature and a large number of burners

3.2.2 Characteristics of Energy Consumption

The fuel consumption rates in 1960's were **from 370 × 10³ to 450 × 10³ kcal/t for a pusher-type furnace** and **from 450 × 10³ to 590 × 10³ kcal/t for a walking beam-type furnace**, for which cooling water loss was large through water cooled beams. Today walking beam-type furnaces are the majority rather than pusher-type furnaces, and **their fuel consumption rates in 1989 were between 203 × 10³ and 566 × 10³ kcal/t, with the average being 267 × 10³ kcal/t**, thanks to the improvement in heat efficiency as a result of the accumulation of measures which are described later. The dissemination of hot charging, which utilizes a high temperature of the previous process, has also made a great contribution to this improvement.

3.2.3 Energy Conservation Technologies

The basic ideas for energy conservation on reheating furnaces are the rationalization of combustion, the rationalization of heating and cooling, the prevention of heat loss by radiation and transmission, and the recovery of waste heat. Figure 10 shows a characteristic diagram of energy conservation for reheating furnace, and Figure 11 illustrates the main items.

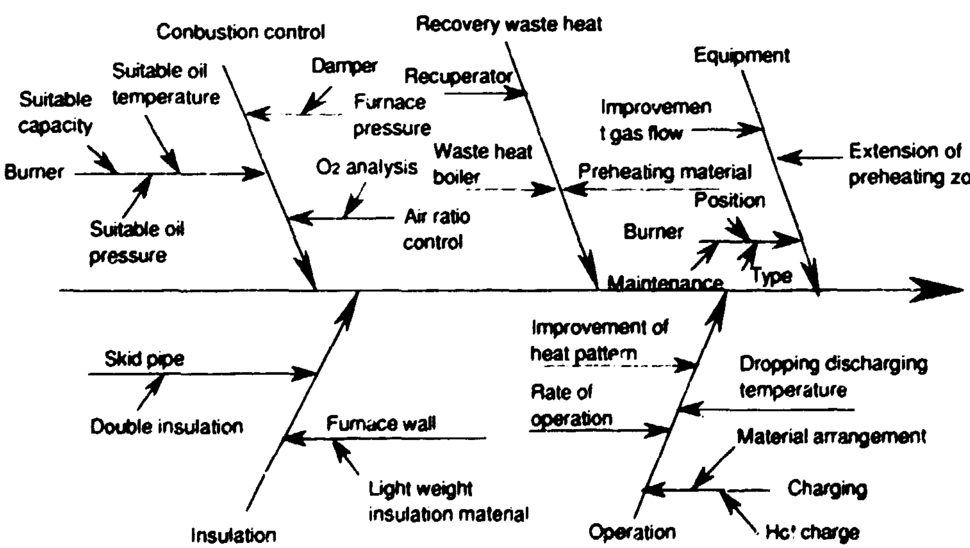


Figure 10 Characteristics diagram of energy conservation for reheating furnace

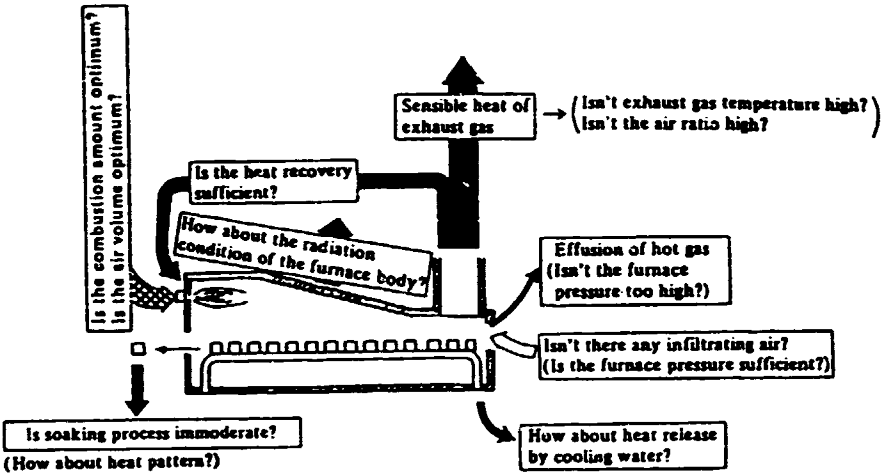


Figure 11 Reduction point for fuel consumption rate

3.2.4 Heat Balance

Heat balance is an effective means of promoting energy conservation. It allows to numerically grasp the present situation of heat loss and efficiency in heating. Then, based on these data, one can find out how to improve operating standards and facilities. Thus, implementation of heat balance is a precondition of promoting energy conservation. Japanese Industrial Standard (JIS) G0702 "Method of heat balance for continuous furnaces for steel" was issued for the purpose of grasping the heat loss and efficiency of reheating furnace sufficiently. Table 7 shows the measurement items and results of measurement. Table 8 is a heat balance table.

Table 7 Table for measurement items and results of measurement

1	Date and time of measurement (Hours)					
2	Person in charge of measurement					
3	Weather	Atmospheric pressure	Atmospheric temp.	Room temp.	Relative humidity	
		mmHg	°C	°C	%	
4	Fuel	Soaking zone consumption	kg/t or m^3N/t			
5		Upper heating zone consumption	kg/t or m^3N/t			
6		Lower heating zone consumption	kg/t or m^3N/t			
7		Pressure	kgf/cm^2 or mmAq			
8		Temperature	°C			
9		Components	%			
10		Low calorific value	kcal/kg or kcal/m^3N			
11	Atomizer	Kind				
12		Soaking zone consumption	kg/t or m^3N/t			
13		Upper heating zone consumption	kg/t or m^3N/t			
14		Lower heating zone consumption	kg/t or m^3N/t			
15		Pressure	kgf/cm^2 or mmAq			
16		Temperature	°C			
17	Secondary air	Soaking zone consumption	kg/t or m^3N/t			
18		Upper heating zone consumption	kg/t or m^3N/t			
19		Lower heating zone consumption	kg/t or m^3N/t			
20		Pressure	mmAq			
21		Pre-preheating temp.	°C			
22		Post-preheating temp.	°C			
23	Cooling water	Consumption	t/t			
24		Inlet temp.	°C			
25		Outlet temp.	°C			
26		Pressure	kgf/cm^2			
27	Combustion gas	Furnace tail temp.	°C			
28		Inlet Temp. of preheater	°C			
29		Outlet temp. of preheater	°C			
30		Components	%	CO_2, O_2, CO, (CH_4, H_2)		
31	Cinder	Combustible amount	%			
32		Cinder amount	kg/kg			
33	Heated steel	Size (Thickness × Width × Length)	mm × mm × mm			
34		Unit weight	kg			
35		Total charged tonnage	t			
36		Charging temp.	°C			
37		Discharging temp.	°C			
38		Burning loss	kg/t			
39		Average in-furnace holding time	h			
40	Furnace pressure		mmAq			
41	Surface temp. of each part of furnace body		°C			

(Remark) As to the measurement method for Item 41, describe in the furnace sketch.

Table 8 Heat balance table

Heat input			Heat output		
Item	10^3 kcal/t	%	Item	10^3 kcal/t	%
(1) Combustion heat of fuel			(8) Quantity of heat contained by extracted steel		
(2) Sensible heat of fuel			(9) Sensible heat of scale		
(3) Sensible heat of air			(10) Sensible heat of exhaust gas		
(4) Heat brought in by atomizer			(11) Heat loss by incomplete burning		
(5) Quantity of heat contained by charged steel			(12) Quantity of heat brought out by cooling water		
(6) Heat of scale formation			(13) Quantity of heat brought out by cooling water		
(7) Heat recovered by preheater	( )	( )			
			(14) Other heat loss		
			(15) Heat recovered by preheater	( )	( )
Total (1) + (2) + (3) + (4) + (5) + (6)			Total (8) + (9) + (10) + (11)+ (12) + (13) + (14)		

Remark 1. For recording the quantity of heat, use 10^3 kcal/t as a unit and round our figures after the decimal point into a single digit.

2. Round out figures after the decimal point into a single digit in the percentage.

The following is a concrete example of heat balance on a continuous steel reheating furnace.

(1) Standard for heat balance

Heat balance is measured for one ton of charging steel with the outside air temperature and the low calorific value of fuel at operation as its standard.

(2) Results of measurement

a) Steel

Charged amount (t/h)	Charging temperature (°C)	Discharging temperature (°C)	Burning loss (kg/t)
99.6	25	1,270	14.2

b) Fuel

Fuel	Consumption (kg/h)	Component of heavy oil						High calorific value (kcal/kg)	Temperature (°C)
		C %	H %	O %	N %	S %	Water content %		
C heavy oil	4572	84.7	11.7	0.8	0.4	2.2	0.2	10,280	64

c) Exhaust gas from combustion

Temperature (°C)	Composition of dry exhaust gas			
	CO_2 %	O_2 %	CO %	N_2 %
520	12.7	1.8	0.0	85.5

d) Cooling water

Amount of water (kg/t)	Inlet temperature (°C)	Outlet temperature (°C)
5,200	34	45

e) Temperature of air for combustion 55°C

f) Outside air temperature 25°C

(3) Calculation of input amount and output amount

a) Input amount

a. Charged steel 1 ton

b. C heavy oil 4572 / 99.6 = 45.9 kg/t

c. Amount of air for combustion (A_0)

$$A_0 = \frac{1}{100}\{8.89 \cdot C + 26.7(H - \frac{0}{8}) + 3.33 \cdot S\}$$

$$= \frac{1}{100}\{8.89 \times 84.7 + 26.7(11.7 - \frac{0.8}{8}) + 3.33 \times 2.2\}$$

$$= 10.7\ m^3{}_N/kg\ fuel$$

$$m\ (air\ ratio) = \frac{21}{21 - 79\{\frac{(O_2) - 0.5(CO)}{(N_2)}\}}$$

$$= \frac{21}{21 - 79\{\frac{1.8}{85.5}\}}$$

$$= 1.09$$

Amount of air per kg fuel (A)

$$A = mA_0$$

$$= 1.09 \times 10.7\ m^3{}_N/kg\ fuel$$

Therefore, the amount of air for combustion for 1 ton of steel is

$1.09 \times 10.7 \times 45.9 = 535\ m^3{}_N/t$

b) Output amount

a. Amount of extracted steel

Due to the 14.2 kg of burning loss for 1 ton of charged steel,

$1 - 0.0142 = 0.9858$ t

b. Amount of scale

When no component analysis is performed for scale, the ratio of Fe by weight is assumed to be 75%. Therefore,

$$(\text{Amount of scale}) = \frac{(\text{burning loss})}{(\text{ratio of Fe in scale by weight})}$$

$$= \frac{14.2}{0.755} = 18.8\ kg/t$$

c. Amount of dry exhaust gas from combustion (G')

$$G' = G_0 + (m - 1)A_0$$

G_0: theoretical amount of dry exhaust gas

$$= \frac{1}{100}\{8.89 \cdot C + 21.1(H - \frac{0}{8}) + 3.33S + 0.8N\}$$

$$= \frac{1}{100}\{ 8.89 \cdot 84.7 + 21.1 (11.7 - \frac{0.8}{8}) + 3.33 \times 2.2 + 0.8 \times 0.4 \}$$

$= 10.1\ m^3{}_N/kg$ fuel

$G' = 10.1 + (1.09 - 1) \times 10.7$

$= 11.1\ m^3{}_N/kg$ fuel

Therefore, the amount of dry exhaust gas for 1 ton of steel is

$11.1 \times 45.9 = 509.5\ m^3{}_N/t$

d. Amount of water vapor in combustion exhaust gas

Moisture content in the air for combustion can be ignored.

$$\frac{1}{100}(9H + \text{water content}) = \frac{1}{100}(9 \times 11.7 + 0.2) = 1.06\ kg/kg \text{ fuel}$$

For 1 ton of steel,

$1.06 \times 45.9 = 48.7\ kg/t$

(4) Calculation of heat input and heat output

a) Heat input

a. Low calorific value of fuel (Hl)

$Hl = Hh - 600(9H + \text{water content})$

Hh: high calorific value

$= 10280 - 600 (9 \times 0.117 + 0.002)$

$= 9650$ kcal/kg fuel

For 1 ton of steel,

$9650 \times 45.9 = 442940$ kcal/t

b. Sensible heat of fuel

Assuming that the mean specific heat of C heavy oil is 0.45 kcal/kg•°C,

$45.9 \times 0.45 \times (64 - 25) = 810$ kcal/t

c. Sensible heat of air

Assuming that the mean specific heat of air is 0.31 kcal/$m^3{}_N$ •°C,

$(535 \times 0.31) \times (55 - 25) = 4980$ kcal/t

d. Contained quantity of heat in charged steel

Since steel is charged at outside air temperature, its contained quantity of heat is zero.

e. Heat of formation of scale

When no component analysis is performed for scale, heat of formation of scale is assumed to be 1335 kcal/kg•Fe for 1 kg of Fe contained in the scale.
Therefore, 1335 × 14.2 = 18960 kcal/t

b) Heat output

a. Contained quantity of heat of extracted steel

[1,000 (kg) – burning loss of Fe (kg)] × [contained quantity of heat of steel at discharging temperature (kcal/kg) – contained quantity of heat of steel at outside air temperature (kcal/kg)]

= (1000 – 14.2) × { (200.4 – (– 2.9) } = 200410 kcal/t

b. Sensible heat of scale

0.215 kcal/kg•°C is used for the mean specific heat of scale. It is assumed that the temperature of scale when it comes out from the furnace is same as the discharging temperature of steel.

18.8 × 0.215 × (1270 – 25) = 5030 kcal/t

c. Sensible heat of dry exhaust gas from combustion

Assuming that the mean specific heat of dry exhaust gas from combustion is 0.33 kcal/m^3_N•°C.

509.5 × 0.33 × (520 – 25) = 83230 kcal/t

d. Heat held in water vapor in exhaust gas

Assuming that the mean specific heat of water vapor is 0.45 kcal/kg•°C.

48.7 × 0.45 × (520 – 25) = 10850 kcal/t

e. Heat taken away by cooling water

Assuming that the mean specific heat of water is 1 kcal/kg•°C,

5200 × 1 × (45 – 34) = 57200 kcal/t

f. Other heat loss

The difference between the total heat input and the total heat output.

(442940 + 810 + 4980 + 18960) – (200410 + 5030 + 83230 + 10850 + 57200)

= 110970 kcal

Table 9 shows the heat balance which summarizes the results above.

Table 9 Heat balance table

Heat input			Heat output		
Item	10^3 kcal/t	%	Item	10^3 kcal/t	%
(1) Combustion heat of fuel	442.9	94.7	(8) Quantity of heat contained by extracted steel	200.4	42.8
(2) Sensible heat of fuel	0.8	0.2	(9) Sensible heat of scale	5.0	1.1
(3) Sensible heat of air	5.0	1.1	(10) Sensible heat of exhaust gas	94.1	20.1
(4) Heat brought in by atomizer	0	0	(11) Heat loss by incomplete burning	0	0
(5) Quantity of heat contained by charged steel	0	0	(12) Quantity of heat brought out by cooling water	0	0
(6) Heat of scale formation	19.0	4.0	(13) Quantity of heat brought out by cooling water	57.2	12.2
(7) Heat recovered by preheater	(0)	(0)			
			(14) Other heat loss	111.0	23.8
			(15) Heat recovered by preheater	(0)	(0)
Total (1) + (2) + (3) + (4) + (5) + (6)	467.7	100.0	Total (8) + (9) + (10) + (11) + (12) + (13) + (14)	467.7	100.0

Remark 1. For recording the quantity of heat, use 10^3 kcal/t as a unit and round our figures after the decimal point into a single digit.

2. Round out figures after the decimal point into a single digit in the percentage.

As this heat balance shows, 20.1% of the heat output was taken away by exhaust gas, 12.2% was taken away by cooling water. Most of the "other heat loss", which amounted to 23.8%, is thought to be the quantity of thermal radiation from the surface of the furnace body. This shows the necessity of reducing these losses.

3.2.5 Rationalization of Combustion

(i) Optimization of Air Ratio

As for a reheating furnace, the optimization of air ratio is the handiest and most economical measure for energy conservation. The effect of this measure is higher when the temperature of furnace is high. Air ratio is the value that is given by dividing the consumed air amount by the theoretical combustion air amount, and it represents the extent of excess of air. In Japan, the standard air ratio for a continuous steel reheating furnace is set at 1.25. And this value of standard air ratio is stipulated as the air ratio measured at the outlet of furnace during the combustion around the rated load after checking and repairing are done.

If the air ratio is too high, the amount of exhaust gas increases. Thus, the loss by exhaust gas increases in proportion to the air ratio, given that the temperature of gas is constant. This relation is shown in Figure 12.

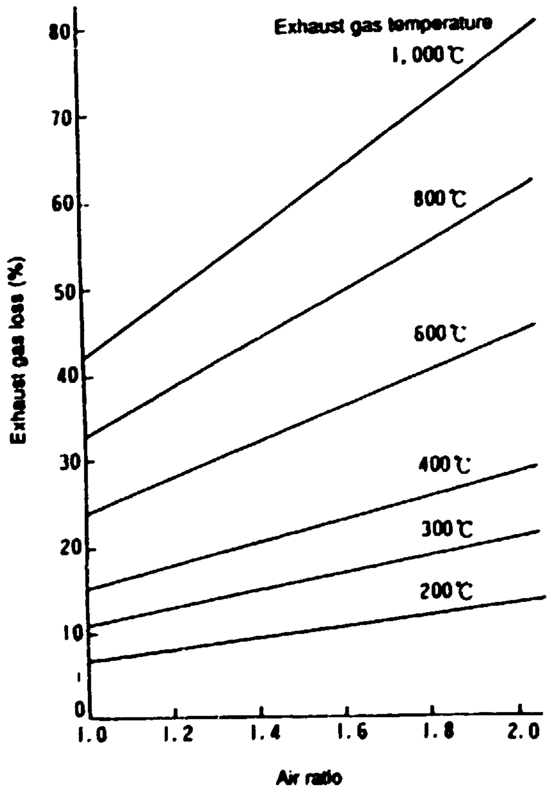


Figure 12 Relation between air ratio and exhaust gas loss

Table 10 shows the effect of improved air ratio on fuel saving. The percentages of saved fuel in this table were calculated with the following formula:

$$S = \frac{L(\mu_1 - \mu_2) \cdot T \cdot C_p}{F - Q - L(\mu_2 - 1) \cdot T \cdot C_p} \times 100\,(\%)$$

where S: saved fuel

L: theoretical combustion air amount $m^3{}_N$/kg fuel

μ_1: air ratio before correction

μ_2: air ratio after correction

T: temperature of furnace

C_p: specific heat of air at low pressure kcal/$m^3{}_N \cdot$°C

F: low calorific value of fuel kcal/kg fuel

Q: exhaust gas loss at theoretical combustion kcal/kg fuel

Table 10 Percentage of fuel saved when air ratio is corrected (case of heavy oil)

Furnace temperature (°C)	Air ratio before correction	Air ratio after correction				
		1.40	1.30	1.20	1.10	1.00
700	1.70	11.6	14.9	17.9	20.8	23.4
	1.60	7.72	11.1	14.3	17.3	20.1
	1.50	3.86	7.43	10.7	13.8	16.7
	1.40	–	3.76	7.27	10.5	13.5
	1.30	–	–	3.65	7.01	10.1
	1.20	–	–	–	3.48	6.74
	1.10	–	–	–	–	3.38
900	1.70	18.7	23.5	27.7	31.5	34.9
	1.60	12.5	17.6	22.2	26.3	29.9
	1.50	6.23	11.7	16.6	21.0	25.0
	1.40	–	5.94	11.3	16.0	20.2
	1.30	–	–	5.66	10.7	15.2
	1.20	–	–	–	5.29	10.1
	1.10	–	–	–	–	5.06
1100	1.70	30.8	37.3	42.6	47.1	51.0
	1.60	20.6	28.0	34.1	39.3	43.7
	1.50	10.3	18.6	25.6	31.4	36.4
	1.40	–	9.43	17.3	23.8	29.4
	1.30	-	–	8.67	15.9	22.1
	1.20	–	–	–	7.91	14.7
	1.10	–	–	–	–	7.36
1300	1.70	55.0	61.9	67.1	70.9	74.0
	1.60	36.7	46.5	53.6	59.1	63.4
	1.50	18.3	31.0	40.2	47.3	52.9
	1.40	–	15.7	27.2	35.9	42.7
	1.30	–	–	13.7	23.9	32.1
	1.20	–	–	–	11.9	21.3
	1.10	–	–	–	–	10.7

If a reheating furnace is not equipped with an automatic air/fuel ratio controller, it is necessary to periodically sample gas in the furnace and measure its O_2 contents by a gas analyzer. Figure 13 shows a typical example of a reheating furnace equipped with an automatic air/fuel ratio controller.

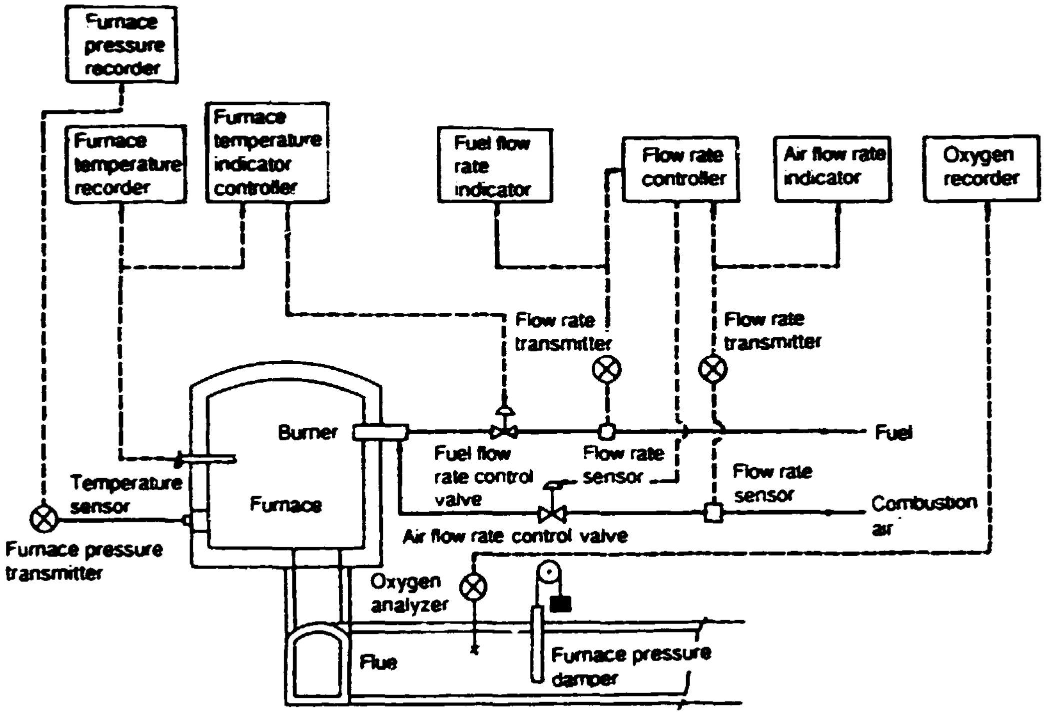


Figure 13 Air/fuel ratio control system with a flow rate controller

(ii) Control on Furnace Pressure

Control on furnace pressure is also important. The preset value for furnace pressure is usually set to be 0.2–0.4 mm H_2O at the level of hearth line where heated steels are charged. Doors on a reheating furnace need to be opened when steels are charged or extracted. If the pressure in the furnace was negative, it would cause intrusion of outside air, increasing heat loss and making the temperature distribution in the furnace uneven. It would also cause problems such as oxidation of steels. Since furnace pressure changes with the position of measurement, the setting of furnace pressure should be done carefully. In a reheating furnace with high furnace temperature, the furnace pressure increases about 1 mm H_2O for every 1 m increase of height due to the buoyancy of high temperature gas in the furnace. Hence, the furnace pressure is set to the value derived by the following formula for the measuring position shown in Figure 14.

$P = (0.2 \sim 0.4) + L$ (mm H_2O)

where P: preset value for furnace pressure (mm H_2O)

L: height of measuring opening from hearth (m)

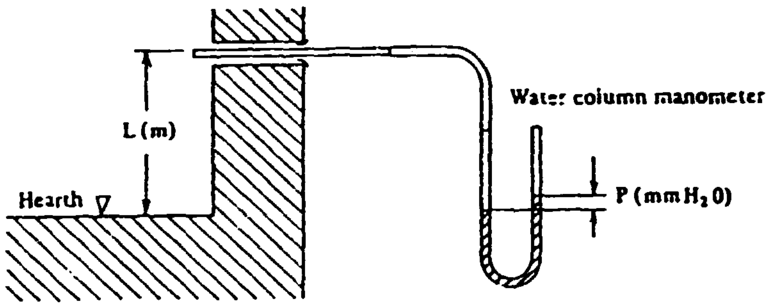


Figure 14 Furnace pressure measurement port and pressure setting

In addition to the proper control on furnace pressure, it is important to keep the openings as small as possible and to seal them in order to prevent the release of high temperature gas and intrusion of outside air through openings such as the charging inlet, extracting outlet and peephole on furnace walls or the ceiling.

3.2.6 Rationalization of Heating and Cooling

(i) Hot Charge

When a continuous casting mill and a reheating furnace of rolling mill are located closely and the layout is advantageous for hot charge, hot charge should be adopted to reduce fuel consumption rate. Hot charge is a method in which steels of high temperature are directly charged to a reheating furnace to conserve energy. In general, however, it is difficult to process the whole amount because of the difference between capacities of the continuous casting mill and the rolling line. In Japan, the rate of hot charge in the hot rolling process is about 50% on the average and about 80% for mills with highest rates; the charging temperature is about 500°C on the average and about 800°C for the highest. The rate of energy conservation by hot charge is 20×10^3 kcal/t per 100°C charging temperature. Thus, a large amount of energy can be saved by raising the percentage and temperature of hot charge.

3.2.7 Prevention of Heat Loss by Radiation and Transmission

The heat loss from a reheating furnace is largely divided into; 1. radiation loss through openings and surface of the furnace body, 2. cooling loss through water cooled skid pipes, 3. heat accumulation loss to internal insulation and members composing the furnace body. Here, the heat accumulation loss can be ignored, if operation is continued for a certain period of time without much change in temperature as is the case with a continuous steel reheating furnace.

(i) Prevention of Radiation Heat Loss from Surface of Furnace

a) Quantity of heat release from surface of furnace

The quantity of heat release from surface of furnace body is the sum of natural convection and thermal radiation. This quantity can be calculated from surface temperatures of furnace. The temperatures on furnace surface should be measured at as many points as possible, and their average should be used. If the number of measuring points is too small, the error becomes large.

The quantity (Q) of heat release from a reheating furnace installed in the building of a factory is calculated with the following formula:

$$Q = a \times (t_1 - t_2)^{5/4} + 4.88\,\varepsilon\,\{ (\frac{t_1 + 273}{100})^4 - (\frac{t_2 + 273}{100})^4 \}$$

where

a : factor regarding to the direction of the surface of natural convection
ceiling = 2.8, side walls = 2.2, hearth = 1.5

t_1 : temperature of external wall surface of the furnace (°C)

t_2 : temperature of air around the furnace (°C)

ε : emissivity of external wall surface of the furnace

The first term of the formula above represents the quantity of heat release by natural convection, and the second term represents the quantity of heat release by radiation. Figure 15 shows the relation between the temperature of external wall surface and the quantity of heat release calculated with this formula.

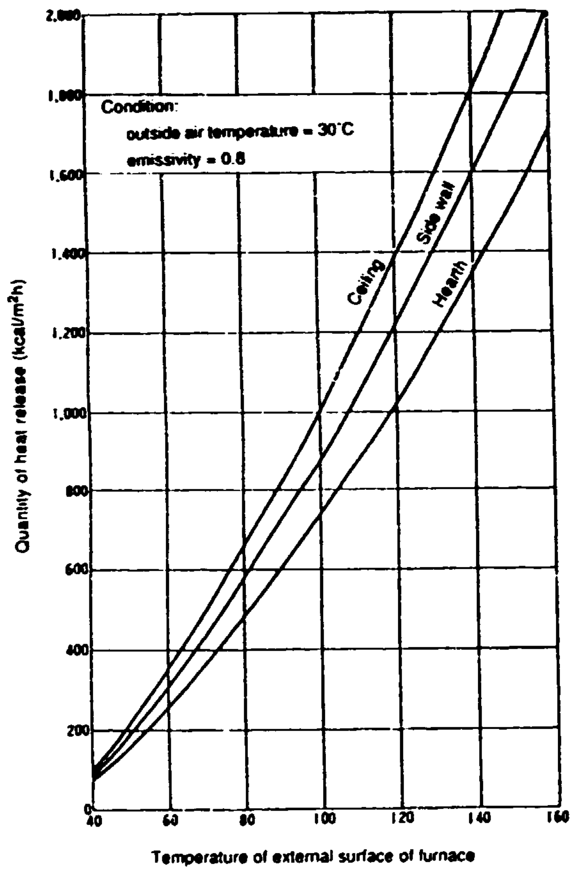


Figure 15 Relation between external surface temperature and quantity of heat release

This is explained with an example as follows.

There is a reheating furnace whose ceiling, side walls and hearth have 20 m^2, 50 m^2 and 20 m^2 of surface area respectively. Their surface temperatures are measured, and the averages are 80°C, 90°C and 100°C respectively. Evaluate the quantity of heat release from the whole surface of this furnace. From Figure 15, the quantities of heat release from ceiling, side walls and hearth per unit area are respectively 650 kcal/m^2h, 720 kcal/m^2h and 730 kcal/m^2h. Therefore, the total quantity of heat release is

$$Q = 650 \times 20 + 720 \times 50 + 730 \times 20$$
$$= 63{,}600 \text{ kcal/h}$$

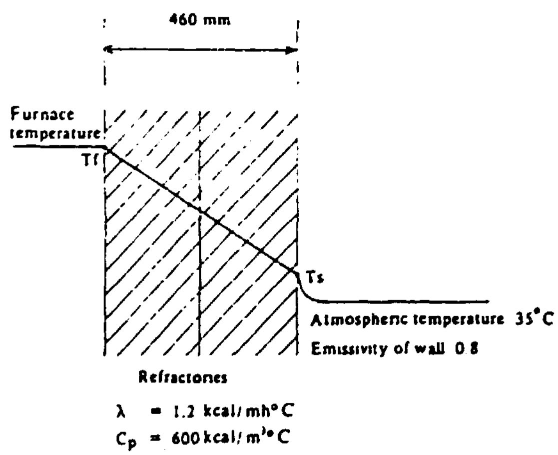
b) Reinforcement of insulation

Improvement on radiation heat loss from surface of a furnace body can be achieved by reinforcing its insulation method. There are two ways to do this; one is to cover the internal wall surface with ceramic fiber, and the other is to cover the external wall surface with ceramic fiber or rock wool.

The following are examples of improvement in which insulation was reinforced.

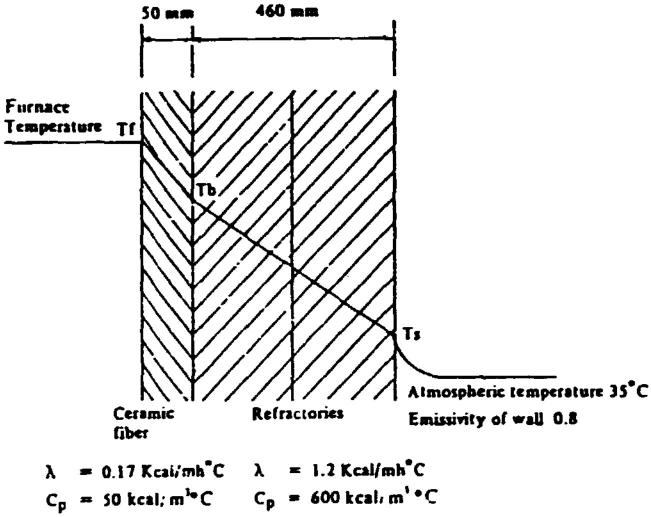
Figure 16 shows a standard composition of walls of a reheating furnace. In this case, furnace walls are exclusively made of fire bricks, and the thickness of the wall is 460 mm.

Figure 17 shows an example in which the insulation was reinforced by putting 50 mm thick ceramic fiber on the internal wall surface of the furnace shown in Figure 16.



Furnace temperature	Tf	1300	1200	1000	800	°C
Surface temperature	Ts	199	190	170	149	°C
Quantity of radiant heat	Q	2,873	2,636	2,165	1,699	kcal. m²h

Figure 16 Typical wall temperature of reheating furnace



Furnace temperature	Tf	1300	1200	1000	800	°C
Boundary temperature	Tb	800	741	621	307	°C
Surface temperature	Ts	149	142	128	112	°C
Quantity of radiant heat	Q	1,700	1,562	1,288	1,015	kcal/m²h

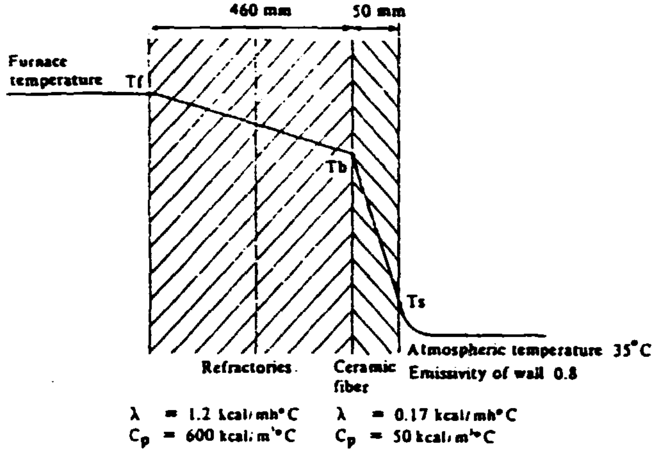
Figure 17 Improvement plan for wall composition of reheating furnace

The energy-saving effect of this improvement is, as is shown in Table 11, 41%, decrease in quantity of radiant heat along with the drop of temperature of external wall surface. Covered with ceramic fiber, which has excellent fire resistance and insulation quality, the temperature of fire bricks drops and the life of the bricks tends to become longer. However, this method can be used only when the reduction of furnace volume is acceptable.

Table 11 Improvement effects of wall composition of reheating furnace

	When furnace temp. is at 1,300°C		Improvement effects
	Before improvement	After improvement	
Surface temperature	199°C	149°C	25% drop of surfacial temperature
Quantity of radiant heat	2,873 kcal/m²h	1,700 kcal/m²h	41% decrease in quantity of radiant heat

Next, Figure 18 shows a case in which external wall surface of the furnace is covered with 50 mm thick ceramic fiber.



Furnace temperature	Tf	1300	1200	1000	800	°C
Boundary temperature	Tb	649	601	506	411	°C
Surface temperature	Ts	149	142	128	112	°C
Quantity of radiant heat	Q	1,700	1,562	1,288	1,015	kcal/m²h

Figure 18 Inferior reconstruction plan for wall composition of reheating furnace

Table 12 Standard wall temperature of reheating furnace in Japan

Infrastructure temperature (Unit °C)	Standard external wall surface temperature of furnace: Ceiling	Standard external wall surface temperature of furnace: Side wall
1,300	140°C	120°C
1,100	125°C	110°C
900	110°C	95°C
700	90°C	80°C

Remark 1. The value of external wall surface temperatures of the furnace listed in this table were determined concerning the average temperature of the furnace's external wall surface (excluding the peculiar parts) at an atmospheric temperature of 20°C during a regular operation.

2. The value of external wall surface temperatures of the furnace listed in the table will not apply to the external wall surface temperatures of the under-mentioned industrial furnaces as a standard:
(1) Those having a rated capacity of not more than 200,000 kcal/hr.
(2) Those whose walls are forcibly cooled.
(3) Rotary kilns.

If the external wall surface is covered with steel plates, their temperature will rise when ceramic fiber is put over the steel plates. And distortion by thermal expansion may cause a damage to the furnace casing.

For reference, Table 12 shows standard temperatures for the external walls of a reheating furnace in Japan.

(ii) Prevention of Heat Loss through Openings

Heat loss through openings consists of the heat loss by direct radiation from openings and the heat loss caused by combustion gas that leaks through openings.

a) Heat loss by radiation from openings

If a furnace body has an opening on it, the heat in the furnace escapes to the outside as radiant heat.

The quantity of heat loss in this way depends on the thickness of furnace wall and the shape of the opening. Figure 19 shows quantities of heat loss by direct radiation from openings with various shapes. Each quantity is represented by factor of quantity of radiant heat from a perfect black body equivalent to the area of opening.

Heat loss from an opening is calculated by the following formula:

$$Q = 4.88 \cdot \left(\frac{T}{100}\right)^4 \cdot a \cdot A \cdot H$$

where

T: absolute temperature (K)

a: factor for total radiation

A: area of opening

H: time (Hr)

This is explained by an example as follows.

A reheating furnace with walls 460 mm thick (X) has a billet extraction outlet which is 1 m high (D) and 1 m wide. When the furnace temperature is 1,340°C, the quantity (Q) of radiation heat loss from this opening is evaluated as follows.

The shape of opening is square, and D/X = 1/0.46 = 2.17. Thus, the factor for total radiation is 0.7 from Figure 19, and we get

$$Q = 4.88 \times \left(\frac{1340 + 273}{100}\right)^4 \times 0.71 \times 1 = 234{,}500 \text{ kcal/h}$$

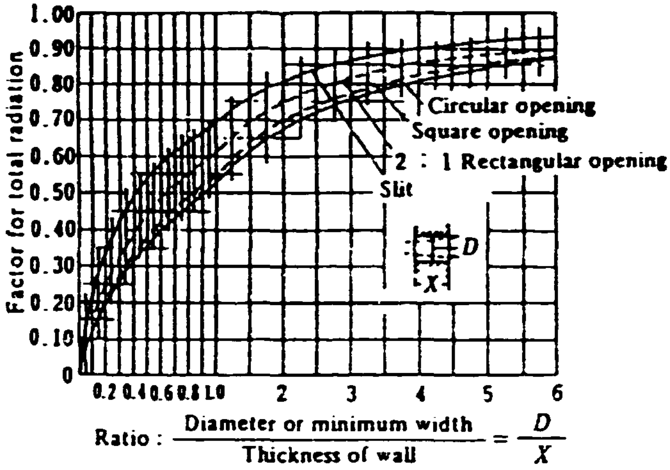


Figure 19 Factor for determining the equivalent of heat release from openings to the quantity of radiant heat from perfect black body

b) Heat loss caused by combustion gas that leaks through openings

Since the furnace pressure of a reheating furnace is slightly higher than outside air pressure during its operation, it is not avoidable that the combustion gas inside blows off through openings and heat is lost with that.

It would cause more damage if outside air intruded into the furnace, making temperature distribution uneven and oxidizing billets. As was mentioned in 3.2.5 (ii), this heat loss is about 1% of the total quantity of heat generated in the furnace, if furnace pressure is controlled properly.

c) Prevention of cooling water loss

Cooling heat loss through water cooled skid pipes in a continuous reheating furnace amounts to as much as 10%–15% of fuel consumption. In particular, a walking beam-type furnace structurally has about 1.5 times as much water cooled area as a pusher-type furnace does. Accordingly, the problem of cooling water loss is more significant.

To overcome this problem, the double insulation method for skid pipes has been widely applied to newly built as well as existing furnaces. This method uses high insulation ceramic fiber for internal surface and covers it with castable.

Figure 20 shows an example of the double insulation, and Figure 21 shows a comparison between cooling loss values (calculated values) of single insulation and double insulation.

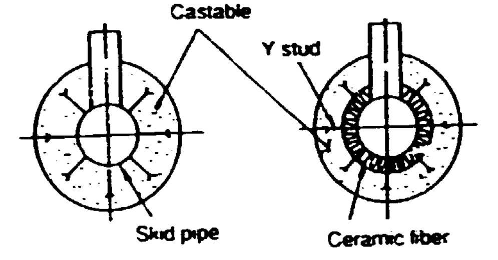


Figure 20 Double insulation method for skid

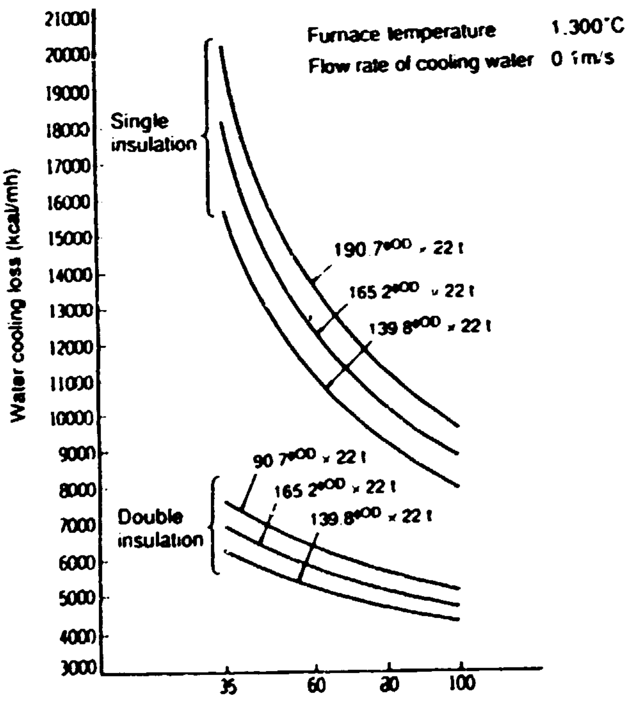


Figure 21 Comparison of water cooling loss (calculated values)

In Figure 21, for the pipe that has an outside diameter of 165.2 mm let the water cooling loss for the 60 mm thick single insulation be 100%. Then Figure 21 shows that the water cooling loss for the double insulation with 15 mm ceramic fiber plus 45 mm castable is 47%. This is a considerable reduction of fuel consumption compared with a furnace with single insulated skid pipes. At the same time, the amount of water used for cooling can be significantly reduced by adopting double insulation. It also has the merit that skid marks are small, because the temperature of the insulation layer surface is lower than single insulation.

3.2.8 Waste Heat Recovery

The quantity of heat taken away from a reheating furnace by high temperature exhaust gas is very large. If this can be reduced, it has a large effect on fuel saving. There are two ways to reduce the quantity of heat taken away. One is to reduce the volume of exhaust gas, and the other is to reduce the temperature of exhaust gas. The former is the rationalization of air ratio, which was described in 3.2.5 (i). The latter is achievable by recovering waste heat from exhaust gas.

Methods for recovering heat from exhaust gas include: (1) to preheat air for combustion by a recuperator, (2) to generate steam or hot water by a waste heat boiler, (3) to preheat materials by exhaust gas and (4) cascade utilization as a heat resource for others.

For reference, Table 13 shows standard waste heat recovery rates of industrial furnaces in Japan.

Table 13 Standard waste heat recovery rate of industrial furnace in Japan

Exhaust gas temperature (°C)	Classification of capacity	Standard waste heat recovery rate (%)	Reference	
			Exhaust gas temperature (°C)	Preheated air temperature (°C)
500	A · B	20	200	130
600	A · B	20	290	155
700	A	30	300	260
	B	25	330	220
	C	20	370	180
800	A	30	370	300
	B	25	410	250
	C	20	450	205
900	A	35	400	385
	B	25	490	285
	C	20	530	230
1,000	A	40	420	490
	B	30	520	375
	C	25	570	315
over 1,000	A	40	-	-
	B	30		
	C	25		

(Note)

1. "Exhaust Gas Temperature" means the temperature of exhaust gas discharged from the furnace chamber at the outlet of furnace.
2. The classification of the capacity of industrial furnace is as follows:
   A. Industrial furnace whose rated capacity is more than 20MM kcal/hr.
   B. Industrial furnace whose rated capacity is from 5MM kcal to not more than 20MM kcal/hr.
   C. Industrial furnace whose rated capacity is from 1MM kcal to not more than 5MM kcal/hr.

(Remark)

1. The values of standard waste heat recovery rate listed in this Table are determined concerning the ratio of a recovered quantity of heat to a quantity of sensible heat in an exhaust gas discharged from the furnace chamber when a combustion is carried out under a load in the neighborhood of a rating.
2. The values of standard waste heat recovery rate listed in this Table shall be a standard for the continuous operating furnaces built on and after January 1, 1980.
3. The values of standard waste heat recovery rate listed in this Table shall not be a standard for the waste heat recovery rate of the under-mentioned industrial furnaces:
   (1) Those whose rated capacity is not more than 1MM kcal/hr.
   (2) Those whose annual operating time does not exceed 1,000 hours.
4. The values of exhaust gas temperature and preheated air temperature listed as references are values obtained by calculating the temperature of exhaust gas when the waste heat of standard waste heat recovery rate has been recovered and the temperature of preheated air when the air has been preheated by the afore-mentioned recovered waste heat, on the following conditions:
   (1) Temperature drop due to released heat loss, etc. from the furnace outlet to the heat exchanger for preheating air: 200°C
   (2) Fuel: liquid fuel
   (3) Atmospheric temperature: 20°C
   (4) Air ratio: 1.2

Now, we will describe preheating of the air for combustion, which is generally done for reheating furnaces.

(i) Preheating the Air for Combustion by a Recuperator

A recuperator is a device that recovers heat from exhaust gas exhausted from a reheating furnace. A metallic recuperator has heat transfer surface made of metal, and a ceramic recuperator has heat transfer surface made of ceramics.

When the exhaust gas temperature is lower than 1,000°C and air for combustion is preheated, a metallic recuperator is used in general.

By using preheated air for combustion, fuel can be saved. The fuel saving rate is given by the following formula:

$$S = \frac{P}{F + P - Q} \times 100\ (\%)$$

where S: uel saving rate

F: low calorific value of fuel (kcal/kg fuel)

P: quantity of heat brought in by preheated air (kcal/kg fuel)

Q: quantity of heat taken away by exhaust gas (kcal/kg fuel)

By this formula, fuel saving rates for heavy oil and natural gas were calculated for various temperatures of exhaust gas and preheated air. The results are shown in Figure 22 and Figure 23.

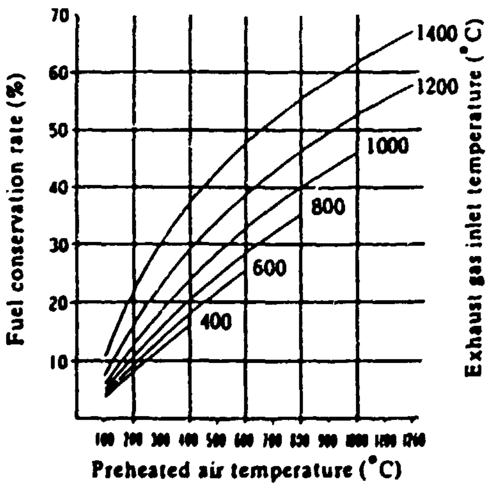


Figure 22 Fuel conservation rate when oil is used

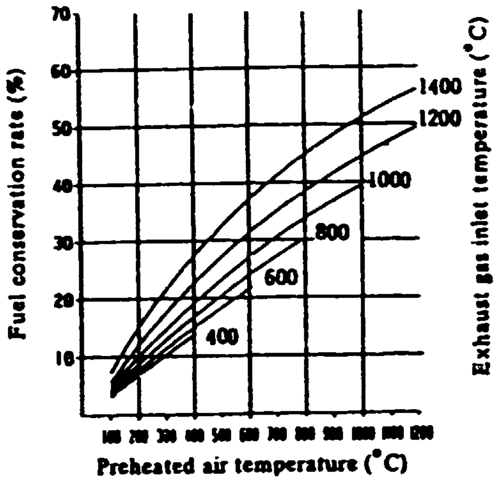


Figure 23 Fuel conservation rate when natural gas is used

When installing a recuperator in a continuous steel reheating furnace, it is important to choose a preheated air temperature that will balance the fuel saving effect and the invested cost for the equipment.

Moreover, the following points should be checked:

(1) Draft of exhaust gas: When exhaust gas goes through a recuperator, its draft resistance usually causes a pressure loss of 5–10 mm H_2O. Thus, the draft of steak should be checked.

(2) Air blower for combustion air: While the air for combustion goes through a recuperator, usually 100–200 mm H_2O of pressure is lost. Thus, the discharge pressure of air blower should be checked, and the necessary pressure should be provided by burners.

Conclusion

If we divide energy conservation measures of the industrial sector in a general manner, we come up with the following three approaches.

Phase 1 is primarily a plan for the complete improvement of operating conditions in stages by strengthening energy management, based on the assumption of existing facilities.

Phase 2 is designed for carrying out only partial improvement of facilities. This phase stresses decreasing energy consumption and plans for more efficient use of energy exhaust emissions.

Phase 3 concentrates on the development of a new process for energy conservation and on plans for a fundamental restructuring of the manufacturing process.

This manual has been mainly concerned with introducing Phase 1. These measures are comparatively simple, and there are many cases where they are not very effective in saving energy. However, the overall effectiveness of these accumulated cases was greater than expected. Certainly, based on this manual, we hope that the facilities being dealt with will be reevaluated with new insight and that concrete measures may be soundly implemented.

In addition, even for measures which have already been implemented, we hope that you will recheck whether or not they have produced results in regards to the energy savings being targeted, and that, if necessary, improvements in heightening efficiency will be made.

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