No. 25

Japan International Cooperation Agency (JICA)
The Republic of Poland
Ministry of Economy
Polish National Energy Conservation Agency (KAPE)

# THE MASTER PLAN FOR ENERGY CONSERVATION IN THE REPUBLIC OF POLAND

## FINAL REPORT

## IV. Guideline

June 1999

The Energy Conservation Center, Japan (ECCJ)
The Institute of Energy Economics, Japan (IEEJ)

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# Contents

## List of Tables

## List of Figures

# IV. GUIDELINE

# 1. ENERGY CONSERVATION IN THE STEEL MAKING INDUSTRY

# 1. ENERGY CONSERVATION IN THE STEEL INDUSTRY

## 1.1 Introduction

Iron and steel-making plants include the following five types:

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

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

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

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

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

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

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

Since a foundry is suitable for producing machine parts with complex shapes, and thus is installed as an auxiliary facility of a machine manufacturing plant such as automobile part plant or as a factory dedicated to the manufacture of general-purpose parts such as, valves, pipe joints.

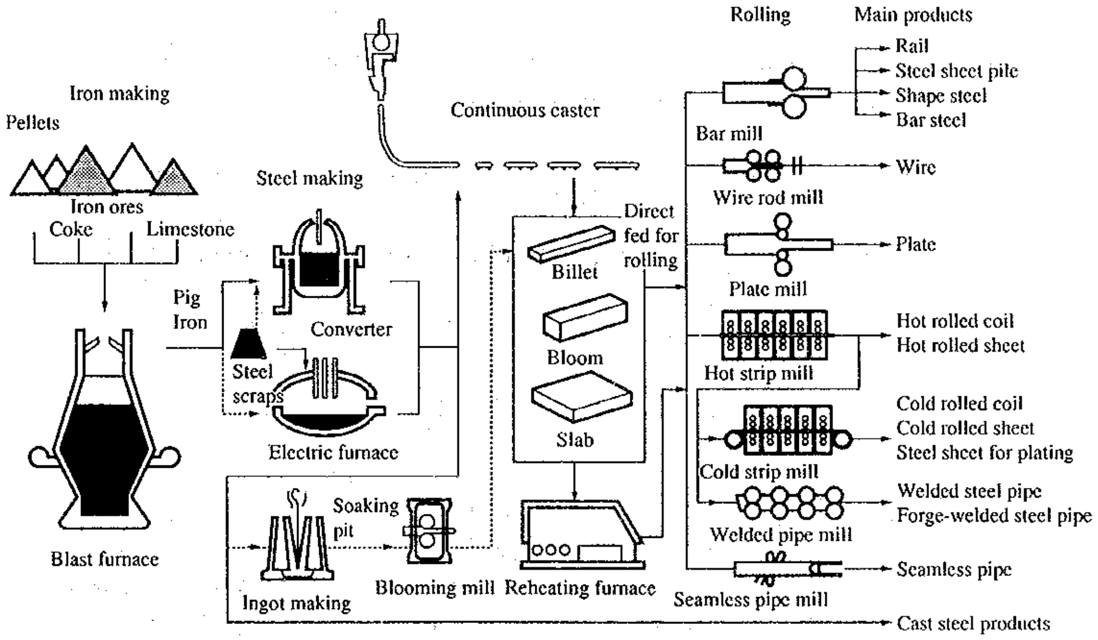
In Poland, there are three kinds of factories: integrated iron and steel works, electric furnace factories and foundries. This chapter will describe mainly the types of equipment consuming large amounts of energy in integrated steel works. With regard to other factories, their specific types of equipment that consume large amounts of energy will be picked up with explanation added.

## 1.2 Outline of Processes in an Integrated Steel Works and Themes of Energy Conservation

Figure 1.1 shows the flow of raw materials and products in an integrated steel works.

In an integrated steel works, energy conservation is, of course, promoted for each process, and production and equipment investment plans for the entire steel works are also drawn up so as to minimize the energy cost for the entire steel works. Moreover, management of production, equipment and energy are implemented based on the said plans, which are to be reviewed whenever required, to achieve the maximum effect.

**Figure 1.1 Flow of Raw Materials and Products in the Integrated Steel Works**



*Fed to surface treatment equipment, to be made into the products such as electrolytic tin plated steel, electrogalvanized steel, zinc hot dipped steel, etc.

### 1.2.1 Sintering Equipment

### 1.2.1.1 Sintering Equipment

There are various methods of solidifying fine ores. Among these methods, this section picks up and explains the most popular and widespread sintering machines.

(1) Sintering process

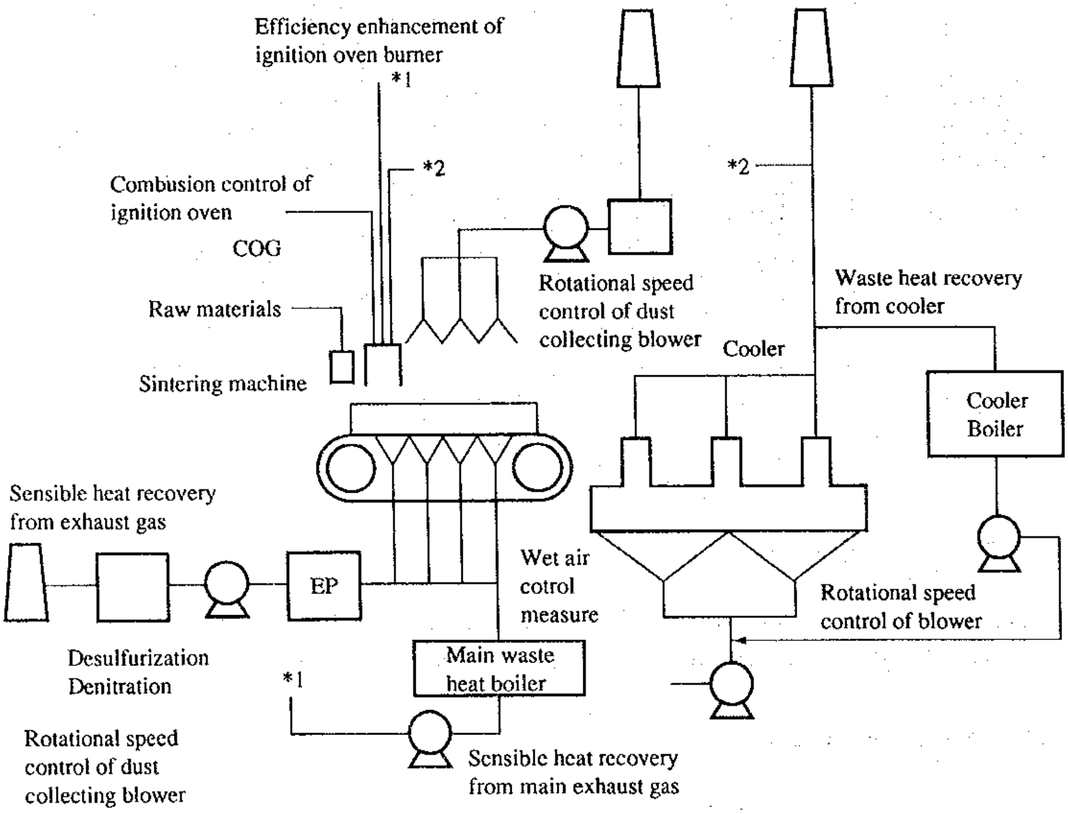
In case of a vertical charging layer furnace such as a blast furnace and COREX, lump-shaped materials need to be used in order to ensure the permeability in the furnace. To this end, sintered ores, pellets, lump ores, lump coke, etc. are used. In recent years, processed ores (sintered ores, pellets) have generally come into use as lump ores, accounting for 70 % or more of all the charged materials.

Sintered ore is prepared by mixing, burning and solidifying iron ore powder, coke breeze and limestone, and the sintering process consists of a material feeder, a sintering machine and a sintering cooler. The sintering machine carries the raw materials using a cast conveyor called a pallet, gets them ignited with coke breeze and burns them with air supplied by an induced draft fan. Thus a sintering machine is used to burn and solidify fine materials by means of burning the coke in the mixed materials to generate low-melting slag. The sintered ore delivered from the sintering machine is air-cooled by the sintering cooler, crushed and subjected to classification, and as a result, only lump ores are transported as materials to be used in a blast furnace or COREX.
Fine ores generated during transportation by a conveyor are subjected to screening again before they are charged into the blast furnace or COREX, and almost all of them are returned to the sintering machine and burnt into sintered ores again.

The energy consumption in the sintering process accounts for about 9 to 10 % of all the energy consumption in the integrated steel works.

Figure 1.2 shows the flow and energy conservation measures of the sintering process.

**Figure 1.2 Flow and Energy Conservation Measures of the Sintering Process**



## (2) Energy conservation by improvements of operation and equipment

### a. Coke breeze

Coke breeze occupies the largest energy intensity in the sintering machine. The energy intensity of coke breeze, which was 60 to 65 kg/t, has decreased to a 40 kg/t to 45 kg level as a result of taking measures for improvement of the yield, operation improvement including cooler waste heat recovery, and recycling of dust containing a large amount of coke generated as a waste material in the blast furnace process.

Two important measures for the improvement of the yield are to improve operation so as to obtain a sufficient strength by conducting homogeneous sintering in the sintering machine, and to prevent degradation of the product during its crushing, classification or transportation.

Regarding the former, i.e., measures for operation improvement, such measures as the use of a permeability rod, segregation charging and agglomeration for the purpose of increasing the quantity of quasi particles are being implemented. At the same time, a thicker bed height operation is carried out to make the sintering layer thicker in order to improve both the product yield and productivity. For the latter , i.e, the measures for reducing the amount of tail return, reduction of conveyor connecting parts, a decrease of the dropping height, etc. are being implemented. Additionally, in order to improve the reduction performance and decrease the slag ratio in the blast furnace and COREX furnace, that is, to promote energy conservation in the blast furnace or COREX process, the effort for reducing $SiO_2$ %, FeO %, etc. is currently being made.

### b. Electricity and fuel

The above-mentioned measures for the improvement of product yield have contributed to reducing the amount of return and thereby decreasing the amount of return to be re-sintered, which leads to an improvement in the productivity and a reduction in energy intensity.

The electricity intensity has decreased to about 20 kWh/t as a result of preventing the air leak by reinforcing the seal around the sintering machine, using a higher efficiency impeller, cutting the impeller when the capacity of the sintering blower is excessive, and controlling the rotational speed of the blower, in addition to the above-mentioned measures. Meanwhile, however, enhancement of pollution-preventive measures by means of a dust collector or desulfurizing device has been needed, thus resulting in the increase of electricity to 35 to 45 kWh/t.

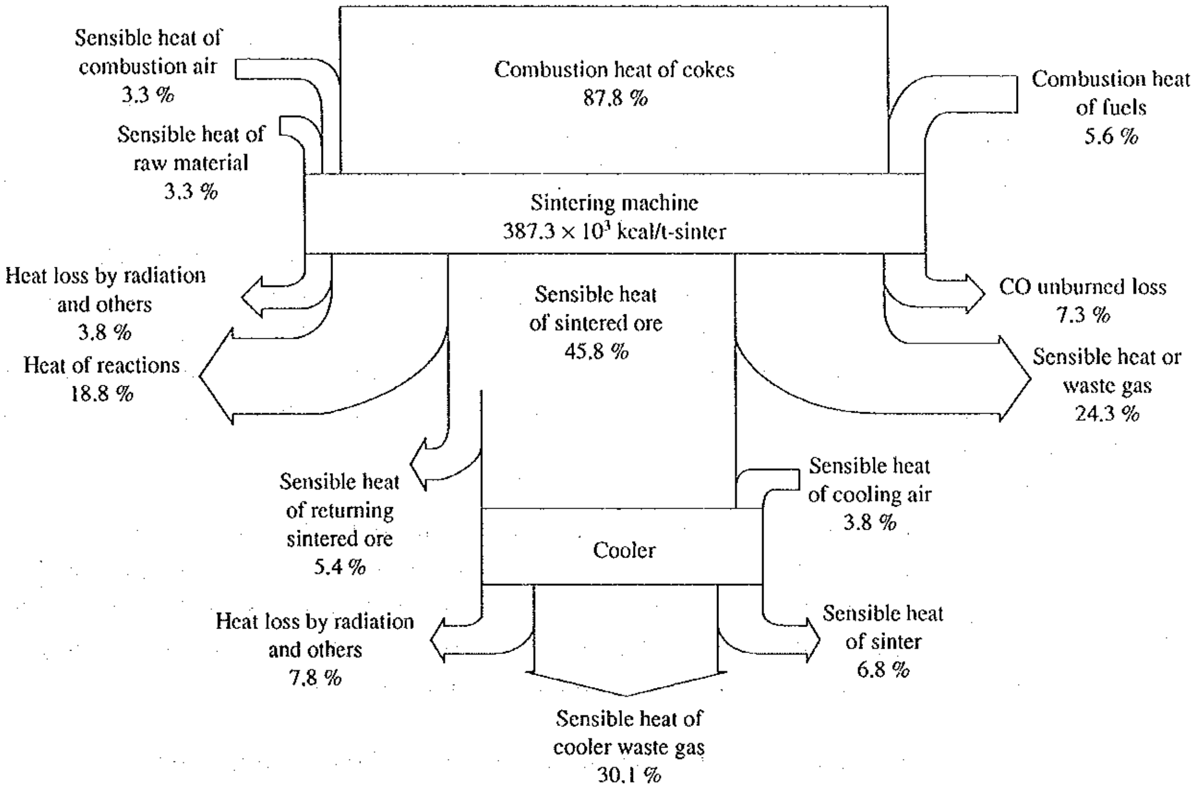
Regarding the ignition furnace fuel, instead of conventional multi-burner atmospheric ignition system that has been thus far widely used, direct-fired burners commonly known as slit burners and line burners are increasingly adopted in recent years, thus significantly contributing to energy conservation. The fuel intensity has decreased from the conventional 30 Mcal/t level to 10 Mcal/t or lower (5 Mcal/t as an excellent example).

### (3) Energy conservation by recovery of waste heat

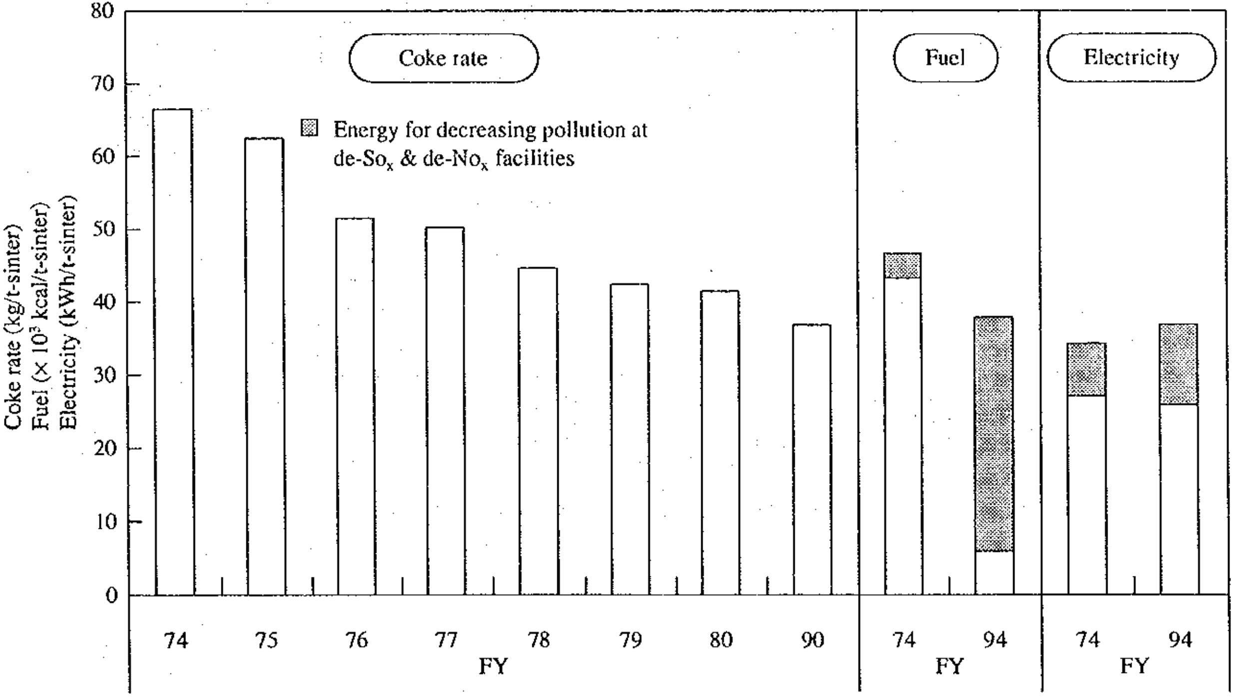
The waste heat from the sintering process includes mostly exhaust gas sensible heat (approx. 85 Mcal/t) from the sintering machine body and the exhaust gas sensible heat (approx. 180 Mcal/t) from the sintering cooler. The former is recovered from the sensible heat of the exhaust gas (250 to 400 °C) in the proximity of the ore discharge section of the sintering machine itself, to be used for recovering the steam or preheating the material and the air for the ignition furnace, etc. On the other hand, the latter is recovered as steam or electricity from the sensible heat of the high-temperature exhaust gas (250 to 400 °C) from the cooler by means of a power-generating system which double-flashes the recovered steam or hot water. Supposing that the temperature of the sintered ore is 700 °C, the temperature (with 0 °C as a reference temp.) of the sintered ore is 180 Mcal/t. However, since only the high-temperature zone waste of the sintering cooler is recovered, the recovery rate is around 65 Mcal/t-sinter, for example, when 10ata saturation steam is recovered.

Figure 1.3 shows the heat balance in the sintering process, and Figure 1.4 shows the trend of each energy intensity (coke breeze, electricity and fuel), which is an example of a sintering plant which succeeded in reducing the coke intensity immediately after the oil shock.

## Figure 1.3 Heat Balance in the Sintering Process (an example)



## Figure 1.4 Transition of Energy Intensity at a Sintering Plant in Japan



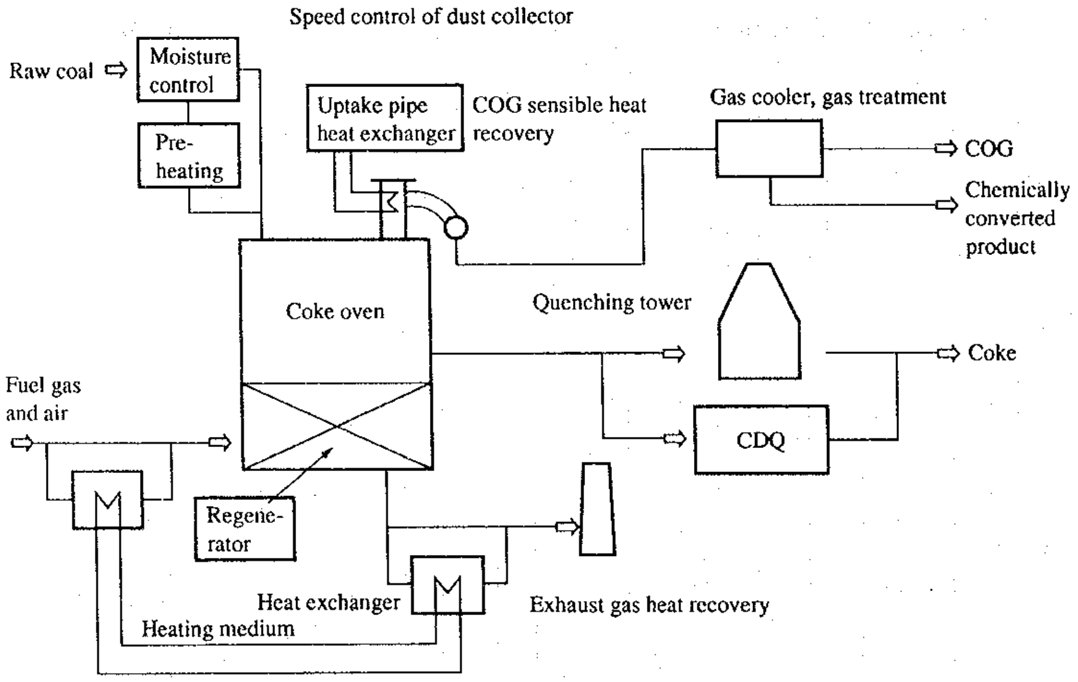
### 1.2.1.2 Coke Oven

(1) Coke process

In the coke process, raw coal is carbonized in a coke oven to produce the coke for reducing the iron ore. The coke oven has carbonization chambers and combustion chambers arranged alternately on a regenerator, forming a furnace battery. The raw coal is adjusted, ground, mixed and carried to be charged into the carbonization chambers, and usually in 15 to 20 hours, carbonization is completed to deliver hot coke. The red hot coke thus discharged is cooled by sprinkling in a quenching tower or cooled by cooling equipment using inert gas and then emerges as a finished product. The product is sieved or screened and thus lump coke only is fed to the blast furnace or COREX, to be used as the raw material there. Coke breeze is utilized as raw material for sintered ore or sold externally.

The energy in the coke process is mainly consumed for heating the raw coal and carbonization. Recently, waste heat recovery such as CDQ is widely adopted, and the energy consumption in the coke manufacturing process accounts for 5 to 6 % of the overall energy consumption in integrated steel works. Figure 1.5 shows a flow diagram and energy conservation measures of the coke coking process.

**Figure 1.5 Flow and Energy Conservation Measures of the Coking Process**



## (2) Energy conservation by improvements of operation and equipment

### a. Fuel

The fuel for carbonization occupies most of the energy intensity.

The fuel intensity was around 650 Mcal/t-coal; but it has decreased to as low as 550 Mcal/t-coal after the following improvements.

- Enhancement of combustion control (control of the oxygen concentration in the exhaust gas)

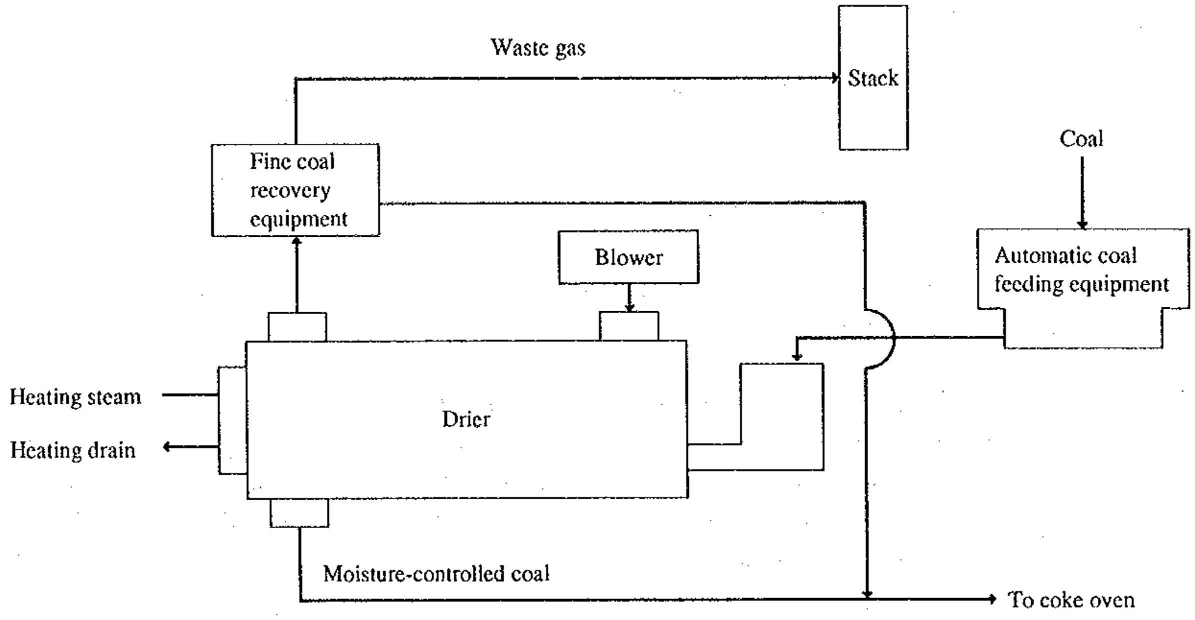
- Adoption of automatic combustion control using a computer on the basis of the coke oven operating schedule (operation rate) including furnace temperature control, as well as proper maintenance of the furnace temperature distribution for an even carbonization of coal to minimize the disparities in the unfiring time and carbonization time.

- Coal moisture control system preheats and dries the raw coal water content of about to 5 to 7 % by heat sources of steam or the plant waste heat, etc., before charging the raw coal into the coke oven. This ensures a stable operation of furnaces and decreases the heat consumption for carbonization. This can also increase the amount of charged coal equivalent to the reduction in the moisture content, and thereby improve the productivity.

  The moisture control system brings about a fuel reducing effect of about 75 Mcal/t, allowing an approximately 5 % production increase.

  Figure 1.6 shows a flow of the coal moisture control equipment.

Figure 1.6 Flow of a Coal Moisture Control System



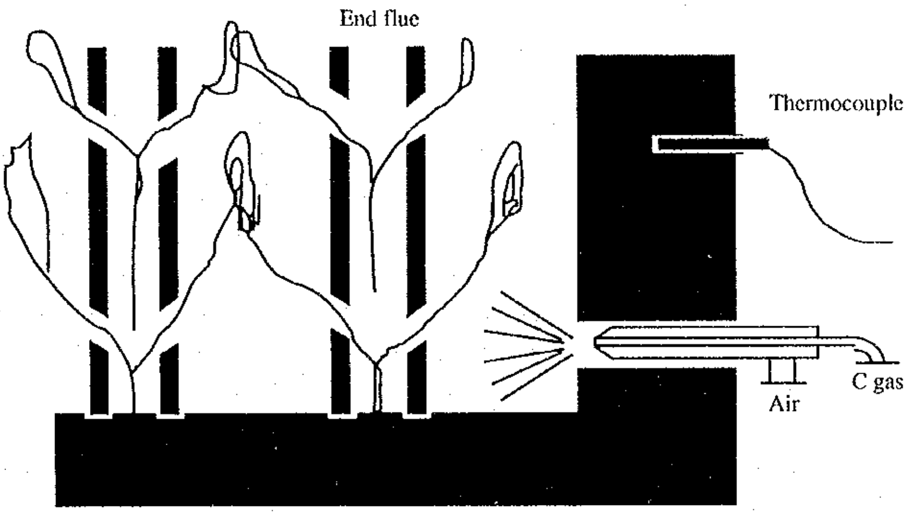
- End flue burners

The both end fuels (coke side and machine side) in the coke oven have a large radiation heat loss and consequently the temperature here tends to decline, thus making the coke carbonation in these portions insufficient. In this respect, if the temperatures at these ends are raised enough to completely carry out coke carbonization, the average temperature for the entire coke oven will have to be raised, thus leading to an increase in fuel intensity. As a recent countermeasure for these problems, a special burner is installed at each end of these flues to prevent the decreasing of temperature, and thereby produce a good result.

Figure 1.7 shows an example of flue temperature control.

## Figure 1.7 End Flue Temperature Control

Countermeasures: C gas burner installation at both ends of ovens

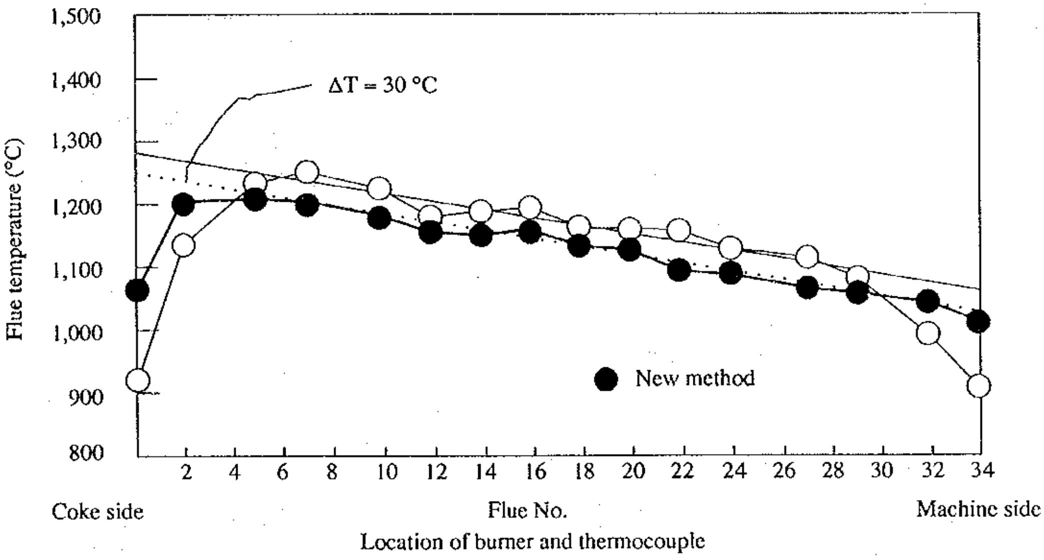


Typical C gas usage: 1.5m$^3_N$/hr each

Result

(a) Temperature increase at end flue 150 °C.

(b) Average flue temperature decrease 30 °C.



b. Electricity

A dust collector is provided at a coal charger, a coke discharge hole, etc. Rotational speed control is introduced for the fan of a dust collector so as to control air flow rate according to the amount of dust generation, thus contributing to energy conservation.

(3) Energy conservation by waste heat recovery

a. CDQ (coke dry quenching)

Coke dry quenching (CDQ) equipment quenches the hot coke delivered from the coke oven, continuously by a circulating inert gas, and recovers the heat as steam (250 to 510 °C) from a high-temperature circulating gas by a waste heat boiler. The steam recovered as low pressure steam is utilized for each process including coal moisture control in steel works. The temperature of the hot coke is higher than 1000 °C, to allow its recovery in the form of high pressure steam, and therefore recovery as electricity can also be effected by using an existing power generator or a newly installed power generator attached to CDQ. The heat recovered by CDQ amounts to 200 to 300 Mcal per ton of coke. A part of the circulating gas in CDQ is recovered as fuel because a leake air is mixed in it, generating CO gas, and the energy intensity for recovery amounts to 20 Mcal/t-coke (gas calory 850 kcal/$m^3{}_N$).

Figures 1.8 and 1.9 show an example of heat balance of coke oven and the processing sheet, respectively.

**Figure 1.8 Heat Balance of a Coke Oven (an example)**

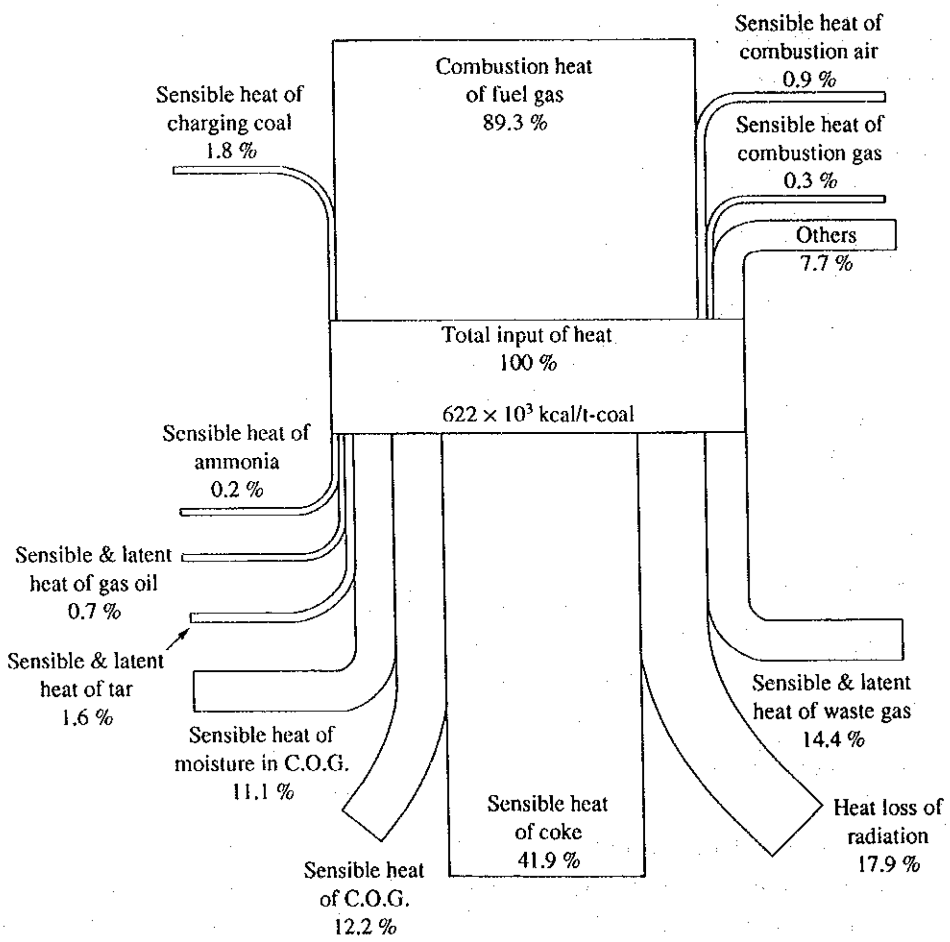
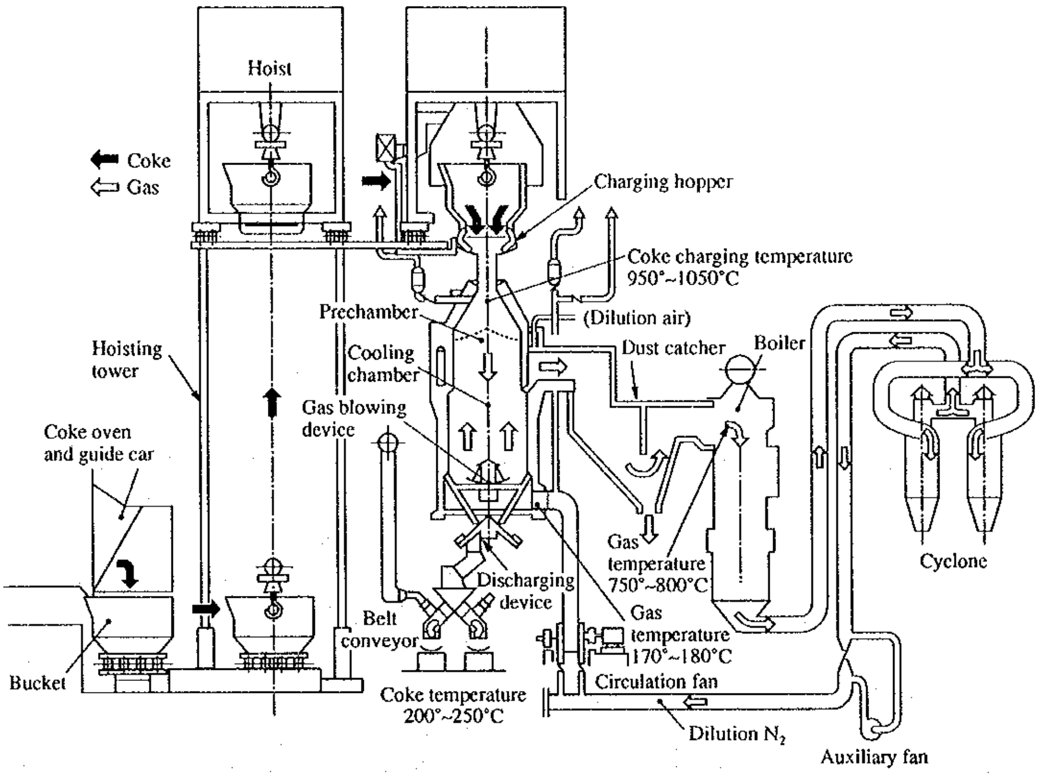


**Figure 1.9 General Arrangement and Process Flow Sheet for CDQ**



b. Recovery of coke oven gas (COG) sensible heat

Riser tube type heat exchangers are now commercially available for recovering a part of the sensible heat (110 Mcal/t-coal at 0 °C as a reference) of the generated COG of a temperature as high as 800 °C. However, they are not so widely used for economical reasons because a coke oven is divided into a lot of chambers, increasing the number of units to be installed. The generated COG cooled by a gas cooler is utilized to preheat feedwater for the CDQ boiler in the gas cooler, to recover the heat of 19 Mcal/t-coal.

### 1.2.1.3 Blast Furnace

(1) Blast furnace process

In the blast furnace process, pig iron is produced using iron ores, sintered ores and pellets, etc. (hereinafter referred to as iron ore) as the raw materials, while using the coke charged together and heavy oil, natural gas, and pulverized coal injected through the tuyere as a melting heat source and a reducing agent.

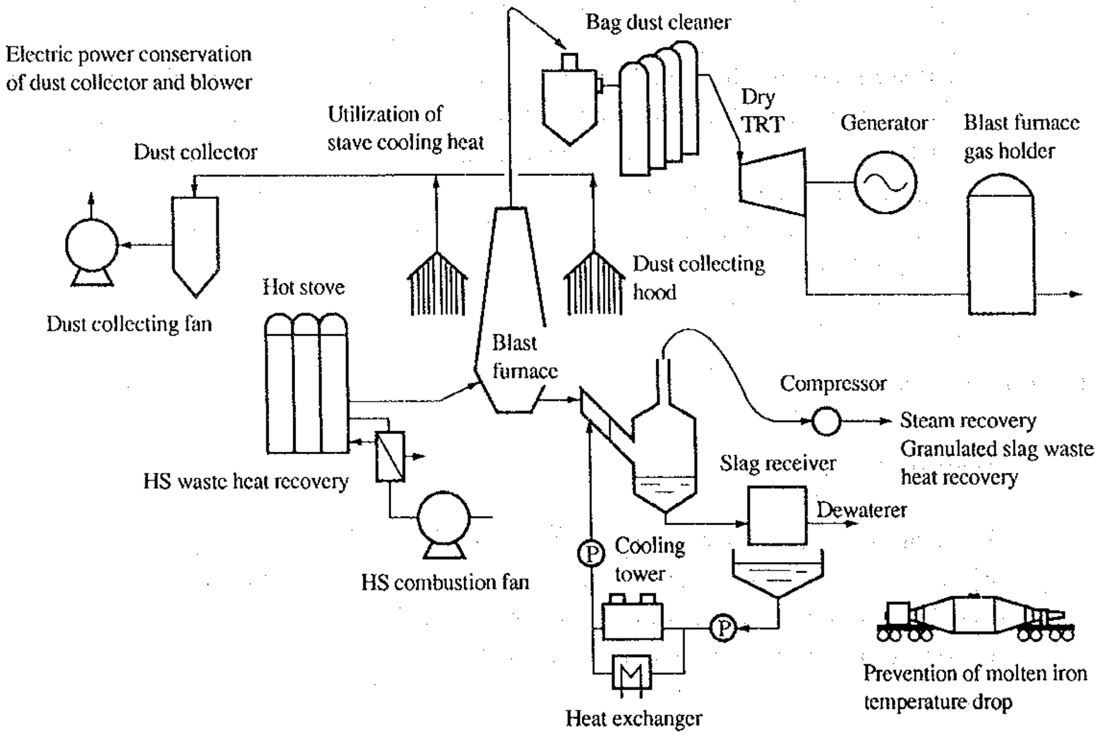
Iron ores, coke and limestone are supplied from the top of the blast furnace. Coke charged into the furnace is burned by the hot air injected in from many tuyeres formed in the lower part of the furnace, thereby generating a reducing gas, which, in turn, reduces iron ore. The iron ore thus reduced remains at the furnace bottom in the form of molten iron, which is taken out of the furnace through a tap hole. The impurities in the iron ore are taken out as molten slag.

On the other hand, as a result of the above reaction, blast furnace gas (BFG) containing non-reacted CO and $H_2$ is discharged from the furnace top, dedusted, and effectively used as a fuel.

In the iron making process, the energy (approx. 1750 Mcal/t pig) used for melting and reducing the iron ore is enormous, and accounts for 57 % of the overall energy consumed for iron making. In recent years, to reduce the production cost for the blast furnace and to extend the life of the coke oven, the operatrion rate (production volume) of a coke oven is lowered, while PCI (Pulverized Coal Injection) technique, in which a large amount of inexpensive non-coking coal is injected as coal supplementary to coke, is getting increasingly popular; as a recent practice, 100 to 200 kg/t is injected.

Figure 1.10 shows a processing flow and energy conservation measures.

**Figure 1.10 Flow and Energy Conservation Measures of the Iron Making Process**



(2) Energy conservation by improvement of operation and equipment.

a. Fuel rate (Coke, etc.)

The blast furnace consumes coke, heavy oil, pulverized coal and natural gas as energy for reducing and melting the iron ore, and the fuel intensity is called fuel rate.

Decreasing the fuel rate or controlling the fuel rate is one of the important techniques for blast furnace operation, exerting a large influence in terms of cost-benefit.

Generally, reduction of fuel rate leads to reduction in production cost; therefore the fuel rate and the net energy consumption have been reduced through the continuous effort for improving the gas availability ($CO/CO + CO_2$) through optimization of the furnace top charge distribution, decreasing the heat loss of the furnace body (e.g. heat insulation of the tuyere), and increasing the air blasting temperature and the treated ore ratio along with the development of the technologies therefor. (Some actual results show that the fuel rate decreased to as low as 420 kg/t) In recent years, a blast furnace has come to be regarded more as a gas generating furnace and operated at a proper fuel rate to minimize the energy cost of the entire steel works. For example, when the unit price of electricity per unit heat value is higher than that of coal, the countermeasure being currently taken include raising the gas generation by increasing of fuel ratio of the blast furnace to increase in-house power generation and thereby reduce the amount of purchased power.

Figures 1.11 and 1.12 show blast furnace fuel rate vs. blast furnace net energy consumption, and the heat balance of a blast furnace, respectively.

## Figure 1.11 BF Fuel Rate vs BF Energy Intensity

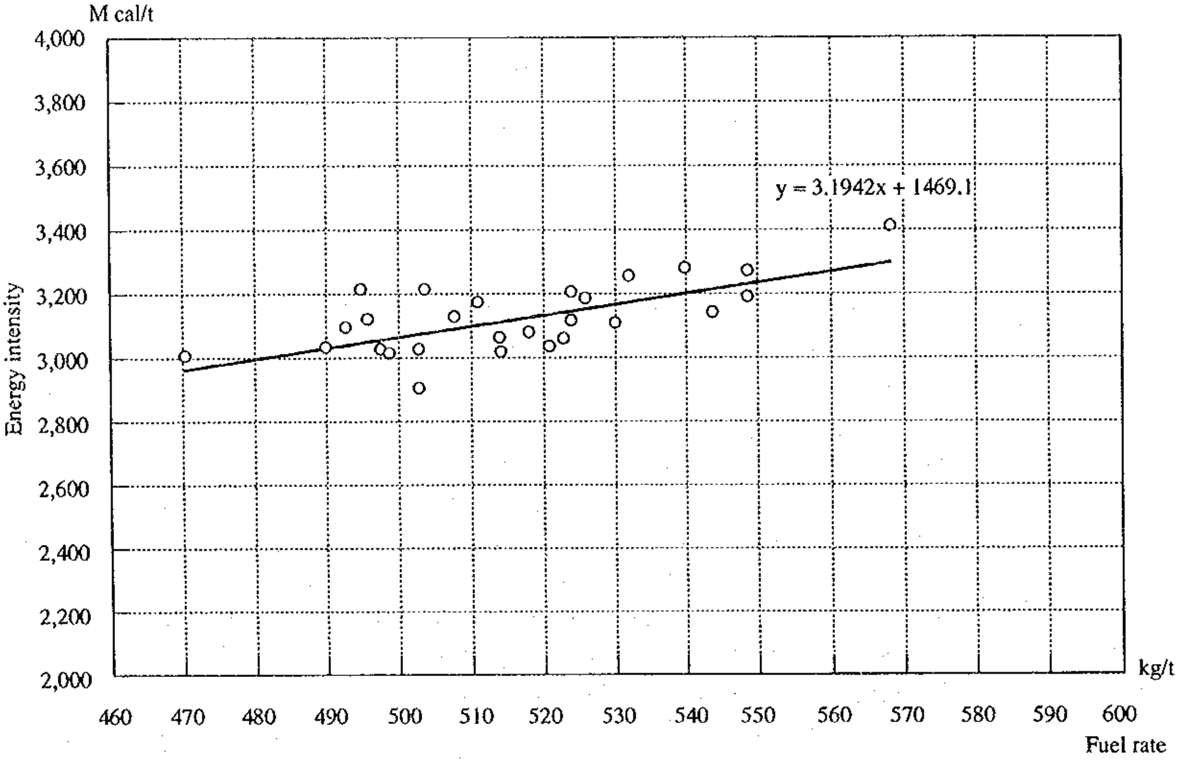
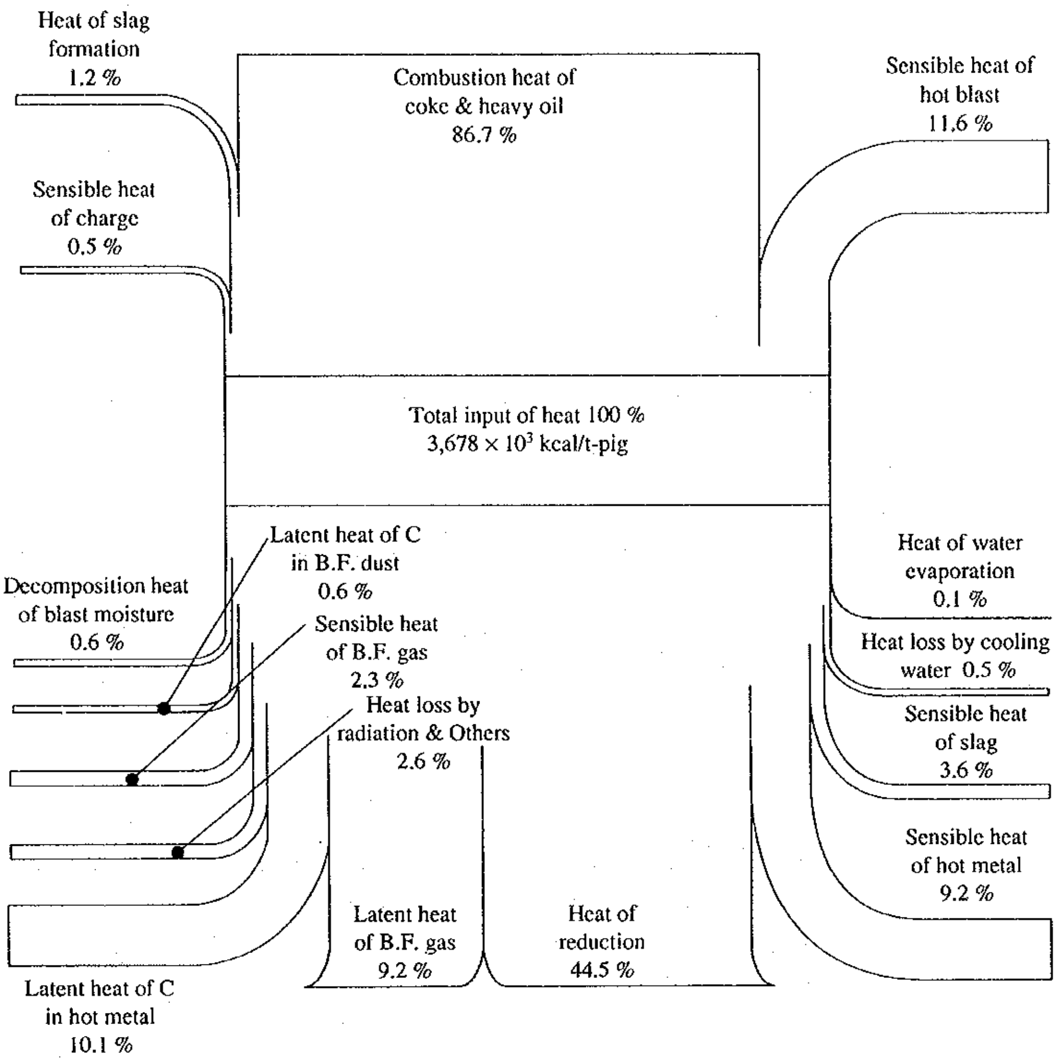


Figure 1.12 Heat Balance of a Blast Furnace (an example)



b. Fuel (Hot stove)

Fuel intensity has been about 2 % decreased by improving the burners; introducing the staggered parallel blowing method; controlling the charge heat amount by means of a computer; controlling low $O_2$ combustion; preventing the generation of uncombusted CO gas by improvement of control method of fuel gas valves and air valves; and reducing the heat intensity by improving high-calory gas combustion.

c. Electricity

Impeller cutting is performed for pumps and fans to obtain a proper capacity, and the concept of rotational speed control is introduced for the dust collecter fan, etc. to increase the air volume only when required, thereby leading to electricity conservation.

- Air volume control of the cast house dust collector fan

- Air volume control of the hot stove combustion fan and the optimization of the capacity

- Rotational speed control of cooling water and dust collecting water pumps and the optimization of the capacity.

(3) Energy conservation by waste heat recovery

a. T.R.T (Blast furnace top gas pressure recovery turbine)

Nearly 100 % of Japanese steel works adopt T.R.T. — most popular in Japan as waste heat recovery equipment — which recovers the top gas pressure energy of a blast furnace operating under a pressure of 1.5 to 3 kg/cm$^2$ (called high-pressure operation) as electricity by an expansion turbine. Wet-process TRT, which is capable of recovering about 45 % of power consumed by a blast blower, can recover electricity of 35 to 50 kWh (85 to 120 Mcal/t) per ton of pig iron. Additionally, the dry-process TRT--gaining popularity in recent years--is intended for recovering both the furnace top pressure and gas sensible heat at the same time, allowing electricity of 40 to 55 kWh/t (100 to 135 Mcal/t) to be recovered.

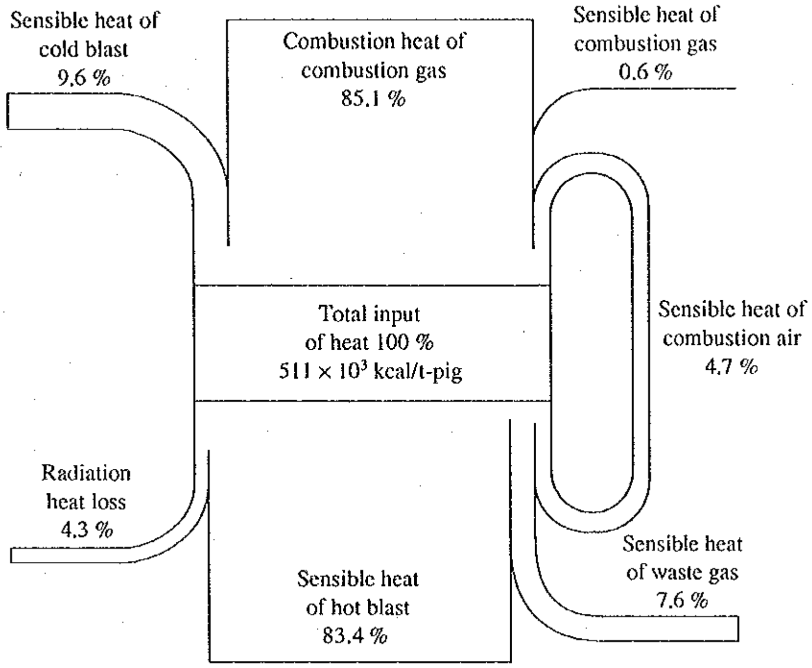
b. Waste heat recovery from a hot stove (Air preheating)

The sensible heat of exhaust gas from a hot stove, which is only 250 °C in temperature but large in quantity, can be utilized for preheating combustion air (also combustion gas) by a rotational heat exchanger or a one using a heating medium. The adoption ratio in Japan is nearly 100 %.

The heat efficiency of a hot stove, which was about 80 % at most, is about 4 % increased through installation of an air preheater and the reduction of the fuel intensity by 20 to 25 Mcal/t, and thus the heat efficiency can be improved by as much as about 84 %.

Figure 1.13 shows a heat balance example of a hot stove.

Figure 1.13 Heat Balance of a Hot Stove (an example)



### 1.2.2 Steel Making

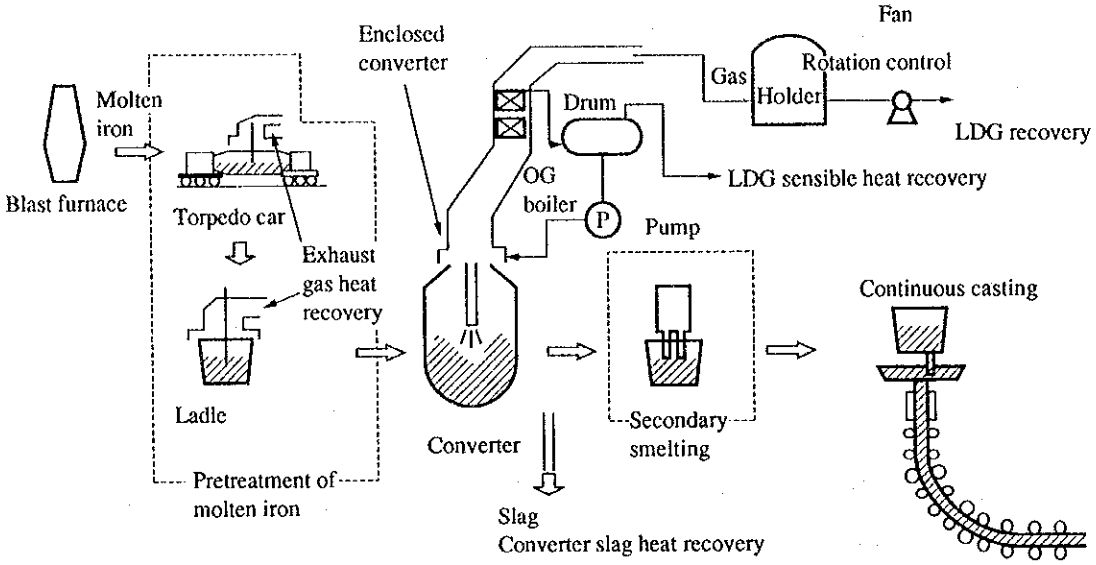
(1) Steel making process

In the steel-making process, impurities such as carbon, silicon, sulfur and phosphor are removed from molten iron by a converter and a refining device, and additives are provided as required, to make steel, which is then made into slabs by ingot making machine or a continuous caster (CC)

Molten metal is tapped from the blast furnace at about 1,500 °C, but charged into a converter at about 1,350 °C due to a drop in the temperature during transportation and pre-treatment (for removing Si, S, P). The amount of latent heat brought in by the molten iron is about 700 Mcal/t-steel. The oxidation reaction heat of each element (C, Si, etc.) in the molten iron and the sensible heat of the molten iron in the converter are both converted into the sensible heat of molten steel/slag, and the sensible and latent heat of exhaust gas from the converter.

Figure 1.14 illustrates the flow and energy conservation measures of the steel making process.

**Figure 1.14 Flow and Energy Conservation Measures of the Steel Making Process**



### (2) Energy conservation by improvement of operation and equipment

In the steel making process the use of a continuous caster and the improvement of the availability have achieved the most remarkable result in terms of energy conservation. In Japan, the continuous casting ratio, which was only about 27 % in 1974, exceeded 93 % in 1986, and reached 98.1 % in 1995. Omission of some processes and improvement of the yield that has been attained to such an extent as to eliminate the ordinary ingot-making and blooming mills along with the introduction of casting machines have resulted in the energy intensity of 150 to 200 Mcal/t steel.

The product yield in the processes from ordinary ingot-making to blooming mill processes is $0.97 \times 0.88 \fallingdotseq 0.85$, whereas the product yield after adoption of a continuous caster is 0.985 to 0.99, thus achieving a significant result.

A converter — the main equipment of a steel-making plant — is usually operating at the rate of a half or two-thirds of the full availability and yet at batch. In addition to a large amount of oxygen consumed for refining in a steel making plant, fuel is used for the heat holding and drying of the converter, ladle, caster, etc., and electricity is used as a power source for pumps and fans.

Since a great amount of high-temperature gas (including 90 to 95 % CO) is generated in a converter because of oxidation reaction of C, Si, etc. in the molten iron occurring along with smelting, the sensible heat and the latent heat are recovered. The gas recovering methods include recovery of steam by a converter waste heat boiler after burning the generated gas or recovery of a converter gas (LDG: approx. 2000 $\mathrm{kcal/m^3{}_N}$) as fuel by a gas recovering device. This results in the net energy consumption being nearly 0 (zero).

Recently, however, to reduce the contents of impurities such as hydrogen, oxygen and phosphor $N_2$, in the steel in order to improve the quality of steel, the rate of secondary refining such as degassing treatment has increased, and as a result consumes the net energy of 50 to 100 Mcal/t.

In addition, to reduce the cost in the steel-making sector, an increasing number of plants make the effort to produce molten metal with as low a content of Si as possible, while at the same time charging the molten metal into the converter after pre-treatment (for removing Si, S and P)

a. Oxygen

Oxygen is mainly used to eliminate impurities such as C, Si, etc. in the molten iron. In order to reduce the oxygen intensity, it is important:

- to improve the approval rate of carbon content and temperature in order to reduce the re-blowing,
- to reduce the content of silicon in the molten iron (this effort to be made in the blast furnace process),
- to decrease the molten steel temperature as low as possible to improve the yield,

One of the methods adopted for implementing the above-mentioned measures is to decrease the iron oxidization loss and thus reduce the oxygen intensity by injecting inert gas from the bottom of the converter, to agitate molten steel, and thereby forcibly dispersing Si, C, etc. to be removed by oxidization so as to accelerate the oxidization reaction.

It is equally important to operate the converter at as constant blowing cycle as practicable and to ensure a smooth communication with the oxygen plant in order to decrease the oxygen dissipation loss in the oxygen generating plant.

b. Electricity

Idle time should be reduced by stopping the pumps and fans when a converter and a continuous caster (CC) are to be stopped for the period of time exceeding a specified time. At the same time, such measures should be taken as checking the capacity in terms of the propriety and replacing it with a smaller one when the equipment capacity is larger than the required capacity.

As for a dust collector, such measures as fan air volume control, damper automatic change-over, etc. are available for collecting a required amount of dust at a necessary timing.

c. Fuel

With regard to fuel, which is used for heat holding, drying, etc. of ladle and tundish, it is advisable to adopt a burner with a combustion air preheater using the recovered exhaust heat, and prepare the heat holding/drying standards appropriate to the ladle/ rotation rate.
Management based on the appropriate standards will allow the fuel consumption to be reduced. In this regard, it should be noted that the absolute use amount and the energy intensity tend to increase particularly at reduction in production.

When a waste heat boiler is installed to recover the heat from the converter exhaust gas, no exhaust gas is generated during a non-blowing/refining time in a converter, thereby reducing the steam pressure. In order to prevent such situation, the boiler needs to be combusted additionally by heavy oil or natural gas. This auxiliary combustion should be completed at a good timing by the start of the subsequent blowing-in to reduce the amount of additional fuel with the target at about 20 Mcal/ ton or less at the two-third operation of a converter.

d. Improvement of yield

Improving the yield of a converter, and a continuous caster (CC) contributes greatly to improving the energy intensity. To this end, the blowing out temperature in the converter should be kept as low as possible, and also the approval rate of carbon content and temperature of molten steel should be kept as high as possible. For a continuous caster, the continuous continuous casting ratio should be improved as much as possible and implementation measures should always be taken into consideration.

(2) Energy conservation by recovery of waste heat

a. Coverter waste heat boiler (combustion type)

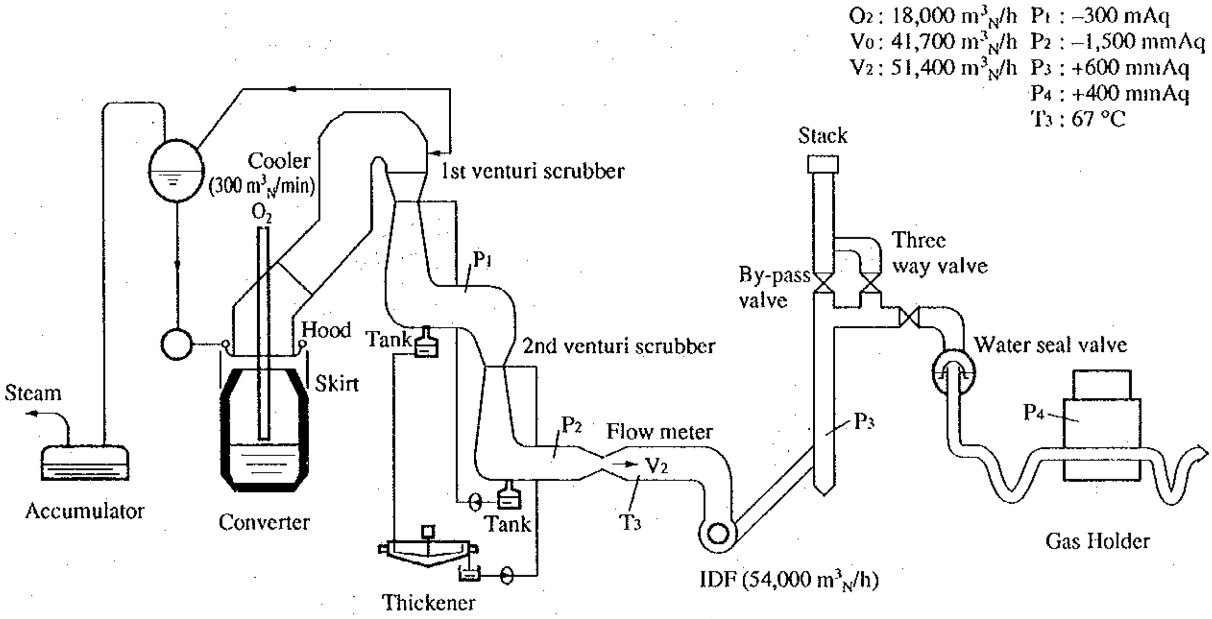
In the converter, exhaust gas of a high temperature containing a large amount of dust is generated in the smelting process by oxygen blowing, and this exhaust gas needs to be cooled and collected. The amount of gas generated is about 100 Nm3 per ton of steel, the content of dust is about 100 g/Nm3, and the gas temperature is 1500 °C. The exhaust gas is mainly composed of CO, accounting for approximately 95% of the entire gas. The converter, on the other hand, was operated on a batch production basis, thus making it difficult to safely cool, collect and recover the gas containing CO of a high temperature. Therefore, a method was first developed in which an exhaust gas boiler is used to burn exhaust gas once and recover it in the form of steam by means of a boiler. However, this waste heat boiler involved such problems as high construction cost, maintenance cost, only about 200 Mcal/t rate of heat recovery, and the difficulty in demand and supply adjustment with the consuming part due to batch-wise generation of recovered steam.

b. Recovery of converter gas (Non-combustion type)

Since the gas-recovery method was put to practical use in 1960's it has come to occupy the main position in the waste heat recovery of a converter, achieving a recovery rate of about 90 to 100 $m^3_N$ (to be calculated in 2000 kcal/$m^3_N$). In recent years, some plants have come to adopt a method to reconfigure a part of gas recovery system into a boiler to recover the sensible heat, and achieves 240 Mcal/t or more of recovered heat.

Figure 1.15 shows the flow diagram of a converter gas recovery system.

**Figure 1.15 Flow Diagram of a Converter Gas Recovery System**



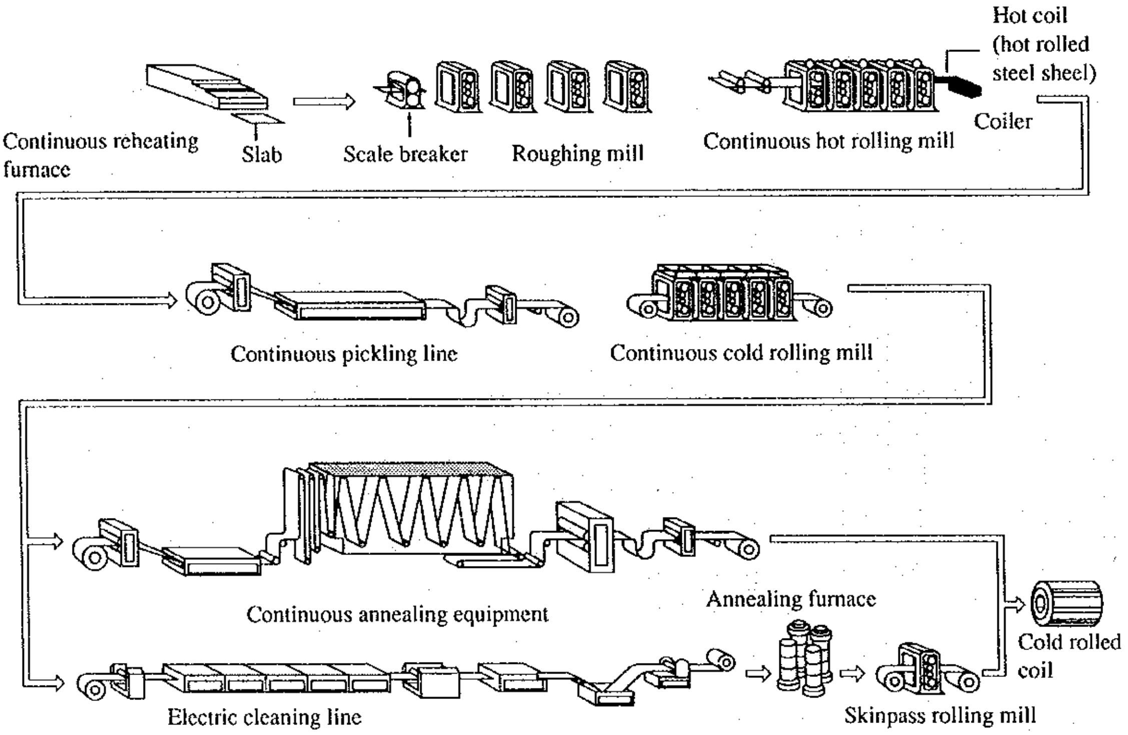
## 1.2.3 Rolling

(1) Rolling process

In the rolling process, a steel product (slab, bloom, or billet) is heated up to a specified temperature in a reheating furnace, then rolled by a rolling mill and processed into a specific shape and size. The rolling process is categorized into the primary hot rolling for manufacture of steel plates, shape steels, bar steels, wire rods, and the secondary cold rolling for hot dipping, electroplating and manufacture of welded steel pipes, butt-welded steel pipes and seamless steel pipes.

Figure 1.16 shows an example of steel sheet (cold-rolled steel sheet) manufacturing process. In the first hot rolling process, the heated slab is rolled into a thin hot strip coil through the roughing mill and the finishing mill, and then tempered into a hot coil while being cooled by scattering water. After removing the scales on the surface by acid cleaning, the sheet is further subjected to thickness reduction by the cold rolling mill and to compositional adjustment. Then the sheet is passed through the continuous annealing system to be processed by soaking, annealing, and quenching for having the processability improved, and then cold-rolled into a steel sheet. The cold-rolled steel sheet may be further subjected to plating, etc. for each specific application.

**Figure 1.16 Cold Steel Sheet Production Process**



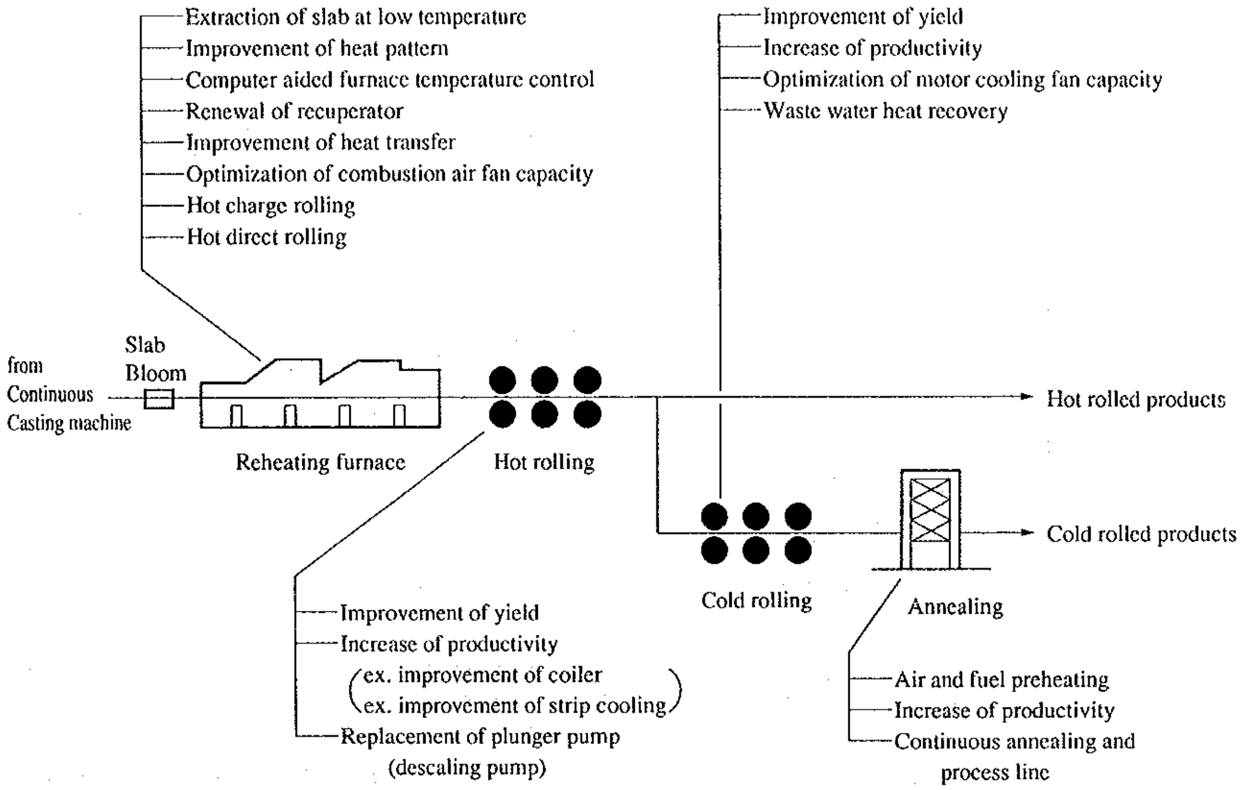
The process for manufacturing steel bars such as shape steels, bar steels, rod steels, etc., steel plates, and steel pipes also consists of such processes as forming processing by means of heating and rolling, welding, heat-treatment, etc. as required. Thus, rolling can be said to consist of various processes depending on the product and the quality.

Energy intensity in the rolling process is 546 Mcal/t in the primary rolling, and 660 Mcal/t in the secondary rolling, accounting for 13 to 15 % of the total energy consumption of an integrated steel works.

This section describes mainly energy conservation measures in the primary rolling process.

Figure 1.17 shows a flowchart and energy conservation measures of the rolling process.

**Figure 1.17 Flow and Energy Conservation Measures of the Rolling Process**



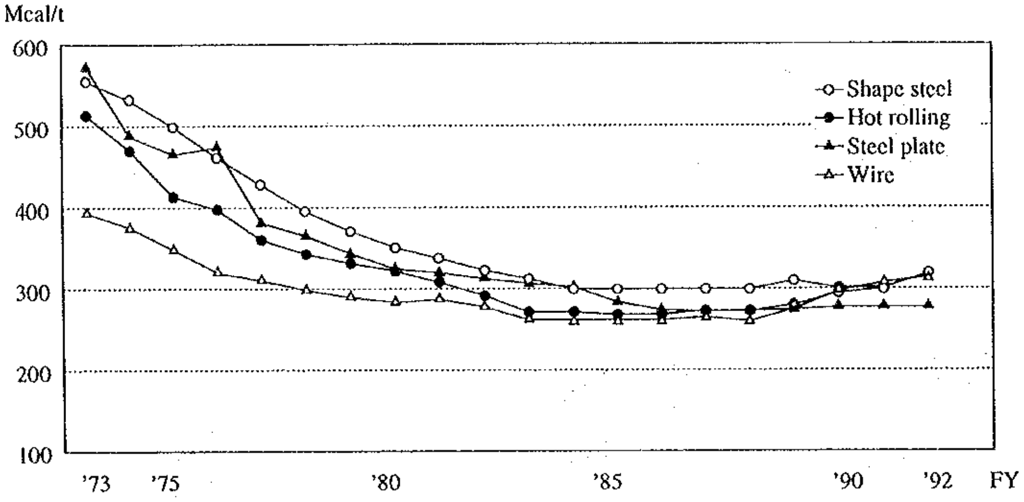
(2) Energy conservation by improving operation and equipment

Fuel accounts for approximately 50 % of the energy consumed in the rolling process, while electricity and steam occupy the rest. Energy conservation measures actually implemented in the primary rolling process include efficiency enhancement of heating and diverse efforts in processes such as rolling, annealing, heat-treatment. Moreover, in the rolling process involving many repetitions of heating and cooling processes, the loss arising from these processes must be reduced as much as possible. This requires heat energy conservation measures are considered in terms of integration, omission, and concatenation of processes, and thus put into implementation. From now on, reviews and improvement from this standpoint will be required.

a. Fuel (An example of reheating furnace)

Figure 1.18 shows the changes in fuel intensity of a reheating furnace.

**Figure 1.18 Trend of Fuel Intensity of a Reheating Furnace**



- Reduction of heat loss

Effective measures to reduce the waste gas heat loss, which occupies the largest portion of various types of heat loss in the reheating furnace are:

- to reduce the exhaust gas amount (control of the oxygen concentration in the exhaust gas,
- to decrease the exhaust gas temperature (optimization of heat patterns, introduction of a computer for that purpose, etc.) and at the same time,
- to take such equipment improvement measures as extension of the furnace length,

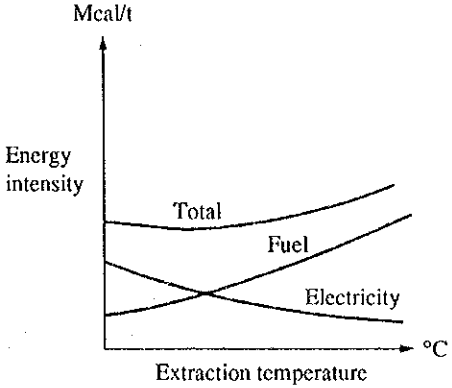
Measures to reduce the cooling water heat loss include reinforcement of heat insulation (double heat insulation) of the skid pipe, increasing the size of skids, crosses and posts to reduce their numbers, prevention of vibration, prevention of heat-insulating materials from dropping, etc. Reduction of the heat capacity of the furnace wall utilizing ceramic fiber and enhancement of heat insulation are available for decreasing the radiation heat of the furnace body.

- Low-temperature extraction, etc.

Extracting a slab from the reheating furnace at a low temperature decreases the fuel intensity in the reheating furnace but it tends to increase the electricity intensity because the hardness of the steel product increases. Considering these effects, influences and skid marks, the slab should be extracted at as low a temperature as possible so as to promote energy conservation.

Fuel intensity is reduced by 3 to 5 Mcal/t for every 10 °C drop in the temperature in Japanese actual cases as shown in Figure 1.19.

**Figure 1.19 Relationship between Energy Intensity and Extraction Temperature**



- Enhancement of heat recovery

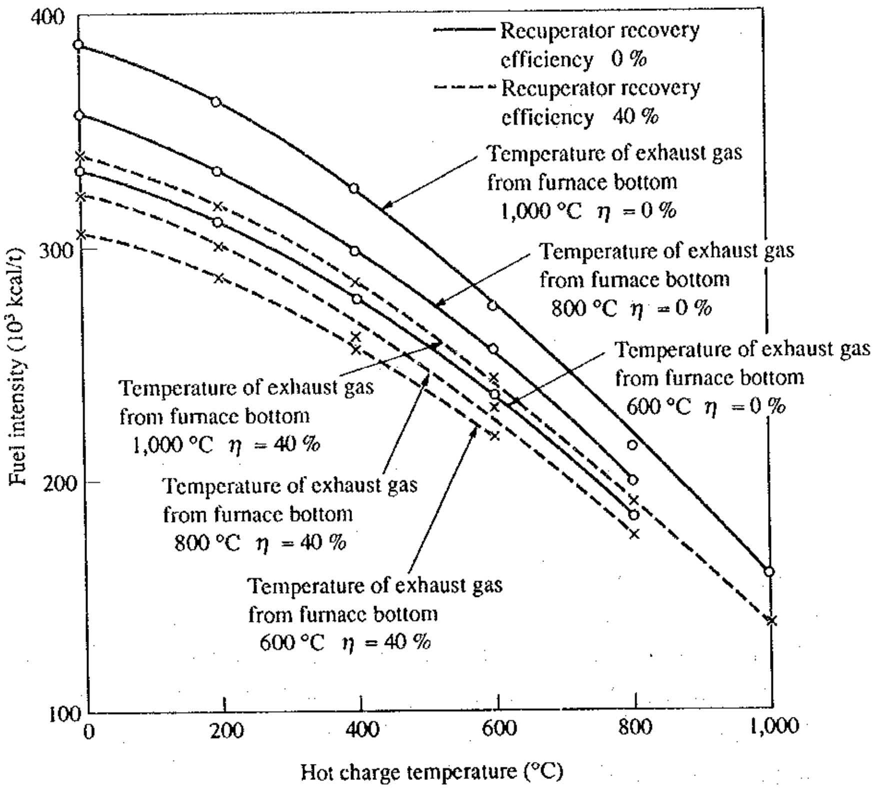
A dirty heating surface of an air preheater (recuperator) will degrade extremely its performance and exert an adverse effect on fuel intensity. Therefore, simple heat balance should be periodically performed to maintain the temperature efficiency at the initial installation. If any problem is found, the preheater must be reinforced or replaced.

- Improvement of hot charge ratio

The fuel intensity of the reheating furnace will be remarkably improved by charging the hot slab from the continuous casting process or the blooming process into the reheating furnace, or by direct-rolling if possible in terms of the layout (The adoption ratio in Japan is 60 %). Supposing that 100 % of the CC material could be direct-rolled, the fuel intensity will be 100 Mcal/t or less even if the heat by an edge heater is added.

Figure 1.20 shows an effect of hot charge rolling (an example of trial calculation).

**Figure 1.20 Effect of Hot Charge Rolling (an example)**



- Heat balance example

Table 1.1 shows an example of heat balance of hot-rolling reheating furnace into which only cold slabs are charged.

## Table 1.1 Heat Balance of a Reheating Furnace

Charged slab temperature: cold

(Example 1)

| Heat Input | Mcal/t | (%) | Heat Output | Mcal/t | (%) |
|---|---|---|---|---|---|
| Combustion heat of fuel | 330.3 | (94.2) | Heat content of extracted slab | 195.3 | (55.7) |
| Sensible heat of fuel | 0.2 | (0.1) | Sensible heat of scale | 5.2 | (1.5) |
| Heat content of charged slab | 0 | (0) | Sensible heat of exhaust gas | 82.7 | (23.6) |
| Scale formation heat | 20.0 | (5.7) | Heat of cooling water | 11.1 | (3.2) |
|  |  |  | Heat loss | 56.2 | (16.0) |
| Heat recovered by recuperator | (34.9) | ((10.0)) | Heat recovered by recuperator | (34.9) | ((10.0)) |
| Total | 350.5 | (100) | Total | 350.5 | (100) |

Overall heat efficiency = {195.3/(330.3 + 0.2 + 20)} × 100 = 55.7 %
Furnace effective length and width: 29.8 L × 9.28 W (m)
Nominal capacity: 170 t/h

(Example 2)

| Heat Input | Mcal/t | (%) | Heat Output | Mcal/t | (%) |
|---|---|---|---|---|---|
| Combustion heat of fuel | 318.7 | (97.6) | Heat content of extracted slab | 194.8 | (59.7) |
| Sensible heat of fuel | 0 | (0) | Sensible heat of scale | 2.1 | (0.6) |
| Heat content of charged slab | 0 | (0) | Sensible heat of exhaust gas | 33.3 | (10.2) |
| Scale formation heat | 8.0 | (2.4) | Heat of cooling water | 43.8 | (13.4) |
|  |  |  | Heat loss | 52.7 | (16.1) |
| Heat recovered by recuperator | (62.7) | ((19.2)) | Heat recovered by recuperator | (62.7) | ((19.2)) |
| Total | 326.7 | (100) | Total | 326.7 | (100) |

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

(Example 3)

| Heat Input | Mcal/t | (%) | Heat Output | Mcal/t | (%) |
|---|---|---|---|---|---|
| Combustion heat of fuel | 462.1 | (90.5) | Heat content of extracted slab | 206.8 | (40.5) |
| Sensible heat of fuel | 0.6 | (0.2) | Sensible heat of scale | 5.5 | (1.1) |
| Heat content of charged slab | 0 | (0) | Sensible heat of exhaust gas | 195.0 | (38.2) |
| Scale formation heat | 20.0 | (3.9) | Heat of cooling water | 65.0 | (12.7) |
| Sensible heat of atomizer | 27.7 | (5.4) | Heat loss | 38.1 | (7.5) |
| Heat recovered by recuperator | (51.1) | ((10.0)) | Heat recovered by recuperator | (62.7) | ((19.2)) |
| Total | 510.4 | (100) | Total | 510.4 | (100) |

Overall heat efficiency = {206.8/(462.1 + 0.6 + 20.0 + 27.7) } × 100 = 40.5 %

b. Electricity

In order to reduce the electricity for rolling, the consumption characteristics for rolling should be studied to first adopt a method which will produce a greater effect. The following items will be empirically proposed, which will be also effective for energy conservation in the secondary rolling process.

- Since the electric power consumption for rolling is generally proportional to the rolling time, rolling productivity (t/h) should be enhanced.
- The capacity of a fan for a reheating furnace, a cooling fan for a rolling motor, pump, etc. should be checked to lower an excessive capacity if any.
- Equipment should be improved so as to stop an auxiliary equipment during the non-rolling time including also lighting time.
- The operation efficiency of a pump or a fan should be checked, and if it is found low, it should be replaced with a one of higher efficiency.

c. Steam

A large amount of steam is used in the secondary rolling process including an acid-pickling line, cleaning line, etc. By measuring the steam flowrate and studying the consumption characteristics, energy conservation measures need to be implemented first for the portion which is expected to easily produce a quick effect. In many successful cases in Japan, as a ersult of adopting the most appropriate measure by this method, the consumption rate could be reduced by about 70 %. (In some actual cases, rather simple improvement measures are taken such as installation of a heat exchanger for waste water and makeup water, the use of water for cascade (2-stage use), etc.)

(3) Energy conservation by waste heat recovery

a. Air preheating

Since slabs need to be heated to a high temperature in order to obtain a high-temperature flame, a combustion air preheater is generally installed.

b. Fuel gas preheating

To conduct a drastic waste heat recovery, fuel gas is, in some cases, pre-heated.

c. The sensible heat of the skid cooling water can be recovered as hot water. Consideration must be also given to the purpose for which it will be utilized. When a reheating furnace boiler is installed, the recovered water will be used as a feedwater preheater.

d. Boiler for a reheating furnace

The use of boilers utilizing the sensible heat of the exhaust gas from the reheating furnace is effective for energy conservation. In this case, however, energy conservation measures should be taken after considering a possible effect of the waste gas reduction based on fuel consumption reduction efforts such as fuel gas preheating, hot charge, etc., and thereby verifying the cost-effectiveness.

(4) Integration, omission and continuation of processes

The rolling process consists of repeated heatings and coolings. Therefore, the ultimate energy conservation results from integration (connection), omission and continuation of processes. The following constitute typical energy conservation techniques in the rolling process.

- Direct combination of the acid cleaning process and the cold rolling process
- Continuation (continuous annealing equipment) of Cleaning → Annealing → Tempering Rolling → Inspecition and Conditioning
- Continuation of the galvanizing processes (Continuous galvanizing equipment)

(5) Improvement of the yield

Improvement of the yield in the rolling process leads directly to the increase in production, and thus it can be said to be a rolling technique itself. The following operation efforts for the entire rolling line including the technological development/establishment, and equipment improvement will result in the improvement of the yield:

- to maintain an even and optimum rolling temperature of slabs extracted from the reheating furnace,
- to ensure an even rolling and prevent the occurrence of surface flaws by the optimum roll pass design, maintenance control, etc,
- to prevent overheating in the reheating furnace (prevention of excessive scale loss),
- to minimize the crop loss.
- to reduce miss roll rate, etc.

### 1.2.4 Energy Utilization Equipment

(1) Functions of the energy department

The energy department in a steel works has two functions: to convert an excessive energy in the steel works (e.g by-product gas such as BFG) into an energy required for that plant (e.g electricity, oxygen, blast air, etc.), and to perform economically a demand and supply control of utilities used in the plant such as electricity, fuel, water, compressed air, oxygen, nitrogen.

The net energy consumed in the energy department is approximately 7 to 9 % of the energy consumption in the entire factory. Major energy consumers in the facilities in the charge of the energy department include a power-generating blast plant and oxygen plant, which will, therefore, be explained below.

#### 1.2.4.1 Power generating/blasting plant

In many old steel works, a power-generating plant and a blast furnace blasting plant have been provided in the same plant for the reasons of decreasing the construction costs, etc. to allow the shared use of boilers. Recently, however, these plants are made separate in terms of enhancing the efficiency of energy in order to improve the heat efficiency of the power plant.

(1) Energy conservation by improvement of operation and equipment

(Boiler)

- To enhance the combustion control
- To to improve the seal mechanism.
- To reduce the boiler blow-down water.
- To control the rotational speed of boiler feedwater pumps, induction blowers, etc.

(Steam turbine)

- To enhance the control of the vacuum of the condenser (determine the effective tube cleaning timing)
- To install a continuous cleaning equipment for a condenser tube.
- To modify existing steam turbine blades to make them more efficient.
- To replace a sealing equipment in the steam turbine at an appropriate timing.
- To improve the steam turbine extraction availability (to enhance its availability as process steam)

(Blast blower)

- To decrease the pressure loss of a suction filter.
- To modify a blower to match it to the blast furnace operation (reduction of blower impeller stages)

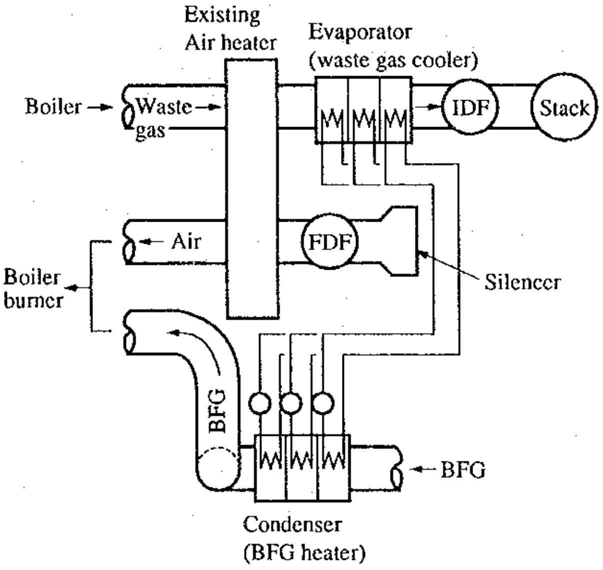
(2) Energy conservation by waste heat recovery

a. Fuel

As an example of energy equipment waste heat recovery, there is a preheater of fuel BFG by the use of boiler waste gas. Since BFG is low in calory (800 kcal/$m^3_N$ or below in Japan), the boiler efficiency is nearly 86 %, which can be increased up to 90 % by installing a preheater for BFG.

Figure 1.21 shows the example.

**Figure 1.21 Effect and Flow of a Fuel Gas Preheater (an example)**



Data at 75 % Load

| | |
|---|---|
| Waste gas flow | 380,000 $m^3_N$/h |
| Waste gas inlet temp | 194 °C |
| Waste gas outlet temp | 133 °C |
| BFG flow | 205,000 $m^3_N$/h |
| BFG inlet temp | 40 °C |
| BFG outlet temp | 160 °C |

b. Electricity

When a pressure reducing valve is used for the supply line of steam for industrial use to reduce the steam pressure, the electricity can be recovered by installing a back-pressure turbine, instead of the reducing valve.

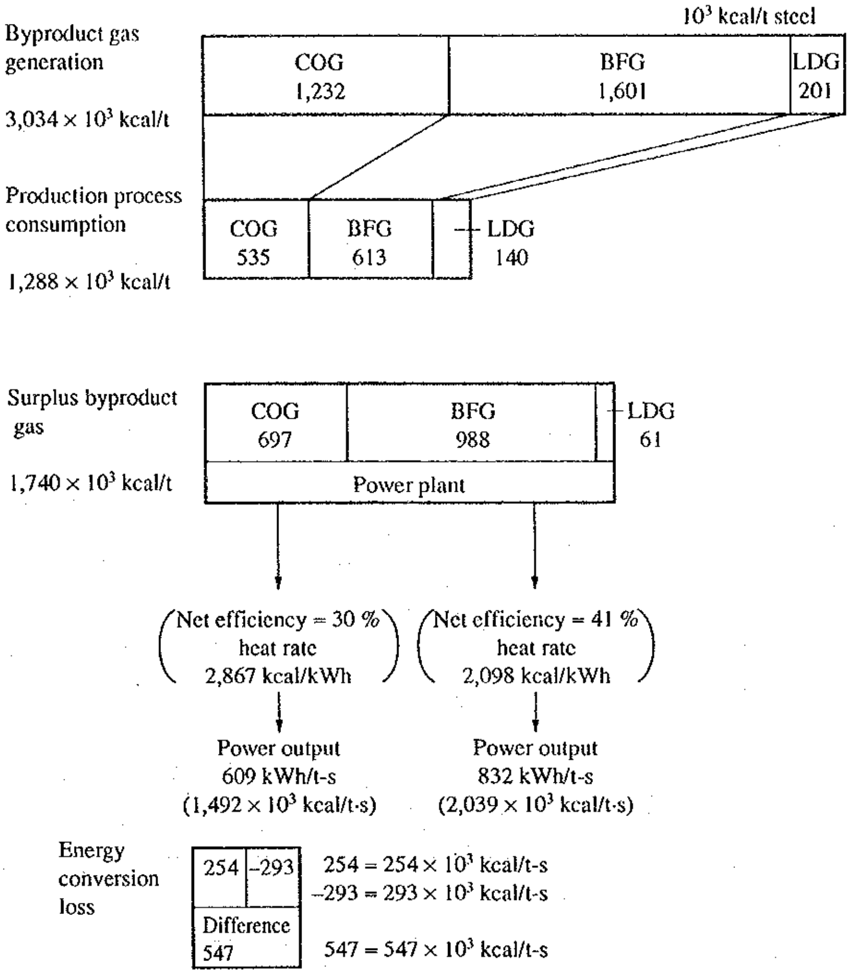
### (3) Modernization and efficiency enhancement of energy equipment

Conventionally power-generating blasting plants were regarded as an auxiliary equipment of a steel works, and thus their energy conversion efficiency was considered much less important. Recently, however, along with the increasing awareness toward energy conservation, these facilities have come to be taken into consideration, while at the same time energy conservation measures for them have begun to be implemented. Improving the energy conversion efficiency has contributed to a reduction in purchased energy, i.e, a great reduction in energy intensity of an integrated steel works, thus leading to the efficiency enhancement of energy equipment.

#### a. Reduction of energy intensity by improving the power-generating efficiency (For consideration).

Figure 1.22 shows an example where higher efficiency in power-generation contributes to improvement of energy intensity for the entire factory. This figure shows excessive gas amounts (consumption rate) in a modern steel works. This figure also shows the amount of generated power calculated on the assumption that the above-mentioned excessive gas is utilized to generate power at a net power generating efficiency (efficiency at the power distribution end). The result obviously reveals that the 832 kW/t required in a steel works can be all self-supplied by an excessive gas, which demonstrates that it can fully cope with a possible increase of power consumption arising from the improvement of the product quality.

**Figure 1.22 Effect of a High Efficiency Power Plant (an example)**



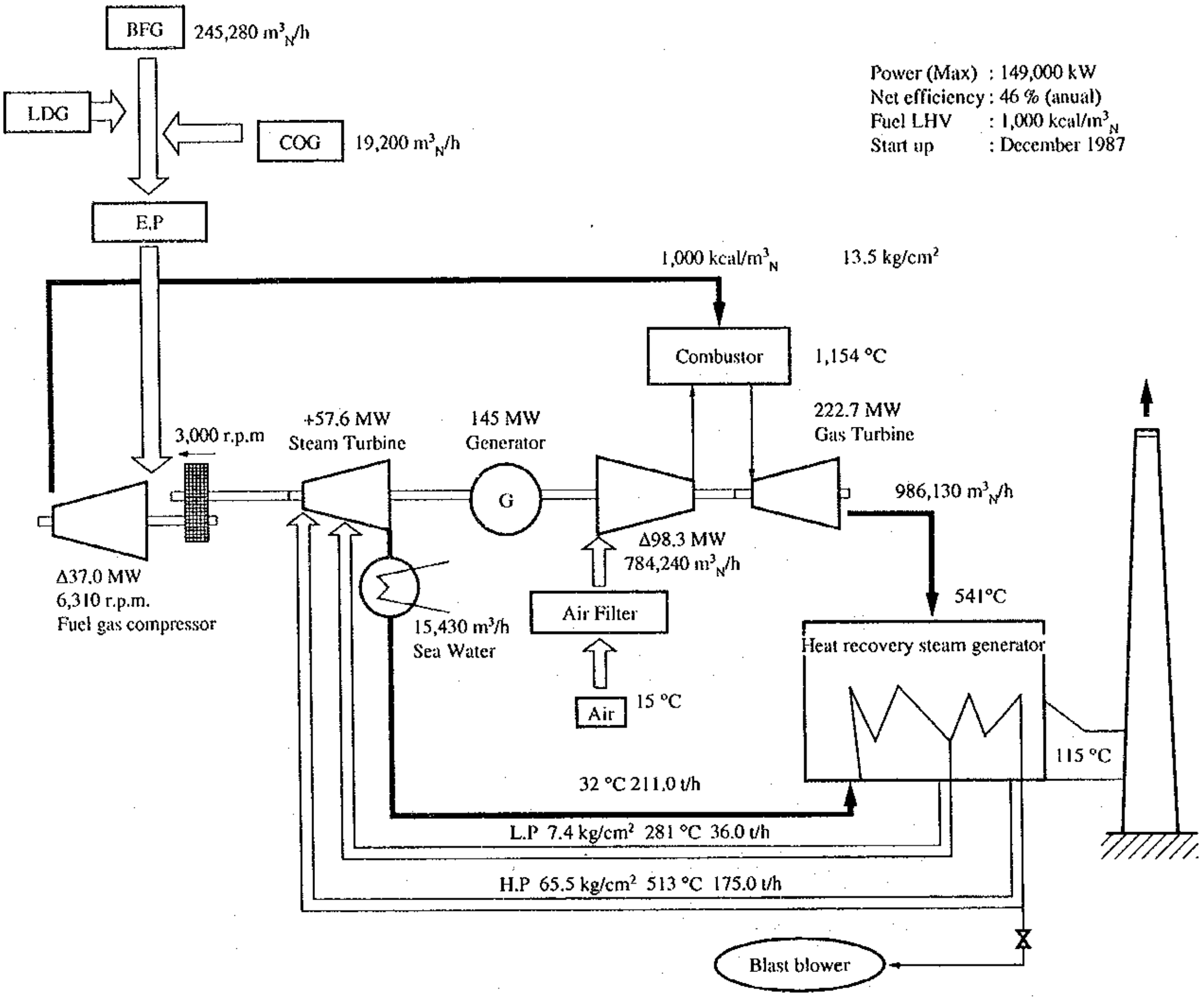
Effect of high efficiency power plant

| Power plant efficiency | Energy intensity | Effect |
|---|---|---|
| 30 % | 6,189 × 10³ kcal/t | 547 × 10³ kcal/t |
| 41 % | 5,642 × 10³ kcal/t | |

b. Gas turbine combined cycle power generation

In recent years, there have been developed high-efficiency gas turbine combined cycle power generating facilities capable of achieving such a high power generating efficiency of 46 % at fuel LHV 1,000 kcal/$m^3_N$. Some steel works have introduced this plant and as a result, have substantially reduced the energy intensity, thus achieving a significant result in terms of cost-benefit. Figure 1.23 shows the flowsheet of gas turbine combined cycle power generation.

**Figure 1.23 Flow Diagram of a Gas Turbine Combined Cycle Plant**



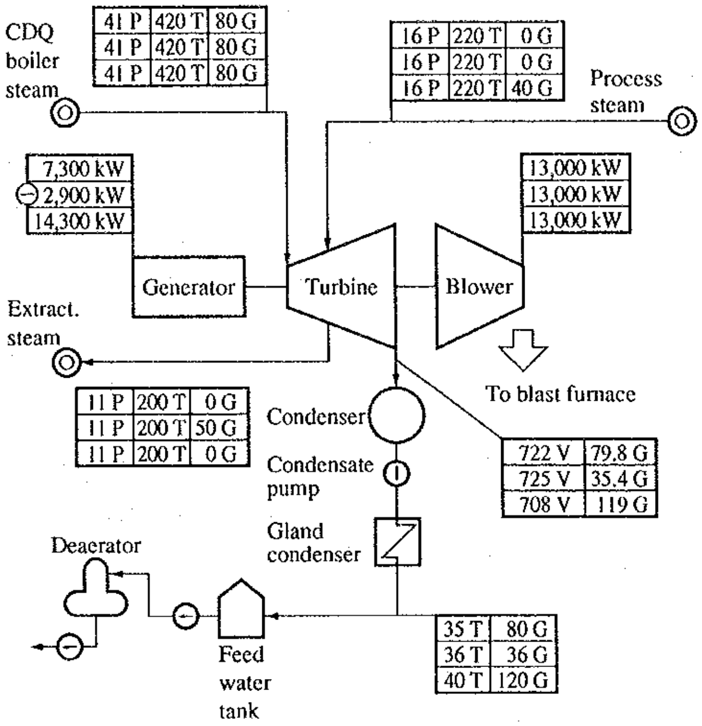
c. Multi-purpose power generation

Since the waste heat from a steel works has a high temperature, it can easily be recovered as steam in terms of economy. This recovered steam (referred to as waste heat steam) is utilized as processs steam at various locations. Meanwhile, the demand for process steam tends to decrease along with the progress of energy conservation. As the waste steam supply rate increases against the entire steam demand, the surplus of steam occurs seasonally or on the maintenance shut-down day of large energy-consuming equipment. On the other hand, when a waste steam generating plant enters into maintenance, steam will be insufficient.

To cope with these situations, it will be necessary to install steam demand-supply control equipment such as mixed-steam/extraction steam/condensing turbines for power generation.

Figure 1.24 shows an example of this turbine.

**Figure 1.24 Heat Balance of a Mixed and Extraction Steam Turbine**



P : pressure (kg/cm$^2$ abs.)
T : temperature (°C)
V : vacuum pressure (mmHg)
G : flow rate (t/h)
kW: output (kW) or shaft power (kW)
⊖ : Required power of motor
Upper line value : blast furnace air supply and power generation with CDQ boiler steam (80 t/h)
Middle line value: maximum extraction (50t/h)
Lower line value : maximum mixing (40t/h)

d. Blast blower

Axial flow compressors are mainly used, and high-efficiency stator blade control of a wider blowing range is adopted. Conventionally a steam turbine was, in some cases, employed as a driver from the standpoint of stable supply of power (consideration for power failure), but in the future it will tend to be replaced by a motorized blast blower from the viewpoints of the recent stable power supply and efficiency and labor saving.

### 1.2.4.2 Oxygen plant

Conventionally, the oxygen plant in a steel works was mainly engaged in the manufacture of oxygen, released and wasted most of nitrogen, and thus only a small amount of it was used for production. Along with the upgrading of steel products and modernization of processes, however, the use of nitrogen have increased, while at the same time argon has come into use for combined blowing-in/refining in a converter. Both nitrogen and argon are produced in the process of oxygen manufacture, and in recent years, therefore, oxygen is, in some cases, released in the atmosphere for the purpose of nitrogen manufacture. Meanwhile, the improvement of measures for this situation are being implemented as well.

(1) Energy conservation by operation and equipment improvement (Oxygen plant)

- Prevention of oxygen dissipation (enhancement of cooperative operation with a converter)
  (Reinforcement of a supply and demand adjustment function through installation of equipment for manufacturing liquid oxygen and nitrogen)
  (Reinforcement of the oxygen generating capacity by installation of air compressors in parallel)

- Adoption of a $CO_2$ absorber

- Modification of air compressors (Replacement with more efficient impellers and adoption of suction vane control)

- Reduction of suction filter pressure loss

(2) High effficiency oxygen plant

Enhancement of oxygen plant efficiency involves the following three points, and it is expected that plants will be enlarged in scale through integration or be gradually replaced, one after another from the oldest one, by a high efficiency plant. The production result at present is 0.42 to 0.46 $kWh/m^3_N$ for electricity intensity for manufacturing oxygen and 0.15 ~ 0.17 $kWh/m^3_N$ for oxygen distribution electricity intensity, and then total electricity intensity is 0.65 ~ 0.70 $kWh/m^3_N$ for usage.

- Air compressor : To improve the electricity intensity by adoption of a high-efficiency impeller, suction vane control, a high-efficiency heat exchanger, and an axial flow compressor.

- Air separating equipment: To reduce as much as possible the suction pressure of an air compressor by adoption of a $CO_2$ absorber.

  To maximize the fluctuation in the oxygen generation amount in order to reduce the dissipation loss.

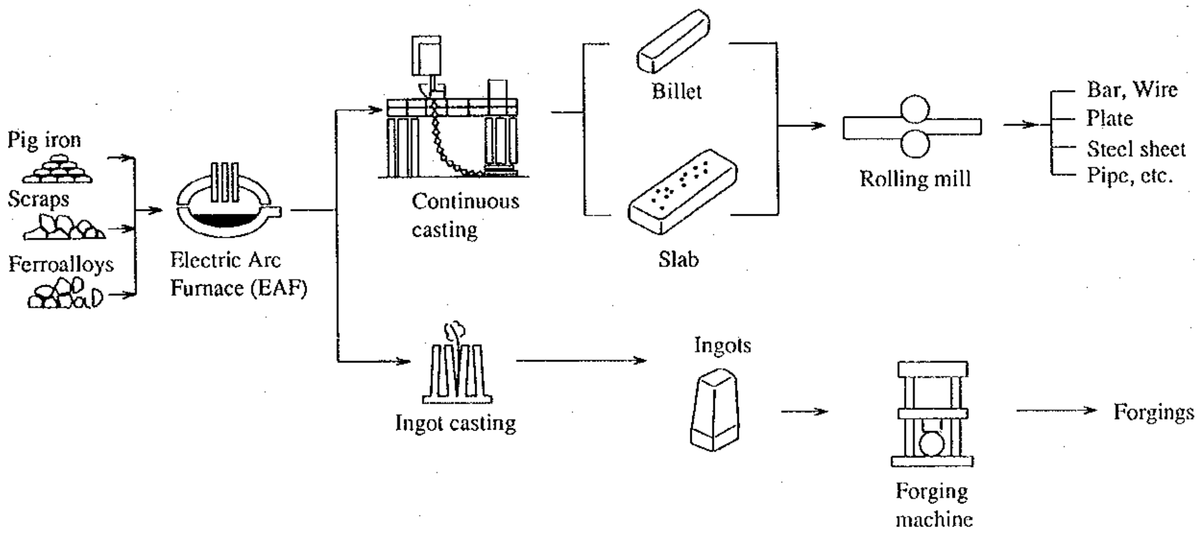
- Oxygen compressor : To adopt a high-efficiency impeller, suction vane control, and a high-efficiency heat exchanger.

## 1.3 Process Overview of Electric Arc Furnace Plants, Foundries and Forging Plants and Their Energy Conservation Themes

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

Figure 1.25 shows the flow of raw materials and products at an electric arc furnace plant.

**Figure 1.25 Flow of Raw Materials and Products of Arc Furnace Steel-making Method**



With regard to a foundry, the melting furnaces (cupola and induction furnaces) using 50 % of the total amount of energy consumed at a plant will be picked up and explained. As in the case of a forging plant, a foundry is characterized by the capability of fabricating products up to the level closer to the finished product (more specifically, mechanical parts). Figure 1.26 shows the flow of raw materials and products of a foundry.

Figure 1.26 Raw Material Flow of Foundry