G) Recovery of condensate

See III-7 Section for Boiler and steam.

(3) Power transmission

A) Using an energy conservation type belt with less slip saves electric power by about 4%. Also, for looseness, adjust so that the belt lowers by the belt thickness when it is pressed by a thumb with ordinary force.

B) Feed a proper amount of lubricating oil periodically.

C) Adjust so that the sound and vibration are at a minimum.

D) Replace the pulley to acquire an optimum speed for both quality and energy consumption according to the yarn count.

E) When renewing the motor, replace with a high-efficiency motor with the proper capacity.

F) Maintenance of cotton opening machine, etc.

Improve the efficiency of cotton opening operation by removing as much foreign matter as possible from raw cotton and by maintaining the blades of the cotton opener periodically.

(4) Air conditioning

What is described in the "Section for Synthetic Fiber" is applied as-is and besides, removal of floating filament produced in large quantities in cotton spinning mills is a problem.

A lot of floating filament not only causes the operating circumstances to worsen, but also causes defective goods by adhering to product.
To remove floating filament, it is necessary to make it easily fall by humidifying air and to frequently clean the floor and duct.

For example, electric power is saved by equipping humidifiers at a unit cost of about ¥50,000 only at necessary places, because even the unnecessary places are humidified when humidified with air conditioner for the whole factory.

(5) Intensification of heat insulation for false twister heater

About 70% of the electric power consumed by a false twister is for heating and only about 30% of the power is effectively used.

Accordingly, it is effective to improve the temperature control sensibility and also to intensify the heat insulation including around the yarn hole. For example, 15 to 18% of electric power was saved and the investment could be refunded within two years by investing ¥750,000 for each unit to intensify the heat insulation. Also, intensifying the heat insulation reduces the air conditioning load as a secondary effect.

(6) Introduction of high-efficiency equipment

A) Automatic cop-winding machine

Of cop-winding machines to roll back spinned yarn round a cheese or cone, there are automatic cop-winding machines to tie yarn together by means of air suction force when yarn is cut. In the past, a large-sized suction blower used to be operated in preparation for when a number of yarns are cut at the same time.

An energy conservation type machine is incorporated with a control device, to allow the drum to wait and tie yarn together in succession when yarns are cut frequently. This reduces the capacity of the suction blower.

B) High performance twister

Smaller spindle diameter (110 mm or less) and lighter weight (600 g or less) than conventional types increase the spindle rotating speed and greatly reduce the consumption electric power per unit production capacity.

C) Friction type false twister

Friction type false twister gives false twisting by frictional force due to rotating belt or rotary disc instead of the spindle, and the electric consumption rate lowers because the yarn is false twisted in a straight line.

D) Non-shuttle type loom

In an ordinary loom, a shuttle about 400 g in weight is rapidly started and stopped to strike weft from left and right and, therefore, the energy loss is great. Accordingly, energy conservation type looms using a light-weighted gripper instead of the shuttle, feeding with water or air, or using an approach bar have been developed. In a portion of a certain factory we visited in the Kingdom of Thailand, Rapier type using the approach bar had been introduced.

4.3 Dyeing

(1) Reduction in bath ratio

Dyeing industry uses water in large quantities and yet the water is mostly used after heating. Therefore, saving service water saves thermal energy.

The amount of liquid (l) used to dye 1 kg of an object is called "Bath Ratio", which considerably differs according to the dyeing method and dyeing machine.

The following countermeasures are taken for the dyeing method:

A) Bath ratio in cheese dyeing (8 to 15) is smaller than that in hank dyeing (25 to 35).

B) Even in cheese dyeing, the bath ratio can be reduced by improvement of winding density, spindle arrangement, etc.

C) The bath ratio can be reduced below 3 by a method to distribute the dye liquor in a foam state and in a fog state uniformly.

D) Changing the process for mix spinning yarn from 2 bath dyeing to 1 bath dyeing is effective to reduce the bath ratio and shorten the time.

Various kinds of low bath ratio type dyeing machines have been developed.

Improving contact between the dye liquor and cloth by rotating the cloth at high speed more than 200 m/min or applying vibration reduces the bath ratio from 1:20 to 30 for general type to 1:11 or below. Examples of performance comparison between low bath ratio and conventional types are shown in Table III-3-10 and Table III-3-11.

Besides, a method to reduce the required energy to 1/10 or below by utilizing rapid heating due to microwave is also developed.

(2) Reduction in amount of washing water

Various washing equipments with high washing efficiency are developed. The principle is to improve the washing effect by the following:

[1] Increase the number of times for contact between cloth and washing water.

[2] Supply water countercurrently to cloth.

[3] Provide the cloth and water with vibration effect.

For example, the amount of water and amount of steam were reduced to 1/10 and the electric energy 1/4 as compared with conventional types.

Table III–3–10 Example of performance comparison table between R.A and U.A.

RA: Low bath ratio type

	Length of work	Amount of liquid	Weight of fabric	Amount of steam	Amount of steam per m	Amount of steam per kg of fabric
U. A	300 m	4,000 ℓ	514 g/m²	1,473 kg	4.91 kg/m	9.54 (100)
R. A	500 m	2,000 ℓ	409 g/m²	440 kg	0.88 kg/m	2.15 (23)

Table III–3–11 Example of power consumption comparison table between R.A and U.A.

	Electric power	Load factor	Dyeing time each time	Electric energy each time	Length of work	Electric energy per m
U. A	24kw ×	0.8 ×	2.5 =	48 ÷	300m	=0.16KWH/m(100)
R. A	16.5 ×	0.8 ×	2.5 =	33 ÷	500	=0.066 〃 (41)

(3) Shortened dyeing time

In polyester dyeing, a method to raise temperature as soon as possible within the temperature range in which dyeing is not affected and to eliminate leveling has been developed.

(4) Lowered treating temperature

Endeavour to lower the temperature for bleaching and dyeing, etc. by changing the dye and chemicals, etc. Study whether it is possible to rinse at lower temperatures.

(5) Saving drying energy

A) Dyeing is a process in which dipping in a liquor and drying are repeated many times, but in some case the drying process is omitted and only squeezing is performed followed by the next process for some classes of fibers (Wet on Wet method).

B) Before drying, save thermal energy by dehydrating completely by a mangle. Adjust rubber covered rolls with adequate hardness so that the linear pressure is uniform in the width direction for use. There are more efficient equipments using nonwoven cloth rolls or of a vacuum type to suck in through the slits. Also, a method to dehydrate by blowing high speed air is effective. Since it is possible to squeeze to 25 to 50% of the moisture, the drying speed is doubled, lowering the drying cost by 17%.

C) Even if a fiber is dried more than a certain limit, it absorbs water again to an equilibrium moisture when it is allowed to stand in air. Therefore, drying excessively more than shown in Table III-3-12 loses energy.

Table III–3–12 Norms for exit moisture percentage
(kg water per kg cloth)

Material	Exit moisture percentage (%)
Cotton	7.0
Polyester	0.7
Nylon	4.0
Viscose	12.5
Wool	16.0
Polyester-cotton blend (2:1)	2.5
Polyester-wool blend (2:1)	5.5

Source: F.C. Harbert, International Dyer, Vol. 142, No. 2, (1972), p. 102.

D) In a hot air dryer, circulating hot air increases the drying speed and saves energy. Periodically measure the moisture content in the exhaust and adjust the amount of exhaust. If a combustible solvent is contained, it is necessary to pay attention to explosion.

E) When applying chemicals such as a waterproofing agent to woven textile, the drying energy can be saved by restricting the addition to a small amount with screen rolls, etc.

(6) Prevention of heat release

A) Almost all of the dyeing and washing machines are not heat insulated. This is because conventional fibrous and porous heat insulating materials are apt to absorb water and complete water proofing would be expensive under a humid atmosphere in such as dyeworks. However, closed-cell foamed type repelling plastic foam has been recently developed and it is used by sticking it with adhesive such as chloroprene. *Polypropylene and hard urethane can be used to maximum service temperature of* 120°C and medium pressure polyethylene foam can be used for places at 100°C or below.

Also, for example, winding heat insulating material and covering it with vinyl sheets to protect from water as a simple method saves the amount of steam by about 20%.

B) Hot water tanks

Also for hot water tanks, heat insulate and also prevent heat release from the surface with a lid or floating lid. Fig. III-3-24 shows amount of heat release from hot water surface.

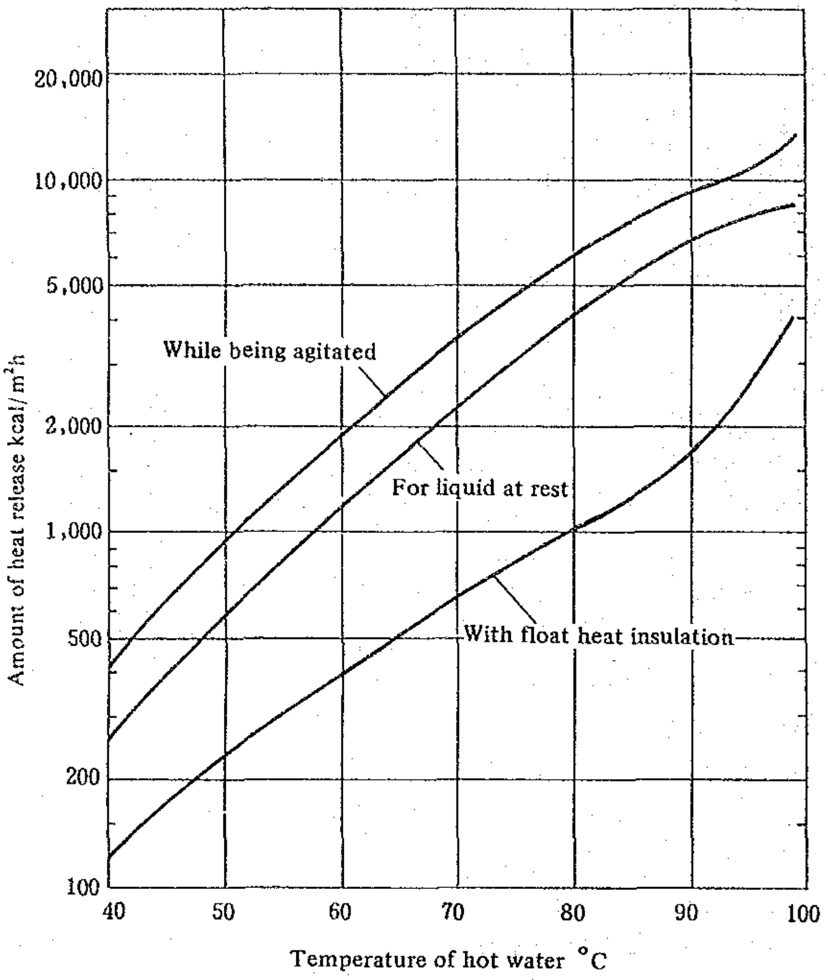


Fig. III–3–24 **Heat release from free surface of hot water**

C) Heat insulate the outer wall of a dryer and also make the opening as small as possible.

(7) Recovery of waste heat

One example of analysis on how thermal energy was consumed at a dyework is shown in Table III-3-13. This indicates how great the percentage of heat carried out by the drainage is. Therefore, in many cases, they recover heat of dyeing waste water with feed water and also use warmed cooling water for the next feed water.

<Example 1>

In a knit dyeing factory, only one portion at 60°C or above of waste water from the dyeing machine is passed through two spiral heat exchangers to obtain hot water at 50 to 60°C, which will be utilized for the next dyeing.

Of 200 m^3/d waste water, 100 m^3/d was heat recovered and thereby 100 m^3/d hot water was obtained. Equipment cost was ¥15,000,000, fuel oil saving ratio was 25% and the fund could be refunded in 2.2 years.

Table III–3–13 Thermal energy consumption state
(Intermediate scale dyeing factory)

Item	Percentage (%)
Product heating	16.6
Product drying	17.2
Waste liquor loss	24.9
Heat release from equipment	12.3
Exhaust loss	9.3
Idling	3.7
Evaporation from liquid surface	4.7
Unrecovered condensate	4.1
Loss during condensate recovery	0.6
Others	6.6
Total	100.0

<Example 2>

In a polyester and rayon yarn dyeing factory with 40 employees, the following countermeasures were taken:

a. They increased temperature of boiler feed water to 80°C by recovering heat of condensate from the dyeing machine and dryer with the feed water.

b. Heat of cooling water from the high-pressure dyeing machine was recovered by the hot water tank.

c. One portion at 57°C or above of the dyeing waste water was selected by a temperature sensor and passed through the heat exchanger with the results that 170 m^3/d hot water at 60°C in average was recovered.

To keep abreast of this, they improved the dye, assistants and dyeing method so that dyeing can be performed even at 60°C. It costed ¥25,000,000 for movement of the dyeing machine, piping, heat insulation, condensate recovery pump, hot water tank, etc., ¥38,000,000 for heat exchanger and pumps, totaling ¥28,800,000, with the results that fuel oil consumption rate was improved by 45%, from 0.85 l/kg to 0.47 l/kg, the fuel cost was reduced by ¥38,000,000/year and the investment could be refunded within 1 year.

<Example 3>

This is an example of heat recovery using a compression type heat pump in a knit dyeing factory (See Fig. III-3-25). They have 11 dyeing machines and 500 t/d of waste water at 30 to 85°C. This waste water after heat exchange with feed water, still have a temperature of about 30°C, which is used to heat feed water at 40°C to 50°C by passing it through the heat pump. (See III-7 Section for Boiler and Steam for the heat pump.) Although the equipment cost was ¥20,000,000, it has become unnecessary to install an additional boiler (¥10,000,000) and as such the increased investment can be accounted as ¥10,000,000. Running cost is as follows:

* In the case of heat pump system,

$$63\ \text{kW} \times 2{,}400\ \text{h/y} \times ¥20/\text{kWh} = ¥3{,}024{,}000/\text{y}.$$

* In the case of boiler installation,

$$\frac{276{,}000\ \text{kcal}}{9{,}060\ \text{kcal/l} \times 0.85} \times 2{,}400\ \text{hr/y} \times ¥70/\text{l} = ¥6{,}021{,}000/\text{y}.$$

Therefore, the amount of increase in investment can be refunded in 3.3 years.

$$\frac{10{,}000}{6{,}021 - 3{,}024} = 3.3\ \text{years}$$

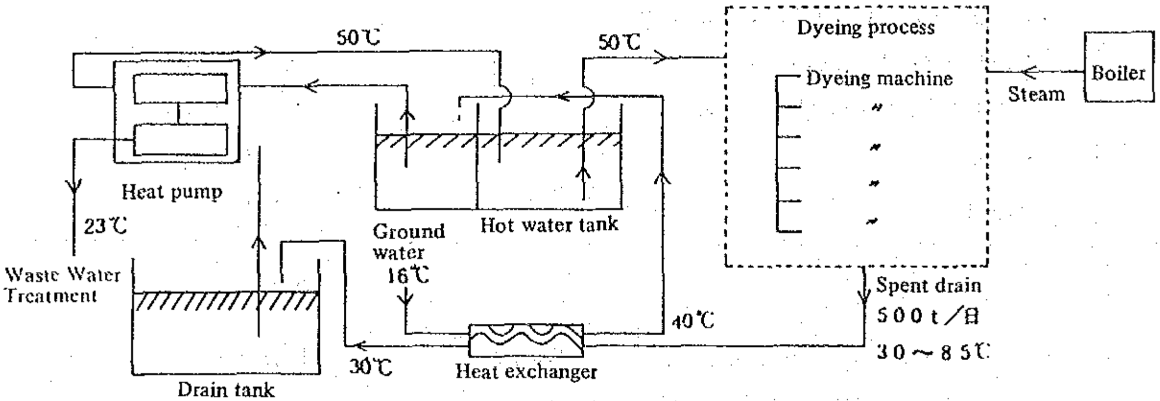


Fig. III–3–25

<Example 4>

In an exclusive yarn dyeing factory with 12 employees, they performed recovery of condensate and heat recovery of dyeing waste liquor as energy conservation countermeasures. Condensate is generated in the dyeing machine and dryer, and since dyeing solution is likely to leak in the condensate, they do not mix it directly with the boiler feed water but allow it to heat the boiler feed water through the heat exchanger. The heat exchanger adopts plate type to facilitate cleaning and is made from stainless (Type 304) in the event of contamination by a acidic bath (Fig. III-3-26).

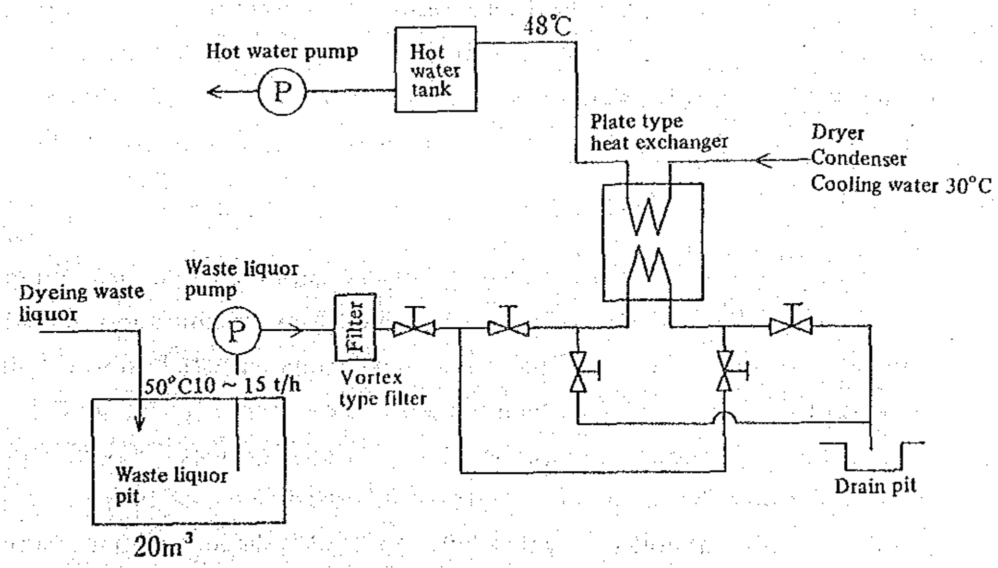


Fig. III–3–26　Dyeing waste liquor recovery equipment

10 to 15 t/h of dyeing waste liquor is generated at 50 to 100°C. After removing cellulose sludge from this discharge by passing it through a vortex type filter, it is used to preheat water at 30°C to 48°C with the plate type heat exchanger (stainless). The heat exchanger is equipped with piping for back washing and designed for automatic operation by setting temperature and flow rate.

Although the equipment cost for pump, tank, piping, etc. as well as two heat exchangers was about ¥17,000,000, fuel can be saved 22% and the annual merit is ¥5,400,000 and the investment could be refunded in about three years.

<Example 5>

Although heat recovery of hot waste water discharged from the dyeing and bleaching process for service water has been carried out using heat exchanger A, an utilizing absorption type heat pump enabled heat recovery from low-temperature waste water. Also, cooling for the knitting factory was simultaneously carried out. Exhaust heat which had been released to the air from the refrigerator and cooling tower until that time was found to be recoverable into hot water and it was materialized in 1980 (See Fig. III-3-27). The flow sheet is shown in Fig III-3-27. The equipment cost was about ¥35,000,000 and the energy conservation effect is shown in Table III-3-14.

Table III–3–14 Energy conservation effect

Fuel oil saving	170 kℓ/Year	About 10,000 thousand Yen/Year
Reduction in contract demand by stop of refrigerator	170 kW	About 4,000 thousand Yen/Year
Reduction in refrigeration electric energy	200 thousand kWH	About 3,000 thousand Yen/Year
Total		17,000 thousand Yen/Year

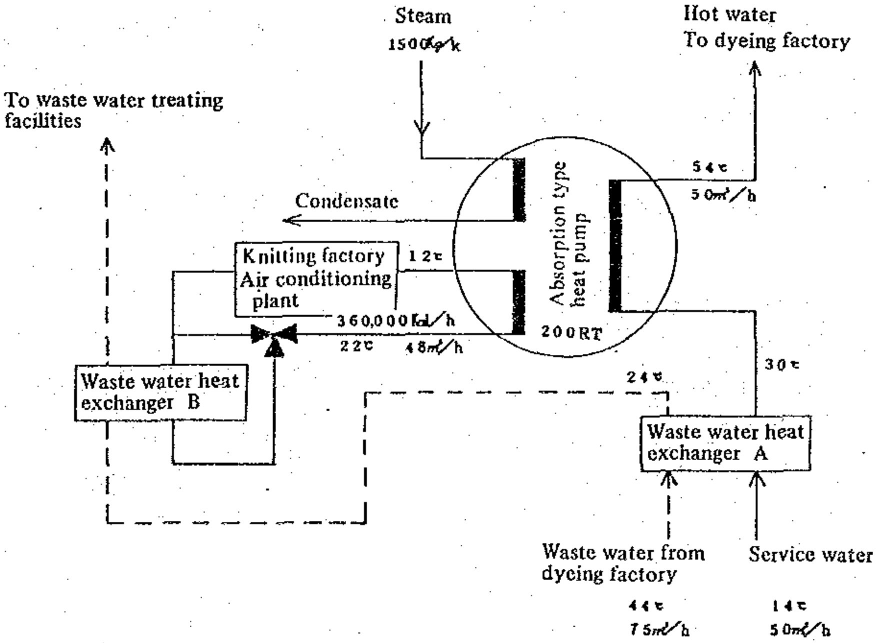


Fig. III–3–27 Flow sheet of heat pump system

4.4 Standard

(1) Heat insulation for equipments

Since expenses for heat insulation for places with surface temperatures at 70°C or above can be refunded almost in one year according to calculations under the following conditions, standard value of surface temperature shall be 70°C. However, for equipments which tend to get wet with water such as dyeing machines, it shall not apply before suitable heat insulation materials are available throughout the Kingdom of Thailand.

(Calculation)

* Basis

1) Room temperature	35°C				
2) Surface emissivity	0.2				
3) Boiler efficiency	85%				
4) Fuel oil price	4.35 Bt/l				
5) Unit price of service heat value	0.54 Bt/10^3 kcal				
6) Combustion heat of fuel oil	9,500 kcal/l				
7) Heat insulation expenses	500 Bt/m^2 (Glass-wool 50m/m)				
9) Internal temperature	250°C				
10) Surface temperature	°C	111.5	78.7	69.7	61.9
11) Heat release	kcal/m^2h	623	308	232	169
12) Surface temperature after heat insulation	°C	58.5	54.8	53.0	50.9
13) Heat release after heat insulation	kcal/m^2h	144	117	104	90
14) Reduction in heat release	kcal/m^2h	479	191	128	79
15) Value for reduction in heat release	Bt/h	0.259	0.103	0.069	0.043
16) Required time for recovery of heat insulation expenses	h	1931	4854	7246	11,628

(2) Others

Various energy countermeasures in textile industries are closely related to know-how in manufacture, class of products, etc. and therefore it is not possible to establish an uniform standard.

III. Guideline for Rationalization of Energy Use

4. Metal

Contents

1. Character of Guide Line

This Guide Line is a summary of technical matters considered important for the promotion of energy saving at the factories of the metal industries. The Guide Line is to be used for the following purposes.

1) (1) As technical reference for factory's engineers when they plan to rationalize use of energy in the factory.
   (2) As a diagnostic guidance manual.
   (3) As referential data for determining the progress of rationalization.
   (4) As a text for seminars.

2) Descriptive level which should be understandable by engineers having only 4 to 5 years' experience of actual service after college graduation, but not actually working in the subject industries.

3) In consideration of the present industrial status of the Kingdom of Thailand, the descriptive coverage is limited to the process-related matters of the factories which we diagnosed. Also, the basic items and numerical values regarding this process —energy-saving techniques and referential instances or actual records — are described.

It is hoped that the Guide Line prepared here will be further supplemented and substantiated by the addition of information obtained in future through NEA's own factory diagnosis and other means.

For information, the Guide Line contains standard values published by the Japanese Government (Ministry of International Trade and Industry) as a basis for judgement in promoting energy saving for factory managers through its notification.

(1) The standard values are the most frequent values (refer to Fig. III-4-1) of statistical distributions of numerous examples. As such they represent a realistic level for factory managers to attain without difficulty from the technical and economic points of view.

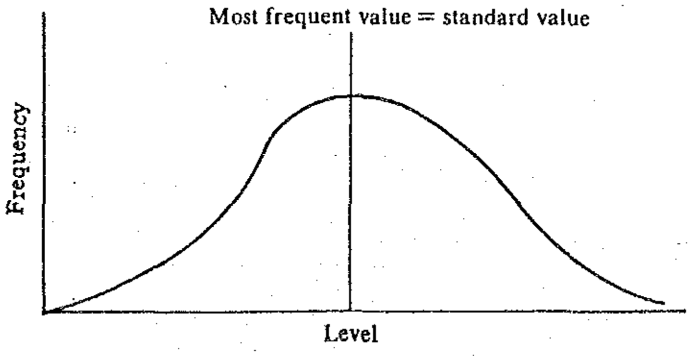


Fig. III-4-1

(2) The standard values do not necessarily represent the values which factory managers should be satisfied with after reaching them and also the minimum values which it must reach by all means. These values are rather those designed to improve the inferior value toward an average level, thus shifting the whole distribution of values into a better direction. Therefore, the most frequent value will be resought and a new standard value established after the elapse of a certain period.

The standard value establishment plan described in the report was prepared based on these standard values considering the present industrial status of the Kingdom of Thailand.

These standard values will be a starting point for the establishment of standard values for the rationalization of energy use in industry of the Kingdom of Thailand. It is recommended that the Kingdom of Thailand itself accumulates data during factory diagnosis to be put into practice, and evaluates it periodically and revises or newly establishes standard values.

2. Characteristics of Energy Consumption

2.1 Manufacturing process and main equipment

2.1.1 Manufacturing process

The main products of the metal industry are steel bars, steel sections, castings, wires, etc. Their respective manufacturing processes are as follows:

(1) Steel bars (electric arc furnace) (Refer to Fig. III-4-2)
(2) Steel bars, steel sections (reroll) (Refer to Fig. III-4-3)
(3) Castings (Refer to Fig. III-4-4)
(4) Wires (Refer to Fig. III-4-5)

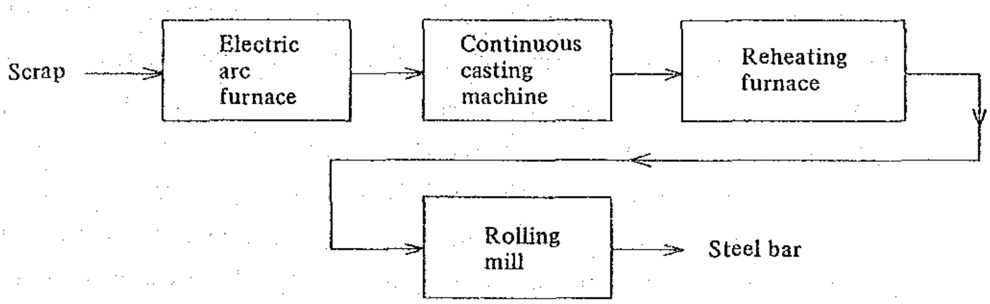


Fig. III–4–2 Manufacturing process chart for steel bar (electric arc furnace)

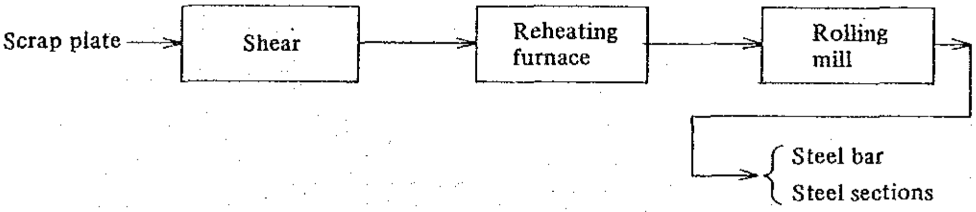


Fig. III–4–3 Manufacturing process chart for steel bar and steel sections (rerolled)

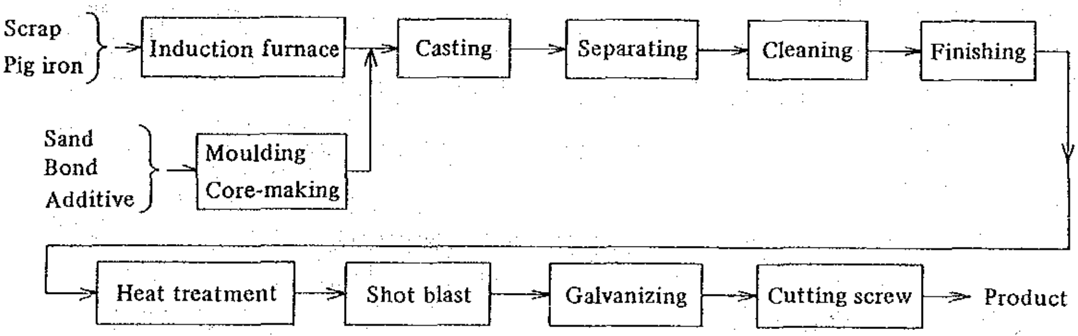


Fig. III–4–4 Manufacturing process chart for casting

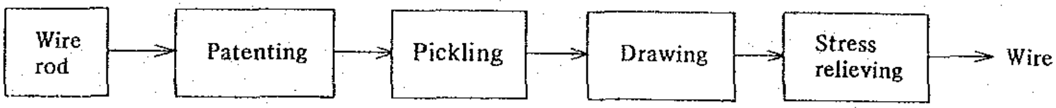


Fig. III–4–5 Manufacturing process chart for wire

2.1.2 Main equipment

(1) Billet reheating furnace

One of the main units in the process of manufacturing steel bars and steel sections is the billet reheating furnace. This reheating furnace is an important unit as a combustion furnace in the metal industry, and various types are available. The reheating furnace is a facility for reheating the billet to a target degree of approx. 1,300° C for hot-rolling steel materials into steel bars and steel sections.

There are two different types of reheating furnaces: batch type and continuous type: the batch type is an auxiliary unit for reheating mainly special-type steel, and the continuous type is a main unit.

Under the category of the continuous-type reheating furnaces, the pusher-type, walking beam-type, walking hearth-type, rotary hearth-type, etc. are available.

As the oldest and rudimentary-type furnace, the pusher-type single-zone reheating furnace is used as shown in Fig. III-4-6. This furnace is capable of maximum 50 t/h. In this furnace, steel billet is heated only through its upper surface over the entire length of the furnace. Accordingly, the temperature differences between the upper and lower surfaces of the billet are significant. Besides, the furnace temperature is controlled in a single zone, so there is no flexibility in the operation. For these reasons, this furnace is not suitable as a long furnace or a large-capacity furnace.

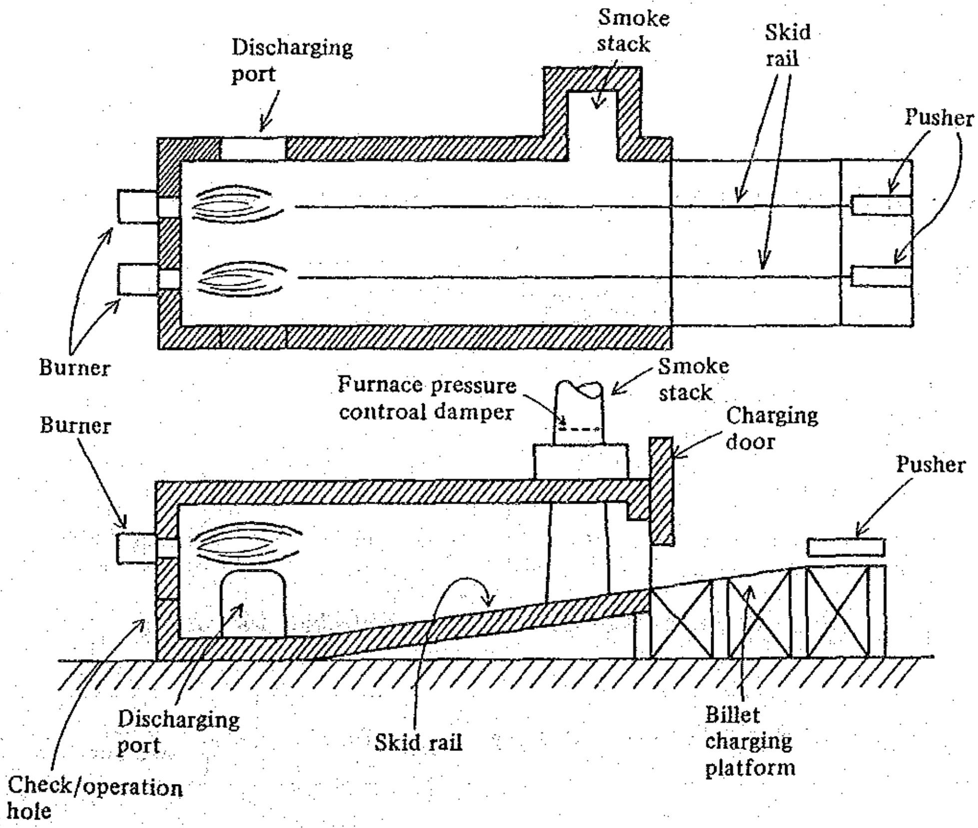


Fig. III–4–6 Pusher-type single zone reheating furnace

As a furnace capable of heating 60 to 120 t/h, the pusher-type 3-zone reheating furnace is available as shown in Fig. III-4-7. This furnace has two distinctly divided zones: heating zone and soaking zone. The heating zone heats billet through its upper and lower surfaces to a temperature level for hot-rolling. The soaking zone minimizes the skid mark and equalizes the inner temperature of billet. It is possible to control the temperature of the three furnace zones and change the heating speed to some extent. That is, this furnace has an operational flexibility.

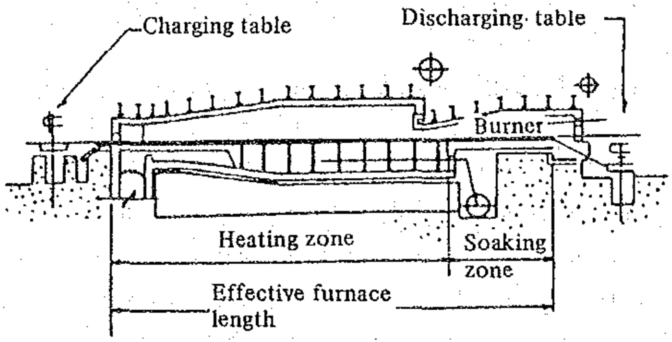


Fig. III-4-7 Pusher-type 3-Zone reheating furnace

In addition, as a furnace with a large heating capacity, the pusher-type 5-zone reheating furnace capable of 200 to 250 t/h is named (refer to Fig. III-4-8).

This type is an advanced version of the pusher-type 3-zone furnace and is distinctly composed of a preheating zone, a heating zone, and an soaking zone (refer to Fig. III-4-8). The shortcomings of the pusher-type are the generation of skid mark, scar on the back of billet caused by the carriage, etc. Further, under the category of large-capacity furnaces designed to eliminate these shortcomings, the walking beam-type furnace is introduced (refer to Fig. III-4-9). This type is provided with a large heating capacity such as 200 to 400 t/h. Recently, in the group of large-capacity furnaces, the walking beam-type heating furnace is the most popular type.

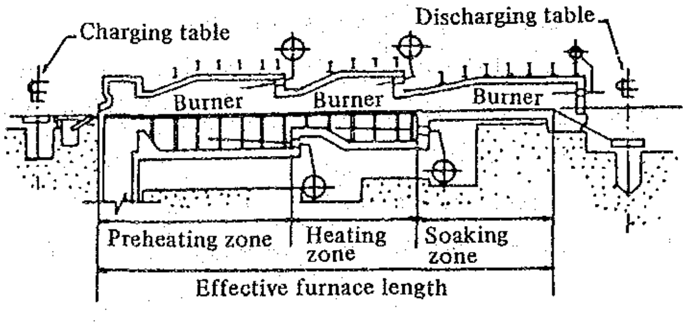


Fig. III-4-8 Pusher-type 5-Zone reheating furnace

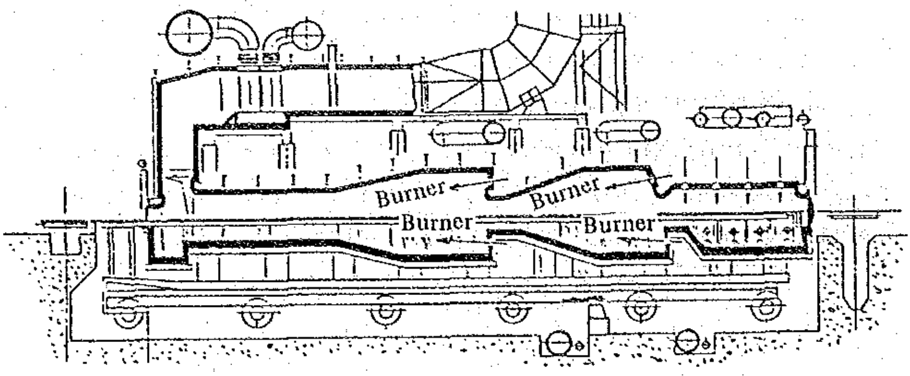


Fig. III–4–9 Walking beam-type reheating furnace

(2) Patenting furnace

Next, the wire patenting furnace is pointed out as one of the major units in the manufacturing process of wires, etc. Hard steel wires and piano wires represented by wire rope, spring, screw, PC wire, bead wire, etc. are cold-rolled or drawn products at the secondary processing factory of wire rod hot-rolled at the hot roll mill.

These products are required high-level mechanical and fatigue-resistant properties, so that not only the purity of components of materials but also the selections of the heat treatment and the cold-processing method are important factors.

Normally, wire drawing is carried out stepwise. The tensile strength and hardness of wires increase in proportion to the frequency of processing. In the drawing process, wire is patented so that it can be workable on the cold-roll mill. Heat treatment, called "patenting", is aimed at processing the wire so that it may have a uniform sorbite structure or a fine pearlite structure. These structures provide wires with high tenacity, so that wires are qualitatively more suitable for drawing. Steel, after being heated to have an austenite structure, is cooled to various textures that can be obtained according to cooling speed. In the case of patenting, if steel is quenched and kept at 450 to 550° C, a high-quality sorbite structure is obtained. As a quenching method, lead quenching and air quenching are available. They are called "lead patenting" and "air patenting". In addition, salt bath hardening is also used. In other means of heat treatment, such as quenching and tempering, there are those used to obtain the same quality as by the "patenting" treatment.

The patenting furnace in practical use is roughly classified as follows:

A) Strand-type furnace

This type of furnace is designed to perform heat treatment by unwinding a coiled wire bundle by a reel into a straight line, and then take up the wire by the reel again after the completion of heat treatment.

a. Direct firing-type heating furnace + lead bath quenching (lead patenting furnace) (refer to Fig. III-4-10).

b. Direct firing type heating furnace + { Atmosperic cooling (static air)
Air blast cooling (nozzle blast) } (air patenting furnace)

c. Direct firing-type heating furnace + cooling by fluidization bed

d. Indirect firing-type heating furnace + cooling by lead batch (non-oxidization patenting furnace)
e. Heating by fluidization bed + cooling by fluidization bed
f. Heating by lead bath + cooling by lead bath (double lead patenting furnace)

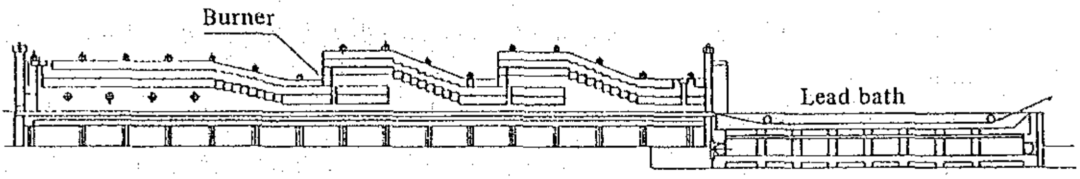


Fig. III–4–10 Lead bath-type patenting furnace (Direct firing method)

B) Loop row-type furnace

This furnace is designed to perform heat treatment by carrying wire rods in loop continuously on a conveyor or roller hearth. This is called the "loop row" method. method.

When this method is used, it is possible to obtain a sufficient operational efficiency with a short furnace length. In addition, it is possible to carry out on-line treatments such as pickling and lubricant coating continuously after the patenting process (refer to Fig. III-4-11).

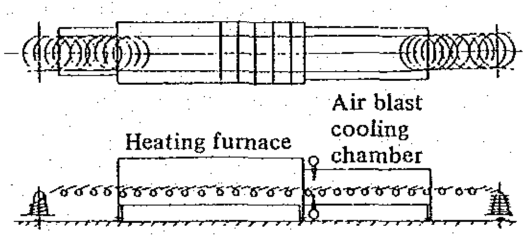


Fig. III–4–11 Loop row-type patenting furnace

In the loop row method, wire rods need to be cooled by air blast or by fluidization bed instead of by the conventional lead bath.

a. Direct firing-type heating furnace + blast cooling
b. Direct firing-type heating furnace + cooling by fluidization bed.
c. Indirect firing-type heating furnace + cooling by fluidization bed.

Next, the cooling means after heating for patenting are shown below.

A) Cooling by lead bath

The lead bath is designed to cool steel wire in molten lead at 450 to 550°C after heating the wire. By this cooling means, it is possible to obtain a uniform cooling and produce a steel wire of high quality the least susceptible to oxidation and decarbonization.

However, it is feared that lead vapor might adversely affect the working environment and further it is desired that a new treating method be developed from the viewpoint of lead's high cost and lead bath's low operational efficiency.

At present, most thick wire rods and high-quality wire rods are still treated by the lead bath-type patenting furnace.

B) Cooling by fluidization bed

This method is to cool wire rods by fluid powder instead of by lead bath in the patenting process. Solid particles such as alumina, sand, silicon carbide and silicon iron heated at appropriate temperatures, are fluidized by high-pressure air injected from beneath. Then heated steel wire is caused to pass through the solid particles for cooling.

A cooling effect, almost the same as that of the cooling method using molten metal, is obtained. It is considered that this cooling method will make rapid progress because the introduction of a pollution-free patenting furnace using no lead is urgently required at present.

(3) Arc furnace

The arc furnace for steel manufacture melts charged scrap iron or reduced iron by a 3-phase AC arc generated between it and the electrode (3 pcs of artificial graphite electrode), and further refines it under arc heating into molten steel at 1,600 to 1,650°C. The obtained molten steel is poured into a ladle.

After the discharge of molten steel, the damaged part of refractories of the arc furnace body is repaired, and then raw materials for iron manufacture are charged and melted in that sequential operational order.

The melting operation carried out between steel discharges is called "one charge" or "one heat".

The arc furnace was invented by Paul Hérout of France in 1899. This furnace generates the arc directly between the electrode and the charged raw materials, and melts the latter. The elementary type of the practical steel-making furnace completed by Hérout laid the foundation for the present model by the alias of "Hérout furnace".

The operational characteristics of the arc furnace are as follows:

(A) High temperature can be obtained and the electric power also made can be controlled easily.

(B) Both oxidation and reduction refinings can easily be carried out.

(C) Restrictions on raw materials for iron are minimized.

(D) Both special and mild steel can be manufactured.

(E) Heat loss due to shutdown is comparatively small.

The epoch-making progress made recently in furnace facilities was the debut of an ultra high power furnace (in short, UHP) proposed by W.E. Schwabe of America, et al, in 1964. This furnace has now been popularized rapidly throughout the world because of its high productivity and economy.

The capacity of the furnace is expressed in melting quantity, transformer's capacity, and internal diameter of the furnace shell.

The furnace ranges extensively from the compact type for experiment (50 kg, 0.1 MVA, 0.88 m of internal dia. of shell) to the large capacity-type (400 t, 163 MVA, 11.59 m of the internal dia. of the shell).

Fig. III-4-12 shows the structural outline of the top charge-type arc furnace for steel manufacture.

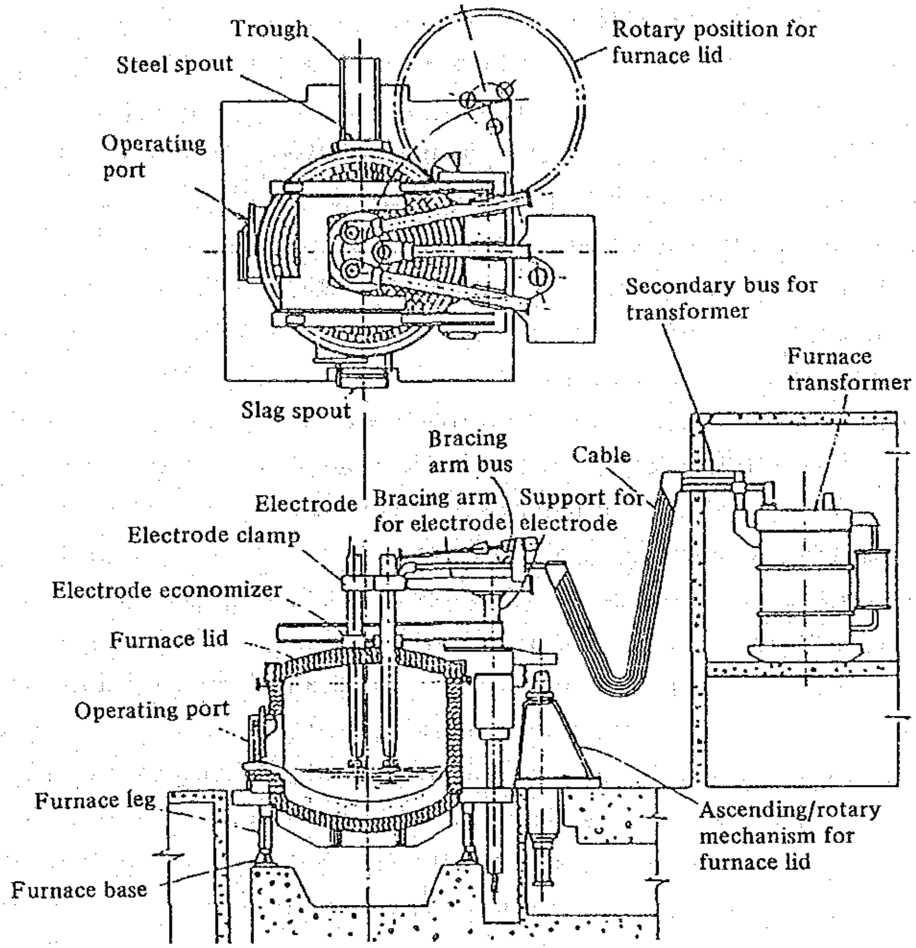


Fig. III-4-12 **Structural outline of top charge-type arc furnace for steel manufacture**

The furnace chamber is composed of a hearth and a furnace wall, both lined with refractories on the steel plate furnace shell, and a furnace cover having brick work on the frame.

The furnace shell side is provided with a slag spout for removing slag, repairing refractories, charging auxiliary raw materials, sampling molten steel, etc. and with a molten steel spout and a trough for discharging molten steel. In the lower part of the furnace shell, a furnace leg, a furnace base and a tilting mechanism for tilting the furnace body are provided.

The electrode is supported by an electrode clamp attached to the electrode bracing arm. It is also designed to automatically travel up and down by an electrode controller so that an electric current, i.e. an electric power, may be set at a constant level.

Scrap is filled in the bucket and then is charged into the furnace through the furnace top with the furnace lid opened.

The arc current runs from the furnace transformer, a secondary bus for transformer, cable, a bracing arm bus, an electrode clamp and an electrode, in that order.

The electrode economizer prevents the oxidization and wear of electrodes due to overheating by suppressing the blow-out of high temperature gas through a clearance between an electrode in a through hole on the furnace lid and the refractories during operation.

During the melting period, the maximum allowable electric power for equipment is made and, during the refining period, an electric power of lower intensity suitable to the kind of steel is made. When scrap is melted and the furnace wall is exposed to an electric arc, special attention needs to be given to the making of electric power. While scrap exists, the furnace wall is not directly exposed to arc radiation. Therefore, a melting damage does not occur. However, if electric power is made at high voltage after the melting of scrap, the furnace wall suffers a severe melting damage. In order to prevent this melting damage, it is desirable to carry out a short arc operation at low power factor (0.65 to 0.7) with high amperage and low voltage. This operation modus is also effective in raising temperature of molten steel. When melting reduced iron, because the furnace wall is always exposed, a short arc operation with high amperage is normally carried out even during the melting.

One charge is divided into "melting period" and "refining period". The melting period is significantly influenced by the capacity of the transformer or the availability of fuel injection or oxygen injection, almost regardless of the kind of steel. In addition, the period is influenced by the frequency of scrap charging, etc. On the other hand, the refining period varies considerably according to the kind of steel; that of special steel is longer than that of mild steel. The furnace wall repair time is approx. 10 to 30 min. The larger the furnace capacity, the longer the time. The scrap charging time is approx. 5 min. almost regardless of the size of the furnace. The time required for discharging steel is approx. 3 to 10 min. The larger the furnace capacity becomes, the longer the time.

The power consumption (kWh/t) is reduced in proportion to the shortening of time per charge. With regard to time shortening factors, a conversion to the high power system, fuel injection and oxgen injection especially influence the power consumption significantly. Besides, the large capacity furnace has a smaller surfacial area of the furnace body per ton as compared to the small capacity furnace. This means that the quantity of radiant heat per ton is decreased and the power consumption reduced.

(4) Induction furnace

The induction furnace is a unit which melts special steel, cast iron, copper, other high-quality metals and alloys, utilizing the principle of induction heating. It is also used for holding molten metal, increasing its temperature, adjusting components, etc.

This furnace has extremely high controllability over melting conditions, thus products quality is excellent. For this reason, the furnace is extensively used in the casting industry as an indispensable unit. The characteristics of the induction furnace are as follows:

(A) The charged raw materials generate heat for themselves. Therefore, the furnace has a high thermal efficiency and, as such, is suitable as a unit for high temperature melting.

(B) As it does not require oxygen for heating, the furnace can be closed hermitically to perform vacuum melting.

(C) Molten metal is automatically stirred by an electromagnetic force so that it is easy to adjust components or temperature. Thus high-quality products can be obtained with a satisfactory yield.

(D) Only charged raw materials are heated, so no heat is generated in the surroundings. In addition, the smoke discharge is at a low level. For this reason, operating and regional environments can easily be protected against pollution.

The induction furnace is classified into the following three types from the viewpoint of structure and power supply frequency:

a. High-frequency furnace....crucible type, 150 to 10,000 Hz

b. Low-frequency furnace.....crucible type, 50 and 60 Hz

c. Low-frequency furnace.....channel type, 50 and 60 Hz

Comparing the high-frequency furnace with the crucible-type low-frequency furnace, the former tends to have a rather larger power supply loss because of the required frequency converter. However, by virtue of a smaller heat loss, the high-frequency furnace displays a higher operating efficiency as a whole. The high-frequency furnace consumes less power consumption per week or month including the holding power and the starting power during early morning operation of a "cold" furnace. An example of this comparison is shown in Table III-4-1.

In comparison of the crucible-type low-frequency furnace to the channel-type furnace, the latter demonstrates higher power factor and electric efficiency because of the adoption of a closed coil iron core. Besides, the channel-type furnace is provided with an upper molten metal chamber whose characteristic refractory structure is not susceptible to electric restrictions. Hence, it can be insulated sufficiently which contributes toward the improvement of thermal efficiency. The channel-type furnace has such a shortening that it needs to hold molten metal in the channel even during shutdown. Nevertheless, it is rather suitable as a unit for increasing the temperature or holding molten metal instead of melting it on account of its low power density.

Fig. III-4-13 shows the structure of the crucible-type low-frequency furnace. High-conductivity copper tube coiled in the form of solenoid is used as an induction coil. This coil, because of the application of high electric power, is cooled by running cooling water through the copper tube. The induction coil is pressure- and water-proof as well as it is resistant against vibration and heat by electromagnetic force and humidity.

Table III–4–1 Compare energy saving-type high-frequency furnace with crucible-type low-frequency furnace

		Low-frequency furnace	High-frequency furnace	Remark
Equipment	Electric power (kW) – capacity (t)	800–3	800–1	
	Frequency (Hz)	50	500	
Materials for melting		Ordinary cast iron	same as left	
Molten metal discharging temperature (°C)		1,500		
Operation		8 h/day, 22 days/month		
Initial Batch	Electric power consumption rate (kWh/t)	650	620	
	Melting time (min)	209	58	
	Number of batch	1	1	
Normal Operation	Electric power consumption rate (kWh/t)	580	565	
	Melting time (min)	73 min/1.5 t	45	
	Number of batch	3	8	
Holding	Holding electric power (kW)	120	85	
	Holding time (min)	10	6	
	Electric power consumption rate (kWh/t)	12.3	8.5	
	Times	4	9	
Operating time (min)		468(7.8h)	472(7.86h)	
Total electric energy consumption (kWh)		4,640	5,216.5	
Production (t/day)		6.5*	9	
Total melting capacity (t/h)		0.84	1.14	
Unit electric power consumption rate for total melting (kWh/t)		714	579.6	
Installation space (X, Y, Z) (m)		6 x 7.5 x 4h	6 x 5.2 x 2.5h	
Total quantity of refractories used (kg)		approx. 1,100	approx. 500	
Tonnage of expected passage (t)		700	430	
Consumption (kg) of refractories per ton of molten metal		1.57	1.16	

*Deduct 1/2 of residual molten metal quantity and 1 ton for Starting Block for low-frequency furnace.

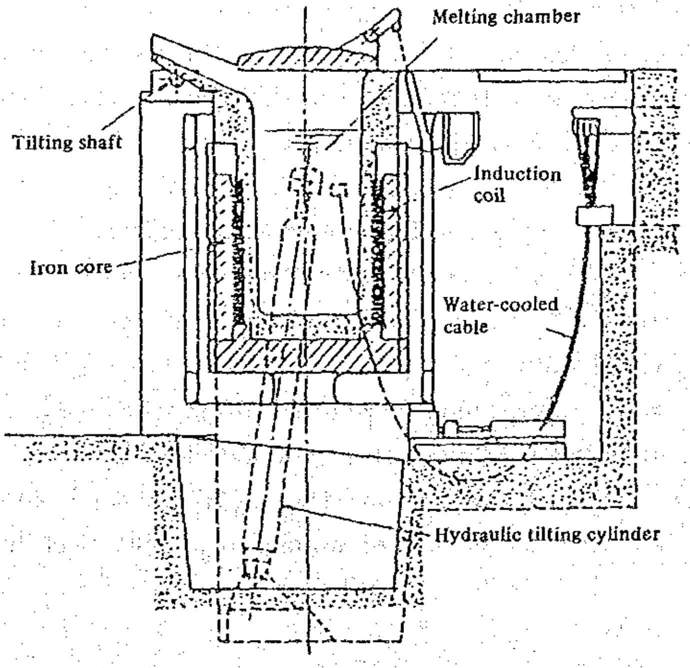


Fig. III–4–13 Cross-section chart for crucible-type low-frequency furnace

For large-capacity furnaces and the high power density furnaces, the induction coil is provided with an iron core in its external circumference to prevent a leaking of magnetic flux. In the meantime, the small-and medium-capacity furnaces and the low power density furnaces are not provided with an iron core.

The furnace tilting mechanism is classified as the hydraulic type, electric type, manual type, etc. The furnace lid operating method is also classified as the hydraulic type and manual type.

Fig. III-4-14 shows the structure of the channel-type furnace.

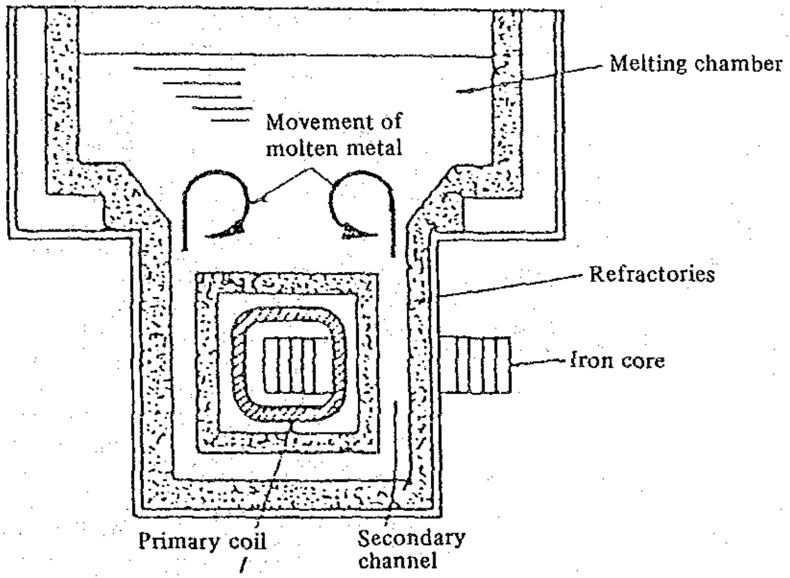


Fig. III–4–14 Cross-section chart for channel-type furnace

This furnace is composed of a melting chamber holding molten metal and the secondary channel (heating chamber) supplying heat energy. The secondary channel is composed of refractories, a closed coil iron core, a primary coil, etc.

The coil and iron core are forcibly cooled by water or air so that they may not be thermally damaged by heat transfer from refractories or their own exothermic action.

For discharging molten metal, the gate tilting system or the furnace rotating system is used. Most of the gate tilting system is hydraulically activated. However, some are electrically operated.

2.2 Status of energy utilization

In the metal industry, manufacturing processes and facilities are diversified and the form of energy consumption is also variegated. Table III-4-2 shows the example.

Electric power accounts for a large percentage of the total cost excepting the re-roll. To look at the fuel consumption of billet reheating furnace for the steel-bar, a new furnace with a recuperator shows a value of 53 l/t in contrast to the high value of 100 to 120 l/t shown by the old-fashioned furnace, indicating an unsatisfactory operational condition. These furnaces are operated on a single shift basis and, therefore, heat are utilized only for warming furnaces at night. For this reason, the fuel consumption rate is deteriorating.

The electric power consumption rate for scrap melting is 600 kWh/t for the arc furnace operated around the clock and 700 to 750 kWh/t for the induction furnace operated on a single shift basis. Both show a moderate power consumption efficiency.

For reference, the examples of satisfactory fuel consumption rates demonstrated by the reheating furnace in Japan are shown in Table III-4-3.

Table III–4–2 Actual condition of energy consumption of metal industries

Produce	Manufacturing method	Ratio of energy consumption (calory based)		Major energy consumption equipment
		Fuel	Power	
Bar steel	Electric arc	42%	58%	Reheating furnace Electric arc furnace Rolling mill
Bar steel Section steel	Rerolled	86%	14%	Reheating furnace Rolling mill, Shear
Casting	Electric arc induction	59%	41%	Induction furnace Electric arc furnace, Heat treatment furnace
Wire	Drawing	68%	32%	Heat treatment furnace Drawing machine
Parts of car screw, nail	by machine	–	100%	Electric heater Machine tool

Note: Unit of power is 860 kcal/kWh

Table III–4–3 Energy consumption rate of reheating furnaces in Japan

			Standard output	Standard energy consumption rate
Plate	Fuel (total)		120 kt/month	273×10^3 kcal/t
	Continuous furnace – cold charging	(70%)	77 〃	280×10^3 kcal/t
	Continuous furnace – Hot Charge	(30%)	36 〃	219 〃
	Batch furnace		7 〃	299 〃
	Heat retaining and heat boosting		120 〃	10 〃
	Electric power		115 〃	90 kWh/t
Strip	Fuel (total)		38 kt/month	219×10^3kcal/t
	Cold charging	(50%)	19 〃	227 〃
	Hot Charge	(50%)	19 〃	191 〃
	Heat retaining and heat boosting		38 〃	10 〃
	Electric power		36 〃	80 kWh/t

The change in the electric power consumption rate of the arc furnace in Japan is shown in Fig. III-4-15. Also, for reference, the average electric power consumption rate for mild steel is shown in Table III-4-4, and the heat balance of the arc furnace in Table III-4-5.

Table III–4–4 Average unit electric energy consumption rate for mild steel

Furnace capacity	10 t	15 t	30 t	60 t	80 t
Electric power consumption rate kWh/ton of good-quality ingot	550	520	480	440	410

Table III–4–5 Heat balance of arc furnace

Item		Kind of steel				Furnace capacity				Total	
		Mild steel (N = 7)		Special steel (N = 11)		30~50 t furnace (N = 7)		50t or more furnace (N = 11)			
		10^3 kcal/steel discharge t	%	10^3 kcal/steel discharge t	%	10^3 kcal/steel discharge t	%	10^3 kcal/steel discharge t	%	10^3 kcal/steel discharge t	%
Heat input	Heat quantity of electric power	373.0	59.1	438.3	61.5	437.6	62.2	398.2	59.8	412.9	60.6
	Calorific value of fuel	24.9	3.9	16.7	2.3	6.7	1.0	29.4	4.4	20.7	3.0
	Oxidation heat of electrode	25.7	4.1	34.3	4.8	35.9	5.1	28.9	4.3	32.1	4.7
	Oxidation heat of charged raw materials	192.4	30.5	208.4	29.2	204.5	29.0	199.5	30.0	201.5	29.6
	Heat of slag formation	11.2	1.8	12.6	1.8	15.0	2.1	10.2	1.5	12.1	1.8
	Others	3.6	0.6	2.7	0.4	4.4	0.6	–	–	1.7	0.3
	Total heat input	630.8	100	713.0	100	704.1	100	666.2	100	681.0	100
Heat output	Potential heat of molten steel	339.6	53.8	347.5	48.7	342.9	48.7	344.7	51.8	344.0	50.5
	Potential heat of slag	46.5	7.4	55.0	7.7	63.4	9.0	44.2	6.6	51.7	7.6
	Heat loss on transformer and secondary conductor	28.1	4.4	37.9	5.3	46.4	6.6	26.7	4.0	34.5	5.1
	Sensible heat of exhaust gas	111.0	17.6	115.9	16.3	115.1	16.3	112.2	16.8	112.4	16.5
	Heat carried out by cooling water	30.3	4.9	72.3	10.1	49.7	7.1	59.9	9.0	56.1	8.2
	Others (heat release from furnace body, radiant heat at time of additional charging, etc.)	75.3	11.9	84.4	11.8	86.6	12.3	78.5	11.8	82.3	12.1
	Total heat output	630.8	100	713.0	100	704.1	100	666.2	100	681.0	100

Next, the relationship between the capacity of induction furnaces and electric power consumption for the melting in Japan is shown in Fig. III-4-16 and Fig. III-4-17 with regard to low frequency furnaces and high frequency furnaces.

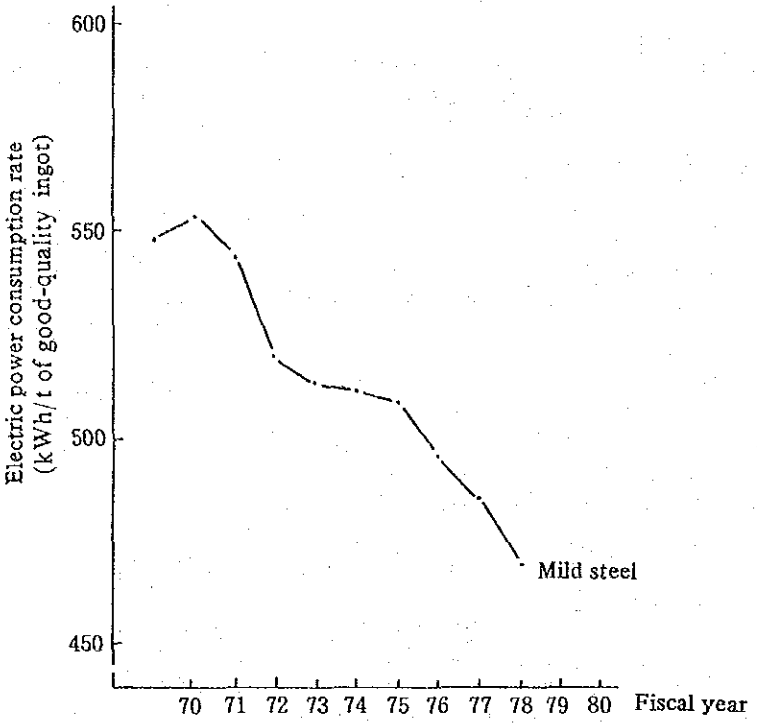


Fig. III-4-15 Changes of electric power consumption rate for arc furnace

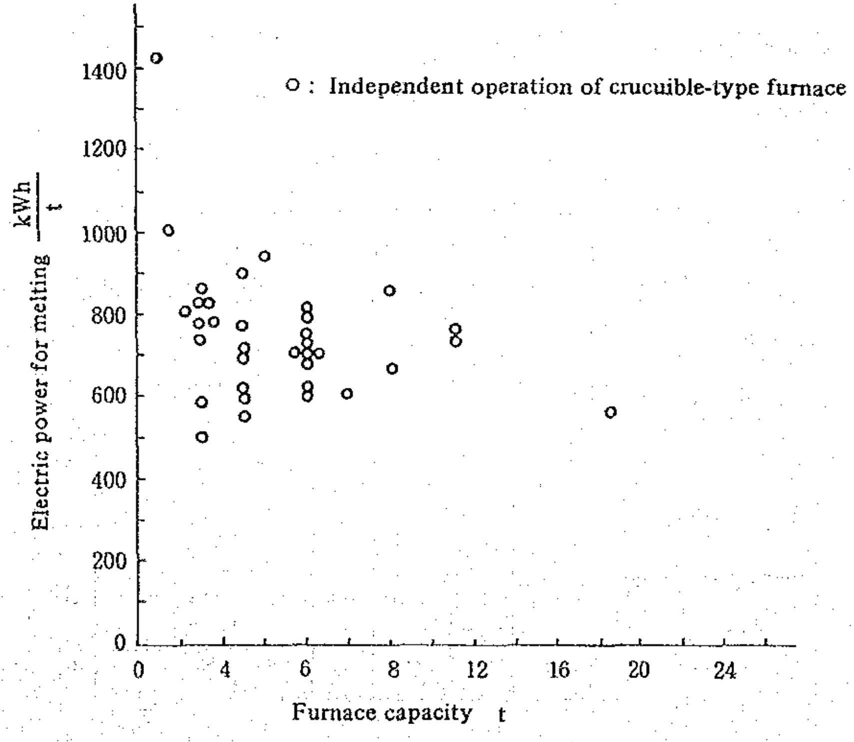


Fig. III-4-16 Relationship between furnace capacity and electric power for melting (Low-frequency furnace)

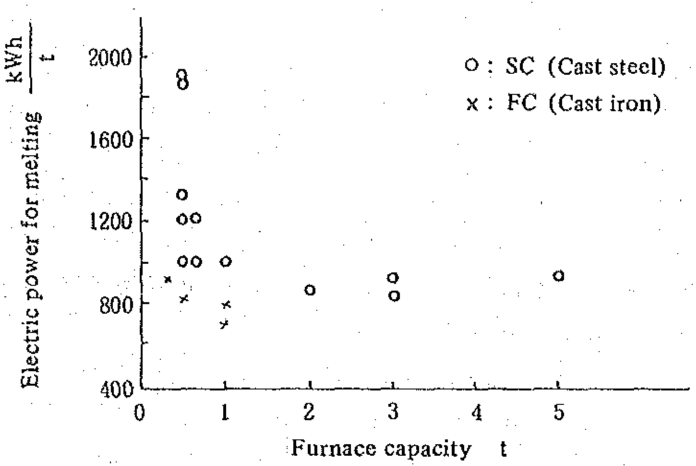


Fig. III–4–17 Relationship between furnace capacity and electric power for melting (High-frequency furnace)

3. How to Manage Energy

In order to improve the efficiency of energy consumption, productivity and product quality as well as raise their overall level, it is essential first to use facilities well adjusted and maintained to the purpose and to operate them correctly. It is most effective for energy conservation to reduce the incidence of equipment failure and increase product yield. Secondly, it is required that those engaged in energy management study the possibilities of further improving the existing facilities and operating method and pursue better means through repeated surveys and factory experiments.

Accordingly, it is not exaggerating to mention that the consciousness and willingness of the total factory employees would influence the actual performance of the factory. And it is important to raise the level of factory management which encourages the employees to have such consciousness and willingness. It is defined that energy management is a systematic effort to achieve energy conservation.

3.1 Clarification of Management Policy

Following the soaring of energy prices, the factory owner and manager have grown more concerned about energy conservation. In order to promote this tendency on a company level instead of letting it merely stay within the frame of the owner's mind as a desire, it needs to be clarified toward all the employees that the top management has the intention to tackle the energy conservation problem seriously as a company policy. In positive terms, the target should be clarified quantitatively; such as what percentage of energy consumption per ton of finished product should be reduced. Simultaneously the restrictions such as the ceiling of annual investment and deadline for pay back time should be clarified.

As explained above, the top management should clearly show the way to proceed on to the employees. Then in turn, the latter become confident about their jobs meeting the direction set by the former. Further, both can develop a smooth collaborative relationship because everybody involved is spiritually aligned in a unified direction.

Since the target of the top management is shown as a comprehensive one for the whole factory, each section and department should set concrete subtargets which do not require too much time and try their best effort to achieve these subtargets. These subtargets should be set concerning items for which any counter-measures can be taken by section and department personnel within their own responsibility range to attain the target set by the top management. As the said target is shown in a familiar and understandable form, it is easy to expect even employees of the lowest rank to fully understand the subtargets and extend their cooperation in attaining them.

When setting subtargets for each section and department, it is suggested that the committee described later or others study if such subtargets would be appropriate for achieving the overall target.

3.2 Arrangement of System for Promotion

In a campaign, for energy conservation where various classes of people take part, persons who play a part to promote the activities of all as a nucleus. If the factory is small, an individual person may be a promoter, but if the factory is large, a section for promotion is sometimes established.

This position should be occupied by a top-notch person and he should always be careful about a progress in energy conservation status and look into a cause, if there is a delay, then try to treat problem.

In concrete terms, the assignments of the position are as follows: the grasping of actual energy consumption, comparison of actual energy consumption with plans, invitation and checking of ideas about improvement, budgetary distribution, management of work progress and evaluation of actual works, mapping-out of education programs, preparations for committee meetings, etc.

The committee is effective for adjustment so that inter-disciplinary understanding may be realized among sections and departments such as manufacturing, sales, raw material purchasing, equipment maintenance and servicing, and accounting, and countermeasures may be put into practice smoothly. At the committee meeting, any possible influence of energy conservation measures to be performed on each section and department should be studied to make sure that no profit is reduced on an entire factory basis.

It is important that a general manager of the factory or a person next to the former in rank who has responsibility and authority in production assume the chairmanship of the committee. Otherwise, no decision would be made, neither would such a decision be implemented.

Even if certain energy measures were based on an excellent idea, any fruitful results would not be expected unless the operator fully understands what the measures mean and applies them to the actual work. There are many cases where the QC (quality control) circle which is effective for quality control is utilized successfully for energy conservation with noteworthy results. The QC circle is an activity of improving human relationship in the job, stimulating people to become more conscious about independence endowed intrinsically to humans and providing them with the pleasure of working actively. However, it is necessary to prepare conditions which make the operator find it easier to conduct activities such as education and incentive granting before he can recognize the advantages and necessity of the circle activities. It is the operator on the front line that is always in touch with energy consuming equipment and sensitive enough to grasp any phenomenon appearing according to a change in the operating conditions. It is extremely effective for energy conservation to make the best of information obtained by the operator and to squeeze out a good idea for improvement.

3.3 Scientific and Systematic Activities

It is an indispensable condition to obtain an exact status of energy consumption when energy conservation is carried out. If data such as change of the unit consumption rate per production, difference in the unit, variation of product grade and difference in raw materials are not available, it would be impossible to formulate plans which guide you toward an area requiring the implementation of immediate procedures. In other words, it is factory data that provide numerous ideas for improvement. If studies are made of these data with a consciousness about problems, it would be able to find something leading to such ideas. Therefore, it is suggested that a measuring instrument be installed at necessary spots, record its readings and obtain information through their periodical arrangement. In this case, such data should be processed from the viewpoint of mathematical statistics to determine if the difference is significant.

Next, it should be made sure that the results are followed up, if improvement plans were implemented. Efforts should be made to enhance the quality of operations according to the PDCA circle advocated by Dr. Deming. The function of the PDCA circle is such as explained below as shown in Fig. III-4-18:

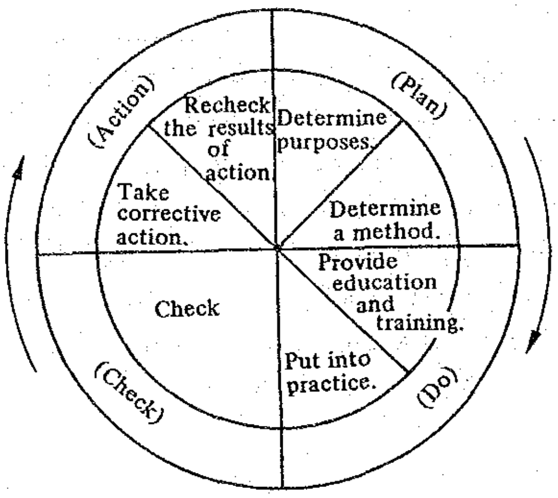


Fig. III-4-18 Deming circle

First, plans should be formulated; that is, a purpose will be set for a certain theme and means decided. This represents "P" for PDCA. People will be trained concerning how to perform these means and given an opportunity to actually do them. This represents "D". The results of the performance will be checked. This represents "C." Results of the check will be evaluated to determine if they are satisfactory. Action will be to standardize the results, if they are satisfactory and to take corrective measures if there is still a problem yet to be resolved. If one step was completed, the function of "PDCA" will be set to work towards a target of higher level. In this way, people proceed with their assignments. This method will be helpful for not only energy conservation but also heightening the quality of jobs in every field.

With regard to the part concerned with "Plan," it is recommended that "improvement plans invitation system" be actively utilized because items to propose can be found rather easily during an early stage. It should be so arranged that proposals may be made by whosoever he may be, an individual or a member of a working place, the QC circle or staff. Proposals presented should not be left alone, but should be examined promptly by the committee and others. The proposals presented should be adopted as far as circumstances allow after being modified on advice depending on the occasion. It is also suggested that a prize be presented to people for their proposals and further, a commendation be given to those whose proposals brought about fruitful results. These measures will be an incentive for people to deepen their consciousness about participation. For proponents whose proposals were not adopted, it is suggested that they be explained about the reasons why the proposals were not taken up and at the same time, be properly guided over better ideas.

In the stage of "D", it is suggested that satisfactory explanation be provided to employees of the lowest rank regarding an intention for improvement, and their cooperation in an effort toward the improvement be solicited. They are also encouraged to report even on minor abnormalities during operation so that they may be able to make scrupulous adjustments. This consideration is necessary to eliminate any possible cause for error.

"Check" should be conducted periodically and at the same time, the results be reported to the committee and the senior official. Along with this procedure, the results also should be made known to the operator so that he may deepen his concern. In this case, it is important to clarify an evaluation criterion from the beginning; it is not desirable to change it easily halfway.

If satisfactory results can be expected following the implementation of an improvement plan, they should be incorporated into the operation standard. Simultaneously necessary measures for the improvement of equipment should be taken so that any extra load may not be brought to bear on the operator. This is a condition for continued favorable results of energy conservation.

In case considerable results have been accomplished continuously as a result of the above, their summarized processes should be published as references. At the same time, those concerned should be officially commended so that they may be motivated for next activities.

3.4 Furnishing of Education and Information

Even if employees are willing to cooperate, any improvement can hardly be expected, unless they have knowledge as to how they should do it. They would become more positive to participate in the energy conservation campaign, if they are capable of presenting their own improvement proposal without being limited to merely pointing out problems. In order to realize this target, an internal education program sponsored by the company itself is important; that is, programs such as seminars and distribution of guide books should be provided. In the Kingdom of Thailand, a considerable number of companies are enthusiastic about education and also numerous cases where their staffers are sent for participation into external seminars are noticed. To our regret, however, such staffers sent for the external seminar tend to keep their acquired knowledge only to themselves instead of passing it on to other staffers or general operators. If it is arranged so that those who received external seminar training become lecturers for internal education and provide training to other people based on their acquired knowledge, it is expected that the entire level of employees' professional quality will be raised and staffers participating in the external seminars will be able to make sure that their obtained knowledge is practically useful.

Next, it is desired that information exchange with other companies of the same industry or raw material suppliers or finished product buyers be activated. Although it is naturally important that competition should take place among different companies of the same industry, it is recommended that technical information be exchanged to some extent on a give and take basis. This is because the technical level of the entire company can be heightened resulting in stronger international competing power and subsequent mutual benefit. For instance, the publishing of actual unit consumption rates will be instrumental for the motivation of commercial competition.

4. Rationalization of the Utilization of Thermal Energy

The rationalization of thermal energy consumption in the metal industry mostly relates to the combustion furnace. Characteristic contributing factors for the conservation of energy in the reheating furnace and the heat treatment furnace are as shown in Fig. III-4-19. The main items of the said factors are shown in Fig. III-4-20.

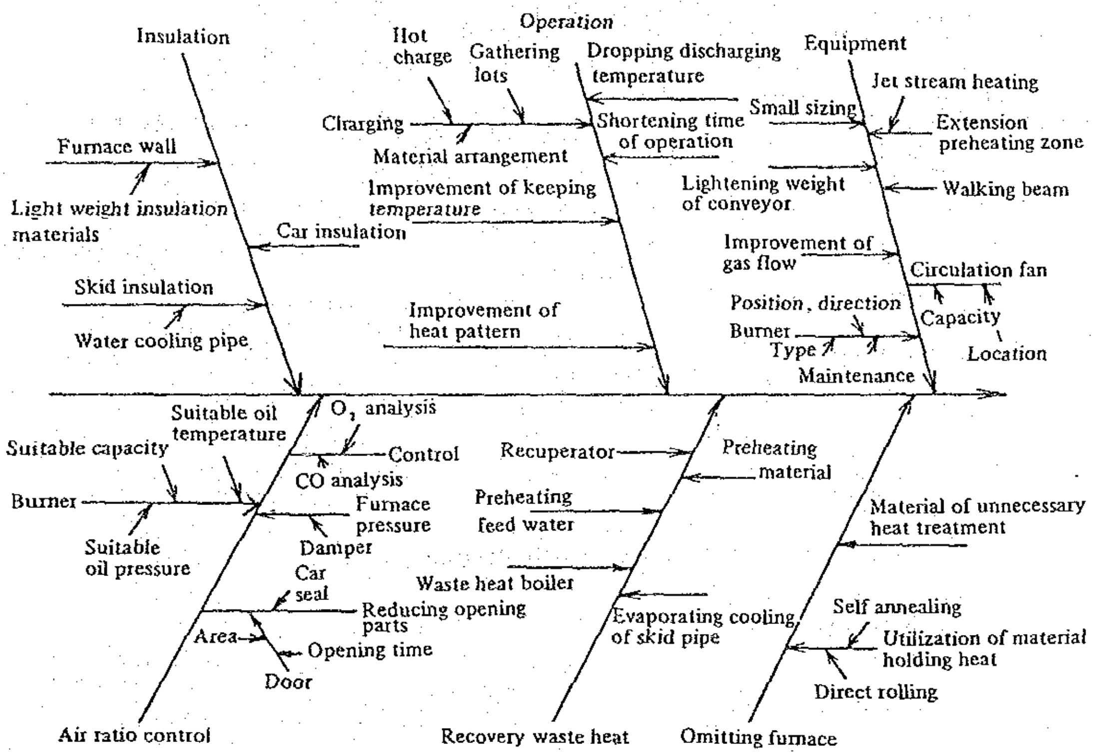


Fig. III–4–19 Characteristic diagram of energy conservation for reheating furnace and heat treatment furnace

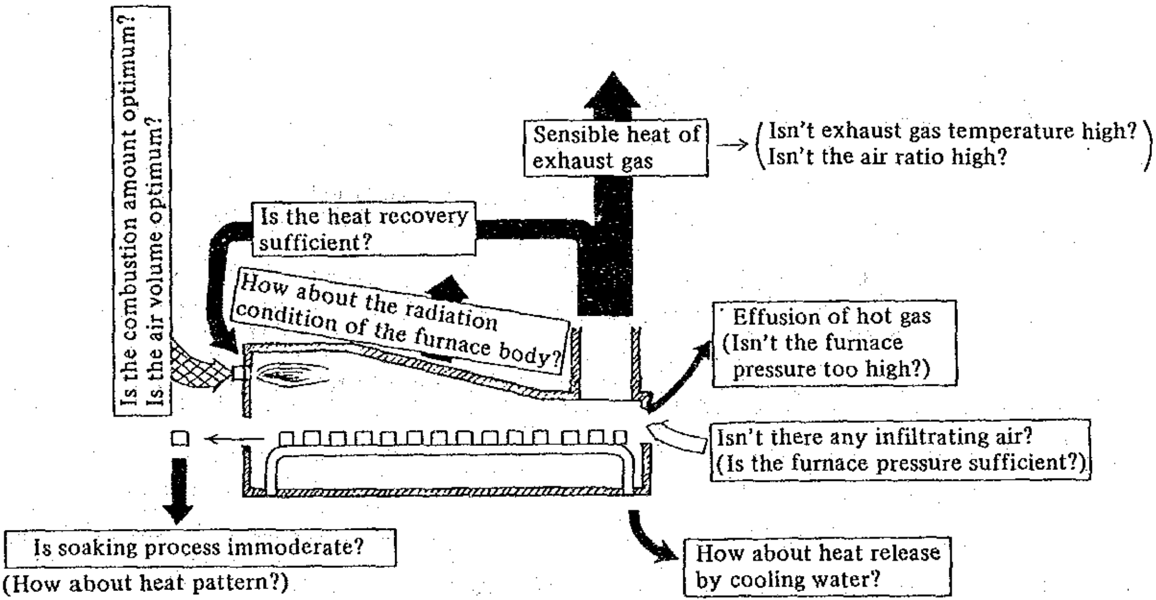


Fig. III–4–20 Reduction point for fuel consumption rate

In addition, characteristic contributing factors for the conservation of energy in the electric furnace and induction furnace as metal melting furnaces are as shown in Fig. III-4-21 and Fig. III-4-22.

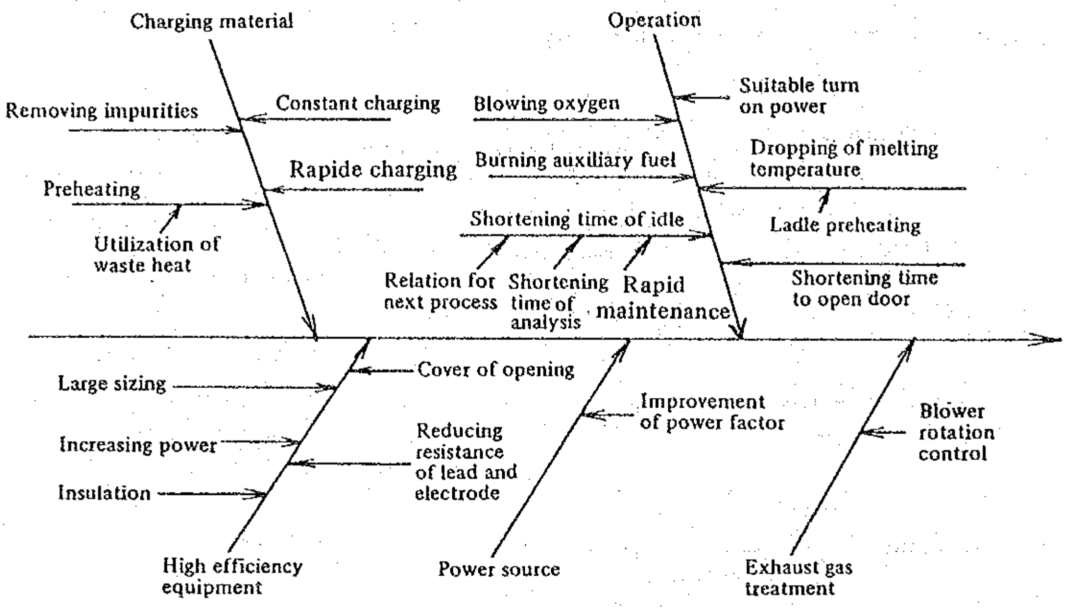


Fig. III–4–21 Characteristic diagram of electric arc furnace

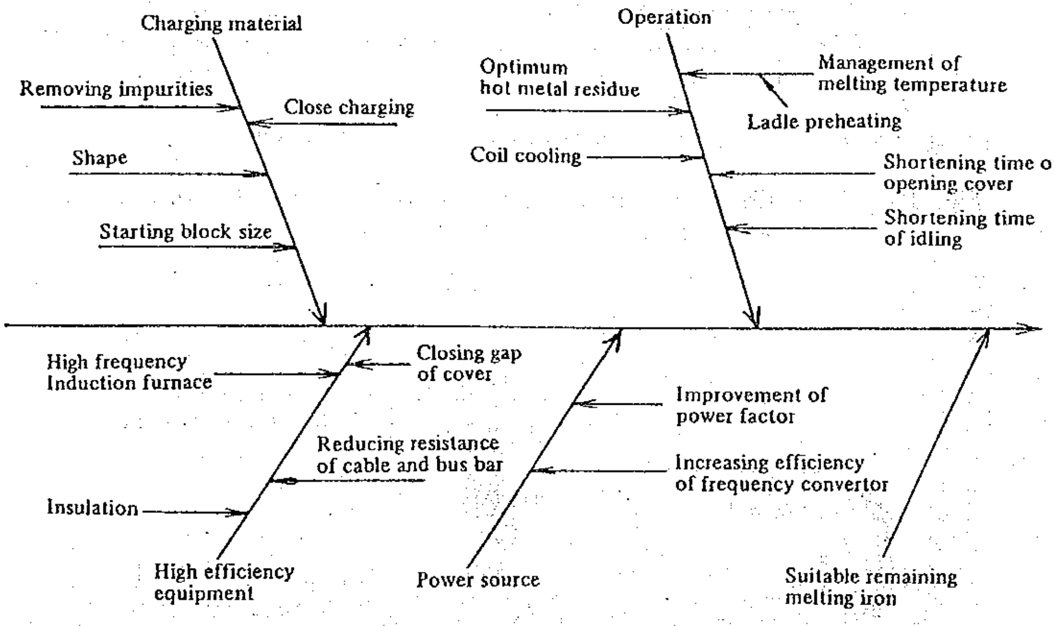


Fig. III–4–22 Characteristic diagram of induction melting furnace

4.1 Rationalization of fuel combustion

4.1.1 Air ratio

It is necessary to improve thermal efficiency to the fullest possible extent by the following means: that is, to burn all the fuel without leaving the combustible and reduce the air volume required for combustion to the value of a theoretically required air volume as far as circumstances allow when the chemical energy of fuel is converted to a thermal energy. In this respect, an important subject for study is a reduction of the air ratio.

As shown in Fig. III-4-23, when the fuel is not completely burned, a heat loss is caused by the remaining combustible of the fuel. In the meantime, if the combustion air is injected beyond the quantitative level required for complete combustion, a heat loss occurs due to the absorption of heat by the excess amount of air.

Accordingly, it is rational combustion to achieve complete combustion while maintaining a state where a slightly higher amount of air than is theoretically required, is injected.

This excess air amount is expressed by the proportion of actual combustion air volume to theoretical air volume required by combustion calculation, that is, air ratio.

Fig. III-4-24 shows the change of fuel consumption rate by air ratio. When the exhaust gas temperature is at 1,000°C, the fuel consumption rate is decreased from 180 to 100, if the air ratio is down from 1.8 to 1.2. This means that the energy is saved approx. 45% compared to the original fuel consumption rate.

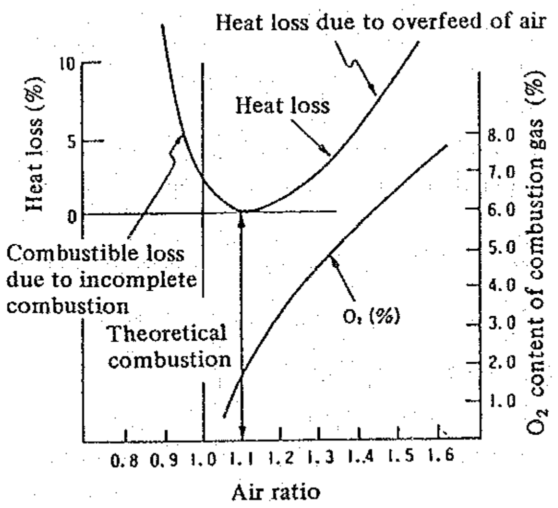


Fig. III–4–23 Rational combustion status

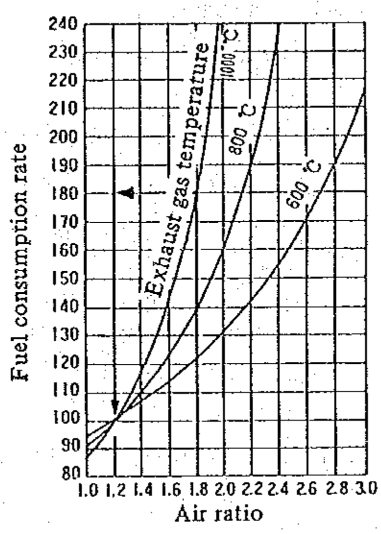


Fig. III–4–24 Energy saving effect under air ratio control

As explained above, the air ratio is an important indicator for the rationalization of thermal energy consumption. Therefore, it is essential to set a standard for the air ratio according to the fuel burning equipment and the kind of fuel used, and to manage the standard.

Based on the diagnostic results for nine manufacturers' factories in the metal industry obtained in January, 1983, we have established a recommendable standard air ratio as a target for continuous billet reheating furnaces in the Kingdom of Thailand as follows:

Classification	Standard Air Ratio
Continuous billet heating furnace	1.3

For reference, the standard air ratio of the industrial furnace in Japan is shown in Table III-4-6.

Table III--4--6 Standard air ratio of industrial furnaces

Classification	Standard air ratio
Melting furnace for metal casting	1.3
Continuous reheating furnace for bloom	1.25
Metal reheating furnace other than continuous reheating furnace for bloom	1.3
Continuous heat treatment furnace	1.3
Gas producer and gas heating furnace	1.4
Petroleum heating furnace	1.4
Thermal cracking furnace and reformer	1.3
Cement kiln	1.3
Alumina kiln and lime kiln	1.4
Continuous glass melting furnace	1.3

(Remark)

1. The values of the standard air ratio listed in this Table are determined regarding the air ratio measured at the outlet of the furnace, when the burning is carried out at a load in the neighborhood of a rating after inspection and repair.
2. The values of the standard air ratio listed in this Table will not apply to the air ratio of the undermentioned industrial furnaces as a standard:
   (1) Those using a solid fuel.
   (2) Those having a rated capacity of not more than 200,000 kcal/hour.
   (3) Those requiring a special atmosphere for oxidation or reduction.
   (4) Those requiring a frequent operation of furnace cover or frequent ignition and fire extinguishment.
   (5) Those requiring a diluted air for maintaining a heat pattern or equalization of intrafurnace temperature.
   (6) Those requiring an opening because of the structure of burning equipment and through which a large amount of external air flows in.
   (7) Those operated annually with the maximum operating time limited to 1,000 hours.

4.1.2 Burners

In the combustion furnace, combustion heat energy constitutes the largest heat input and thermal efficiency in the process of heat generation and utilization influences the thermal efficiency of the whole furnace significantly. Accordingly, when selecting the burner, the most rational-type should be chosen after studying, from various angles, the furnace type, kind of fuel, usage conditions and purpose of the furnace. The burner type is classified by fuel as shown in Fig. III-4-25. Fig. III-4-26 shows the capacity range of various types of burners and Table III-4-7 the characteristics of oil burners.

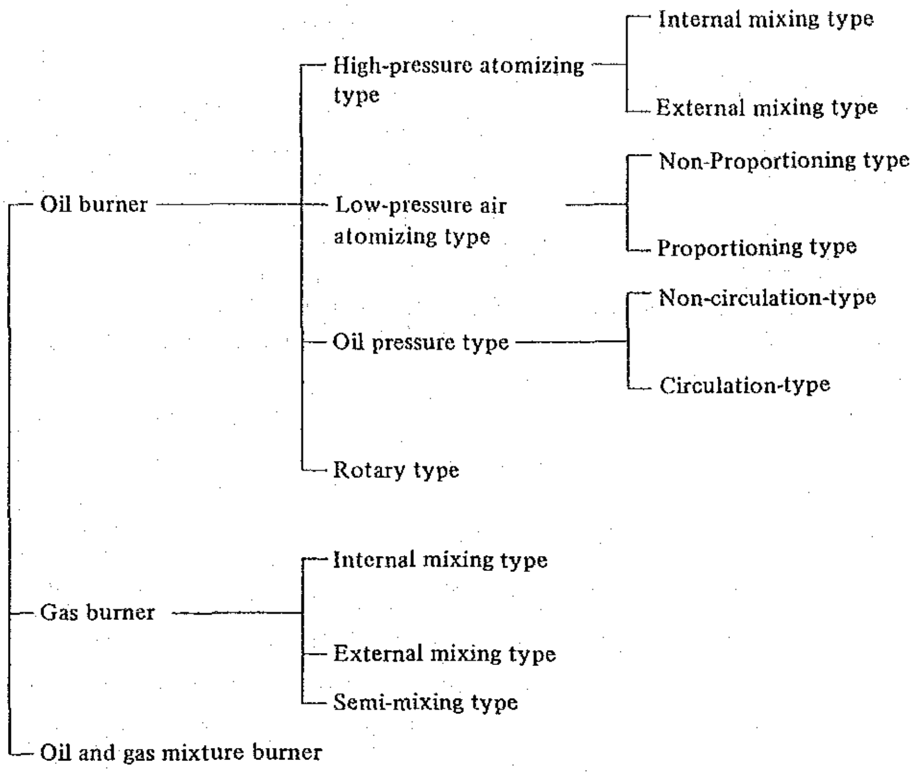


Fig. III–4–25 Classification of burners

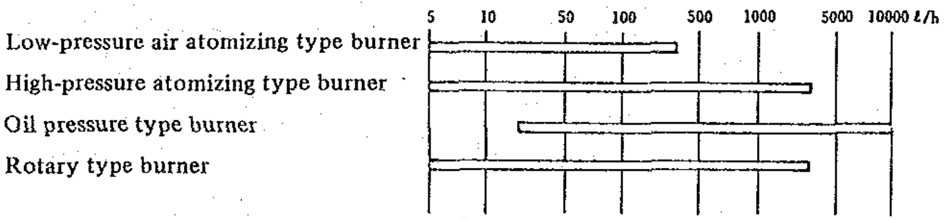


Fig. III–4–26 Capacity range of various burners

(1) High pressure atomizing-type oil burner

Of the various types of oil burners, the high pressure atomizing type normally uses compressed air or steam at approx. 2kg/cm^{2}G to 10 kg/cm^{2}G as an atomizing medium, thus shearing and atomizing oil.

The assembly chart of the high pressure atomizing-type oil burner is as shown in Fig. III-4-27. In addition to the body of the burner, an air register for supplying and controlling combustion air is required. The high pressure atomizing-type oil burner is roughly classified as the internal mixing-type and the external mixing-type depending on the mixing position for oil and atomizing medium.

The burner shown in Fig. III-4-28 represents the internal mixing-type characteristic of the mixing of oil and atomizing medium right before the blow-out nozzle.

Table III–4–7 Characteristics of oil burner

			Low-pressure air type		High-pressure atomizing type		Oil pressure type		Rotary type
			Proportioning type	Nonproportioning type	Internal mixing type	External mixing type	Return oil type	Non return oil type	
Quantity of fuel oil			1.5~150ℓ/h	4~180ℓ/h	10~5,000ℓ/h	10~600ℓ/h	50~10,000ℓ/h	5~10,000ℓ/h	10~1,000ℓ/h
Oil pressure			1~3.5kg/cm^{2}G	1~2kg/cm^{2}G	3~10kg/cm^{2}G	0.2~1kg/cm^{2}G	5~40kg/cm^{2}G	5~70kg/cm^{2}G	1~3kg/cm^{2}G
Atomization medium	Classification		Air	Air	Air or vapor	Air or vapor	–	–	Rotation of air and cup
	Pressure	Air	400~2,000mmAq	400~2,000mmAq	3~10kg/cm^{2}G	2~8kg/cm^{2}G	–	–	200~500mmAq
		Steam	–	–	3~10kg/cm^{2}G	2~8kg/cm^{2}G	–	–	–
	Required volume	Air	7~10Nm^3/kg	1~3Nm^3/kg	0.15~0.3Nm^3/kg	0.2~0.4Nm^3/kg	–	–	1~3Nm^3/kg
		Steam	–	–	0.1~0.3kg/kg	0.15~0.33kg/kg	–	–	–
Air for burning	Pressure		400~2,000mmAq	50~500mmAq	0~300mmAq	0~200mmAq	100~400mmAq	100~300mmAq	0~300mmAq
	Temperature		Constant temp. ~350°C	Constant temp. ~350°C	Constant temp. ~700°C	Constant temp. ~700°C	Constant temp. ~700°C	Constant temp. ~700°C	Constant temp. ~350°C
Appropriate viscosity of oil			15~25 cst	15~25 cst	20~50 cst	20~50 cst	15~30 cst	15~30 cst	15~30 cst
Combustion adjusting range			4~6:1	4~8:1	4~10:1	4~6:1	3~6:1	1.5~3.5:1	2~6:1
Type of flame			Generally long flame	Generally long flame	Short flame and long flame	Generally long flame	Generally short flame	Generally shor flame	Generally short flame
Advantage			Proportional adjustment by one lever operation is possible. Low equipment operating cost.	Easy handling and low equipment operating cost.	Optional selection of flame form. Satisfactory atomization.	Clogging won't occur easily, so even inferior quality oil can be burned.	Low burning sound, and low operating cost.	Low burning sound, and low operating cost.	Easy handling and low equipment operating cost.
Short coming			Air blower having high discharging pressure is required. Air temp. is restricted structurally.	Air blower having High discharging pressure is required. Air temp. is restricted structurally.	High burning sound. Air compresser or boiler is required as a gas source for atomization.	High burning sound. Air compresser or boiler is required as a gas source for atomization.	Insufficient response against lead fluctuation. High-pressure pump for oil is required.	It is impossible to respond to load fluctuation. High pressure pump for oil is required.	Generally, adjusting range is narrow.

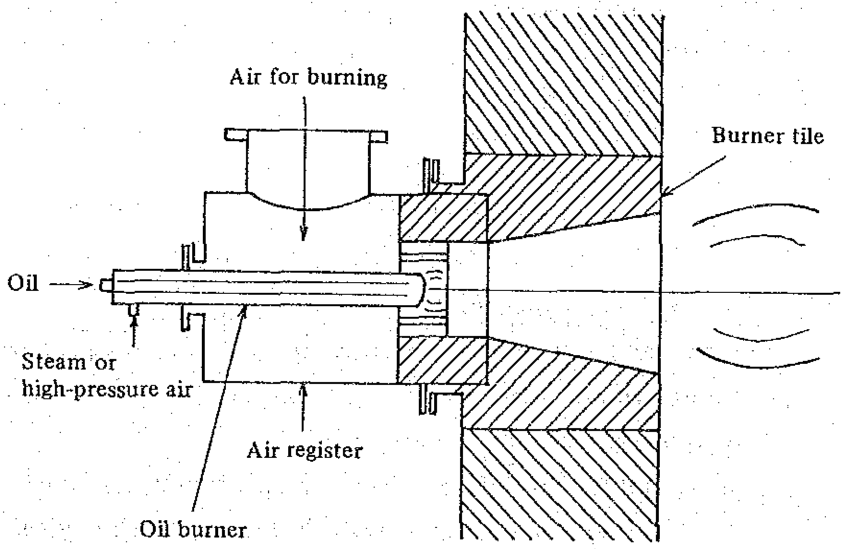


Fig. III–4–27 Installation chart for high-pressure atomizing type oil burner

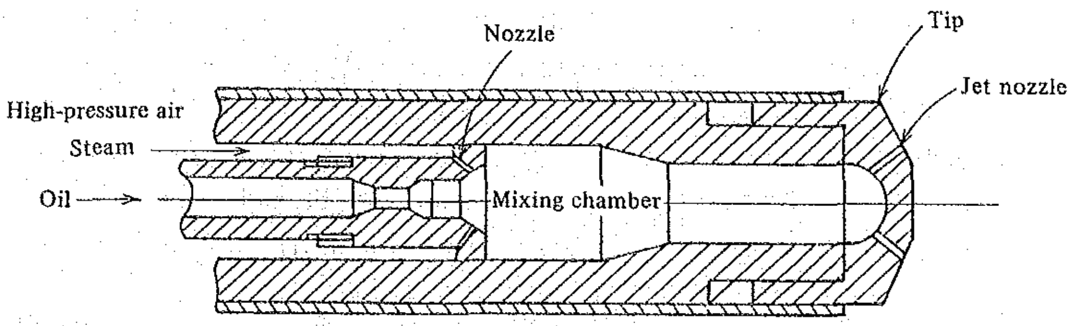


Fig. III—4—28 **Structure of high-pressure atomizing type oil burner (Internal mixing type)**

This example shows a comparatively large mixing chamber into which oil flows from the axial direction and atomizing medium from the surroundings. After mixing oil and atomizing medium in the mixing chamber, the mixture is blown out and expanded. Generally this burner is provided with several blow-out nozzles for the mixture. It is possible to obtain an optional form of flame such as short, long and flat by changing the position and shape of the blow-out nozzles. The burner demonstrates the forming of a stable flame and the high combustion rate because of the satisfactory mixing with the combustion air. Normally the oil pressure is maintained at a lower level than the atomizing medium pressure by 0.5 to 2 kg/cm^2. In the automatic operation of the burner, a pressure difference between oil pressure at the burner inlet and the atomizing medium pressure is, in most cases, kept at a constant level by providing a pressure difference regulator on the pipe for the atomizing medium. This is called "constant pressure difference control".

The burner shown in Fig. III-4-29 represents the external mixing-type which mixes oil and atomizing medium outside of the blow-out nozzle. The oil is blown out from the blow-out nozzle and the atomizing medium from nozzles provided around the oil blow-out nozzle. The atomizing medium atomizes the oil blown out, at certain angles, into extremely fine particles. In this burner, the atomization effect is extremly high because of the effective utilization of the atomization action by atomizing medium when the combustion capacity is small. On the other hand, if the capacity is large, it is difficult to assure complete atomization, unless a special design is provided. The flame tends to be long in shape because of the atomization mechanism.

The burner has such an advantage that due to the comparatively large diameter of the oil blow-out nozzle, the possibilities of clogging by the inferior-quality oil are very low and the oil supply pressure is low.

(2) Low pressure air-atomizing type oil burner

The low pressure air-type oil burner uses a low pressure air at 600 to 1000 mm H_2O as an oil atomizing medium. The atomization principle is the same as for the high pressure atomizing-type; that is, this burner atomizes oil into extremely fine particles by utilizing the blow-out energy of air. The burner of this type is roughly classified as the non-proportioning-type supplying only the required volume of air for oil atomization to the burner and the proportioning-type supplying the all required volume of air for combustion to the burner.

Fig. III-4-30 shows an example of installing the non-proportioning low pressure air type oil burner in a state of natural draft. Fig. III-4-31 shows the structure of the said burner. Most of the non-proportioning low pressure air type oil burners are of such a design as to atomize and supply an air equivalent to approx. 20 to 30% of the theoretical air volume required for combustion to the burner. Accordingly, in order to assure complete combustion, it is necessary to separately supply the remaining 70 to 80% of air by means of natural draft or forced draft.

As shown in Fig. III-4-31 "Example of Structure", oil is supplied to the oil nozzle through the oil quantity adjusting cock. In the meantime, the atomization air is supplied to the burner nozzle through the butterfly valve and part of it acts as an impact pressure in the first stage against the oil discharged from the oil nozzle after entering the interior of the nozzle. On the other hand, the remaining air is discharged from the clearance between the air nozzle and the burner nozzle, inflicting a second-stage impact to the oil into atomized particles. The air volume is adjusted by changing the area of the clearance between the air nozzle and the burner nozzle through the operation of the air volume adjusting handle. The butterfly valve at the air inlet is fully opened during normal operation, but is throttled during ignition.

This burner is called "non-proportioning-type" because the oil volume and the air volume are adjusted individually.

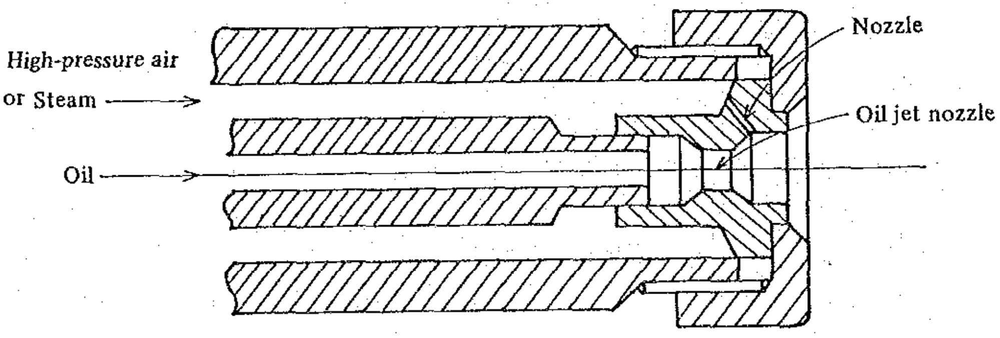


Fig. III–4–29 ***Structure of high-pressure atomizing type oil burner (External mixing type)***

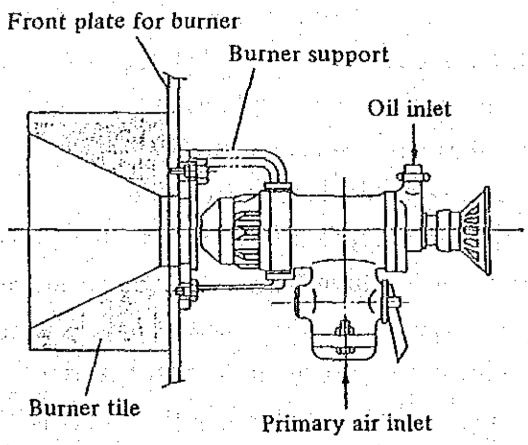


Fig. III-4-30 Structure of low-pressure air type oil burner (Non-Proportioning type)

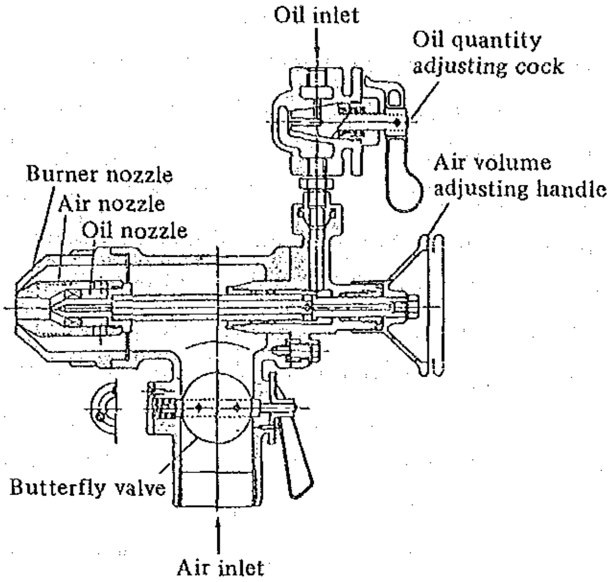


Fig. III–4–31 *Structure of low-pressure air type oil burner (Non-Proportioning type)*

Fig. III-4-32 shows an example of installing the proportioning low pressure air type oil burner, and Fig. III-4-33 the structure of the burner.

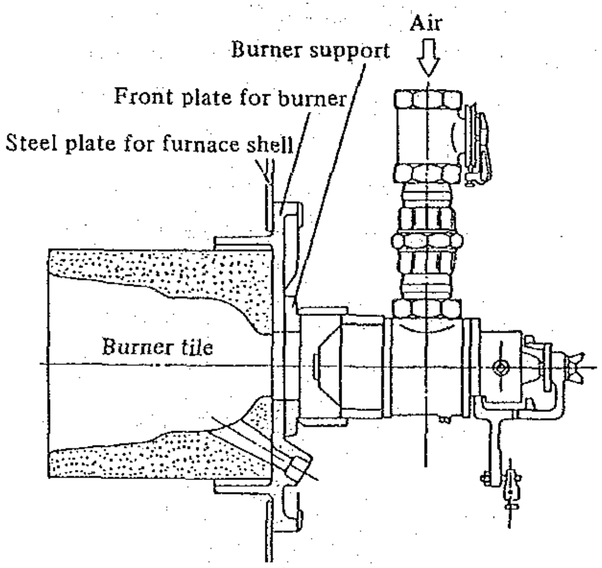


Fig. III–4–32 Installation of low-pressure air type oil burner (Proportioning type)

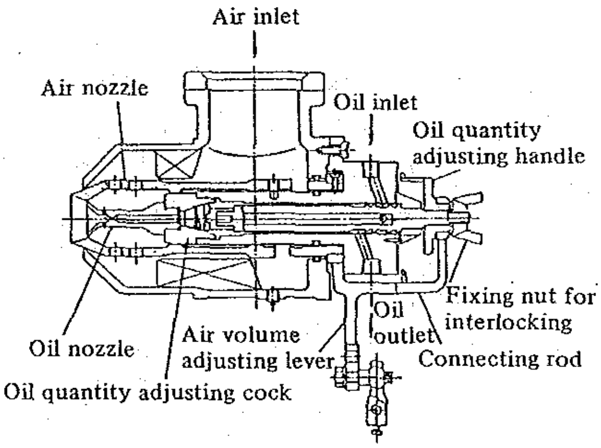


Fig. III–4–33 Structure of low-pressure air type oil burner (Proportioning type)

The burner of this type is generally called "proportioning burner". The total combustion air including the atomization air is supplied to the burner, and the adjustment of the oil volume and the air volume is interlocked.

The air volume required for combustion is supplied to the burner, so that the burner is least susceptible to the adverse effects of furnace pressure. In addition, it is possible to maintain the air ratio relatively accurately. In Fig. III-4-33, the oil supplied to the burner is adjusted to a prearranged flow by the oil quantity adjusting handle, and then is discharged through the oil nozzle. It is desirable to keep the viscosity at a constant level when supplying the oil because a change of the viscosity could cause a change in the discharge. The burner is so designed as to return the excess oil in the burner for keeping constant the viscosity as much as possible when supplying the preheated oil to the burner.

In the meantime, the air flow is adjusted by operating the air volume adjusting lever which moves the air nozzle back and forth to change the air discharge area.

In the interlocking action, both oil and air volumes are simultaneously adjusted through the connecting rod by tightening the fixing nut for interlocking.

(3) Oil pressure burner

The oil pressure burner is of such a design as to atomize the oil only by oil pressure energy.

The oil is supplied at a comparatively high pressure: air or steam for atomization is not required.

It is generally accepted that the oil pressure for atomization is at 5 to 20 kg/cm^2. Recently, however, burners at a maximum pressure of 100 kg/cm^2 or higher have been introduced under the tendency to use large-capacity burners.

The atomization characteristics of the oil pressure burner are that, if the oil pressure is lowered or the atomization angle narrowed, the diameter of atomized particles is large and the combustion state is unsatisfactory. Hence the adjustment range and flame characteristics are restricted. Generally it is known that this burner has characteristics of a wide angle short flame generation and a narrow adjustment range.

Nevertheless, the oil pressure burner offers such an advantage that air or steam for atomization is not required,the equipment is simplified and the operating cost is cheap.

Fig. III-4-34 shows the structure of the non-return-type oil pressure burner.

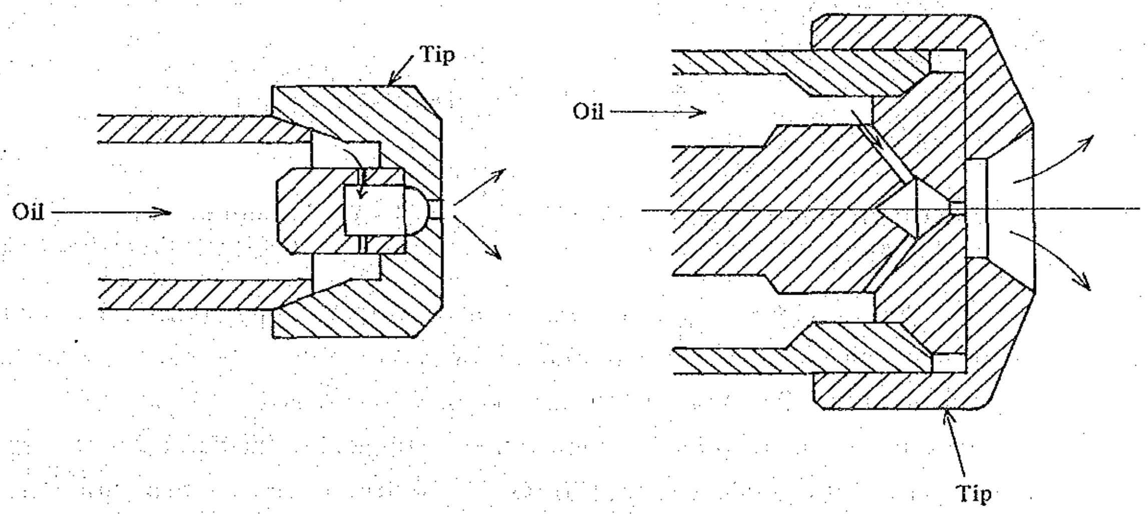


Fig. III-4-34 Structure of non-return oil type oil-pressure burner

This burner is of the oil pressure type in that the oil once fed into the body of the burner cannot be returned and the supplied oil is blown out through the tip in a strong turning current, thus atomizing the oil.

The burner is simple in structure and easy to operate, but is adjustable within a narrow range. Therefore, it is suitable as a burner which burns at a constant oil flow rate. In normal cases, the on/off control method or the method to "decrease" the number of operation of several burners sequentially is adopted. The oil discharge quantity is almost proportional to the square root of oil pressure. Therefore, when a change of the adjustment range is desired, it is required to change to supply oil pressure or to select the tip of proper nozzle diameter. In so doing, attention should be given to the fact that if the oil pressure is lowered beyond the reasonable level, the atomization characteristics will be worsened.

Fig. III-4-35 shows the structure of the return type oil pressure burner.

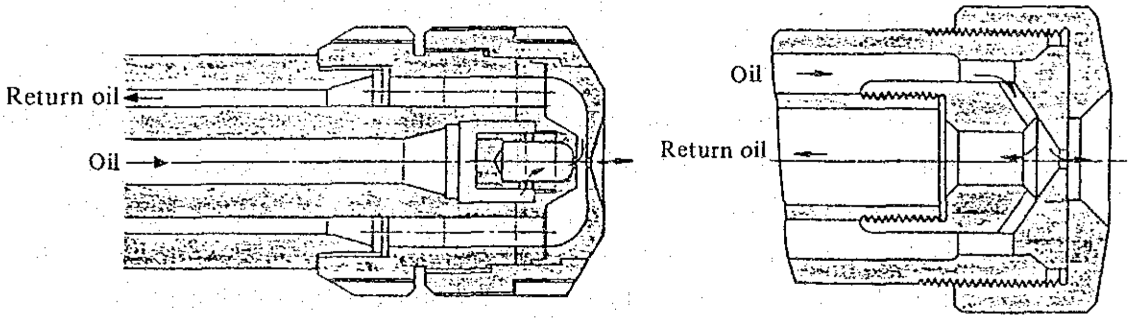


Fig. III–4–35 Structure of return oil type oil-pressure burner

The burner of this type is of such a design that the oil once fed into the body of the burner can be returned. The oil blown out of the tip in a strong turning current is atomized into fine particles.

In order to compensate for the shortcoming that the diameter of atomized particles is large when the oil flow is reduced, as seen in the non-return type oil pressure burner, this burner, provided with a return oil circuit, controls the turning force of the oil in the tip during low flow operation to maintain the atomization characteristics. The return type oil pressure burner has a wide adjustment range.

The oil flow is adjusted by the flow regulating valve provided at the return oil line. In this case, the discharge quantity is adjusted by the return oil quantity. Therefore, attention needs to be given to this difference from the burner of the other type in that the flow is at minimum when the flow regulating valve is fully opened and the flow is at maximum when the flow regulating valve is fully closed.

(4) Rotary-type oil burner

The rotary-type oil burner atomizes oil by the atomization action of the rotary disc. Fig. III-4-36 shows the structure of this burner. The atomization mechanism of the burner is such that: the oil flowing out along the tapered internal surface of the rotary cup (atomization cylinder) is spun out by the centrifugal force of the rotary cup at its end, forming a film running at a tangent, and this film is atomized by the primary air blown out from the exterior of the atomization cylinder. It is said that this burner is an advanced form of the low pressure air atomizing burner.

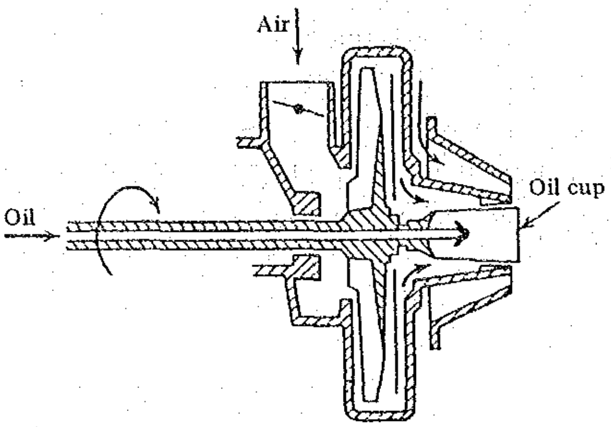


Fig. III–4–36 Structure of rotary type oil burner

The number of rotations of the atomization cylinder is 3,000 to 3,600 rpms for the ordinary type and 6,000 to 8,000 rpms for the high speed type. The high speed type has, by far, a wide flow adjusting range so that a burner of this type at the ratio of 25:1 is now available. The atomization method uses the rotary energy of the atomization cylinder and the energy of the primary air, thus unnecessary with any pressure in the oil itself.

If the oil is fed at high pressure, the blow-out velocity of oil is too high at the tip of the oil inlet so that the oil splashes inside the atomization cylinder. Consequently, the atomization does not take place effectively. For this reason, the oil feed design to let it drop by gravity is introduced. When the oil pump is used, it is suggested that the oil be fed at low pressure to eliminate the splashing of oil in the atomization cylinder.

The rotary-type oil burner can use oils ranging from light gas oil, kerosene, to "C" heavy oil because the change of oil particle diameter by viscosity is comparatively small.

The important point about this burner is that the fan installed on the main shaft of the burner is for primary air only and another fan should be installed or a natural draft be utilized to supply the secondary air.

(5) Gas burner

Gas fuel can easily be mixed with air and a long luminous flame, a non-luminous flame, or a semi-luminous flame be obtained freely depending on the mixing method. At the same time, it is possible to create an oxidizing and reductive intrafurnace atmosphere by adjusting the mixing ratio.

The gas burner ranges from large capacity to small capacity and is capable of adjusting the combustion amount over an extensive range.

The gas burner is classified into three different types such as internal mixing, external mixing and semi-mixing, according to the mixing mechanism for gas and air.

Fig. III-4-37 shows the structure of the internal mixing-type gas burner.

The internal mixing-type gas burner is so designed as to blow out and burn the gas mixture and all the required volume of air for gas combustion. It also can burn rapidly in a non-luminous flame without the secondary combustion air. If the mixing ratio of gas and air is set, it is possible to create a desired intrafurnace atmosphere.

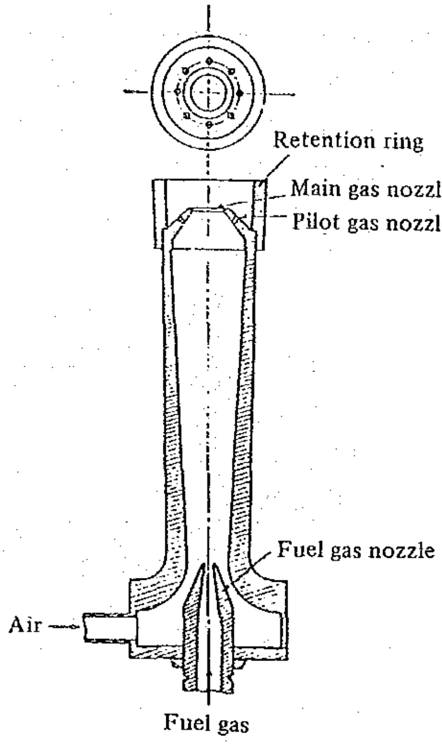


Fig. III–4–37 Structure of internal mixing type gas burner

Since rapid combustion takes place, the combustion chamber can be made compact. In addition, it can generate high temperatures and also adjust the mixing ratio accurately.

In the internal mixing-type gas burner, the operator must be careful about backfire.

The mixture of gas and air can only burn or explode within a certain range of the mixing ratio. This is called the "combustible range." This range varies according to the kind of gas. The combustible range slightly changes due to gas pressure and temperature. But the propagation velocity of flame changes according to the mixing ratio of gas and air.

The backfire of the burner occurs when the blow-out speed of the gas mixture is lower than the propagation velocity of flame at the tip. This backfire runs back in the pipe through the burner and retreats as far as the mixing section.

For the above reason, it is necessary that the blow-out speed of the gas mixture be sufficiently higher than the propagation velocity of flame even when the combustion quantity is minimized. Accordingly, the gas mixture at high pressure allows a selection of a wide combustion adjustment range.

When the blow-out speed of the gas mixture is extremely high, there is a fear that it might be accompanied by a "blow off flame" phenomenon. So some measures are taken. For instance, the mixture gas is blown out of numerous small holes so that the blow-out speed may be reduced by a vortex generated in the neighborhood of an individual blow-out nozzle, or is stabilized the combustion by making the gas mixture run into the surface of refractories so that the blow-out speed may be reduced.

Fig. III-4-38 and Fig. III-4-39 show the structure of the external mixing-type gas burner.

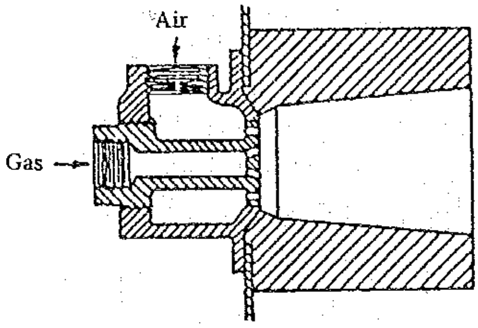


Fig. III–4–38 Compact external mixing type gas burner

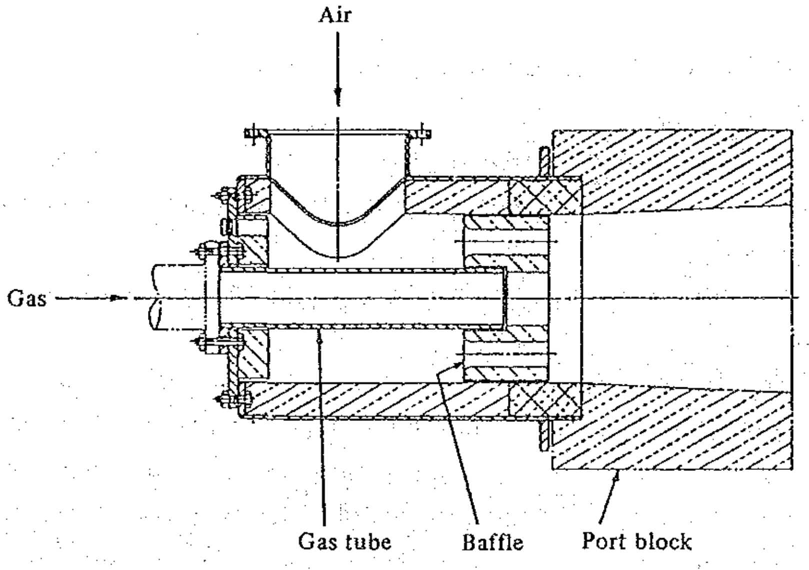


Fig. III–4–39 Structure of external mixing type gas burner

The external mixing-type gas burner is so designed as to diffuse and mix gas and combustion air outside of the burner and burn the mixture. This type has another name, "nozzle mixing-type". In this type, a combustible gas mixture cannot be made in the burner, so it is possible to adjust the combustion quantity over a wide range without danger of backfire. It is also possible to use an air preheated at high temperatures for combustion purposes and also preheated gas for use. The burner of this type ranges from large capacity to small capacity and is used extensively as a gas burner for the industrial furnace.

One of the major characteristics of this burner is that it can generate the flame, varying in terms the brightness, length, and temperature characteristics by selecting the structure of the blow-out section, and the blow-out speed of air and gas properly. As a type of burner, the port type is named. The typical external mixing-type burner is as shown in Fig. III-4-38 and Fig. III-4-39.

The burner shown in Fig. III-4-38 is used as a burner of comparatively small capacity. Gas is supplied from the nozzle located in the middle and air is formed into a uniform jet stream in the burner tile from the surroundings of the nozzle. Thus the air is supplied so that it may be diffused and mixed effectively. When the air and gas are blown out at low velocity, a soft long flame at a comparatively low temperature is obtained. For this reason, a burner of this type is suitable as a burner for a radiant tube which needs to block from local overheating.

The burner shown in Fig. III-4-39 is one used for the soaking pits and the reheating furnace, some of which are provided with a baffle of refractories at the outlet, or with a venturi of refractories throttling the outlet properly. Normally a preheated air of high temperature is used in this burner, so that the internal surface of the casing is covered with a heat insulation lining of an appropriate thickness.

Fig. III-4-40 shows the structure of the semi-mixing-type gas burner.

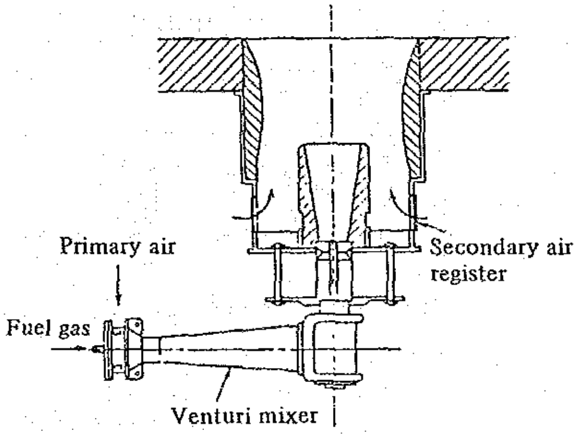


Fig. III–4–40 Structure of semi-mixing type gas burner

The semi-mixing-type gas burner is a burner designed to supply to the burner a premixed gas with part of combustion air and burn it by supplementing a required amount of secondary air in the blow-out section. This type has another name, "atmospheric pressure burner". For premixing the air, normally the venturi tube is used, and the air is sucked and mixed from the atmosphere by the dynamic pressure energy of gas.

The premixed air volume is equivalent to approx. 30 to 70% of the total combustion air volume. The length and brightness of flame can be changed by adjusting this primary air volume.

A burner of this type is used as a compact burner for simple equipment at such a low gas pressure as 50 to 250 mm H_2O. However, as an industrial burner using a large combustion quantity, a higher gas pressure is required for an appropriate gas mixture pressure from the viewpoint of such factors as the kind of gas, the ratio of premixed air volume, and the adjustment range for the required combustion quantity.

Even if only part of combustion air were mixed, it is just premixing. Therefore, in most cases, the mixture gas falls within a combustible range. For this reason, consideration should be given about backfire.

(6) Oil and gas mixed firing burner

This burner is so designed as to burn oil or gas exclusively or burn both simultaneously. Normally the oil burner gun is arranged in the center of the burner and used in combination with various types of the external mixing-type gas burners.

As for oil burners, generally the high pressure draft-type is used. However, the oil pressure-type burner is also used as a mixed firing burner for the large-capacity boiler and the rotary kiln. In addition, some versions of the compact-type mixed firing burner have built-in low pressure air-type burners. Fig. III-4-41 shows the types of the mixed firing burners used for most of the soaking pits and the reheating furnaces.

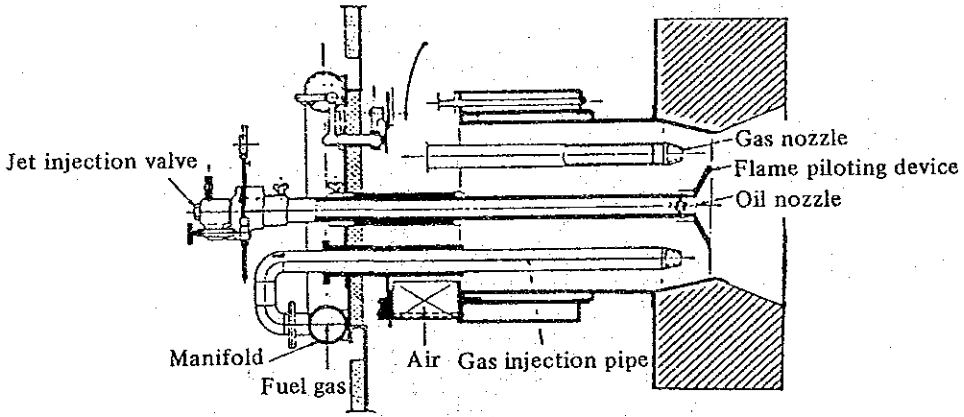


Fig. III-4-41 Structure of oil and gas mixture burner

When gas is exclusively burned in the mixed firing burner, the oil burner gun should be removed, but if it is necessary to keep the oil burner in "standby" condition all the time, the residual oil in the burner should be discharged into the furnace by using steam or compressed air, so that carbonization may be prevented. At the same time, it should be taken into consideration that during the burning of the gas burner, a small quantity of steam or compressed air needs to be blown out continuously to prevent damage on the tip due to heat.

Table III-4-8 shows check points for burning equipment.

Table III-4-8 Points of check and maintenance services for burning equipment

Check spot	Points of check	Procedures (Maintenance)
Fuel piping (oil and gas)	• Check leaking spots and tightened parts. • Check if there are any foreign matter or accumulated materials in piping.	• Retighten defective spots. • Blow the air into piping.
Attached equipment with piping	• Disassemble and check the oil pump	• Check worn-out parts, specially bearing, and if defective, replace them. • If the whole pump is defective replace it with a spare pump. • Check V-belt and coupling, and replace them, if necessary.
	• Disassemble and check oil strainer	• Check the interior of strainer. • Clean the clogged strainer. • If broken, replace the strainer or repair by partial welding and padding.
	• Disassemble and check oil heater	• Check and clean the heater. • If defective, replace it.
	• Check valves such as pressure adjusting, stop and relief.	• If any function is found, disassemble and check, and replace the whole set of valves. • For the relief valve and safety valve, check and adjust their working pressure.
Interior of furnace	• Check burner tiles.	• Check if there is any carbon attaching to the burner tile scrape it off while it is hot as for as circumstances allow. • Check if there are any cracks.
	• Check refractories.	• Check if there are cracks or a large break. • Check the joints of refractories. • Check the alignment of refractories.
	• Check the castable or furnace body.	• In addition to the castable, check the furnace body. • Check the peep hole and the explosion door.
Instruments	• Check the flow meter. • Check the thermometer. • Check the manometer. • Check, the fuel safety device.	• Check the accuracy of indication. (check the zero point) • Check a leakage and breakage of the connections. • Test the flame suppression action. It is necessary to disassemble and clean the flame detector (e.g. ultra-violet detector).

Table III–4–9 (a) Causes for trouble with heavy oil burner and trouble-shooting

Trouble	Cause	Trouble-shooting
Ignition is impossible.	Oil is empty.	First check an oil outflow at the time of ignition and then operate.
	Water and sludge are contained in piping, high viscosity.	Be sure to install an oil strainer. Drain the tank and piping periodically.
	Flash point is too high.	Proper flame for ignition is required. Prepare an ignition burner, if necessary.
	Clogging of burner nozzle.	Clean the burner at the time of fire extinguishment. Confirm the outflow of oil at the time of ignition.
	Insufficient heating of fuel.	Heat oil until atomized particles are extremely fine. Increase an atomizing pressure.
	Air does not exist.	Confirm the draft force, and also the opening of a damper when forced draft.
	The flue is closed.	Clean the intake port, flue and exhaust port periodically.
	Excess pressure and volume of primary air.	Appropriate oil concentration in the atomized air current is necessary.
The flame flickers and is not stable.	Sludge, water and other foreign matter in oil.	Be sure to provide an oil strainer. Drain tank and piping periodically.
	Viscosity is too high.	Increase a heating temperature and also an atomizing pressure.
	Burner hole is too large.	Provide an appropriate burner tile and use radiant heat.
	Unstable pressure of air and oil.	Provide a decompression valve, relief valve, etc. to keep a constant pressure.
	Insufficient pump-sucked oil.	Provide a pump of larger capacity.
	Excess pressure and volume of primary air.	Adjust to an appropriate pressure and volume.
	Air in the oil pipe.	Provide an air vent on the pipe.
	Oil heating temperature is too high.	Prevent the generation of bubbles and provide an air vent on the pipe.
Unsatisfactory injection or combustion.	Viscosity is too high.	Increase heating temperature and also the pressure of primary air.
	Insufficient fuel preheating temperature.	Make sure that atomized particles are extremely fine.
	Over or insufficient injection or oil pressure.	Follow burner nozzle specification.
	Air shortage.	Provide an appropriate air intake hole according to draft force.
	Insufficient exhaust port area.	Study an exhaust gas quantity and draft force for an amount of combustion.

Table III–4–9 (b) Causes for trouble with heavy oil burner and trouble-shooting

Trouble	Cause	Trouble-shooting
Excess fuel consumption.	Oil is too light.	Maintain an appropriate heating temperature because the quantity of heat tends to be short despite a sufficient capacity.
	Low calorific value of oil.	Use a proper oil.
	Water, foreign matter and excess or shortage of air.	Provide an oil heater, a strainer, etc. and adjust the air volume all the time.
	Flue hole is too large.	Prevent the inflow of excess air.
	Oil heating temperature is too high.	Determine a heating temperature after recognizing oil quality sufficiently.
Back fire.	Flash point is too low.	Select a proper burner and also change the injection specification.
	Water and foreign matter.	Provide a strainer, a drainage, an air vent etc.
	Excess oil pressure.	Be careful about the size of oil particles and particle injection velocity.
	Insufficient pressure of primary air.	
	Closing of an exhaust port.	Check the opening of a damper and draft force.
	Air in the oil pipe.	Provide an air vent.
Accumulation of carbon in the burner nozzle.	Viscosity is too high.	Make sure that atomized particles are extremely fine.
	Unsatisfactory injection.	Use an appropriate primary air.
	Excess oil pressure.	Use a pressure suitable to the atomizing mechanism.
	Extremely high heating temperature.	Adjust oil and vapor quantities.
	Unstable oil supply.	Keep a constant pressure by the relief valve. Heat up to a fixed viscosity. Be careful about pump failure.
	Air shortage.	Increase the primary air volume and prevent the vortex of the secondary air in the burner tile.
	Leakage of the burner valve after fire extinguishment.	Blow off residual oil in the burner to the maximum allowable degree.
	Excess carbon amount in oil.	If it is possible to increase the primary air pressure and volume, change to forced draft.
	Non-uniform injection.	Be careful about the clogging or scar of nozzle.
	Improper mounting of nozzle.	Make sure that the nozzle is mounted in the center.
Accumulation of carbon on the furnace wall.	Direct impact of atomized particles.	Narrow the injection angle of burner or widen the combustion chamber.
	Viscosity is too high.	Increase a heating temperature and also the primary air volume.

Table III–4–9 (c) Causes for trouble with heavy oil burner and trouble-shooting

Trouble	Cause	Trouble-shooting
	Viscosity is too low.	Reduce the injection velocity.
	Excess oil pressure.	If the pressure and volume of the primary air do not match the oil quantity, the oil is unburned.
	Excess primary air.	If the injection velocity is high, the ignition distance is long.
	Low intrafurnace temperature.	Avoid a rapid combustion of a large quantity of oil.
	Narrow furnace width.	Design after making sure that the amount of combustion matches the injection angle of burner.
Clogging of burner nozzle	Sludge and foreign matter.	Provide perfectly working strainer and heater.
	Accumulation of carbon in the nozzle.	Make sure that the burner is cleaned at the time of fire extinguishment and is not exposed to intrafurnace radiation for a long time.
Soot and dust	Excess ash content	Oil burned at high temperature by forced draft.
	Unsatisfactory burning.	Carry out perfect atomization.
	Heavy oil components.	Induce the secondary air to burn them at high temperature.
	Air shortage.	Increase the air volume so that the flame length is short.
	Excess combustion load	Be careful about the relationship between the size of combustion chamber and oil quantity.
	Insufficient blast.	Increase the exhaust port area, and also draft force.
Clogging of strainer.	Sludge, wax, other foreign matter, extremely high viscosity and extremely low oil temperature.	Provide a strainer suitable to oil quality.
Clogging of piping.	Coagulation of sludge, wax and oil, extremely high viscosity rag, wooden chip, iron rust and other foreign matter.	Provide piping of larger size. Minimize resistance. Apply insulation. Install a strainer.
Pump suction is impossible.	Low oil temperature, extremely high viscosity, clogging of pipe filter, sludge, leakage of suction pipe, slipping of pump and extremely high oil temperature.	
Mixing of water.	Separation of water from oil, condensation of moisture in air, leakage of heating pipe, rain water leakage due to breakage of tank roof and other causes.	
Corrosion.	Components of ash, sulphur and salt in oil.	
Discoloration of brick	Sulphur, iron and ash.	
Odor.	Extremely high preheating temperature, sulphur and other foreign matter.	

4.1.3 Furnace Pressure and Draft Force of Smoke Stack

Fuel, if the draft is incomplete, is not burned sufficiently. Draft means "supplying combustion air and discharging combustion gas". The draft force is indicated by a differential pressure (the unit is water column (mm)). The draft force is very important in determining the draft capacity of a burning furnace and the manner of furnace operation.

The draft is carried out by means of a smoke stack and an air blower, and is roughly classified as follows:

(1) Natural draft (smoke stack)

(2) Forced draft (air blower)

(A) Forced draft

Combustion air is blown in the furnace by an air blower and combustion gas is discharged by a smoke stack. The furnace pressure is sometimes higher than the atmospheric pressure, so if there is any clearance in the furnace body, the gas might spew out.

(B) Induced draft

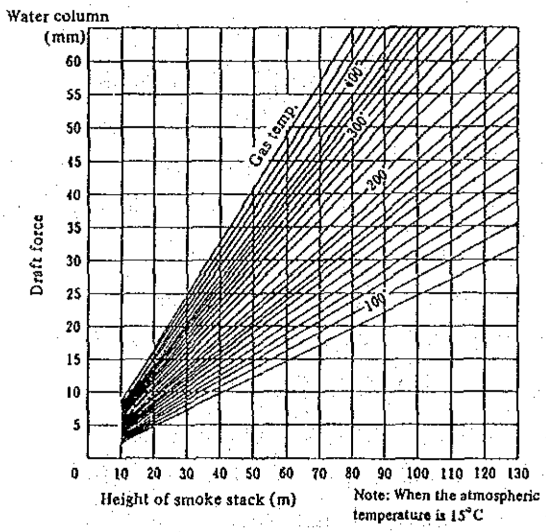
Combustion gas in the flue is discharged by a blower or an ejector. The furnace pressure is sometimes lower than the atmospheric pressure, so if there is any clearance in the furnace body, air might infiltrate within it.

(C) Balanced draft

This is a combination system of forced draft and induced draft, so it is possible to freely adjust the furnace pressure.

- When the draft force is in excess, (1) the quantity of excess air is large, (2) the heat loss by an exhaust gas increases, and (3) the furnace temperature goes down, thus causing an unequal temperature distribution.
- When the draft force is insufficient, (1) soot is generated because of incomplete combustion, (2) fuel consumption is increased and (3) backfire might occur when gas fuel is used.

Fig. III-4-42 shows the relationship between the average gas temperature and draft inside the smoke stack.



Note: When the atmospheric temperature is 15°C

Fig. III–4–42 Average gas temperature and draft force inside smoke stack

The required draft force is determined by the type of burner and the combustion quantity of fuel. The draft force should be higher than the total value of the register resistance generated when air passes through the burner and the flue resistance generated when combustion gas runs through the flue.

The flue draft resistance when the cross-section of the flue is constant and straight is expressed in 0.2 to 0.3 mm of water column in terms of pressure drop per 1 m of length. However, if there is a bend in the halfway or a variation in the cross-section, a superheater, an economizer, or an air preheater provided in the route to the smoke stack, the required draft force is bound to be high on account of draft resistance.

Table III-4-10 shows an example of a draft power in the flue.

Table III–4–10 Example of draft resistance (Water column mm) in flue

Heat transfer area	Flue tube boiler	4 ~ 7
	Smoke tube boiler	7 ~ 10
	Horizontal multitubular boiler	3 ~ 6
	Water tube boiler	2 ~ 5
Superheater		2 ~ 3
Economizer		3 ~ 5
Air preheater		3 ~ 5
Dust collector		2 ~ 3
Damper		1 ~ 3
Horizontal flue per 1 m		0.2 ~ 0.3
Flue 90° bend		3

If an air preheater is installed in the flue, not only the draft resistance is increased but also the exhaust gas temperature goes down, resulting in a reduction of the draft force.

If the combustion gas contains sulphur, a sulphur oxide is produced by combustion. This sulphur oxide corrodes the air preheater, economizer, steel-plate smoke stack, etc. Therefore, the exhaust gas temperature should not be allowed do drop below the dew point. Normally it should be over 250° C.

The principle causes for the shortage of draft force are as follows:

a. Insufficient smoke stack height and smoke stack cross-section area.
b. Clogging of the flue by soot and dust.
c. Blocking of the secondary air intake for the burner.
d. Infiltration of air through the brick wall of furnace body, flue, etc.
e. Insufficient opening of the damper.
f. Shortage of the capacity and pressure of air blower.

The draft power of the smoke stack is generated by a difference between the gas density in the smoke stack and the air density. Its intensity is determined by the gas temperture in the smoke stack and the height of the smoke stack.

The simple equation for obtaining the draft force of the smoke stack is as follows:

$$h = 355 \times H \left(\frac{1}{T_1} - \frac{1}{T_2} \right)$$

h: Theoretical draft force generated by the smoke stack (mm water column)

H: Height of smoke stack (m)

T_1: Atmospheric temperature (°C) + 273

T_2: Average temperature (°C) in the smoke stack + 273

The general gas current velocity in the smoke stack is 4 to 5 m/s. The smaller the diameter of the smoke stack, the higher the current velocity of gas becomes. Therefore, it is necessary to provide a smoke stack having a sufficient sectional area.

It is recommended that the furnace pressure value be set 0.2 to 0.4 mm H_2O in terms of pressure on the hearth.

As shown in Fig. III-4-43, set the furnace pressure by regulators such as dampers, considering the effect of both buoyancy force of furnace gas and position of the measuring port for furnace pressure as follows:

$P = (0.2 \text{ to } 0.4) + L \text{ (mm } H_2O)$

Where

P: Setting value of furnace pressure (mm H_2O)

L: Height of the measuring port from the hearth (m)

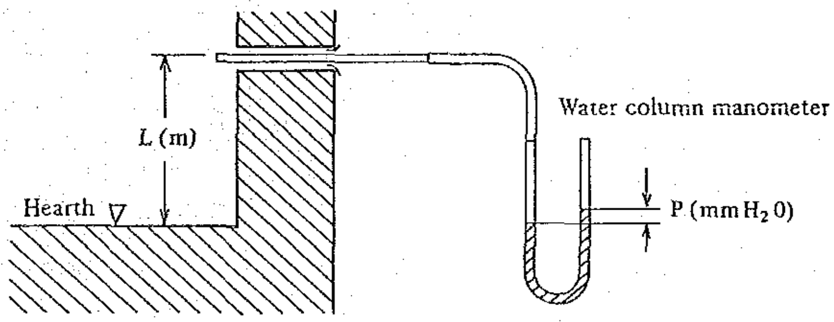


Fig. III–4–43 Furnace pressure measurement port and pressure setting

4.1.4 Preheating of Heavy Oil

In order to atomize heavy oil in a normal condition when the oil burner is used, it is necessary to meet an oil viscosity at the burner intake, to the value shown in Table III-4-11.

Table III–4–11 Required viscosity of oil at burner inlet

Type of burner	Required viscosity of oil at burner inlet	
	RW. No. 1	Kinematic viscosity
High-pressure atomizing type	230 sec. max.	59 cst max.
Low-pressure air type	230 sec. max.	59 cst max.
Oil pressure type	150 sec. max.	32 cst max.
Rotary type	150 sec. max.	32 cst max.

It is not necessary to preheat light gas oil, kerosene, and "A" heavy oil. However, "B" heavy oil and "C" heavy oil need to be preheated for use.

Fig. III-4-42 shows a diagram for the relationship between the viscosity of fuel oil and temperature.

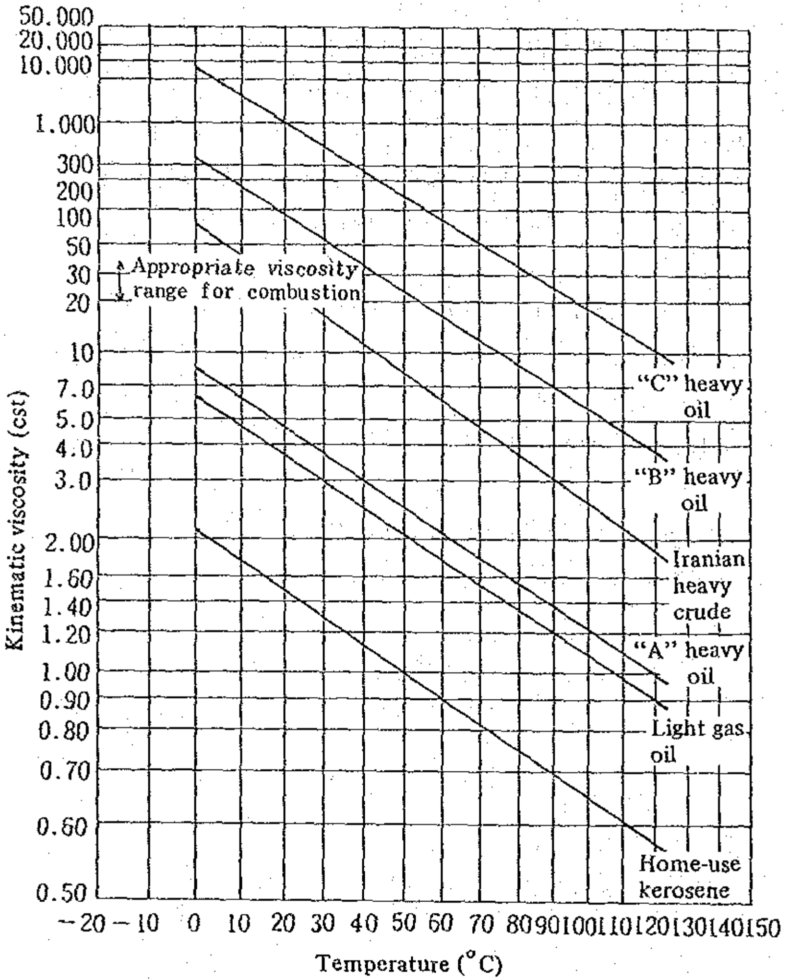


Fig. III–4–44 Viscosity-temperature-related linear chart for fuel oil

4.2 Rationalization of Heating, Cooling and Heat Transfer

Heat is transferred to materials in the reheating furnace as follows:

(1) Heat transfer by conduction

When a raw material at low temperature is put on the hearth at high temperatures, heat is transferred by conduction. When two pieces of solids touch each other, the contact surface reaches a certain intermediate temperature between both contact surfaces instantaneously.

The quantity of heat actually transferred to a material by conduction is comparatively small.

(2) Heat transfer by convection

In case a gaseous fluid flows parallel with the surface of a solid as shown in Fig. III-4-45, heat is transferred through a static layer (border layer) of a fluid attaching to the surface of solid by an attraction. Heat transfer by convection is most important, when the furnace temperature is below 600° C.

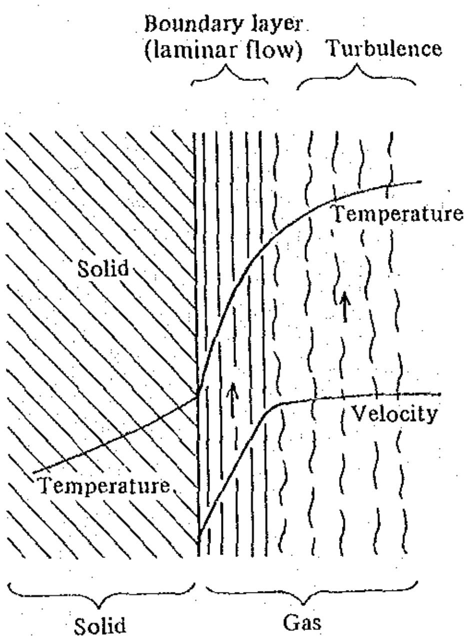


Fig. III–4–45 Heat transfer to surface by convection

According to experiments, the quantity of transferred heat from a gas flowing along a plane per unit area and unit time is function of mass, velocity of gas and temperature difference. For the purpose of increasing the quantity of transferred heat, in some cases, the gas velocity is increased and the heat transfer coefficient is set at 30 kcal/m^{2}h°C or more.

In the low-temperature reheating furnace, it is the only way to increase the heat transfer coefficient to accelerate the gas velocity in the furnace.

Actually in the furnace, the temperature and velocity of gas vary according to location and the gas flows along the ceiling sometimes not touching the material to be heated. Some of the furnaces heat many of small materials put together on a tray. In this case, each material does not necessarily have a flat surface. Therefore, if the gas runs into this surface, the pattern of heat transfer will be different.

(3) Heat transfer by radiation between solids

If the temperature of solid is high, the quantity of emitted heat is increased.

The quantity of heat transferred to a low-temperature solid from a high-temperature solid by radiation is represented a difference between the quantity of heat emitted from a high-temperature solid to a low temperature solid and the quantity of heat emitted from a low-temperature solid to a high-temperature solid.

The quantity of heat emitted from a solid is proportional to the value obtained by raising the absolute temperature of the solid's surface to the fourth power and also to the emissivity of the solid.

This emissivity is equal to the absorption factor and the absolute emissivity is called "black body emissivity".

Fig. III-4-46 shows the emissivity by surfacial temperature of different kinds of metal.

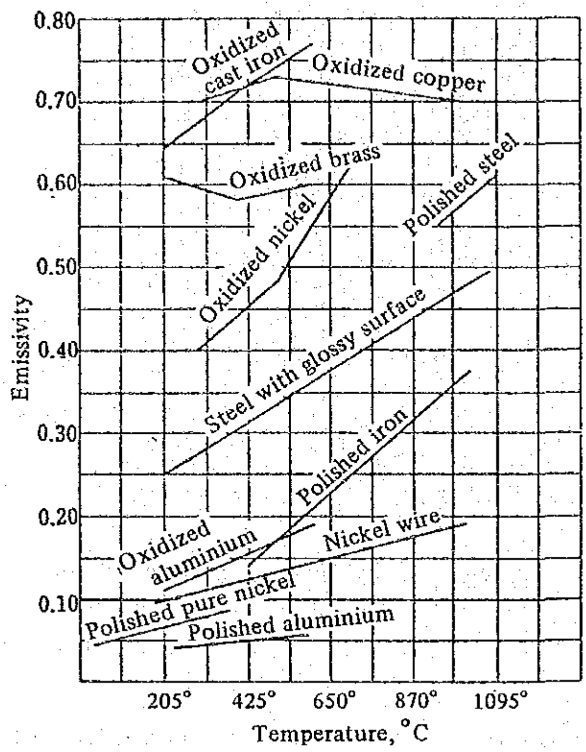


Fig. III–4–46 Emissivity of metal

(4) Heat transfer from clear gas to solids by radiation

With regard to the radiation of heat from combustion gas to a solid, the radiation from clear gas and the radiation from the so-called luminous flame shall be distinguished from each other.

The rule of raising to the fourth power does not apply to the radiation from clear gas. Only CO_2, H_2O, and SO_2 in the clear gas emit a considerable quantity of heat. On the other hand, other gases such as O_2, N_2, and H_2 emit only a negligible quantity of heat.

And heat radiation by CO_2 and H_2O is generally important. The radiant intensity is influenced by a geometrical product of the partial pressure of each gas and the thickness of the gas layer, and the gas temperature.

(5) Heat transfer from luminous flame by radiation

When burning a liquid fuel, burning a gas fuel in the presence of a scant air or burning pulverized charcoal, the yellowish orange-color flame noticed is called the "luminous flame".

It is considered that the radiation of luminous flame is a compound of the radiation of gases such as CO_2 and H_2O and the radiation of solids such as carbon microparticles at high temperature contained in the flame.

The gas radiation of luminous flame is generally far higher than that of nonluminous flame.

(6) Utilization of heat generated in the preceeding process for hot charge

When the charging machine of reheating furnace and the continuous casting mill are located adjacent to each other, thus providing a very advantageous layout for hot charge, it is suggested that the hot charge be adopted to reduce the fuel consumption rate.

It is desirable to charge continuous-cast billets at high temperatures into the reheating furnace directly for hot charge. However, it is very difficult to treat the total quantity of billets because of the difference between the production capacities of the continuous casting machine and the roll line. Accordingly, a reserving box which stores continuous-cast billets at high temperature temporarily as a buffer function is usually provided. The reserving box is a steel plate structure lined with a heat insulating material and is provided with a removable cover for charging and discharging billets.

The storage capacity and the number of the boxes are determined by the capacity of a continuous casting machine and a billet storage plan.

The amount of energy conservation through the hot charge is 20×10^3 kcal/t (2.2 l/t in terms of "C" heavy oil) per 100° C of the charging temperature.

(7) Enhancement of the efficiency of furnace heat transfer by the improvement of the material charging method

It is possible to improve furnace heat transfer by improving the billets charging method.

We noticed that steel billets (for instance, 1.5 m long × 5 cm wide and 1.5 cm thick) had been piled up in 6 to 9 layers. In this charged condition, the billets in the lower layer won't be easily heated. This is because both transferred radiant heat and transferred convection heat in the furnace work only on the upper part of piled steel billets and heat is not effectively transferred to the billets due to the small contact area of each billet.

It is desirable to use a steel billet charging method for arranging billets in 1 to 2 stages, thus making the furnace heat transfer effective. In this case, the billet carriage method also needs to be improved simultaneously.

Through the enhancement of heat transfer efficiency in the furnace, the heating capacity will be improved 2 to 3 times.

As explained above, the heat transfer in the combustion furnace is basically influenced by the thermal radiation power of combustion gas. In order to increase this power, it is required to increase the furnace volume considerably compared to the size of the object to be heated, that is, to increase "thickness of effective gas". In the meantime, however, the increased furnace volume tends to contribute toward an increase in heat loss by the regeneration of heat in the furnace wall, heat release, or the increase of equipment and construction cost. From this viewpoint, it is necessary to figure out the best means to improve the efficiency of heat transfer from combustion gas to an object to be heated by increasing the thermal radiation power.

The thermal radiation power of solids is stronger than that of gas. Some examples of operation observed were from the viewpoint that, the heat radiated by gas was converted to that by a solid by attaching a gas-permeable solid in the reheating furnace, thus resulting in the increase of thermal radiation power and in energy conservation.

4.3 Prevention of heat loss by thermal radiation and transfer

(1) To prevent heat loss from the surfaces of the furnace body and the accumulated heat loss in the furnace body, the heat conductivity of the furnace walls and ceiling is reduced and, at the same time, the heat capacity of wall is decreased.

As to the furnace walls, a fixed performance is required in terms of strength and fire resistance. According to this performance requirement, the composition of elements such as kind, construction, and thickness of materials for furnace walls varies.

Once built, the wall construction of the industrial furnace cannot easily be changed significantly. Generally, the ceiling is relatively thinner than the side walls on account of furnace strength and other reasons. The side walls are provided with a peep hole, a door, a burner attachment, etc., and the walls are sometimes thick or thin depending on its construction.

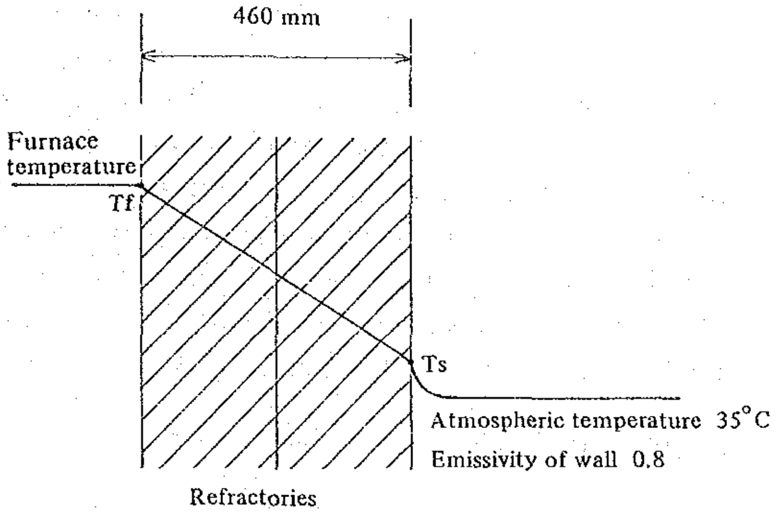
The walls of recently installed furnaces are composed of light-weight ceramic fiber having a small value of specific heat. This ceramic fiber has a high heat insulating effect, a small quantity of accumulated heat, and an improved heat loss from the furnace walls.

In the existing furnace constructed of brick walls, the only measure is to line the walls with ceramic fiber as explained later. However, this is limited only to the case where the reduction of furnace volume is allowed. The improvement of a released heat loss from the surface of the furnace body can be achieved by adopting a more effective heat insulating method.

This heat insulating method is classified as a method for attaching ceramic fiber on the internal walls of the furnace and a method for attaching ceramic fiber or rock wool or glass wool on the external walls of the furnace.

Fig. III-4-47 shows the typical temperature of furnace walls for the reheating furnace. In this case, 460 mm-thick fire bricks are used as furnace wall materials.

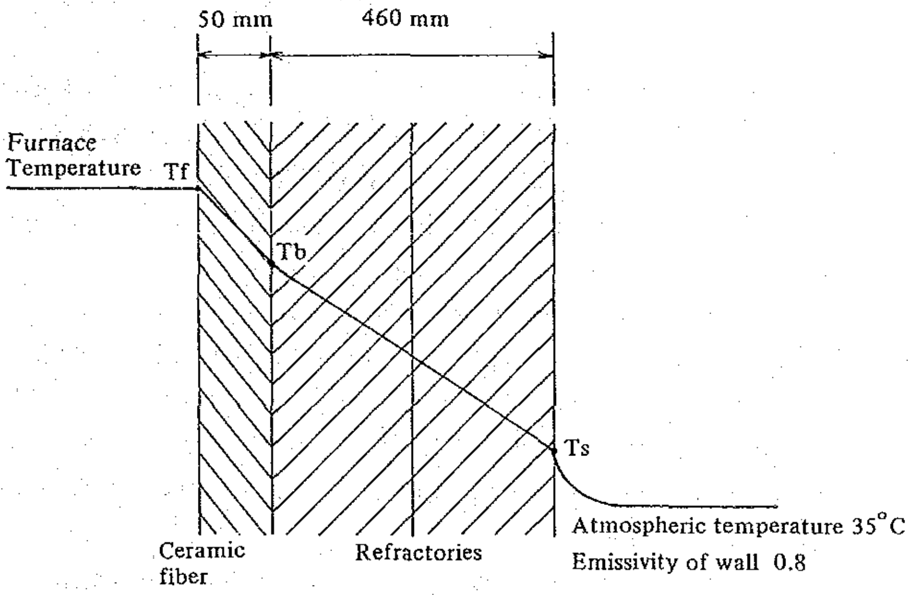
Fig. III-4-48 shows an example of the insulation reinforcement with 50 mm-thick ceramic fiber lined on the internal walls of the furnace as shown in Fig. III-4-47.



$\lambda = 1.2$ kcal/mh°C
$C_p = 600$ kcal/m^{3}°C

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/m^{2}h
Quantity of accumulated heat	H	206,837	191,765	161,463	130,914	kcal/m^2

Fig. III–4–47 Typical wall temperature of reheating furnace



$\lambda = 0.17$ Kcal/mh°C $\lambda = 1.2$ Kcal/mh°C
$C_p = 50$ kcal/m^{3}°C $C_p = 600$ kcal/m^3 °C

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/m^{2}h
Quantity of accumulated heat	H	133,562	124,215	105,384	86,341	kcal/m^2

Fig. III–4–48 Improvement plan for wall composition of reheating furnace

To look at the energy saving effect through insulation improvement, the surface temperature of the external walls goes down and the quantity of released heat and the quantity of accumulated heat are reduced 30 to 40% as shown in Table III-4-12. The temperatures of fire bricks goes down by virtue of highly fire-resistant and heat insulating ceramic fiber, so the life of fire bricks tends to be longer. This improvement method is favorable from various viewpoints. The only problems are that the furnace volume is reduced by lining the internal walls of the furnace with ceramic fiber and it is difficult to line to entire area of the hearth with ceramic fiber. Nevertheless, these problems will not be a significant operational impediment.

Table III-4-12 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
Quantity accumulated heat	206,837 kcal/m²	133,562 kcal/m²	35% decrease in quantity of radiant heat

Next, let's study the improved design of the furnace with rock wool attached on the external surface of furnace walls. In this case, if the external surface of furnace walls is covered with steel plate, the temperature of the steel plate will be goes up by rock wool, resulting in the generation of a distortion by thermal expansion and a subsequent breakage of the furnace shell.

Accordingly, when the external surfaces of the furnace walls are covered with steel plate, the insulation shall not be reinforced by rock wool, etc. Fig. III-4-49 shows the temperature of furnace walls, etc. when 50 mm-thick ceramic fiber is attached directly on the external surfaces of the fire bricks. Here the average temperature of fire bricks shows a significant goes up and the quantity of accumulated heat also increases, which are disadvantages.

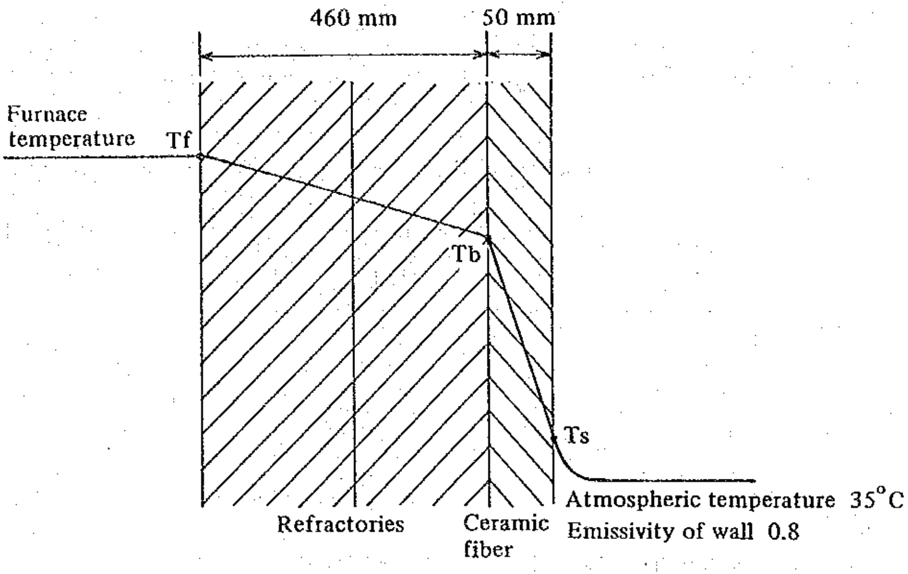
In this case, the reason why ceramic fiber is installed instead of rock wool is that the border temperature exceeds the safety working temperature range for rock wool.

If the temperatures of refractories goes up, their strength is reduced, resulting in the breakage or short life of the furnace walls.

Based on the analytical results for 9 companies' factories in the metal industry obtained in January, 1983, the recommended target value of a standard wall surface temperature of the continuous billet reheating furnace is as shown in Table III-4-13.

For reference, the standard external surface temperature of the industrial furnace in Japan is shown in Table III-4-14.

In addition, the main characteristics of principal insulating fire materials are shown in Table III-4-15, and the working temperature range of typical insulation materials is shown in Table III-4-16.



λ = 1.2 kcal/mh°C λ = 0.17 kcal/mh°C

C_p = 600 kcal/m^3°C C_p = 50 kcal/m^3°C

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/m^2h
Quantity of accumulated heat	H	269,893	249,506	208,676	167,761	kcal/m^2

Fig. III–4–49 Inferior reconstruction plan for wall composition of reheating furnace

Table III–4–13 Standard wall temperature of reheating furnace in Thailand

Furnace temperature (°C)	Standard external wall surface temperature of furnace	
	Ceiling	Side wall
1,300	150°C	130°C
1,100	135°C	120°C
900	120°C	105°C
700	100°C	90°C

(Remark)

1. The values 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 35°C during a regular operation.
2. The values 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.
3. When newly building an industrial furnace starting with a furnace floor, it is recommended

that insulation be carried out for improvement of the insulation property of furnace wall under a guideline that the portion equivalent to more than 50% of the total internal surface area of furnace wall excepting the furnace bottom should be composed of insulation material having a bulk specific gravity of less than 1.3. This rule shall apply to the furnace whose internal temperature stands at 500°C min. among intermittently operating furnaces or industrial furnaces operated to the max. operating time limits of not more than 12 hours per day.

Table III–4–14 Standard wall temperature of reheating furnace in Japan

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

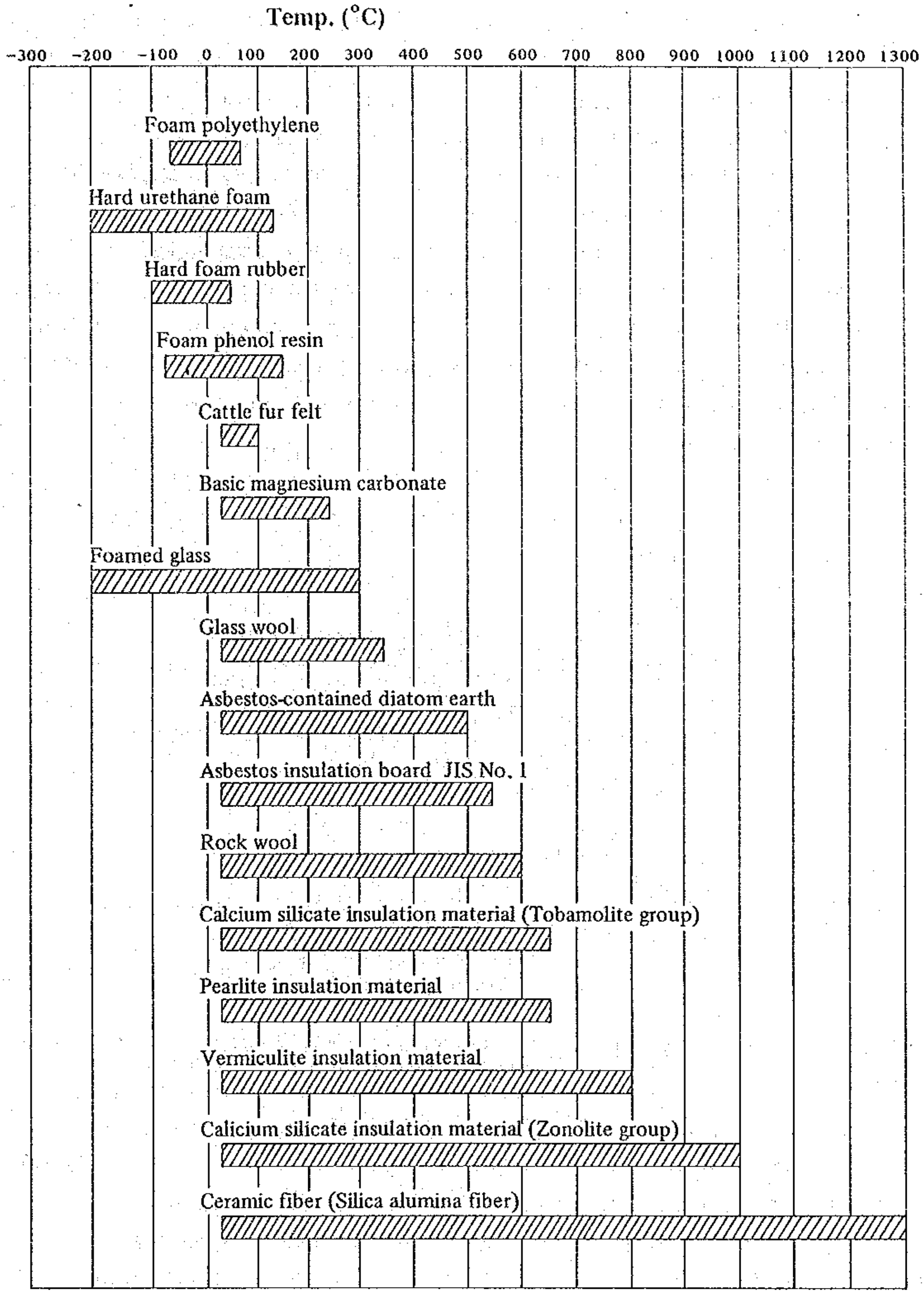
(Remark)

1. The values 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 values 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.

Table III–4–15 Main characteristics of insulating fire materials

	Bulk specific gravity t/m³	Specific heat kcal/m³ °C	Thermal conductivity kcal/mh °C	Safe working temp. °C
Refractory brick S K32	2.0~2.5	520~650	0.9~1.4	1,300
Plastic refractory S K32	1.9~2.3	380~500	0.6~1.4	1,300
Insulating fire brick B 5	0.7~0.8	160~200	0.2~0.4	1,100
Insulating fire brick B1	0.6~0.7	140~160	0.1~0.2	700
Insulating fire castable (1,300°C)	1.0~1.3	240~300	0.2~0.4	1,100
Ceramic fiber (lower than 1,300°C)	0.06~0.3	20~ 80	0.05~0.3	1,100

Table III–4–16 Working temperature range of typical insulating materials



(2) Prevention of heat loss from the opening

There are two different types of heat loss from the opening. One of them is a heat loss radiated directly from the opening, and the other is a heat loss caused by the leakage of combustion gas from the opening.

(A) Heat loss radiated from the opening

When there is an opening in a part of the furnace body, heat in the furnace escapes to the outside as radiant heat. The quantity of heat loss varies according to the thickness of furnace walls and the shape of the opening. The temperature of the thick wall part of the opening rises due to heat radiation from the interior of the furnace. The total of the quantity of heat loss caused by the secondary radiation of a part of the heat at the aforementioned wall to the outside and the quantity of heat loss caused by the direct radiation of heat from the interior of furnace, represents the quantity of heat loss from the opening.

The ratio of the quantity of radiant heat from a plate exposed completely to the outside and the quantity of radiant heat from the opening of furnace is as shown in Fig. III-4-50 according to J.D. Keller.

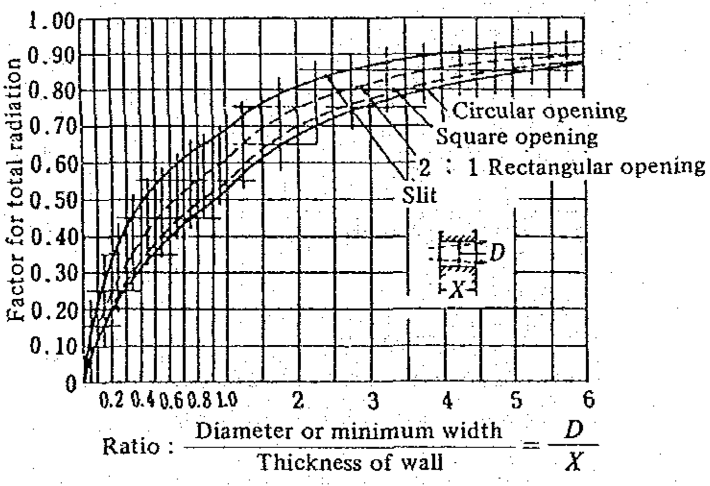


Fig. III–4–50 Factor for determining the equivalent of heat release from openings to the quantity of radiant heat from perfect black body

An explanation of this ratio is given by providing an exmaple as follows:

The opening of furnace body is 1-m high (D) and 1 m-wide rectangular for steel discharging port without a door and the furnace wall is 0.46 m-thick (X).

The opening is square. So the following equation is established:

D/X = 1/0.46 = 2.17 Accordingly, the factor of the total radiation is 0.71.

Suppose that the furnace temperature is 1,340° C. Then the radiant heat loss from the opening is as follows:

$$4.88 \times \left(\frac{1{,}340 + 273}{100}\right)^4 \times 0.71 \times 1 \times 1 = 234{,}500 \text{ kcal/h}$$

The above example is applicable at steady condition where the furnace has no door and an opening is always open. It cannot apply to the case where the furnace has an opening with a door. The reasons are: while the door is closed, the wall temperature of the opening is uniformly the same as the furnace temperature from the part close to the inside furnace to the part contacting the door. Therefore, the quantity of radiant heat at the moment the door is opened is equal to that of a plate exposed to the outside completely. After the opening of the door, the wall of the opening cools down rapidly and approaches at steady condition temperature and the quantity of radiant heat is decreased to the proportion as shown in Fig. III-4-50.

B) Heat loss caused by the leakage of combustion gas from the opening

It is difficult to estimate a heat loss caused by the spewing of combustion gas from the furnace through the opening. Since the furnace pressure of the reheating furnace is slightly higher than the atmospheric pressure during operation the heat loss, if generated, is taken for granted. Compared with this heat loss, the infiltration of air into the furnace to cool it down or oxide materials is more harmful. For this reason, generally the reheating furnace is operated at high furnace pressure. The quantity of combustion gas ejected through the clearance between the door and the opening is small. This heat loss is equivalent to approx. 1% of the total quantity of heat generated in the furnace.

(3) Heat balance

For grasping the heat balance and efficiency of the reheating furnace sufficiently, JIS G0702 "Method of Heat Balance for Continuous Furnace for Steel" is prepared. Table III-4-17 shows "Survey Table for the Outline of Equipment", Table III-4-18 "Survey Table for Actual Long-Term Operation," Table III-4-19 "Measurement Items and Results Chart" and Table III-4-20 "Heat Balance Table".

4.4 Recovery of waste heat

Waste heat from the reheating furnace is roughly classified as "radiant heat from the furnace body", "heat carried away by exhaust gas", and "heat carried away by cooling water for the furnace body".

Of these different types of heat, "radiant heat from the furnace body" can be minimized by increasing the heat insulating effect of the furnace wall.

Cooling water for the large scale furnace body is used and in some cases, is recovered as steam. However, it is not used for the single-zone or 2-zone reheating furnace, so this item is not described in this manual.

As means for recovering heat from exhaust gas, it is used for (1) preheating combustion air or fuel gas on the heat exchanger, (2) steam generation by the waste heat boiler, (3) preheating materials with exhaust gas, etc. Based on the analytical results for the factories of 9 companies in the metal industry obtained in January, 1983, the heat recovery rate of a factory was at the same level as in Japan, so the recommended target value of a standard waste heat recovery rate for the continuous billet reheating furnace in the Kingdom of Thailand was set as indicated in Table III-4-21 or the same as the waste heat recovery rate in Japan.

For reference, the standard waste heat recovery rate for the industrial furnace in Japan is shown in Table III-4-22.

Table III–4–17 Survey report on the outline of equipment

1	Name of Co. Factory			
2	Address			
3	Name of furnace manufacturer			
4	No. of furnace			
5	Rolling mill	Type		
6		Nominal capacity	t/yr	
7		Name of main finished product		
8	Reheating furnace	Type		
9		Nominal capacity	t/h	
10		Effective furnace length x furnace width	mm x mm	
11		Size and quality of furnace refractories and insulation material		
12		Kind of fuel used		
13		Type, capacity and No. of burning units		
14		Type and capacity of draft equipment		
15		Type and heating surface area of preheater	m^2	
16		Quality, size and unit weight of main heated steel	mm, kg	

(Remark) As to Items 10, 11 and 15, attach simple charts representing the vertical and horizontal cross-sections of the furnace (including the size of main parts of the furnace and preheating unit, kind of refractories and main measurement-spots).

Table III-4-18 Survey report on actual long-term operations

1	Date of operation					
2	Breakdown of operating time		Heating	Heat boosting	Heat retaining	Shutdown
		h/month				
		%				
3	Heated tonnage	t/month				
4	Tonnage per heating time	t/hour				
5	Average weight of typical heated steel (Max. and Min. range)	kg				
6	Fuel consumption	t/month, kℓ/month or Nm³/month				
7	Low calorific value of fuel	kcal/kg or kcal/Nm³				
8	Energy consumption rate per ton of heated steel	10³kcal/t				
9	Status of operational shift					

(Remark) The definition of the breakdown of operating time is as follows:

Heating times: Time during which steel is extracted, i.e. the rolling mill runs.

Heat boosting time: Time required for increasing the furnace temperature upto an "extractable" temperature.

Table III-4-20 Heat balance table

Heat input			Heat output		
Item	10³kcal/t	%	Item	10³kcal/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 cinder		
(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 10³ kcal/t as a unit and round out figures after the decimal point into a single digit.

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

Table III–4–19 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^{3}N/t		
5		Upper heating zone consumption	kg/t or m^{3}N/t		
6		Lower heating zone consumption	kg/t or m^{3}N/t		
7		Pressure	kgf/cm^2 or mmAq		
8		Temperature	°C		
9		Components	%		
10		Low calorific value	kcal/kg or kcal/m^{3}N		
11	Atomizer	Kind			
12		Soaking zone consumption	kg/t or m^{3}N/t		
13		Upper heating zone consumption	kg/t or m^{3}N/t		
14		Lower heating zone consumption	kg/t or m^{3}N/t		
15		Pressure	kgf/cm^2 or mmAq		
16		Temperature	°C		
17	Secondary air	Soaking zone consumption	kg/t or m^{3}N/t		
18		Upper heating zone consumption	kg/t or m^{3}N/t		
19		Lower heating zone consumption	kg/t or m^{3}N/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 x Width x Length)	mm x mm x 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 III–4–21 Standard waste heat recovery rate of industrial furnaces in Thailand

Exhaust gas temperature (°C)	Classification of capacity	Standard waste heat recovery rate (%)
500	A · B	20
600	A · B	20
700	A	30
	B	25
	C	20
800	A	30
	B	25
	C	20
900	A	35
	B	25
	C	20
1,000	A	40
	B	30
	C	25
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 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.

Table III–4–22 Standard waste heat recovery rate of industrial furnace in Japan

Exhaust gas temperature (Unit °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

(1) Preheating of combustion air in the recuperator

There are available two different types of recuperator, i.e. the metalic recuperator having a metal heat transfer surface, and the ceramic recuperator made of refractories. Nowadays, the metalic recuperator is most popularized.

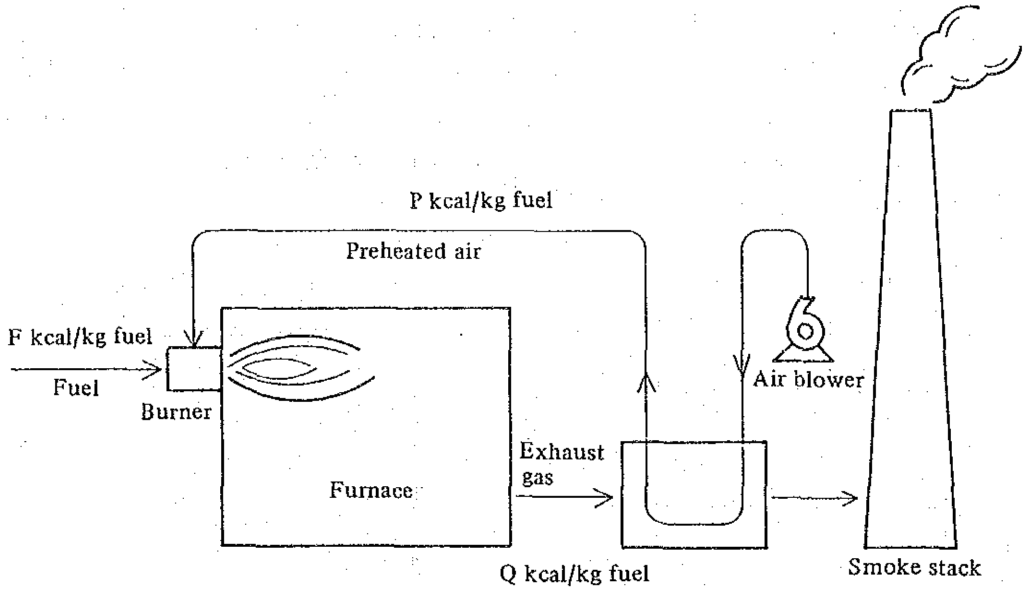


Fig. III–4–51 Preheating of air for burning

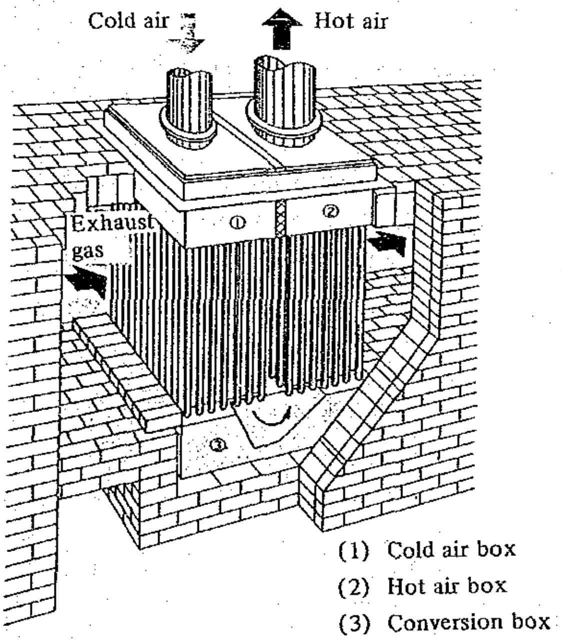


Fig. III–4–52 Example of preheater of air for burning (Recuperator)

If hot air is used for combustion, fuel can be saved.

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

Where

S: Fuel saving rate (%)

F: Calorific value of fuel (kcal/kg fuel)

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

Q: Quantity of heat carried away by exhaust gas (kcal/kg fuel)

The results of calculating the saving rate of heavy oil and natural gas by exhaust gas temperature and preheated air temperature in the above equation are shown in Fig. III-4-53 and Fig. III-4-54.

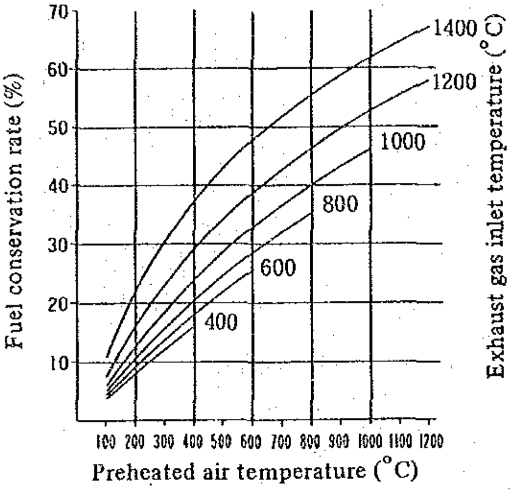


Fig. III–4–53 Fuel conservation rate when heavy oil is used

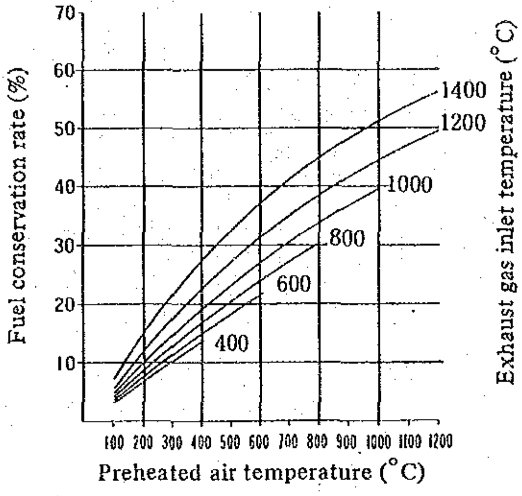


Fig. III–4–54 Fuel conservation rate when natural gas is used

If the temperature of exhaust gas is high, the fuel saving rate is high even at the same preheated air temperature.

Fig. III-4-55 shows the classification of use of a recuperator by exhaust gas temperature when it is selected.

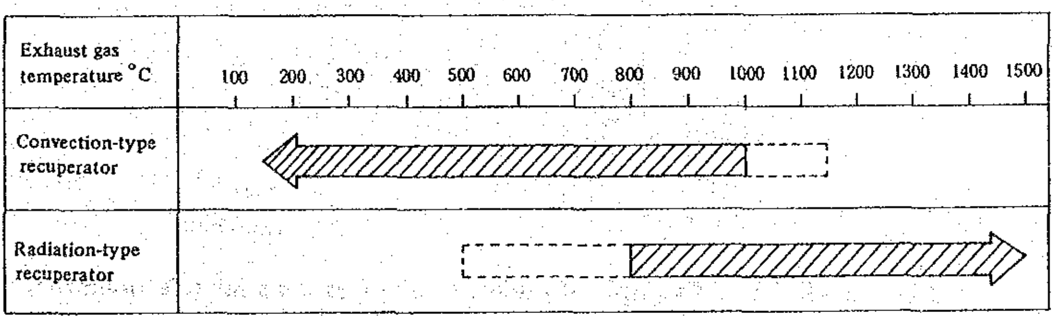


Fig. III–4–55 Selection of recuperator type according to exhaust gas temperature

The guideline is as follows:

- Convection type ..... exhaust gas temperature —1,000°C max.
- Radiation type ..... exhaust gas temperature — 800°C min.

The convection-type recuperator is a heat exchange system composed mainly of a convection heat transfer function. The convection heat transfer rate is proportional to the exhaust gas velocity and in inverse proportion to the diameter of a heat transfer tube. If the temperature of exhaust gas is increased, it will be difficult to consider thermal expansion, etc. Therefore, the convection-type recuperator is suitable at temperatures below 1,000°C.

The radiation-type recuperator is a heat exchange system consisting mainly of a radiant heat transfer function. Heat transfer is influenced by the fourth power of an absolute temperature, but is hardly affected by the exhaust gas velocity. Normally the radiation-type recuperator is provided with a simple cylindrical heat transfer surface and is suitable at temperatures above 800°C.

The types of recuperators are also classified as "parallel flow-types", and "counter flow-types" from the viewpoint of exhaust gas and air flows. This difference makes a difference in the logarithmic mean temperature, resulting in a difference in the heat transfer area of recuperators.

The heat transfer area of recuperators is expressed by the following equation.

$$F = \frac{Q}{\Delta tm \times k}$$

Where

F: Heat transfer area (m^2)

Q: Calorific value of exchanged heat (kcal/h)

Δtm: Difference in logarithmic mean temperature (°C)

k: Total heat transfer coefficient (kcal/m^2 h°C)

This equation indicates that F is proportional to Q and is in inverse proportion to Δtm and k. When installing a recuperator, Q is a constant from the viewpoint of specified requirements, and k is influenced by the performance of the recuperator. However, its variable value is not extreme. Δtm is determined depending on whether it is "parallel flow-type" or "counter flow-type".

This difference in logarithmic mean temperature is expressed by the following equation.

$$\Delta tm = \frac{\Delta t\ max - \Delta t\ min}{ln \frac{\Delta t\ max}{\Delta t\ min}}$$

Δt max and Δt min in the case of "parallel flow-types" are as shown below based on Fig. III-4-56:

$\Delta t\ max = t_1 - t_1'$

$\Delta t\ min = t_2 - t_2'$

In addition, Δt max and Δt min in the case of "counter flow-types" are as shown based on Fig. III-4-57:

a. In the case of $(t_1 - t_2') > (t_2 - t_1')$

$\Delta t\ max = t_1 - t_2'$

$\Delta t\ min = t_2 - t_1'$

b. In the case of $(t_1 - t_2') < (t_2 - t_1')$

$\Delta t\ max = t_2 - t_1'$

$\Delta t\ min = t_1 - t_2'$

The difference in logarithmic mean temperatures of "parallel flow-types" and "counter flow-types" is shown below by using the example:

First, suppose that the temperature of the inlet and the outlet are as follows:

$t_1 = 800°C$ $t_2 = 500°C$

$t_1' = 20°C$ $t_2' = 350°C$

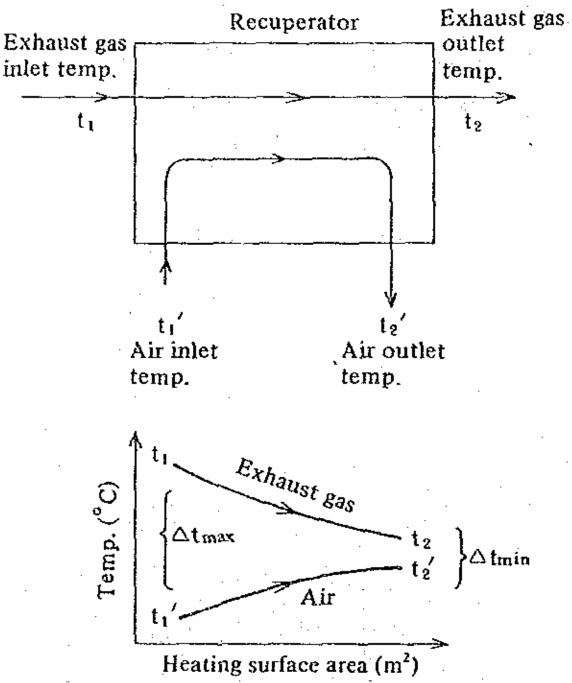


Fig. III–4–56 Temp. difference in case of parallel flow

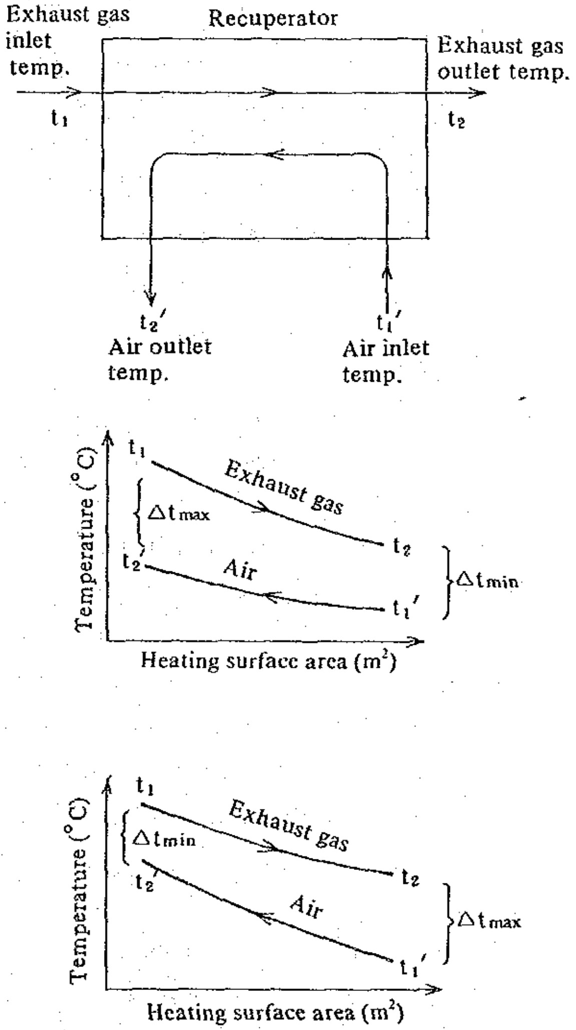


Fig. III–4–57 Temp. difference in case of counter flow

In the case of "parallel flow-types"

$\Delta t\ \mathrm{max} = 800 - 20 = 780°\mathrm{C}$

$\Delta t\ \mathrm{min} = 500 - 350 = 150°\mathrm{C}$

$$\Delta tm\ (\mathrm{parallel}) = \frac{780 - 150}{ln \dfrac{380}{150}} = 382°\mathrm{C}$$

In the case of "counter flow-types"

$\Delta t\ \mathrm{max} = 500 - 20 = 480°\mathrm{C}$

$\Delta t\ \mathrm{min} = 800 - 350 = 450°\mathrm{C}$

$$\Delta tm\ (\mathrm{counter}) = \frac{480 - 450}{ln \dfrac{480}{450}} = 465°\mathrm{C}$$

Accordingly, Δtm in the case of "counter flow-types" is 22% larger than that in the case of "parallel flow-types". If it is supposed that k is the same value for both "parallel flow-types" and "counter flow-types", the heat transfer area of the latter will be approx. 18% smaller than that of the former.

If the temperatures of heat transfer areas were set as an mean temperature between the exhaust gas temperature and the air temperature, that would not be a serious error. Therefore, in the case of the above example, the temperatures of heat transfer areas are calculated as shown in Table III-4-23.

Table III—4—23 Temperature of heat transfer area

	Parallel flow		Counter flow	
Exhaust gas temperature	800°C	500°C	800°C	500°C
Air temperature	20°C	350°C	350°C	20°C
Temperature of heat transfer area	410°C	425°C	575°C	260°C

In this example, the said temperature averages from 410 to 425°C in the case of "parallel flow-types". On the other hand, it ranges from 260 to 575°C in the case of "counter flow-types".

Factors which seriously affect the recuperators are oxidation resistance, corrosion resistance, mechanical strength, absorption means for thermal expansion, etc. In the aforementioned example, materials selected from the viewpoint of oxidation resistance are as follows:

In the case of "parallel flow-types"
High temperature section ... carbon steel
Low temperature section ... carbon steel
In the case of "counter flow-types"
High temperature section ... stainless steel

Low temperature section ... carbon steel

From the viewpoint of thermal expansion, "parallel flow-type" characteristics of even material temperature are more stable than "counter flow-types". It is essential to study by setting conditions, prices, etc. to determine which type should be selected, "parallel flow-types", or "counter flow-types". The selection of materials for heat transfer area depends on temperature conditions, exhaust gas components, pressure conditions, etc.

A) Thickness reduction by oxidation

Metal shows its thickness reduction caused by the formation of an oxide on the surface through oxidation with oxygen at high temperatures.

Generally, oxidation is apt to advance, if oxide film on the surface strips off easily because of its chemical properties or the film is porous and allows oxygen to be infiltrated easily.

In addition, if oxides are volatile or have low melting points like molybdenum or tungsten, the oxidation rate is high.

Chromium forms a highly adhesive oxide. The higher the content of chrominum, the higher the oxidation resistance of metal is.

Aluminium and silicon also improve oxidation resistance but deteriorate mechanical properties.

Nickel provides a dense oxide, so it forms a protective film for blocking the encroachment of oxidation in the interior of metal. Oxidation also would slightly take place by CO_2 gas. It is caused by oxygen generated by the reaction of $2CO_2 \rightarrow 2CO + O_2$.

Further if moisture exists in the oxidizing atmosphere, oxidation will generally be accelerated, because the formed oxide protective film becomes porous in the existence of moisture.

If the thermal cycle of heating and cooling or the oxidizing and reductive atmospheric cycles are added at high temperatures, the environment will be more severe.

Table III-4-24 shows the working temperature by material and Fig. III-4-58 shows the relationship between temperature and the reduction of weight by oxidation.

B) Vanadium attack

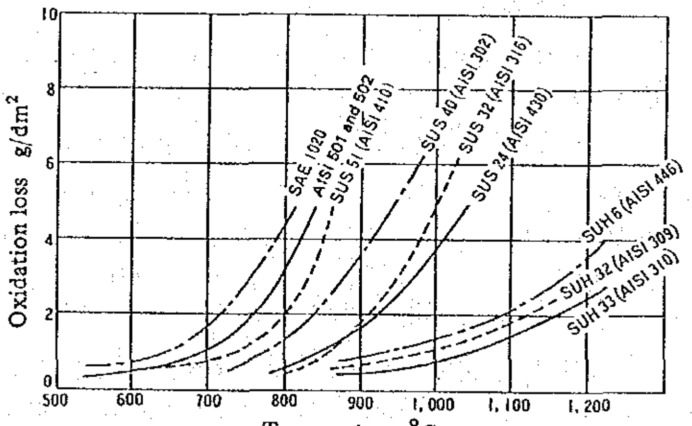
Heat resistant materials are protected by an oxidation-resistant film. However, in the atmosphere of combustion gas such as heavy oil, oxidation will be unusually accelerated by vanadium contained in the fuel. This is because the melting point of V_2O_5 is as low as 670° C and adheres to and deposits on the oxide film of the metal surface and decreases its melting point, if the temperature is above 700 to 800° C.

Also if Na_2SO_4 co-exists, an eutectic crystal is created, further reducing the melting point. Thus the metal will be easily susceptible to vanadium attack. In addition, the eutectic crystal would act as an oxidation catalyst at 500 to 600° C. Fig. III-4-59 shows the behavior of scaling in the existence of V_2O_5 by the rapidity test.

Table III–4–24 Working temperature1) of heating pipe by material

Material (Customary indication)	Max. working temp. (°C)	Ordinary working temp. (°C)
Carbon steel	565	400
½ Mo steel	565	450
1 Cr-½ Mo steel	565	450
1¼ Cr-½ Mo steel	590	550~575
2¼ Cr-1 Mo steel	635	600
5 Cr-½ Mo steel	620~650	600
9 Cr-1 Mo steel	650~700	600~650
13 Cr steel	650	600
25 Cr steel	1,000~1,100	1,000
18 Cr-8 Ni steel	870	800
18 Cr-12 Ni-Mo steel	870	800
18 Cr-12 Ni-Ti steel	870	800
18 Cr-12 Ni-Nb steel	870	800
25 Cr-12 Ni steel	1,000~1,100	1,000
25 Cr-20 Ni steel	1,100	1,000

(Note) The max. working temperature varies slightly according to literature.
The ordinary working temperature was determined considering oxidation limits, tolerable stress, graphitization, etc. and referring to US Steel's technical data.



Test conditions : 12 intermittent cycles of heating and cooling

By courtesy of : Welding Research Council Bulletin Series No.31
"Stainless Steel for Pressure Vessels"

Fig. III–4–58 Relationship between temperature and oxidation loss

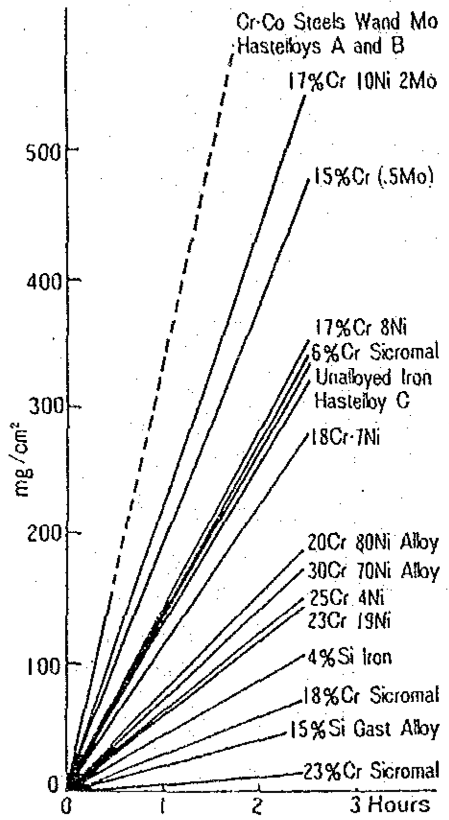


Fig. III–4–59 Scaling behavior of various kinds of steel by V_2O_5 rapid test

C) Sulfuric acid dew point corrosion

When recovering waste heat from exhaust gas, attention must be given to low temperature corrosion by sulphuric acid mist in the exhaust gas.

If fuel containing sulphur is burned, SO_2 is produced and is partly turned into SO_3. *Accordingly, if combustion exhaust gas is below the dew point after contacting* the low temperature wall of a heat exchanger, etc., this SO_3 reacts with water, *producing sulphuric acid (H_2SO_4) of high concentration. As a result, the heat* exchanger or duct is corroded.

Fig. III-4-60 shows the relationship between the sulphur content of fuel and the percentage of SO_2 in exhaust gas. Fig. III-4-61 shows the ratio of conversion from SO_2 to SO_3. Fig. III-4-62 shows the relationship between the concentration of SO_3 and the acid dew point. In the neighborhood of an inelt for low-temperature fluids on the heat exchanger, some part is at a low temperature. For this reason, it is necessary to keep the gas temperature slightly higher than the acid dew point temperature level as shown in the Fig.

In order to avoid these impediments, a glass tube or lead-coated tube is used in some of the heat exchangers as a material. In addition, air entering into the air preheater is sometimes preheated by an external heat source, so that the temperature of exhaust gas may not decrease excessively.

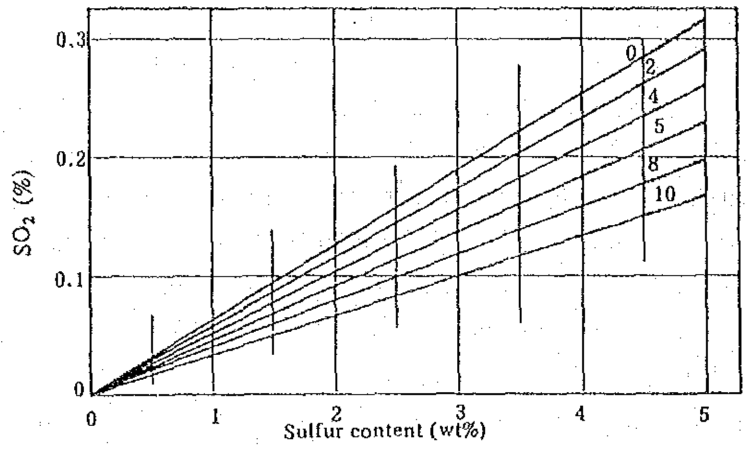


Fig. III–9–60 Relation between sulfur content in fuel and SO_2 content in fuel gas

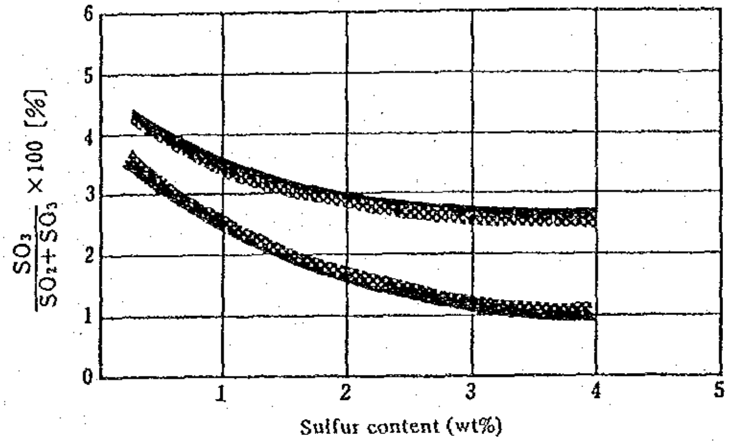


Fig. III–4–61 Relation between sulfur content in fuel and conversion ratio from SO_2 to SO_3

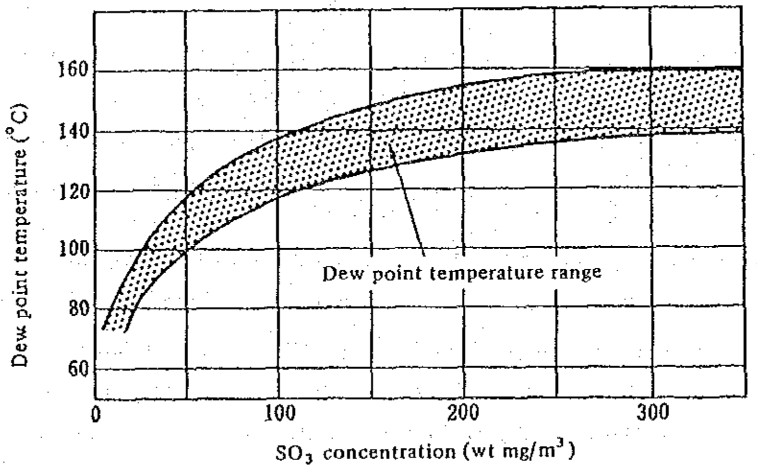


Fig. III–4–62 Relation between SO_3 concentration in exhaust gas and dew point temperature

(3) Steam generation by the waste heat boiler

The waste heat boiler uses exhaust gas originating from a furnace other than the boiler as a heat source. The smoke pipe boiler or the water tube boiler is employed (refer to Fig. III-4-63).

Generally, the inlet gas temperature of the waste heat boiler is lower than that of the combustion boiler. Therefore, the former is provided with a large area for convection heat transfer and is also provided with a wider space between the tubes for gas containing a high percentage of dust. The superheater uses vertical tubes in many cases.

The waste heat boiler uses gas at comparatively low temperatures as a heat source. In order to make thermal transmission to the heat transfer tube effective, it is required to increase the exhaust gas velocity and sometimes to provide an exhaust fan.

The evaporation amount of the waste heat boiler is influenced by the quantity and temperature of exhaust gas from the other furnace. As such, the evaporation amount tends to be unstable.

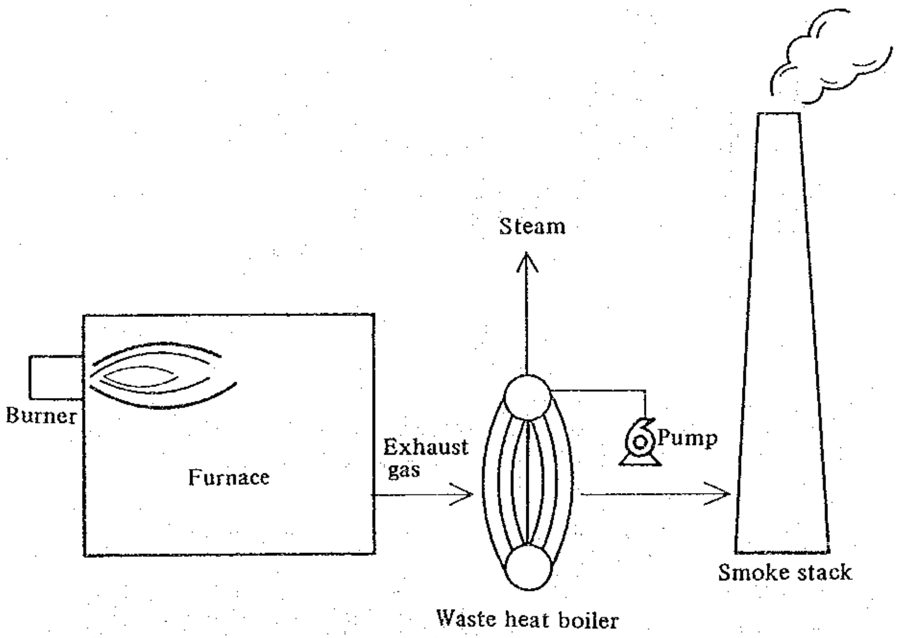


Fig. III–4–63 Recovery of waste heat by waste heat boiler

(4) Preheating of materials by exhaust gas

If the material is preheated by exhaust gas before being charged into the heating furnace, the calorific value in the furnace will be reduced by the calorific value of the exhaust gas for preheating. Thus, fuel saving will be realized.

Fig. III-4-64 shows the method of preheating materials with a preheater provided in the flue. Fig. III-4-65 shows the method of preheating materials with a preheating zone provided in the extended length of the heating furnace. In this case, it is necessary to study the problem of piling up or the capacity of a pusher.

When planning waste heat recovery, attention must be first given to the improvement of combustion, rationalization of heat transfer, prevention of heat release, etc, and then the decrease of temperature and quantity of exhaust gas as far as circumstances allow. After these procedures are taken, the conditions should be determined. Otherwise, unnecessarily large-scale equipment will be installed, contributing toward an excessive decrease of the exhaust gas temperature. Further, if such a condition that black smoke is generated under incomplete fuel combustion, the heat transfer surface would be fouled, instantly preventing the heat exchanger from displaying its performance satisfactorily.

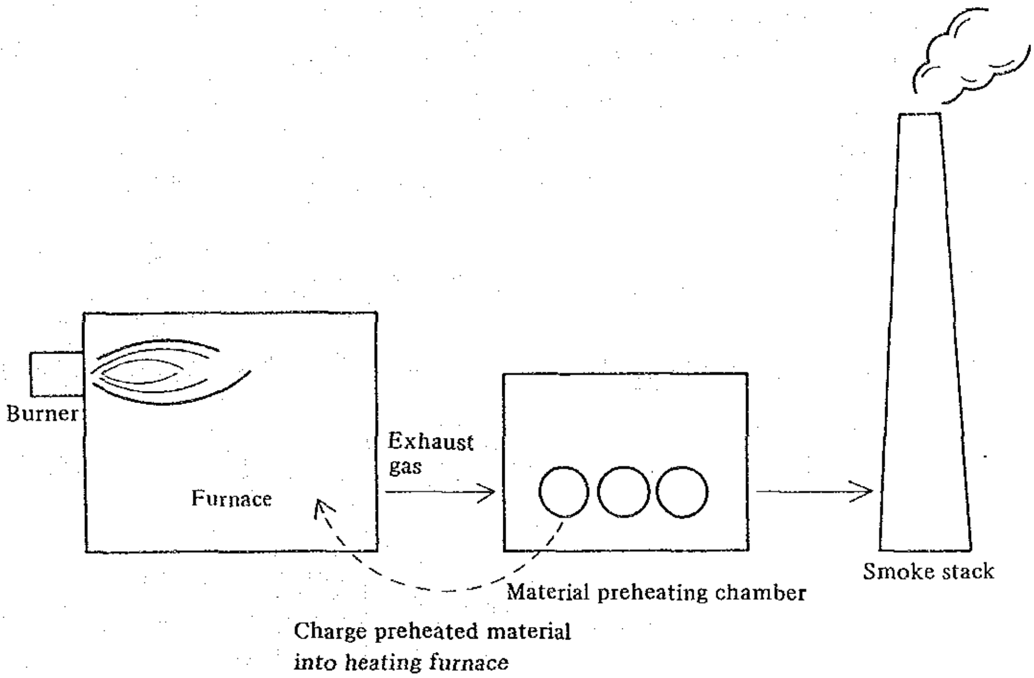


Fig. III–4–64 Recovery of waste heat by material preheating chamber

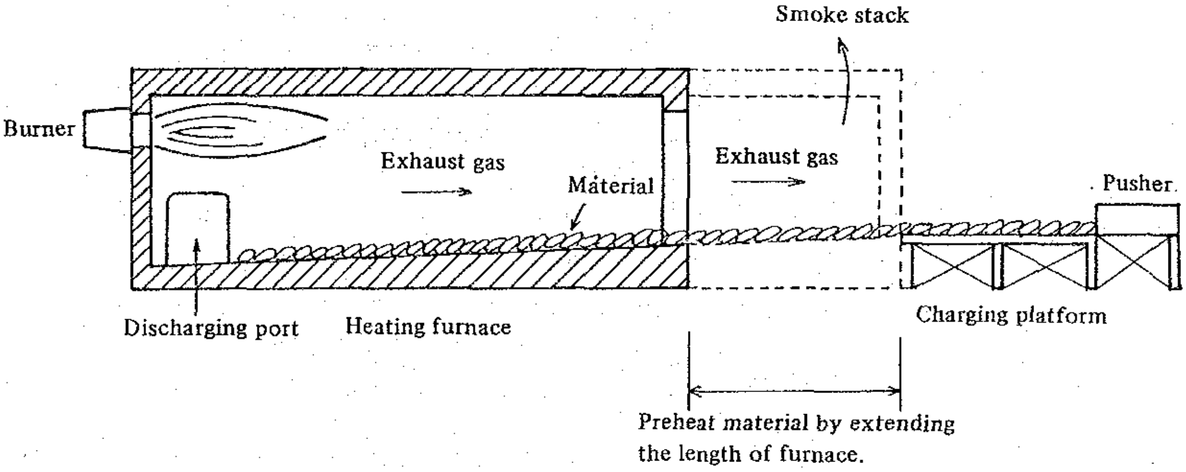


Fig. III–4–65 Preheating of material by extending the length of furnace

4.5 Rationalization of conversion of electric power to heat

(1) Arc furnace

The basic principle of energy conservation in the manufacture of steel by the arc furnace is to reduce the release of unavailable heat against productivity by the improvement of furnace heat efficiency and productivity. Next, it is also an important counter-measure for energy saving to try to make effective use of heat output.

In the arc furnace, the direct energy-saving measures are to reduce heat imput and decrease heat loss. On the other hand, the indirect energy-saving measures are to improve the yield of finished products and effectively utilize waste heat on a total system basis.

Fig. III-4-66 shows an idea on energy conservation for the arc furnace.

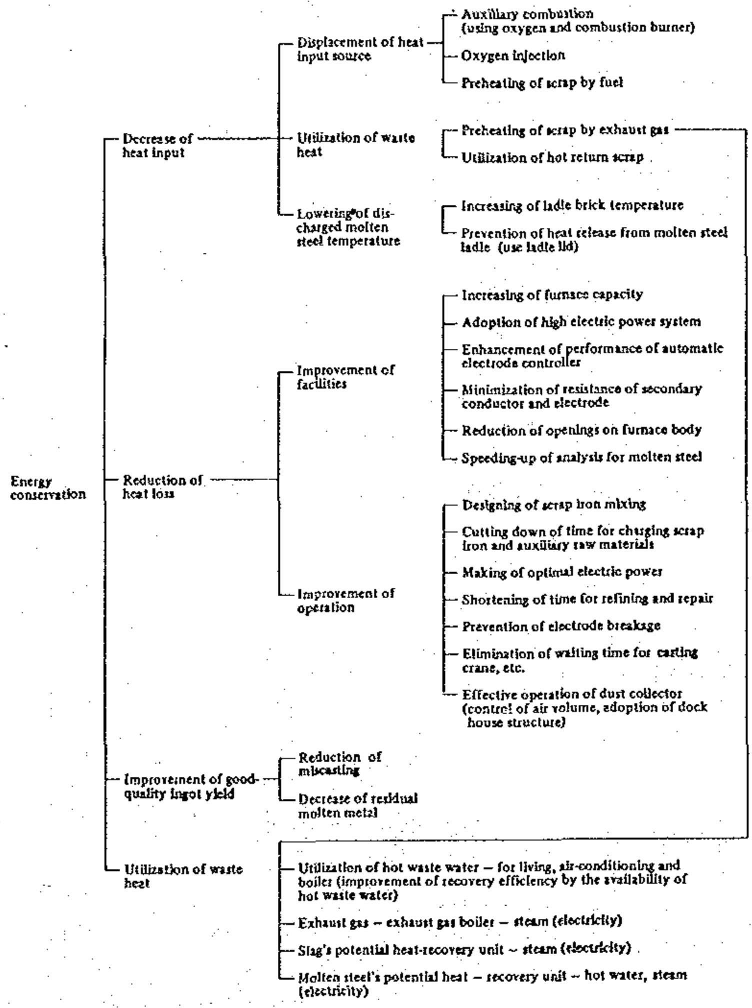


Fig. III–4–66 Idea on energy conservation

1) Supporting of combustion by burner

One to three pieces of petroleum fuel burners are installed on the furnace wall, and are fired during the melting period. Their combustion heat is utilized to shorten the melting time. The burner is positioned toward the cold spot between electrodes.

Fig. III-4-67 shows one example of the installation of a combustion supporting burner. Fig. III-4-68 shows the relationship indicating an effect of combustion support between the fuel oil consumption rate and the electric power consumption rate.

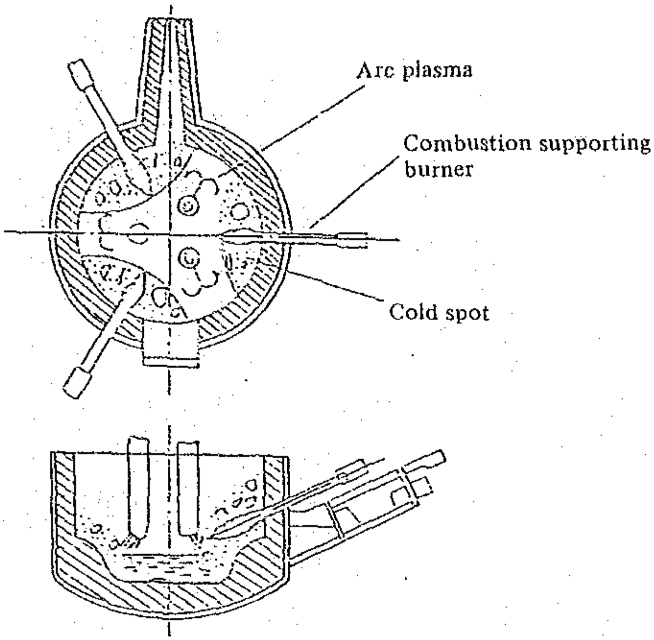


Fig. III–4–67 Example of installation of combustion supporting burner

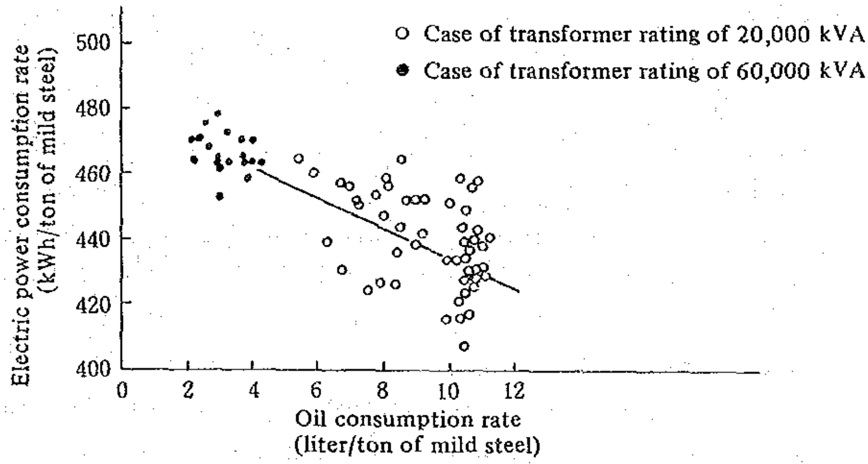


Fig. III–4–68 Oil consumption rate and electric power consumption rate showing the effect of combustion supporting (per ton of mild steel)

2) Enriching of oxygen

Oxygen is injected into the furnace and an oxidation heat of carbon or iron is utilized to shorten the melting time.

Fig. III-4-69 shows the relationship between a oxygen consumption rate in the oxygen enriching operation and the electric power consumption rate.

3) Charging of hot return scrap

Hot scrap produced in the rolling process, etc. is returned immediately to the electric furnace to carry out energy conservation.

Fig. III-4-70 shows the effect of electric power saving by charging hot return scrap.

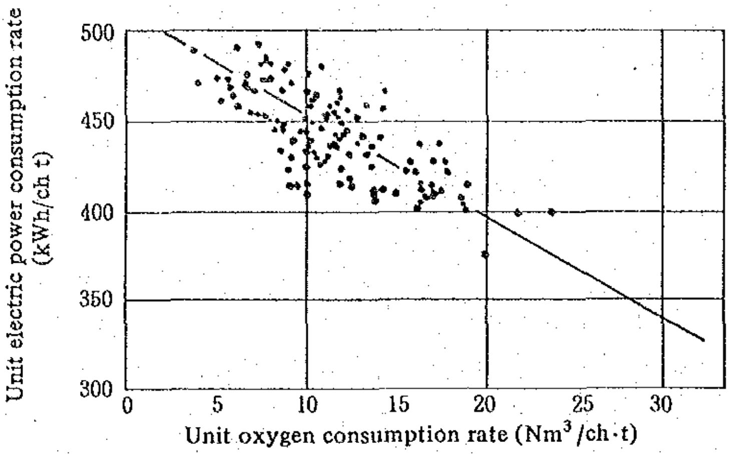


Fig. III–4–69 Relationship between unit oxygen consumption rate and unit electric power consumption rate in oxygen enriching operation

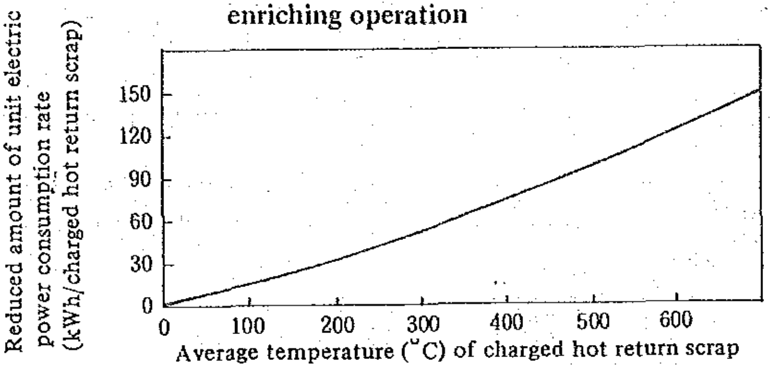


Fig. III–4–70 Effect of electric power saving by charging hot return scrap (Thermal efficiency of Arc furnace = 0.8)

4) Preheating of Scrap

With regard to preheating scrap prior to charging it into the arc furnace, one method is to burn fuel to preheat scrap, and the other method is to utilize exhaust gas from the arc furnace.

Fig. III-4-71 shows an example of the scrap preheater for heating the scrap in charging bucket with exhaust gas from the arc furnace.

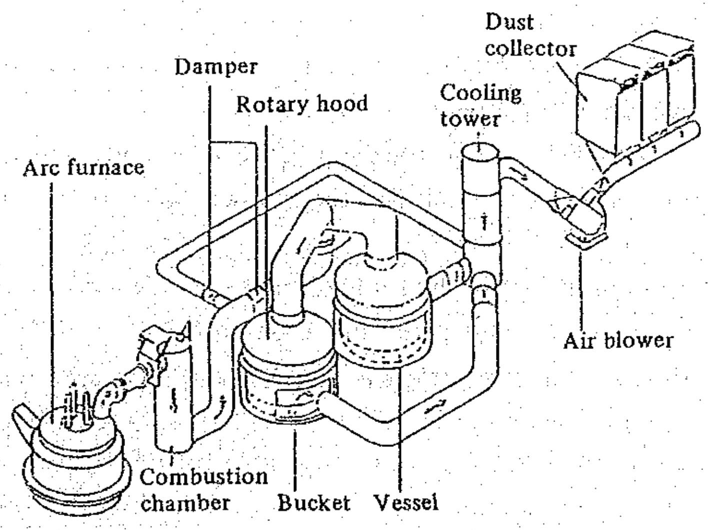


Fig. III–4–71 Scrap preheater using arc furnace exhaust gas for heating scrap in charging bucket

The charging bucket filled with scrap is placed in a vessel provided between the exhaust gas combustion chamber and the cooling tower of the dust collector. The exhaust gas of the arc furnace sucked by an air blower for the dust collector is released into the atmosphere through the dust collector after heating scrap in the vessel.

Table III-4-25 shows an example of the energy conservation effect obtained by preheating scrap with an exhaust gas from the arc furnace.

Table III–4–25 Example of energy saving effect in scrap preheating by arc furnace exhaust gas

Applicable furnace	Reduction of unit electric power consumption rate (kWh/t)	Reduction of electrode wear amount (kg/t)	Shortening of steel making time (min.)
30 t	30.6	0.17	10
30 t	36	0.7	8
50 t	40 ~ 50	0.2 ~ 0.4	5 ~ 8
60 t	40 ~ 45	0.2 ~ 0.3	5 ~ 7

5) Restriction of heat release from openings of the furnace body

The arc furnace is provided with openings such as slag spout, a steel spout, an operating port, etc. on the side wall.

These openings are closed except when they are used. However, cold air is allowed to penetrate into the furnace by the suction effect of a dust collecting blower, because the openings are not necessarily sealed sufficiently. This penetration might result in an exhaust gas loss. The reduction of this loss through improved sealing of the openings will contribute toward energy conservation.

As a referential example, it was reported that the unit electric power consumption rate was reduced by 20kWh/t (approx. 4%) as a result of the closing of the operating port following the improvement of the operating method.

6) Restriction of heat release during furnace repair

The arc furnace is internally checked every time steel is discharged to repair a spot where a melting loss has occurred on the furnace floor during melting. This repair time could lead to the deterioration of productivity or the release of regenerated heat in the furnace body. However, recently a mortar sprayer capable of a large discharge has been popularized, contributing toward the shortening of repair time at a rapid pace.

(2) Induction furnace

1) Condenser for power factor improvement

The furnace power factor of the induction furnace is generally low. The said factor of the crucible-type low-frequency furnace is approx. 20% and that of the high-frequency furnace 5 to 10%.

Accordingly, the induction furnace uses a condenser of large capacity for power factor improvement. In the past, the mineral oil-impregnated paper condenser was used for this purpose. Recently, however the all-film-type special insulation oil-filled