11.5 Boiler Performance Indication

The boiler efficiency is indicated by an input-output method which is represented by a ratio of the available output heat to the total input heat as shown in Table 11.10 or by a heat loss method which subtracts the heat loss rate.

Also, to indicate the boiler performance, an equivalent evaporation multiple is often used.

$$\text{Equivalent evaporation multiple} = \frac{\text{Equivalent evaporation}}{\text{Consumed fuel quantity}} \text{ kg steam/kg } (m^3_N)\text{-fuel}$$

In the same boiler, when the vapor pressure and other conditions are almost constant, an evaporation multiple should be obtained as an actual evaporation without conversion. It is sometimes used as a good rating for daily management.

The performance may sometimes be indicated by a rate of evaporation of heating surface (kg/ $m^2 \cdot h$) which is divided by the equivalent evaporation by the heating surface area (except an economizer and a superheater), or by a rate of heat generation (kJ/m^3h) in the combustion chamber which is divided by the total input heat by the volume of the combustion chamber.

11.6 Consideration in Installation Steps

11.6.1 Cogeneration

When steam is applied to heating, its heating temperature is almost 200 °C or less and the temperature of steam is also around the same temperature. While, the flame temperature when fuel is burned, reaches one thousand and several hundred degrees centigrade, but the temperature difference between its temperature and the steam temperature is not utilized effectively.

The basis of a heat engine in which heat is converted to work is the Carnot cycle. When an effective work occurs by the completion of cycle through that of an operating fluid receives heat at the temperature of T_1K from a high temperature heat source and releases the heat at the temperature of T_2K to a low temperature heat source, the theoretical efficiency of the Carnot cycle can be represented by the following equation.

$$\eta = 1 - \frac{T_2}{T_1}$$

Accordingly, a higher T_1 is a higher efficiency.

Cogeneration gives a work (electric power) by utilization of the higher temperatures when fuel is burned and utilizes the remaining exhaust heat as heat (see Figure 11.12). And various systems are considered as follows.

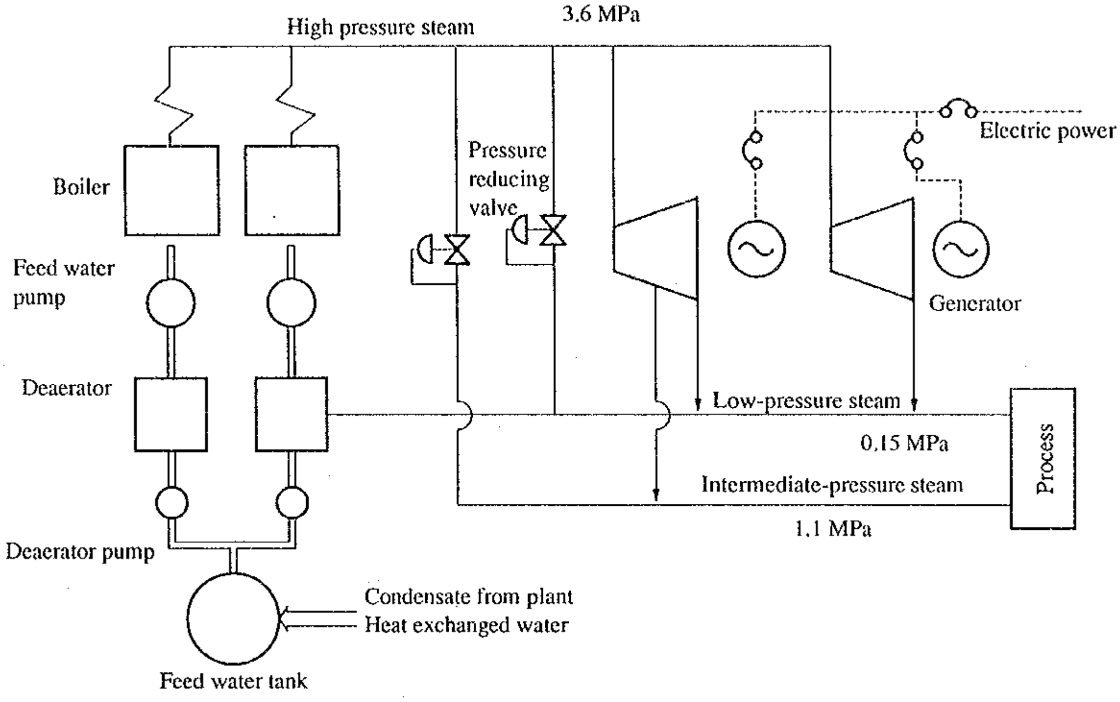
(1) **(Gas turbine power generation) + (Steam turbine power generation)**

(2) **(Diesel or gas engine power generation) + (Hot water supply)**

(3) **(High pressure steam turbine power generation) + (Steam supply for heating)**

In the plants of a steam consumption type, the last system (3) is usually used in such as a petroleum refinery, a paper and pulp plant, or a chemical plant. From the point of view of efficiency, the steam pressure is desirable in 2.94 kPa (gauge) (30 kgf/cm^2 (G)) or more and it is almost 9.8 kPa (gauge) (100 kgf/cm^2 (G)). And the capacity is 50 t/h or more. With the sharp advance of an energy price, the economical efficiency is improved even in further lower pressure and a lower capacity boiler and the case equipped with a generator instead of the pressure reducing valve has increased.

Figure 11.12 An Example of Cogeneration System



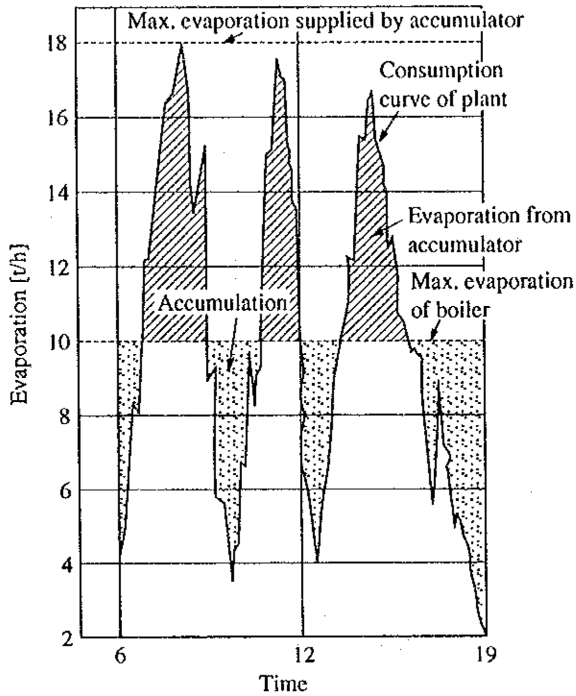
11.6.2 Coping with Steam Demand Variation

When the steam demand fluctuates largely in a short time or a difference in the steam demand between day and night is large, an excessive capacity boiler compared with the average load must be installed and the air ratio must be kept at a higher level to prevent black smoke occurring at the load fluctuation.

To prevent a declining of the boiler efficiency due to those, balancing the demand should be done through managing the manufacturing plants as much as possible and the following measures to the system should be taken.

As a method, the steam accumulator should be equipped to store some excess steam which is used when short of steam (See Figure 11.13). If an accumulator is accompanied when the boiler is installed, a boiler of the capacity near the average load can cover sufficiently the demand.

Figure 11.13 Effect of Steam Accumulator



In another method, several small size once-through boilers which are quick to start up are installed and the operating number of boilers is controlled automatically according to load (see Figure 11.14). Since this method increases the efficiency in a lower load compared with the case of a single boiler (see Figure 11.15), energy conservation can be taken as a whole with a counterbalance of some loss increase due to the start-up and shut-off operation.

Figure 11.14 Operation Number Control

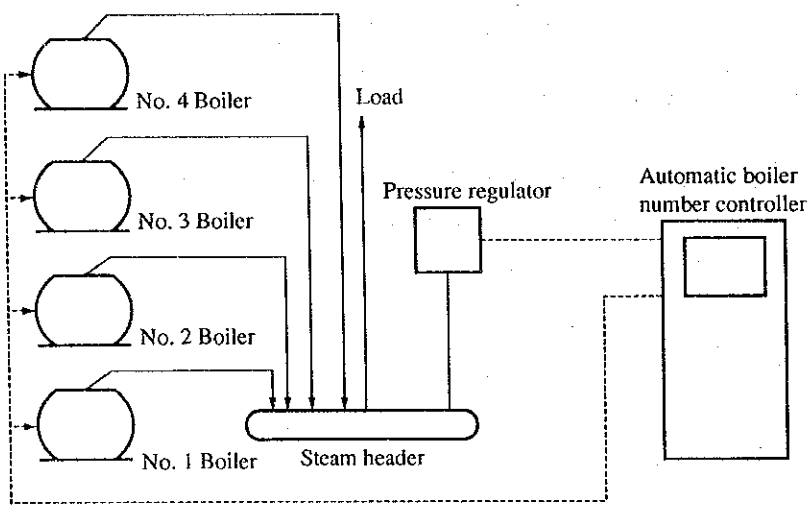
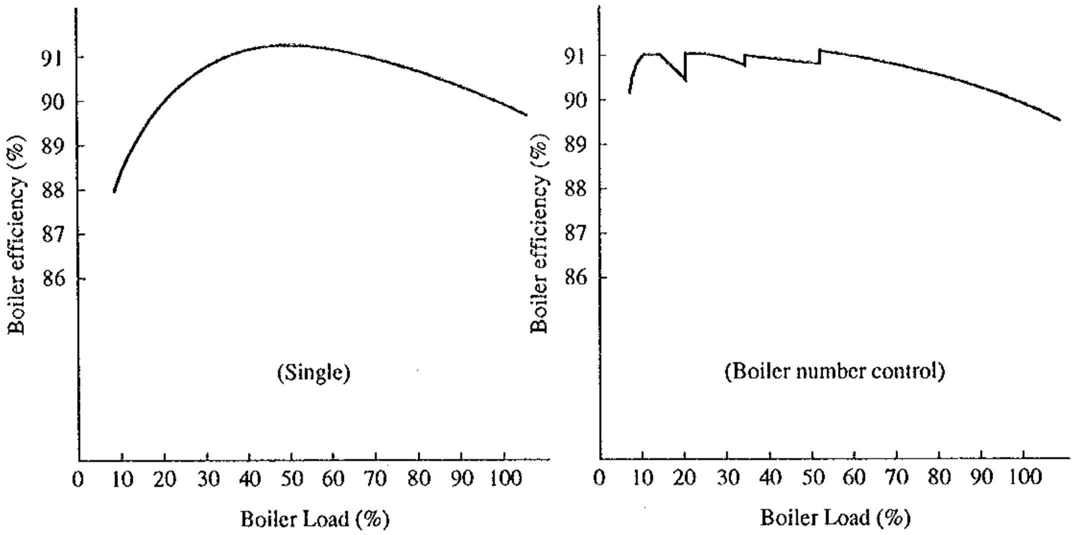


Figure 11.15 Boiler Efficiency Improvement by Operation Number Control



11.6.3 Installation of Proper Capacity Boiler

Installation of an excess capacity boiler causes not only a higher investment but also requires a relatively longer start-up time to the required steam quantity and for much heat loss. In addition to this, when the number of ON-OFFs in operation is increased, the exhaust gas loss due to purge at each operation is increased. In a high-low combustion changeover system boiler, although a proper air ratio is held at a high combustion, it will often be transformed to a higher value at a lower combustion.

For installation of a boiler, a proper capacity boiler should be installed, after saving of steam consumption and control of fluctuation should be taken.

If the capacity of an existent boiler becomes excessive and if the time of a low combustion is longer, an exchange to a small capacity burner may bring about a better result.

11.7 Energy Conservation Measure of Boilers

There are various items for the energy conservation in the boilers as shown in Figure 11.16, the characteristic factor chart. The important points of these items are described below.

11.7.1 Air Ratio

The largest heat loss of boilers is an exhaust gas loss (see Figure 11.17). The exhaust gas loss is determined by an exhaust gas volume and an exhaust gas temperature. A proper air ratio must be kept to minimize the exhaust gas volume.

Figure 11.16 Energy Conservation Items of Boiler

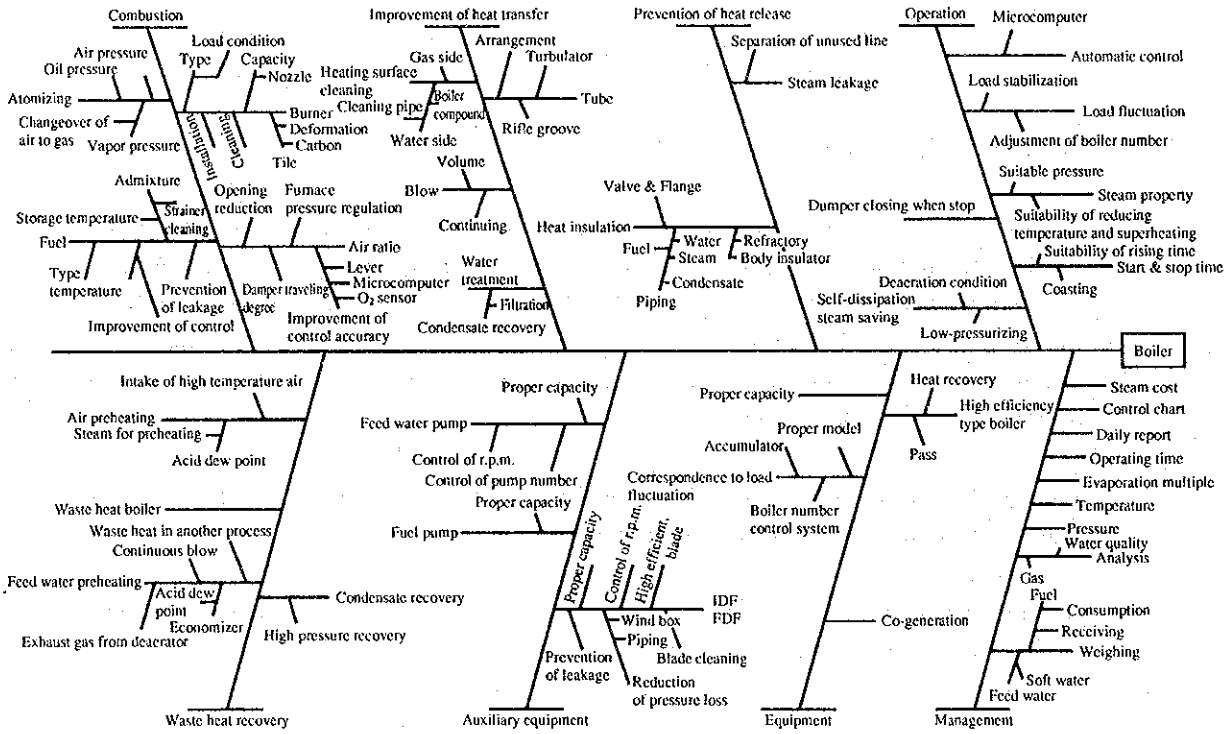
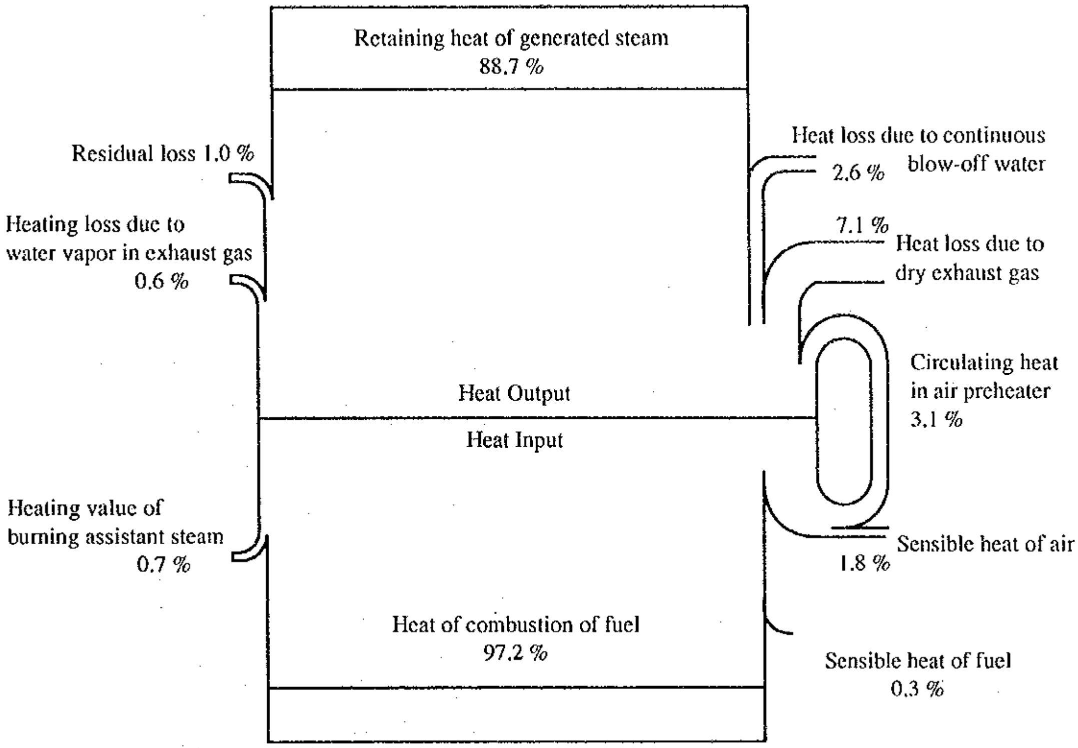


Figure 11.17 Example of 20 T/H Boiler Heat Balance



$$\text{Evaporation multiple} = \frac{13.67 \text{ kg}}{1 \text{ kg} \times 0.93 \text{ kg/L}} \times 1000 = 14.7 \text{ t/kL}$$

Considerable points to maintain the proper air ratio are as follows:

(1) Maintaining of proper fuel oil temperature

Fuel oil should be preheated to 80 – 100 °C to maintain the viscosity of fuel oil within the range of 20 to 45 cSt. (See Figure 11.18).

(2) Inspection and tuning up of burner

- Clogging of oil strainer
- Clogging, abrasion and assembling of burner tip
- The mounting direction of the burner and distance to the burner tile
- Damage of and deposit of carbon on the burner tile
- Oil leakage from the oil valves and the pipe connections

(3) Maintaining of steam pressure for atomization

The steam pressure, air pressure or fuel oil pressure should be maintained to the specified value by the manufacturer to be atomized sufficiently. For the characteristics of oil burners, refer to Table 11.15.

(4) Prevention of air invasion

Prevent air invasion by keeping the furnace pressure properly and reducing the area of the opening parts.

Figure 11.18 Viscosity of Fuel Oil

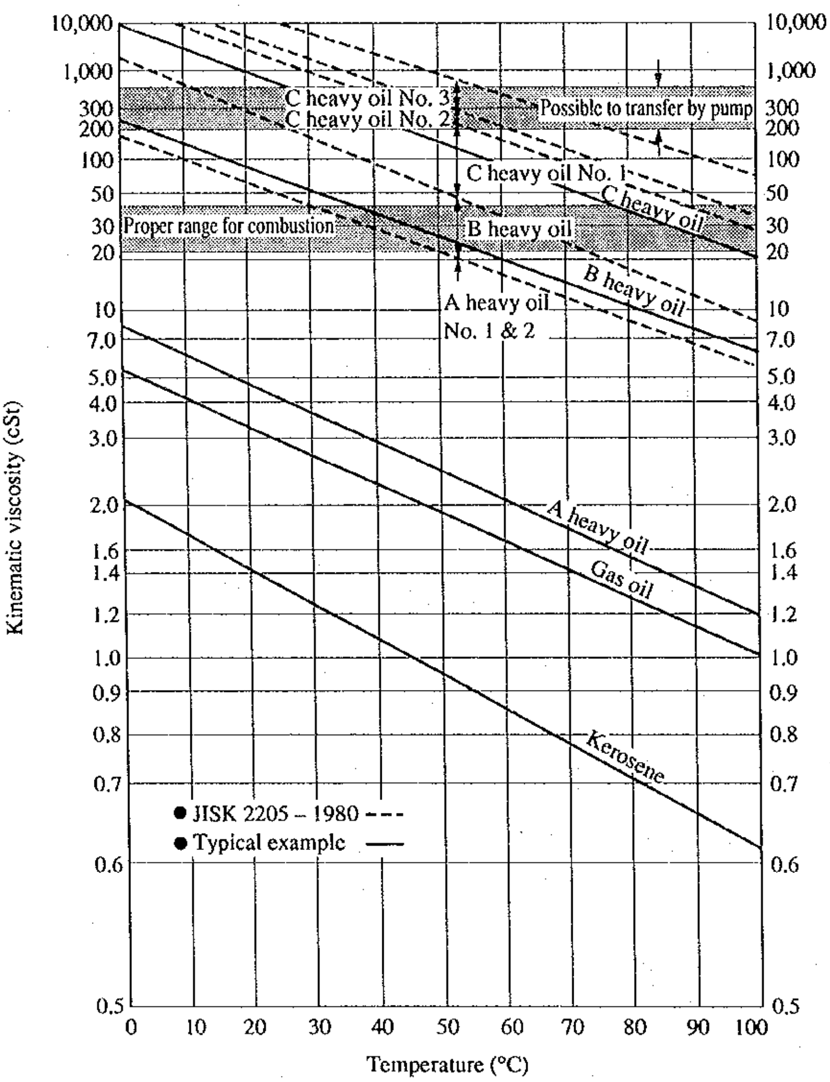


Table 11.15 Characteristics and Application of Oil Burner

		Low pressure air system		High pressure atomizing system		Oil pressure system	
	Unit	Interlock-ing type	Non-interlock-ing type	Internal mixing type	External mixing type	Return oil type	Non-return oil type
Fuel oil amount	L/h	1.5 ~ 120	4 ~ 180	10 ~ 5,000	10 ~ 600	50 ~ 10,000	50 ~ 10,000
Oil pressure	bar	0.4 ~ 1	0.1 ~ 0.3	2 ~ 9	0.2 ~ 1	5 ~ 40	5 ~ 70
Atomizing pressure		mmAq (400 ~ 2,000)	mmAq (400 ~ 2,000)	3 ~ 10 bar	2 ~ 8 bar	–	–
Atomizing medium amount	A m^3_N/kg S kg/kg	2 ~ 3 m^3_N kg	1 ~ 3 m^3_N kg	A 0.2 m^3_N kg S 0.25 kg/kg	A 0.26 m^3_N kg S 0.33 kg/kg	–	–
Atomizing medium		Air	Air	Air or steam	Air or steam		
Combustion air pressure	mmAq	400 ~ 2,000	100 ~ 2,000	0 ~ 250	0 ~ 50	100	100
Combustion regulation range		4 ~ 6 : 1	4 ~ 8 : 1	8 : 1	6 : 1	3 : 1	3 : 1
Flame characteristic		Short flame	Slightly short flame, Long flame	Short flame, Long flame	Slightly long flame	Short flame	Short flame
Merit		Possible for propor-tional control by one lever. Low cost of installa-tion and operation	Easy handling Same as left	Good atomizing Small clogging	Same as left	Low combustion noise Low cost of operation	Same as left
Weakness		Blower required	Same as left	Power cost required	Power cost required	Not respond to load fluctuation High pressure pump required	Same as left
Boiler application	Flue smoke tube	O	O	O	O	O	O
	Once-through			O	O	O	O
	Vertical	O	O		O		
	Water tube	O		O	O	O	O

1 bar = 0.1 MPa

1 mmAq = 9.80665 Pa

(5) Regulation of air

The air ratio can be checked for its appropriateness by an oxygen analysis in the exhaust gas but air must be adjusted by observation of flame and smoke for daily management. The air amount is adjusted with observation of the smoke sent forth from the stack and should be a little more than that under which a slightly black smoke will be emitted.

In fuel oil or kerosene burning, through observation of the flame from the front peep hole, the combustion under conditions that the center of flame is a slightly dark shade and a dazzling flame around it is stable is near to the proper air ratio.

If the air amount drops a little shorter than the proper value, the neighborhood of the flame tip has a tinge of black and soot generates.

On the other hand, if the air is excessive, the flame shortens extremely and becomes like a branch swaying violently. The color of the flame becomes yellow closer to white.

(6) Automatic control

It is the most simple method when the fuel control valve is interconnected mechanically with the air damper and the lever is driven by the control motor of the automatic combustion. But this method is difficult to change the setting of the air ratio during the operation and the air ratio is more likely to be set at a little higher level not to generate black smoke even at a lower loading.

Therefore, there is a method improvement in part of this method.

The example shown in Figure 11.19 has a ratio setting mechanism in the linkage and the O_2 content in the exhaust gas is fed back to adjust the air damper to the O_2 setting by fine adjustment.

The example shown in Figure 11.20 remains the function of linkage and the controller of the revolution of the blower is added to it to adjust the O_2 concentration in the exhaust gas using a setting value suitable to the load.

For a large capacity boiler, a flow controller should be installed for fuel and air respectively to perform a parallel or series cascade control by the steam pressure signal as shown in Figure 11.21.

These controls have little problem under the steady operation, but they do not have a mechanism to prevent black smoke generation which controls fuel or air by preceding air when boiler load increases and preceding fuel when boiler load decreases. Accordingly, these controls have the problem that the air ratio must be set at a little higher level not to generate black smoke even in a load fluctuation.

To dissolve this defect, the example in Figure 11.22 is applied with a cross limit to check fuel or air flow whether to conform to the actual flow of each other: for fuel, the master signal coming from the steam pressure meter is compared with the smoke limit fuel quantity signal obtained by a calculation from the actual air flow, then smaller value is selected as a fuel value. In the air side, contrary to this, the air flow is set to a larger value between the master signal and the smoke limit air quantity signal obtained from the actual fuel flow. Thus, since a control of the air preceding type is done in a load increasing and a control of the fuel preceding type is done in the load decreasing, the air ratio is not required at a large margin.

Even in this method, however, since, at a load rapid decreasing, the air ratio comes temporarily to a higher level, an upper and lower limit mechanism of the air ratio may be attached.

When the fuel component fluctuates, there are some cases in which air flow is controlled more exactly through transmitting the signal to the controller from the O_2 analyzer in exhaust gas.

Figure 11.19 Boiler Air Ratio Controller (1)

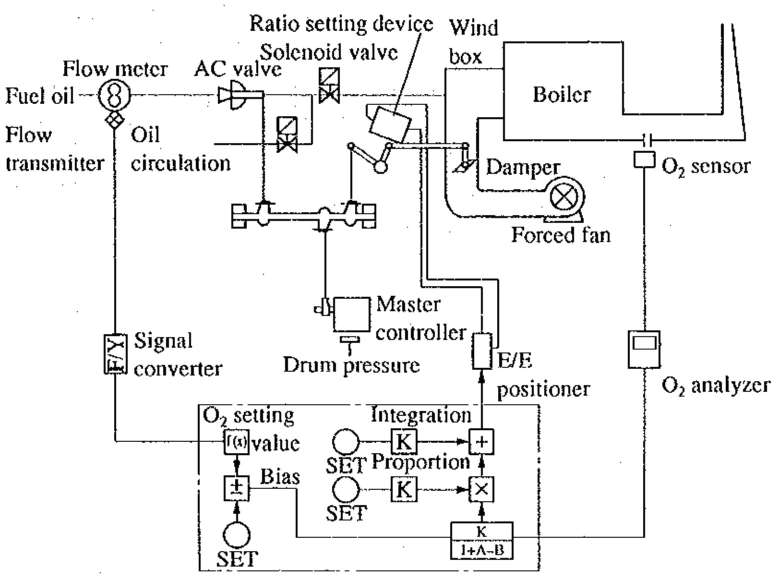


Figure 11.20 Boiler Air Ratio Controller (2)

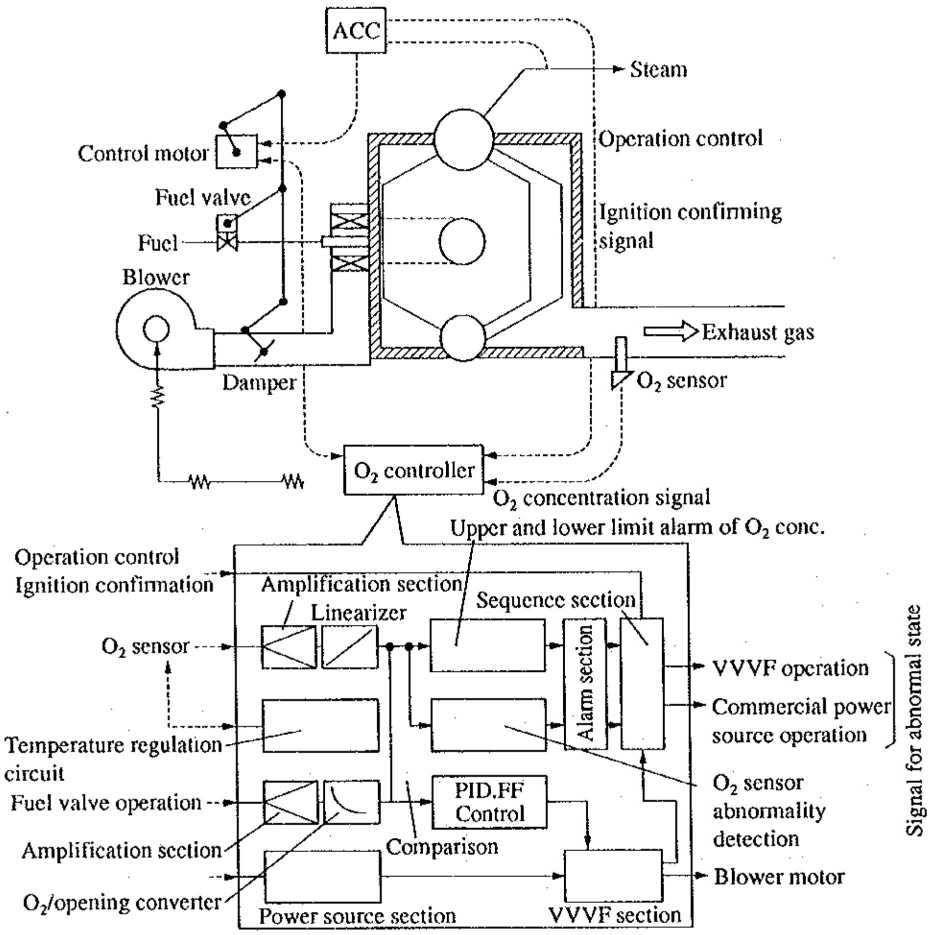


Figure 11.21 Basic Combustion Control System

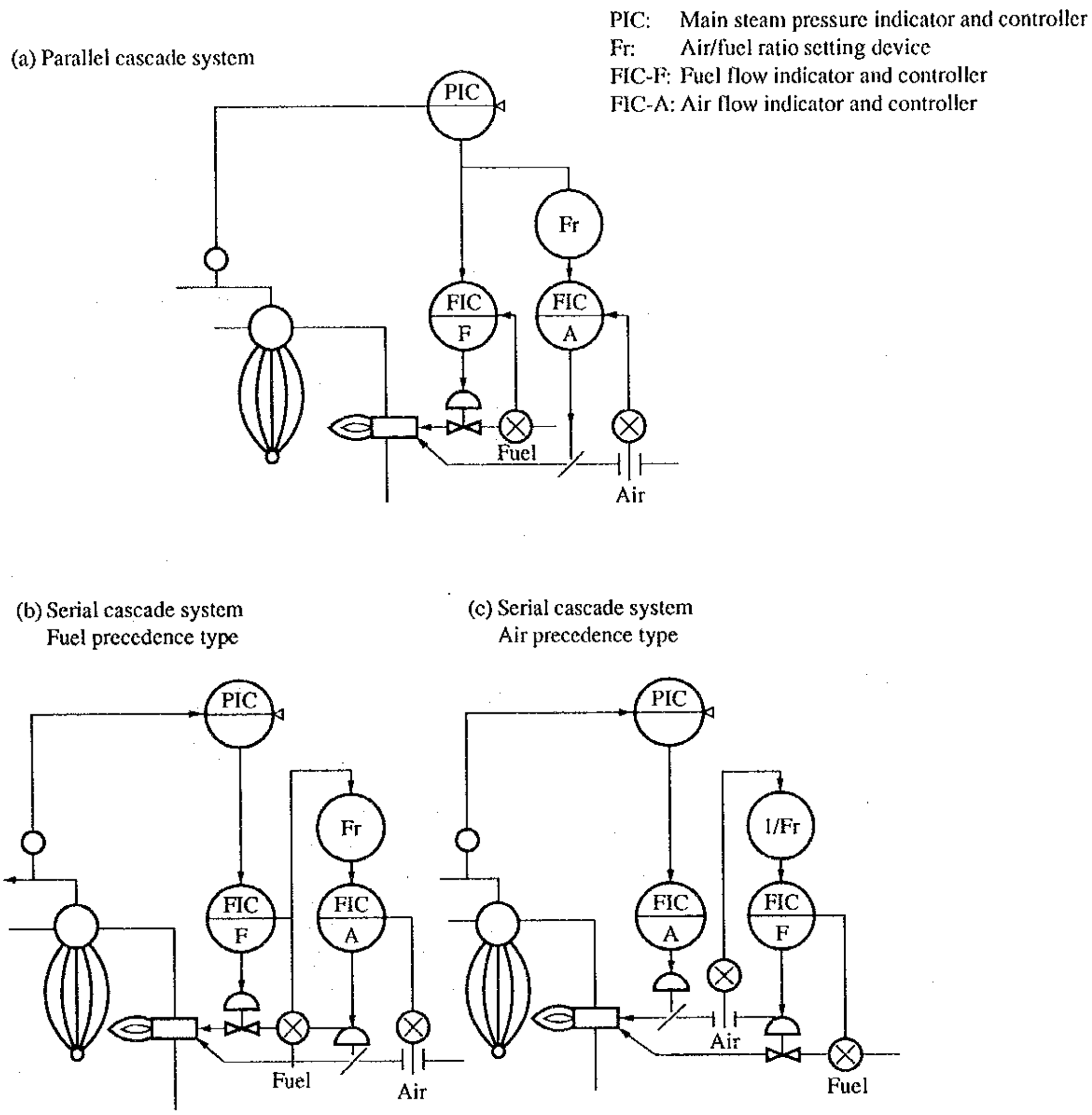
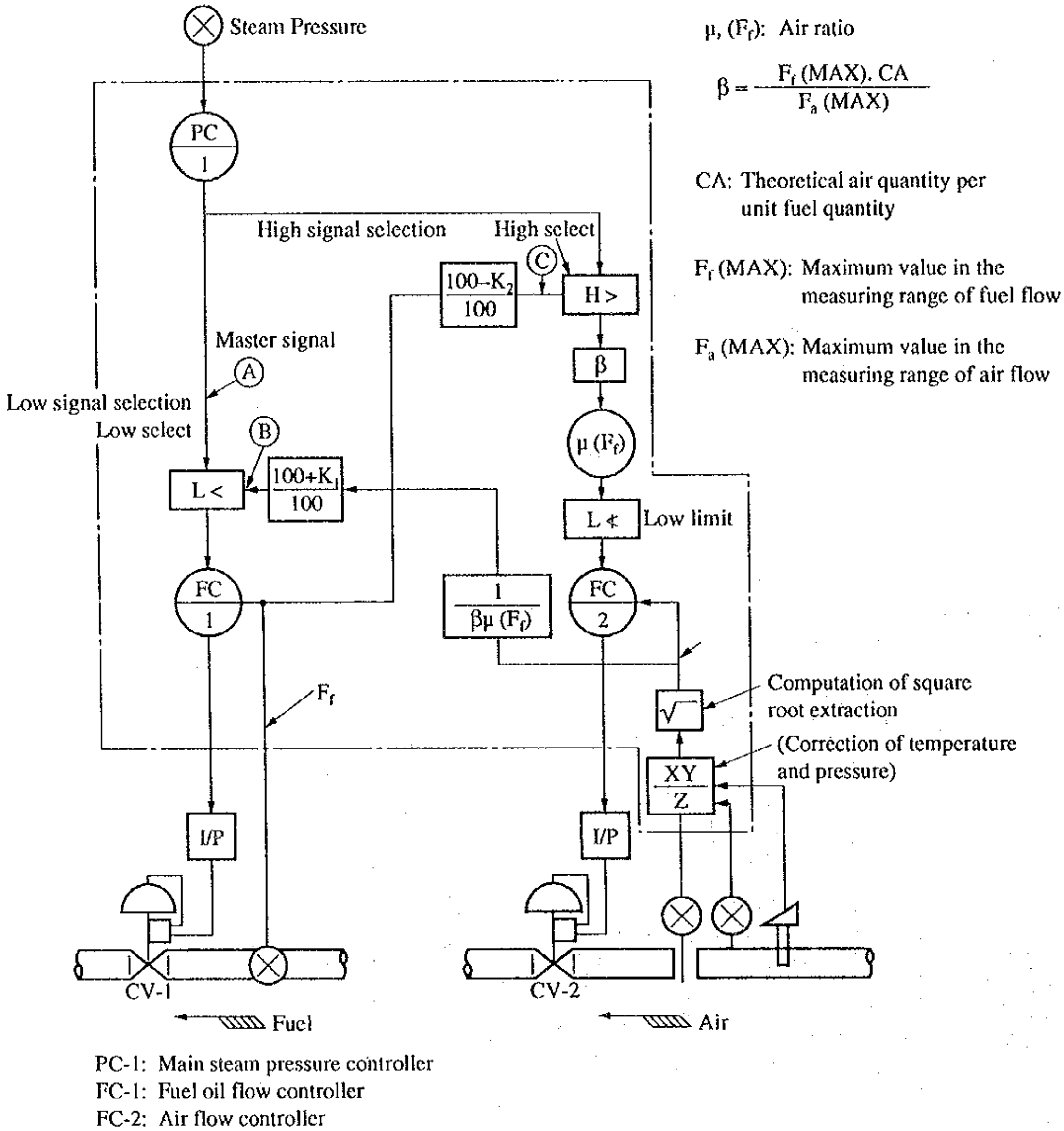


Figure 11.22 Block Diagram of Single Cross Limit Combustion Control System



(7) Standard of air ratio

Since the air ratio is influenced by the type of fuel, the load factor and the composition of control devices, these points must be considered for setting of the standard. The values of Japanese standard are shown in Table 11.16 as reference.

Table 11.16 Standard Air Ratio of Boiler

Classification of evaporation		Load factor (Unit: %)	Standard air ratio				
			Solid fuel		Liquid fuel	Gas fuel	By-product gas from blast furnace, etc.
			Fixed bed	Fluidized bed			
For electric enterprises		75 to 100	–	–	1.05 to 1.2	1.05 to 1.1	1.2
Others	Boilers whose evaporation is 30 ton or more per hour	50 to 100	1.3 to 1.45	1.2 to 1.45	1.1 to 1.25	1.1 to 1.2	1.2 to 1.3
	Boilers whose evaporation is 10 ton to less than 30 ton per hour	50 to 100	1.3 to 1.45	1.2 to 1.45	1.2 to 1.3	1.2 to 1.3	–
	Boilers whose evaporation is 5 ton or more to less than 10 ton per hour	50 to 100	–	–	1.3	1.3	–
	Boilers whose evaporation rate is less than 5 ton per hour	50 to 100	–	–	1.3	1.3	–

Note: The boiler "for electric enterprises" is installed by the electric power companies (those specified in Clause 2.6 of the Electric Enterprises Act. Hereinafter this will also apply.) for the purpose of electric power generation.

These values shall be applied to the operations of load factor in the range shown in the Table and to steady operation.

11.7.2 Exhaust Gas Temperature

(1) Improvement of heat transfer

The thermal conductivities of soot and scale depend on their composition and the deposit situation, and they are of values of no more than 1/100 to 1/1,000 of those of mild steel as shown in Table 11.17. Accordingly, these deposits make the thermal efficiency of boilers decline remarkably as in the case of some insulation on the heating surface (see Figure 11.23 and Figure 11.24).

Table 11.17 Thermal Conductivity of Scale and Other Substance

Scale and other substance	Thermal conductivity (kJ/mh °C)
Soot	0.25 ~ 0.4
Oily matter	0.42
Scale as main component of silicate	0.8 ~ 1.8
Scale as main component of carbonate	1.8 ~ 2.5
Scale as main component of sulfate	2.5 ~ 8.4
Mild steel	170 ~ 250

Figure 11.23 Example of Fuel Loss due to Soot on Heating Surface

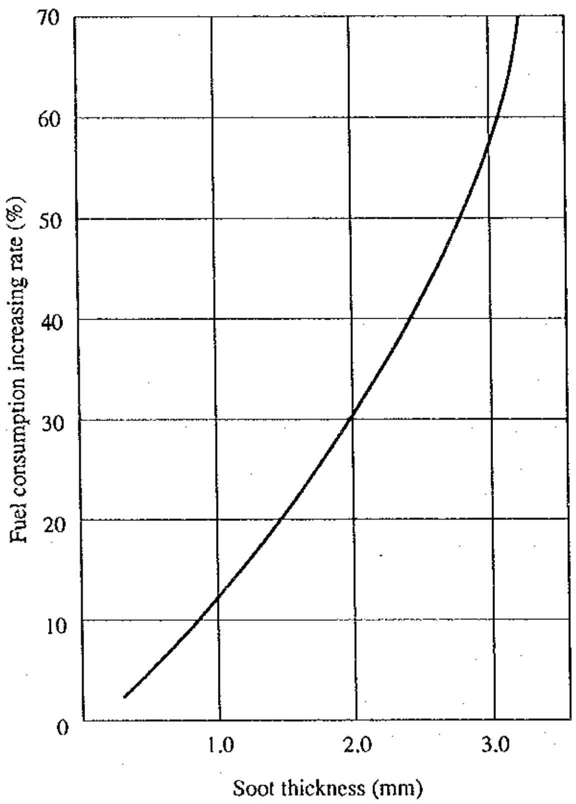
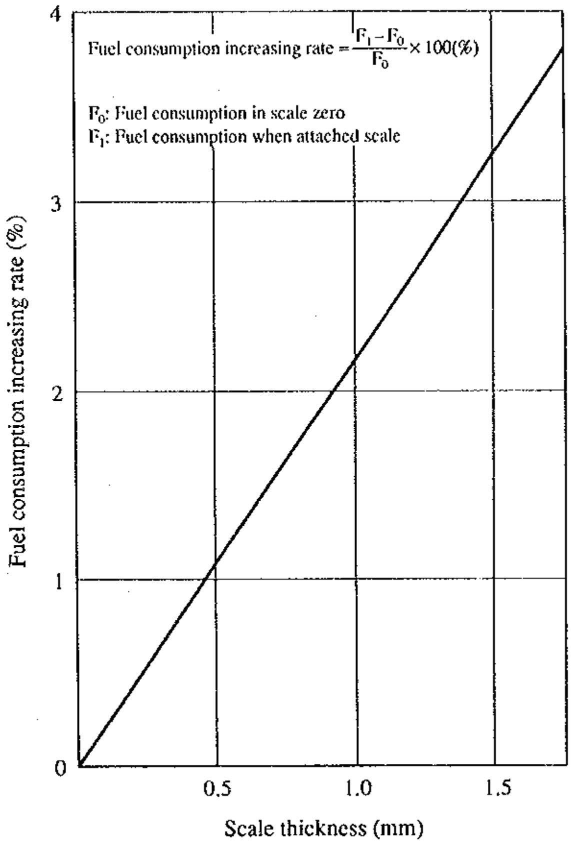


Figure 11.24 Example of Relation between Scale Thickness and Fuel Loss



In order to avoid any hindrance due to the scale, it is required to perform properly a water treatment and a blow and to clean periodically as described in item (3) of paragraph 11.2.3.

Cleaning of the heating surface for the water side should be carried out commonly once per year, though it depends on the degree of the water treatment, by manual cleaning with a brush or by a chemical cleaning of acid containing an inhibitor.

Cleaning of the heating surface for the gas side should be carried out by a brush every month or three months for smoke tube boiler. Even in its period, when the temperature of exhaust gas is higher by 30 °C compared with the temperature just after the cleaning, cleaning is again required. For a water tube boiler, periodic soot blowing is required.

When a flue smoke tube boiler has an enough capacity, a special steel turbulator in the smoke tube is inserted to improve the coefficient of heat transfer by bringing turbulent flow in the gas flow (see item (3) of paragraph 11.7.7).

(2) Recovery of waste heat in exhaust gas

In boilers, it is basic that the exhaust gas temperature does not rise by keeping air ratio in proper values by lessening contamination on the heating surface. If the exhaust gas temperature is higher, the waste heat in the exhaust gas is recovered to preheat the feed water or the air for combustion and the thermal efficiency as a whole should be improved. In general, a large size boiler is often equipped with both an air preheater and a feed water preheater (economizer). A middle or small size boiler is often provided with either of them.

The point to be given attention for recovery of waste heat in the exhaust gas, is corrosion in low temperatures due to sulfuric acid mist in the exhaust gas.

When a fuel containing sulfur is burned, SO_2 is formed and a part of it is converted to SO_3. Accordingly, the temperature of exhaust gas comes to the dew point or less by contact to the low temperature wall of the heat exchanger, SO_3 reacts with water to produce sulfuric acid (H_2SO_4) in a high concentration, which provides corrosion to the heat exchanger or the duct.

The relation between the sulfur content in fuel and the SO_2% in exhaust gas is shown in Figure 11.25, the conversion of SO_2 to SO_3 is shown in Figure 11.26 and the relation between the SO_3 concentration and the dew point of acid is shown in Figure 11.27. In the vicinity of the inlet for a low temperature fluid of the heat exchanger, a low temperature part exists partially. Therefore, the gas temperature must be kept at a higher level than the dew point of acid shown in the figure.

Figure 11.25 Relation between Sulfur Content in Fuel and SO_2 Content in Fuel Gas

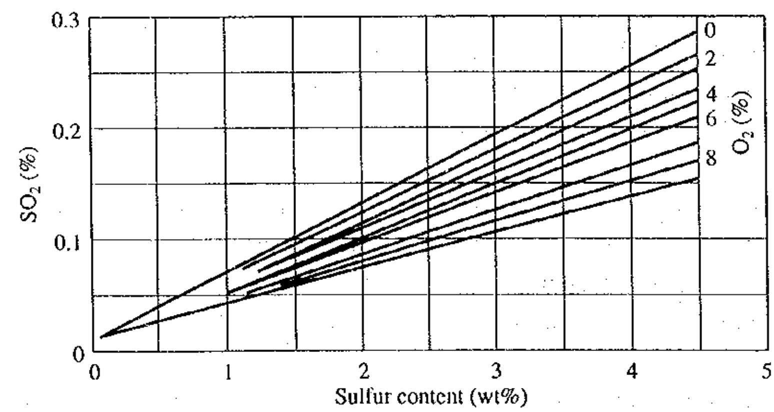


Figure 11.26 Relation between Sulfur Content in Fuel and Conversion Ratio from SO_2 to SO_3

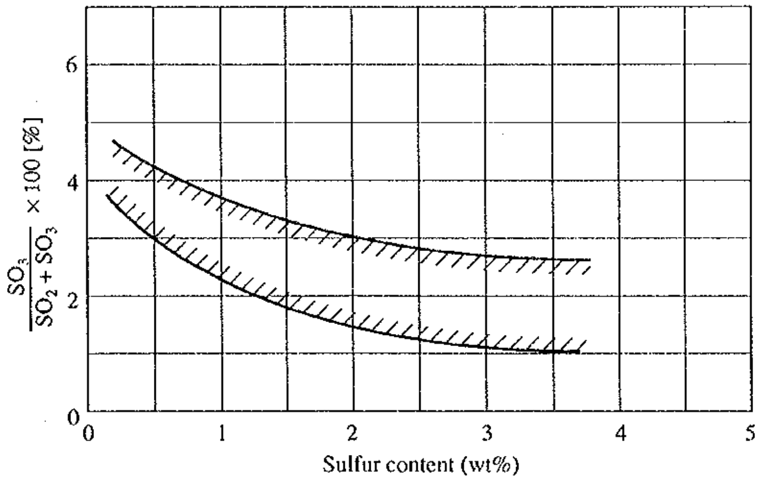
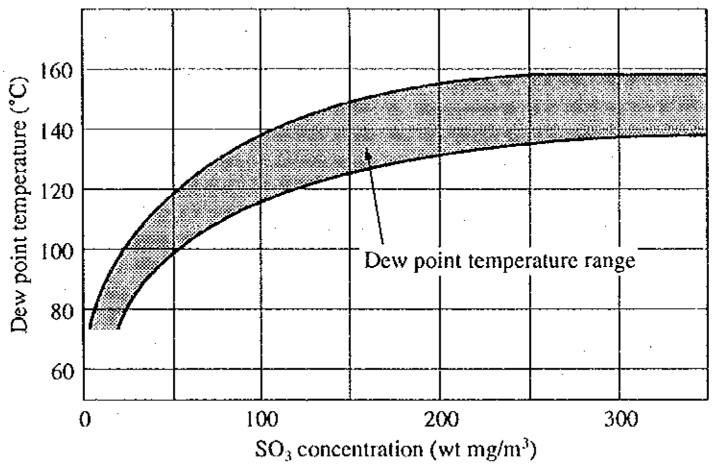


Figure 11.27 Relation between SO_3 Concentration in Exhaust Gas and Dew Point Temperature



To avoid this trouble, some heat exchangers are used with a glass tube or a lead coating tube as the material. As shown in Figure 11.7 in paragraph 11.4 of the heat balance, a measure to prevent overdropping of the gas side temperature of heat transfer surface may sometimes be taken by means of preheating the air with an external heat source prior to feeding the air to the air preheater.

The rising of feed water temperature not only causes a direct increase of the input heat but also it has a merit which makes the thermal stress generated in the drum very low by a small temperature difference between the temperatures of feed water and boiler water in the drum.

The saving rate of fuel due to air preheating is as follows:

Where,

Q :	Carrying-away heat of the combustion gas	kJ/kg-fuel
P :	Carrying-in heat of the preheated air	kJ/kg-fuel
F :	Calorific value of fuel	kJ/kg-fuel
H :	Available heat and required heat = F – Q	kJ/kg-fuel

In a case, where air is not preheated

$H_A = F - Q$

In a case of preheating air

$H_B = F - Q + P = H_A + P$

Taking the required heat of furnace as X kJ/h, the fuel consumption when air is not preheated:

$$\frac{X}{H_A} \text{ kg-fuel/h}$$

When air is preheated:

$$\frac{X}{H_B} = \frac{X}{H_A + P} \text{ kg-fuel/h}$$

Accordingly, the fuel saving rate is as follows:

$$\frac{\frac{X}{H_A} - \frac{X}{H_A + P}}{\frac{X}{H_A}} = \frac{P}{H_A + P}$$

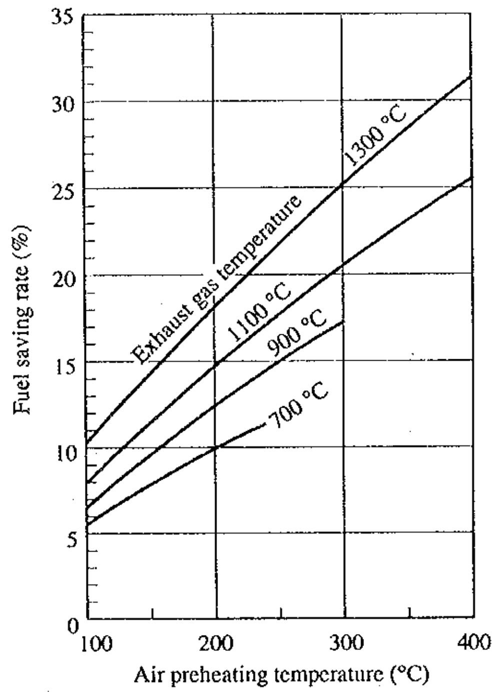
The fuel saving rate in case of 1.2 in the air ratio is shown in Figure 11.28.

The preheating of air brings an energy conservation effect by increasing of the carrying-in heat, a reduction of the air ratio through an improvement of the ignition and stability of the flame and an acceleration of combustion and a rising of the flame temperature.

In the case of an air preheating, however, care must be used to the increasing of NOx generation due to the rising of flame temperature and the heat resistance of the burner.

When an installation of an economizer is planned, it should be overall investigated in comparison with the recovery of condensate, the heat recovery in a continuous blow and the feed water preheating effect by solar energy or utilization of waste heat in other processes. If the feed water temperature has already risen by other heat sources, the economy of an economizer may sometimes drop to a lower level.

Figure 11.28 Fuel Saving Rate due to Air Preheating



(3) Exhaust gas temperature standard

The heat efficiency of boilers is generally at a higher level compared with an industrial furnace and the exhaust gas temperature is also at a relatively lower level. A large size boiler is in a favorable economical condition to equip with a waste heat recovery unit and has the exhaust gas at a lower temperature. A gaseous fuel generally has a lower sulfur content and heat recovery from the exhaust gas comes to extent of lower exit temperature.

In the Japanese exhaust gas temperature standard, the standard of an exhaust gas temperature by capacity and by fuel is determined in consideration of these points as shown in Table 11.18.

Table 11.18 Standard Exhaust Gas Temperature of Boiler (unit: °C)
(Load factor: 100 % at the outer temperature of 20 °C)

Classification of evaporation	Solid fuel		Liquid fuel	Gas fuel	By-product gas
	Fixed bed	Fluidized bed			
Large-sized boiler for electric utilities	–	–	145	110	200
Other boilers					
30 t/h or more	200	200	200	170	200
10 to 30 t/h	250	200	200	170	–
5 to 10 t/h	–	–	220	200	–
< 10 t/h	–	–	250	220	–

This standard value is a temperature in a condition of 20 °C in an ambient temperature and 100 % in a load factor just after the periodical maintenance.

11.7.3 Prevention of Heat Release

Boilers are designed to restrict heat release as much as possible under consideration that most of the heat radiation surface is water or steam part and heat insulation is also generally sufficiently provided.

However, the feed water tubes, valves and flanges around the boiler are sometimes not provided with that insulation.

In the event that hot water such as condensate is recovered into a feed water tank, some examples allow the hot water recovered with much effort to overflow in vain owing to poor level control. If overflow is required, piping should be arranged to allow the low temperature water at the bottom to overflow.

The heat insulation reference of boilers is not shown in the Japanese standard but it is taken to be according to the Japanese Industrial Standards (JIS A9501). In JIS, it is provided to insulate heat with a thickness so that the sum of the fuel cost corresponded to the heat loss from the surface after the heat insulation and the annual amortization for the cost demanded to the heat insulation work is minimized. Namely, it is provided that the heat insulation thickness may be selected to cause the greatest economy according to fuel cost and working cost of insulation.

11.7.4 Energy Conservation of Accessory

For a large scale boiler, an optimization of the capacity of blower and feed water pump should be taken. If most of the operation is under a low load, the number of revolutions should be controlled to reduce the pressure loss at the valve and the damper.

Dust attached on the air preheater and the fan should be cleaned periodically to prevent an increase of pressure loss and a reducing of the efficiency.

11.7.5 Operation

If the use of steam is limited to only day time, a once-through boiler of quick start-up operation is desirable, but for a flue smoke tube boiler, some consideration is needed not to advance the start-up time and to stop beforehand the termination of operation with choosing a time utilizable to the remaining pressure. When the boiler is stopped, the flue damper should be shut down to prevent cooling of the furnace.

11.7.6 Routine Management

To advance the energy conservation of boilers, it must be settled first to provide required instruments and grasp the daily operating situations. Especially the relation between the evaporation and the fuel consumption, that is the evaporation multiple (see paragraph 11.5), should be observed. If a declining of the performance is recognized, its cause should be investigated immediately and an appropriate measure must be taken.

Table 11.19 is a sample of operation records. These items must be recorded for the boiler management. The items such as the evaporation multiple, the feed water temperature, the exhaust gas temperature and O_2% in the exhaust gas should be prepared in chart to know a long-term tendency and these data make use of detection in its early stage of any abnormality. The indication of data is useful to promote the operator's interest to energy conservation.

Table 11.19 Daily Report of Boiler Operation

Manager	Chief operator	Early attendance	Day service	Night service

Date Weather Ambient temperature inside °C Outside °C

Every hour measured matters (Hours should be entered from the bottom to the upper.)

Hours	Pressure MPa	Feed water temperature °C	Feed water quantity: Meter reading	Feed water quantity: Consumption L	Fuel oil quantity: Consumption L	Fuel oil quantity: Meter reading	Fuel oil temp.: Service tank °C	Fuel oil temp.: Heater outlet °C	Oil pressure: Primary MPa	Oil pressure: Secondary MPa	Exhaust gas temperature °C	Exhaust gas % CO_2	Furnace pressure Pa	WB static pressure Pa	Outlet static pressure Pa
				(A)	(B)										
				(Take care to the ratio, Example: 13:1)											
			Reading in previous day		Reading in previous day										

	Item	Result: Good	Result: No	Checker	Reference
Daily inspection	Relief valve				
	Water gage blowing				
	Automatic feedwater regulator				
	Low water Level Governor: 1st step, 2nd step, 3rd step				
	Flame detector				
	Combustion state				
	Firing equipment				
	Feedwater device				
	Automatic controller				
	Control interlocking devices				
Total	Feedwater quantity (A)			L/d	
	Fuel oil quantity (B)			L/d	
	Evaporation multiple A/B			L/L	
	Boiler efficiency			%	
	Operating time			h	
Fuel	Carry-over			L	
	Today receiving quantity			L	
	Stock			L	

Boiler water blowdown

Blowing time	Pressure bar	Blowing quantity L
Continuing blow		
Total blowing quantity		

Cleaning agent

Chemical name	Input g	Input hour

Chemical pouring device

Previous day	Today	Pour

Water softener

Reading in previous day	
Previous meter reading	L
Today's meter reading	L
Treating water quantity	t
Basic cycle	t
NaCl quantity	kg
Hardness analysis	Good or no

Boiler water

Sampling	Pressure MPa	State of boiler Before and after blowing
Yes		
No		

Water quality test

	Item	Unit
Feed water	pH	—
	Conductivity	$\mu\Omega$/cm
	Chloride ion	ppm
	Hardness	ppm
Boiler water	pH	—
	Conductivity	$\mu\Omega$/cm
	Chloride ion	ppm
	Hardness Phosphate ion	ppm

Description:

11.7.7 Example

(1) Feedwater preheating with waste heat in other processes (Petrochemical plant)

In an ethylene manufacturing process, the water used for cooling of the process fluid has been discharged at a temperature of 63 °C with 1,500 t/h. The water has been cooled to 35 °C in a cooling tower and has been used again for cooling.

On the other hand, the boiler in the adjoining plant has preheated air to 60 °C in a preheater with steam to prevent a low temperature corrosion of the air preheater.

The persons in charge of both plants have taken notice of this point, arranged a pipe between both plants, installed a hot water system air preheater and disused the steam system preheater.

The results saved the steam for preheating of 13 t/h. The investment cost was 70 million yen. The saved cost of fuel was 330 million yen a year. The investment fund recovery period was 3 months.

(2) Improvement of boiler air ratio (Building material manufacturer)

The heat balance of a boiler (30 t/h) which burns fuel oil was as follows:

• Boiler efficiency	87 %
• Exhaust gas loss	8 %
• Steam loss for atomization	1 %
• Heat release and others	4 %

Various tests were carried out by changing the air ratio automatic controller to a manual operation in order to try to reduce the exhaust gas loss. The result proved to be possible to reduce from 5.0 % of the conventional O_2 % limit to 3.0 %. As a result, O_2 has been reduced to 3.0 %

a. by replacing to a microcomputer control system which can cope with a load fluctuation and

b. by installation of a zirconia system O_2 analyzer which is a low time delay.

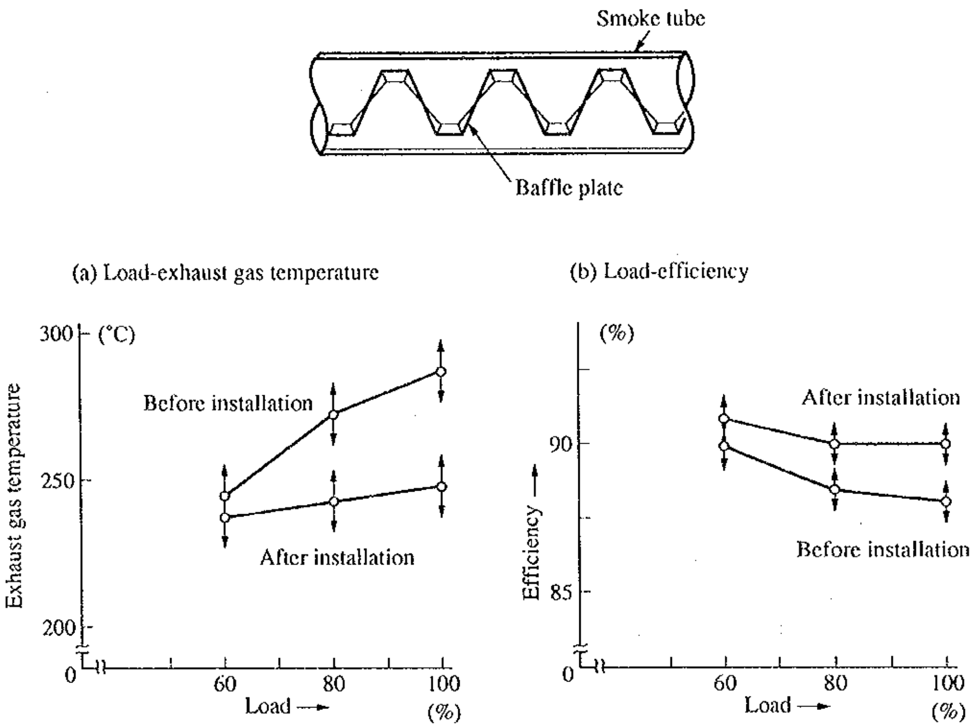
Since the opening of the damper for the forced draft fan was a low degree of 10 to 20 %, the revolution control by inverter was carried out.

As a result, fuel oil was reduced by 37.5 kL/year, power was reduced by 145×10^3 kWh/year, the merit was 5.15 million yen/year and the investment cost was recovered in about one year.

(3) Heat transfer improvement of smoke tube (See Figure 11.29)

A special steel turbulator was inserted in the smoke tube of a flue smoke tube boiler (6 kg/cm^2 (G), 7 t/h) which burns fuel oil and the heat transfer was improved by giving a turbulent flow to the gas flow in the smoke tube. As a result, the boiler efficiency was improved from 87.5 % to 89.7 %.

Figure 11.29 Turbulator Insertion Effect



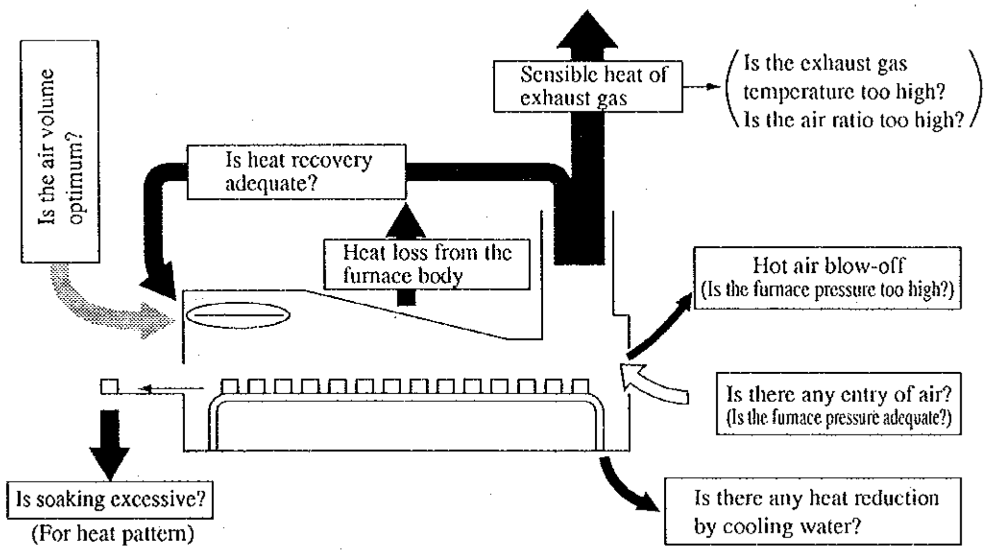
12. ENERGY CONSERVATION IN HEATING FURNACES

12. HEATING FURNACE

This chapter describes general key points for energy conservation for combustion type heating furnaces. Although there are also heating furnaces that use electricity as the heat source instead of combustion system, they are not taken up here.

Figure 12.1 shows important points in energy conservation for heating furnaces.

Figure 12.1 Key Points in Energy Conservation for a Heating Furnace



12.1 Air Ratio (Reduction of exhaust gas volume)

If air more than required is supplied for complete combustion, heat loss due to the exhaust gas increases. The value of the actual air volume represented in units of the air volume for complete combustion is referred to as air ratio and therefore, the air ratio is 1 for theoretical combustion. Actually, the theoretical air volume alone can hardly achieve complete combustion of the fuel. In this case, CO is generated in the combustion exhaust gas and the corresponding heat quantity constitutes the loss.

For the gas fuel, fuel consumption is said to be smallest when CO in the exhaust gas is approximately 200 ppm.

If oxygen content and CO content in the exhaust gas are measured, the air ratio, heat loss due to the exhaust gas, and fuel amount that can be saved when the air ratio is adjusted can be obtained through calculation of combustion. Calculation of combustion, as a spreadsheet, is provided along with "V. Measurement Manual". Its handling is provided in "V. Measurement Manual", which is used for reference. Table 12.1 shows the values assumed for calculation of combustion.

Table 12.1 Assumed Values for Calculation of Combustion

Gas content		Wet volume
CO		0.0 %
CO_2		0.1 %
H_2		0.0 %
CH_4		97.9 %
C_2H_4		0.0 %
C_2H_6		0.4 %
C_3H_8		0.1 %
C_4H_{10}		0.1 %
N_2		1.4 %
O_2		0.0 %
H_2O		0.0 %
Fuel temperature	°C	28
Air temperature	°C	28
Atmospheric temperature	°C	28
Relative humidity		60 %
Gas density	kg/m³	0.730
Calorific value Net	kcal/m³	8,487
	kJ/m³	35,525
Calorific value Gross	kcal/m³	9,416
	kJ/m³	39,414

Since measurement of the exhaust gas is expressed by contetns of oxygen and CO, various characteristics of combustion calculation can be directly represented by using oxygen in the exhaust gas as a variable. If the air ratio is used as a variable as shown later, many characteristics are linearly represented. Thus, various characteristics are represented in this section by using the air ratio obtained from oxygen in the exhaust gas as the horizontal axis.

12.1.1 Oxygen in Exhaust Gas and Air Ratio

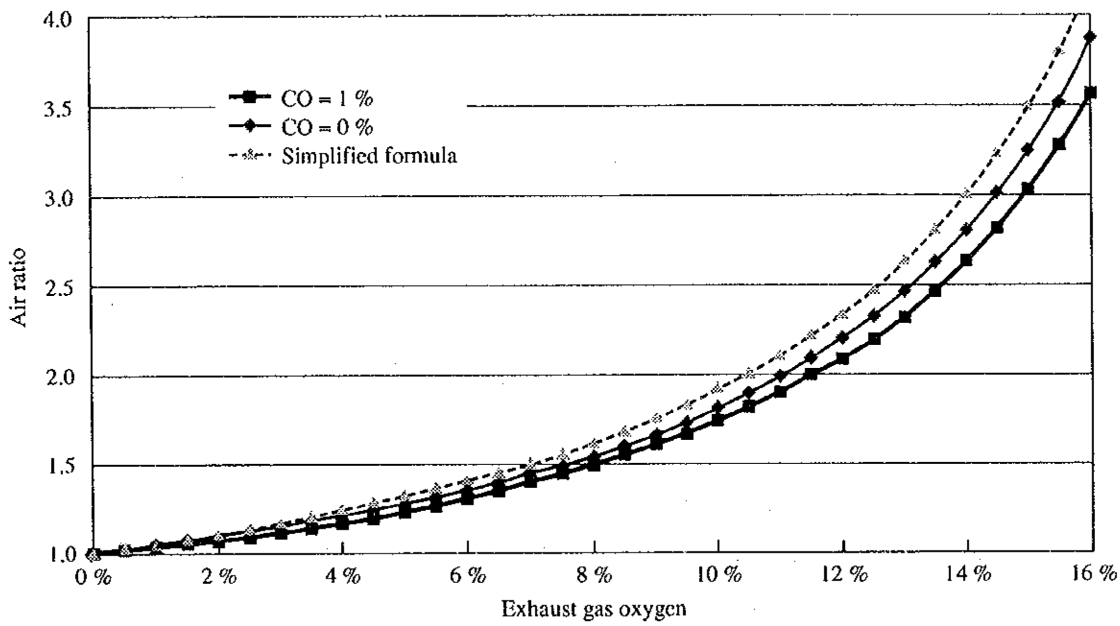
For the gas fuel, if the fuel composition is known, oxygen and CO contents in the combustion exhaust gas are measured and then the air ratio can be obtained by calculating them. As a simplified formula, the following formula is proposed to obtain the air ratio directly from oxygen concentration in the exhaust gas:

$$\text{Air ratio} = 21/(21-(O_2))$$

where (O_2) represents oxygen content in the exhaust gas (%).

Figure 12.2 shows the result of calculating the oxygen concentration in the exhaust gas and air ratio assuming the fuel as natural gas (assuming CO to be zero). This figure shows the value obtained through the simplified formula indicated above as well as the calculated value.

Figure 12.2 Air Ratio by Exhaust Gas Oxygen



In the case of this fuel, as shown in this figure, there is no significant difference between the result of calculation based on fuel components and that obtained from the simplified formula based on oxygen content alone in the exhaust gas. This figure also shows the calculated value for the case in which CO content is 1 % in the exhaust gas. The effect of CO content on the air ratio is small unless oxygen content is extremely large.

Figures 12.3 and 12.4 show the cases where the exhaust gas volume and air volume are represented by oxygen content in the exhaust gas and by the air ratio, respectively.

Figure 12.3 Air, Exhaust Gas and CO_2 by Air Ratio

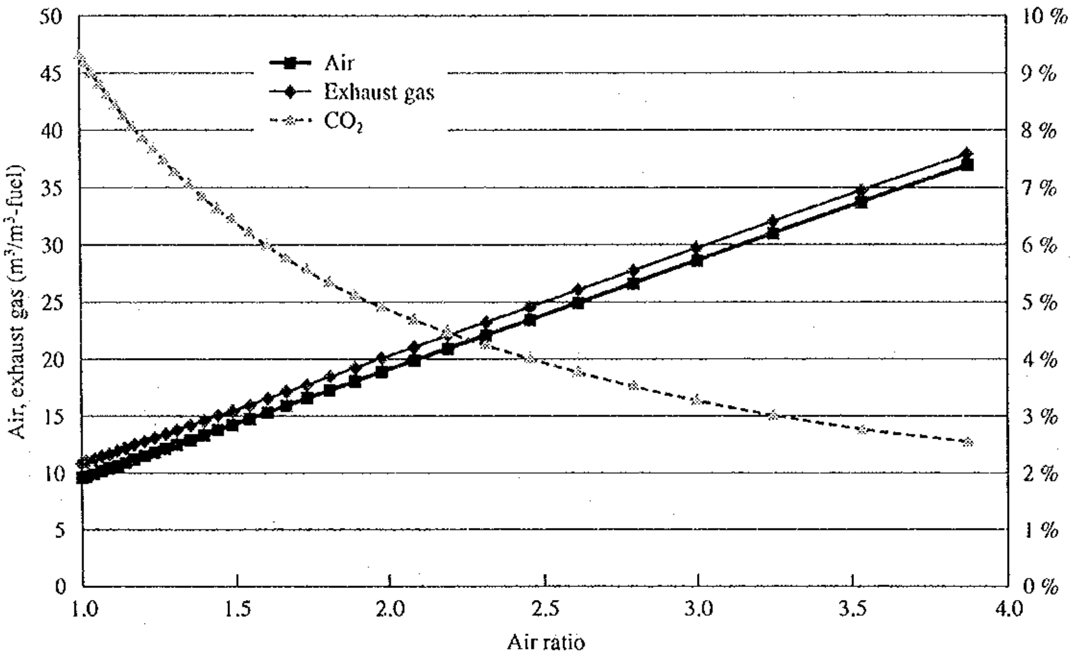
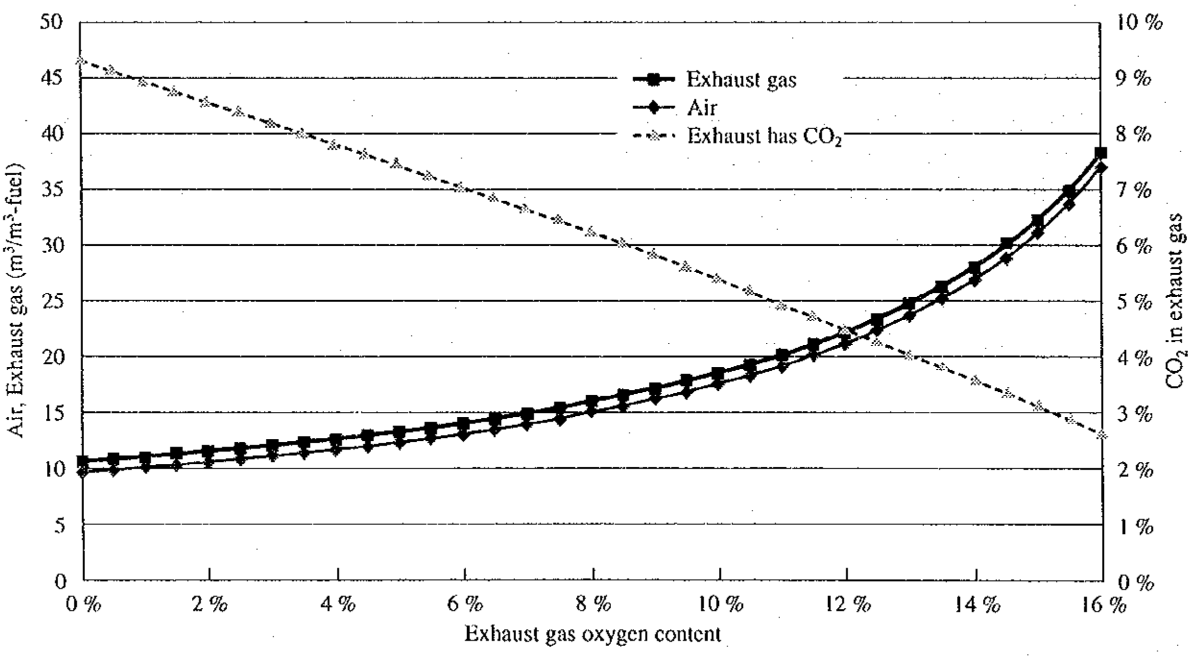
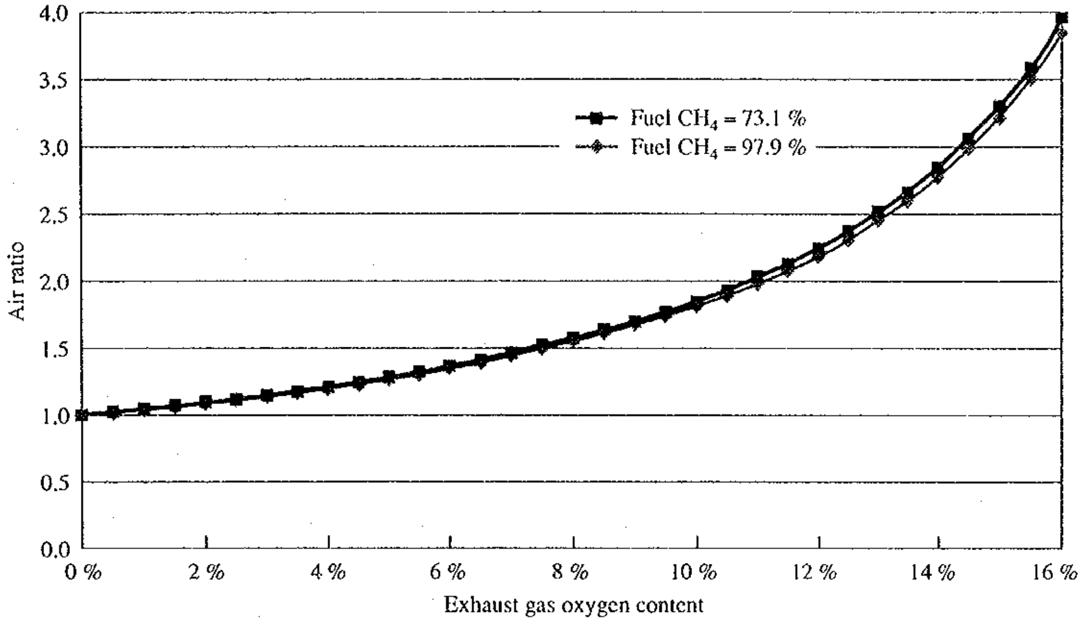


Figure 12.4 Air, Exhaust Gas and CO_2 by Exhaust Gas Oxygen Content



Although the relationship between the oxygen content in the exhaust gas and air ratio depends on the fuel contents in calculation, its effect is actually small. Figure 12.5 shows the result of calculation for different gas fuels.

Figure 12.5 Air Ratio by Exhaust Gas Oxygen Content with Fuel Composition



12.1.2 Exhaust Gas Loss

Exhaust gas loss is a value obtained by multiplying the exhaust gas volume, exhaust gas temperature, and the specific heat of exhaust gas. Among them, as shown in Figure 12.3, the exhaust gas volume is greatly affected by the air ratio. Therefore, the fuel intensity is improved by reducing the air ratio. Also reduction in the air volume allows the power for the blower to be reduced if a blower is used for combustion air.

12.1.3 Fuel Reduction through Reduction of Air Ratio

If it is assumed that the exhaust gas temperature does not vary even when the air ratio is adjusted, reduction of fuel consumption as a result of reducing the air ratio can be calculated with the heat balance formula. Figures 12.6 and 12.7 show the calculation results.

Figure 12.6 Fuel Saving by Adjusting the Air Ratio (Exhaust gas temperature = 400 °C)

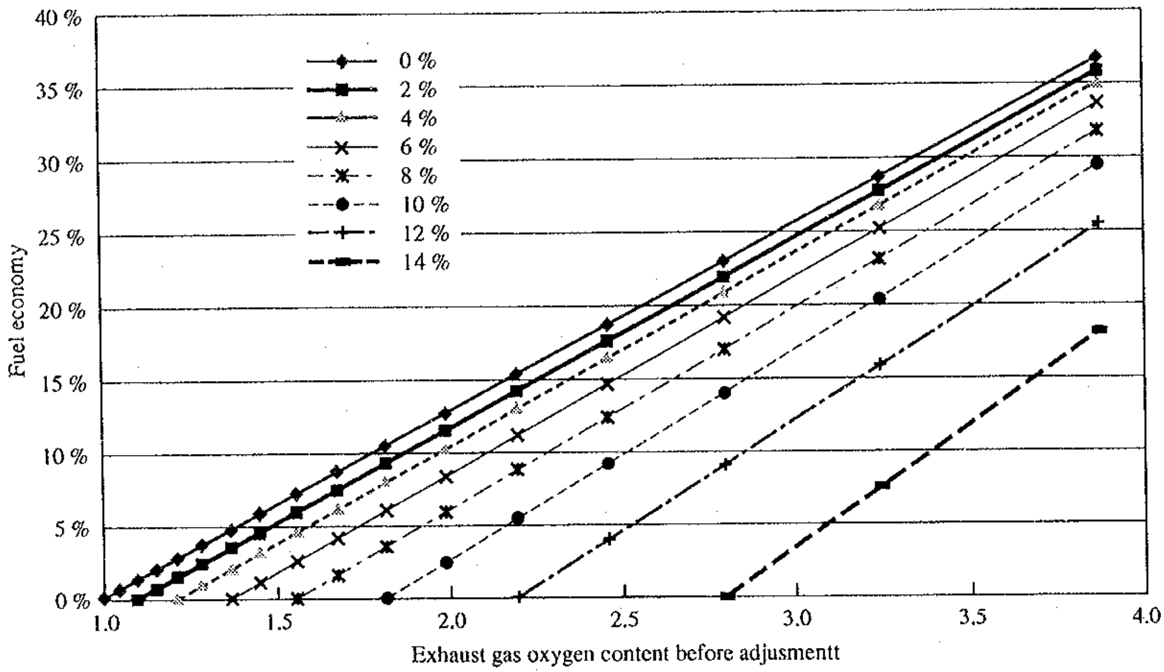
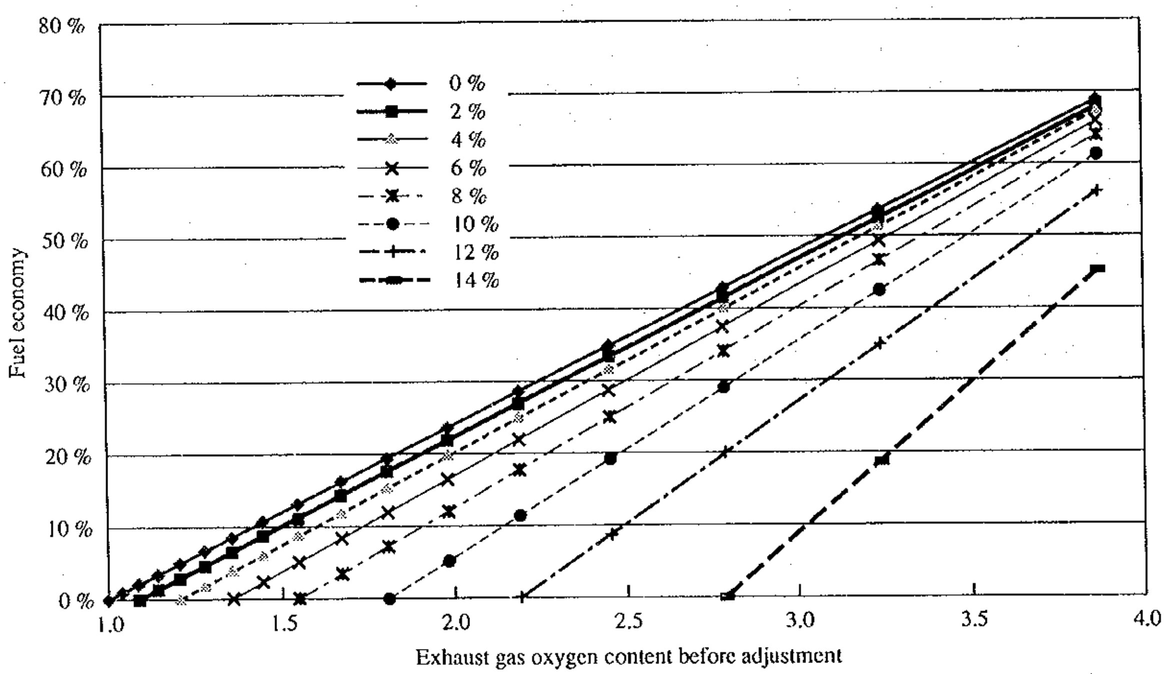


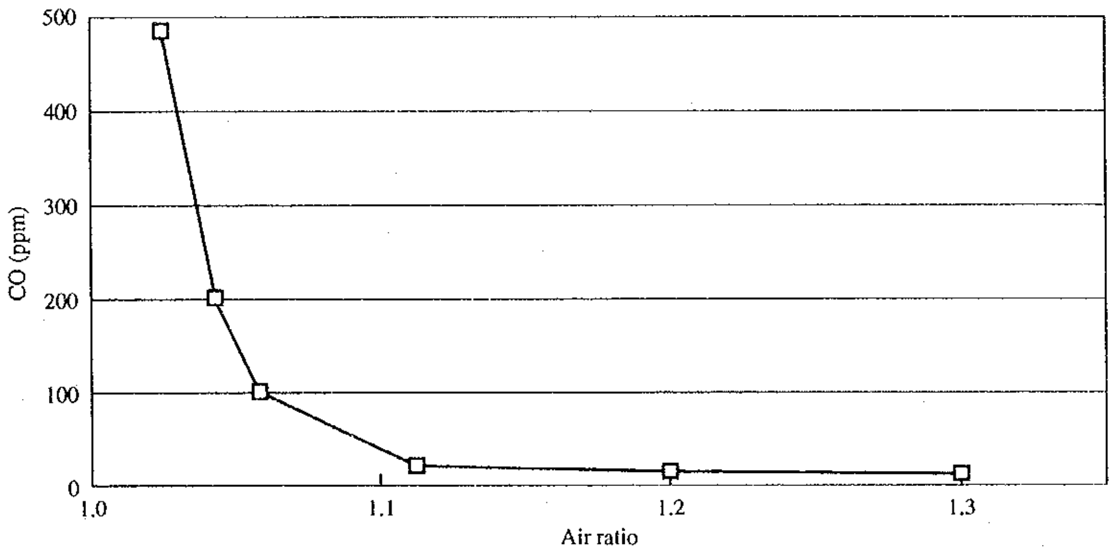
Figure 12.7 Fuel Saving by Adjusting the Air Ratio (Exhaust gas temperature = 600 °C)



As shown in Figures 12.6 and 12.7, the effect of fuel savings through air ratio control is more noticeable as the air ratio is larger and the exhaust gas temperature is higher.

Air ratio should preferably be 1 for theoretical combustion; however, CO is generated to cause heat loss due to non-combustion to arise actually if the air ratio comes closer to 1. Although the relationship between CO generation and the air ratio cannot simply be represented, an example of the relationship is shown in Figure 12.8

Figure 12.8 Example of Air Ratio and CO Generation



For boilers that use gas combustion, it is said that the highest efficiency is attained when CO is 200 ppm.

12.1.4 Standard for Air Ratio in Japan

In Japan, the air ratios for industrial furnaces are numerically specified for the judgment criteria specified in the Energy Conservation Law. The specified values are divided into the "standard value" and "target value". The standard value is the one that should be achieved by most of "designated energy management factories" (i.e. factories that consume a large amount of fuel). On the other hand, the "target value" should be used as the value achieved in future through modification/new construction of the facility. (See Table 12.2.)

Table 12.2 Standard Values and Target Values of Air Ratio Specified by the Law

Categories	Type of furnace operation				Remarks
	Continuous operation		Batch operaiton		
	Standard	Target	Standard	Target	
Melting furnace for metal casting	1.3	1.25	1.4	1.3	
Continuous reheating furnace for steel	1.25	1.2	–	–	
Metal heating furnace except continuous steel reheating	1.25	1.2	1.35	1.3	
Metal heat treatment furnace	1.25	1.2	1.3	1.3	
Petroleum heating furnace	1.25	1.25	–	–	
Heat cracker, reformer	1.25	1.25	–	–	
Cement kiln	1.25	1.25	–	–	
Lime kiln	1.30	1.25	1.35	1.35	
Dryer	1.30	1.3	1.5	1.5	Only for burner

12.1.5 Actual Condition of Air Ratio in Japan

The Energy Conservation Center, Japan conducted a survey on the energy management status in 1992 through questionnaires to large-scale factories in Japan. The focus of the investigation was placed on the designated energy management factories specified in the Energy Conservation Law in Japan. A questionnaire was sent to each of 3,500 factories and answered by 2,200 of these factories.

Figures 12.9 to 12.12 show the results of picking up air ratios (actual operation values) for heating furnaces and rearranging them by heating furnace type. Since the uses and fuels are different even for the same heating furnace type, the air ratios show a wide range of distribution but they will be useful as data representing the actual status.

Figure 12.9 Air Ratio Distribution (Metal heating furnace of 315 units)

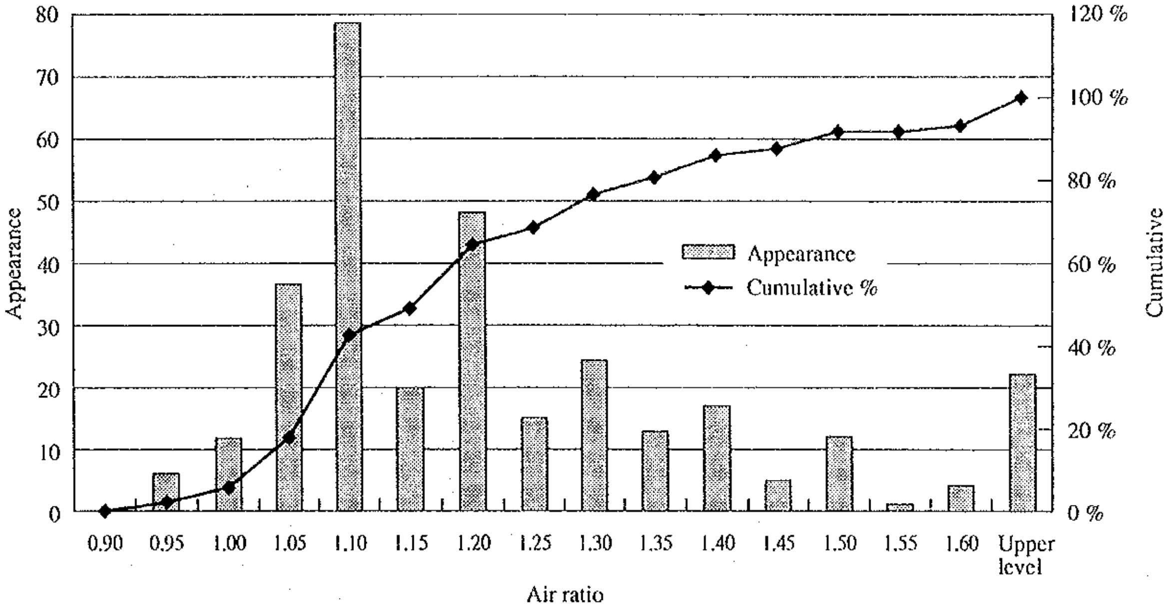


Figure 12.10 Air Ratio Distribution (Metal heat-treatment furnace of 264 units)

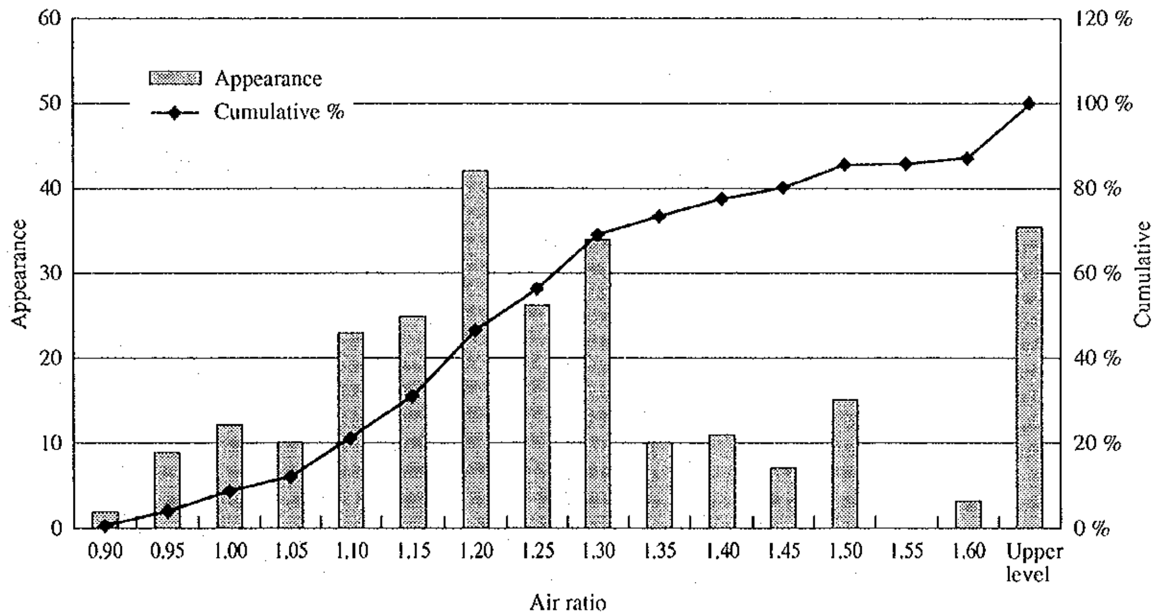


Figure 12.11 Air Ratio Distribution (Ceramic industry furnaces of 431 units)

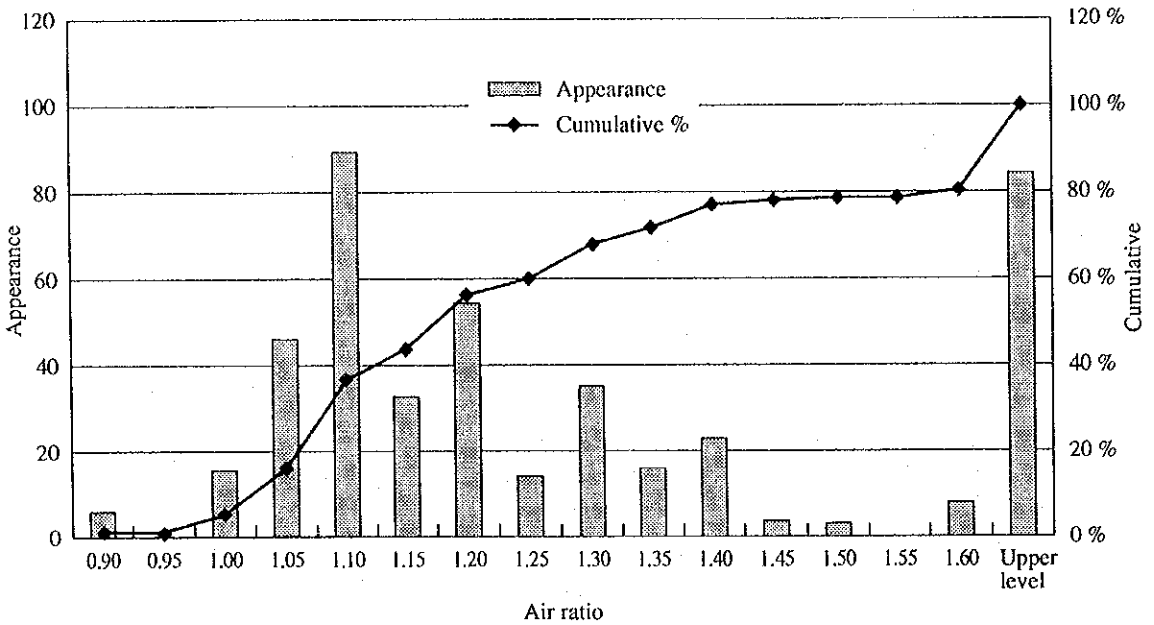
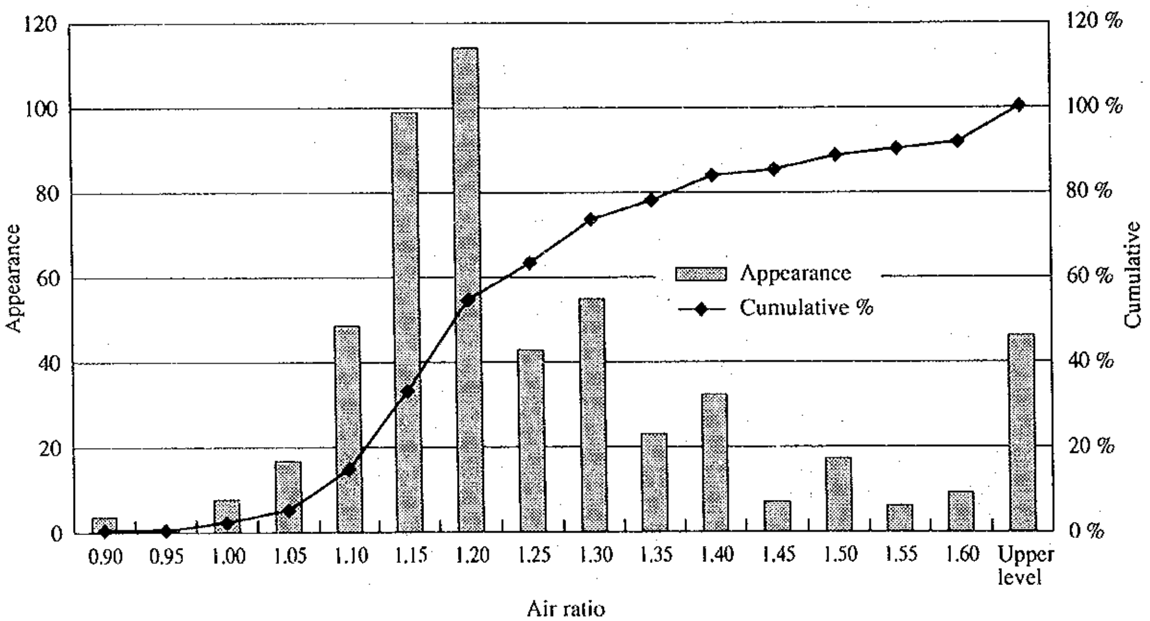


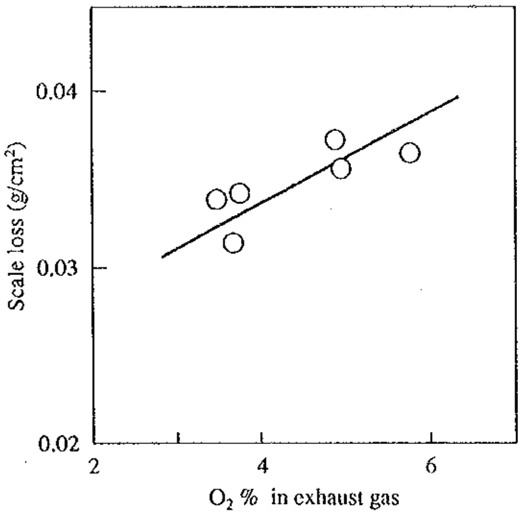
Figure 12.12 Air Ratio Distribution (Chemical industry furnaces of 530 units)



12.1.6 Amount of Scale Generated

The oxidized scale generated on the surface of a steel product when it is heated may be associated with the oxygen in the combustion gas, heating temperature, and period during which the steel product is present in the furnace. Therefore, keeping the air ratio small reduces scale generation and improves the yield of steel products. Figure 12.13 shows an example of relationship between oxygen in the exhaust gas and scale loss.

Figure 12.13 Relationship between Air Ratio and Scale Loss (Fuel oil-fired, heating time: 120 minutes)

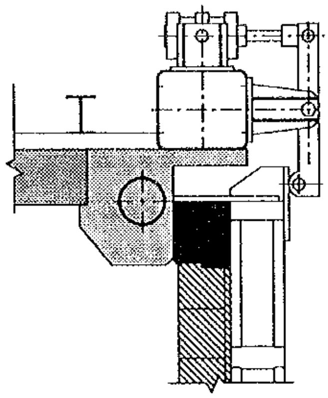


12.1.7 Invasion of Outside Air into the Exhaust Gas Line

If cold outside air enters the high-temperature flue between the combustion zone in the furnace and the air preheater, the exhaust gas temperature drops to reduce heat recovery by the air preheater. For example, there is air invasion through the material charging hole on the continuous heating furnace. If the air ratio is measured at two points in the flow of the exhaust gas, the difference between the air ratio values indicates outer air invasion between the two points. If the air ratio before the air preheater is compared with that after the air preheater, air leak from the air preheater (i.e. leak from the air side to the exhaust gas side) can be known.

Such air leak lowers the preheated air temperature and results in loss of the blower power, and thus the optimum maintenance timing should be grasped through measurement of air leak. Cold air enters through the charging door on a batch type forging furnace as well. To enhance sealing at this part, the charging door should be pressed on the furnace body by air pressure cylinders. Figure 12.14 shows an example.

Figure 12.14 Example of Pressing the Door to the Furnace Body by Air Cylinder



Source: Handbook for Industrial Furnaces
(published by The Energy Conservation Center, Japan)

12.2 Decreasing the Exhaust Gas Temperature

As explained earlier, the exhaust gas loss is a product of the exhaust gas volume and exhaust gas temperature. Therefore, the exhaust gas loss can also be reduced by decreasing the exhaust gas temperature.

12.2.1 Fuel Saving by Air Preheating

If the combustion air is preheated by the heat exchanger using the high-temperature exhaust gas from the furnace, an additional amount of heat is supplied to the furnace, thereby reducing the amount of fuel required. Such a heat exchanger is called recuperator. The resulting fuel saving effect can be obtained through calculation using the heat balance. This fuel reduction rate (i.e. rate of the fuel reduction effect against the fuel before preheating) differs depending on the preheated air temperature and oxygen content in the exhaust gas (air ratio). This means that the fuel-saving rate becomes larger as the air ratio is higher and the exhaust gas emission is larger during the operation even when the air preheating temperature is constant. Figures 12.15 and 12.16 show examples of calculation results. As is evident from Figure 12.15 and Figure 12.16, the fuel-saving rate is larger as the exhaust gas temperature is higher even for the same air preheating temperature, that is, as the operation is less efficient. This suggests the importance of heat recovery from the exhaust gas.

Figure 12.15 Fuel Saving by Air Preheating (Exhaust gas temperature before preheating: 400 °C)

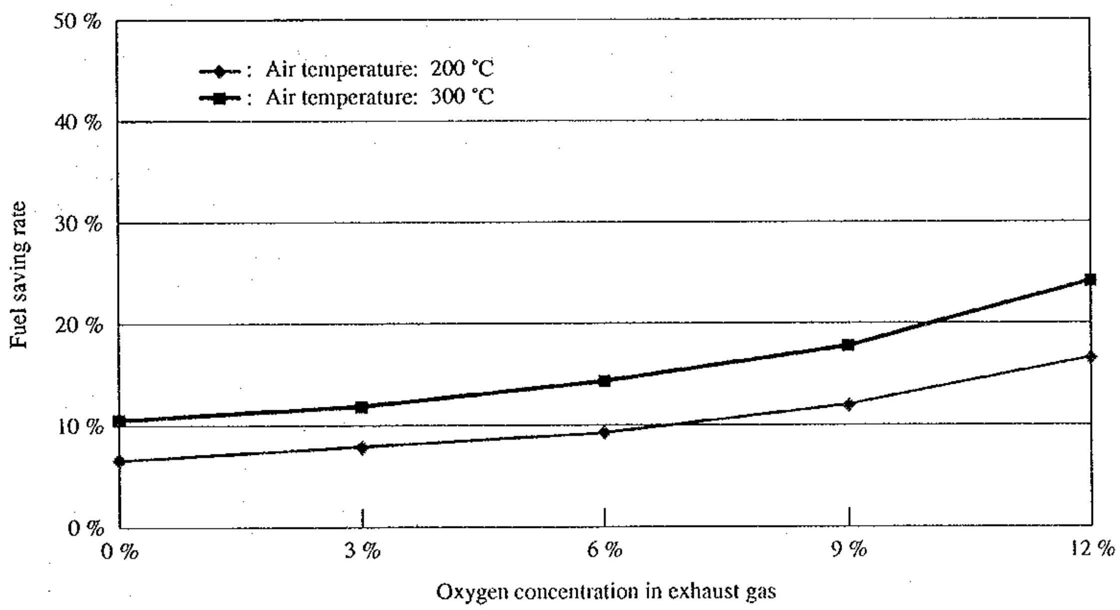
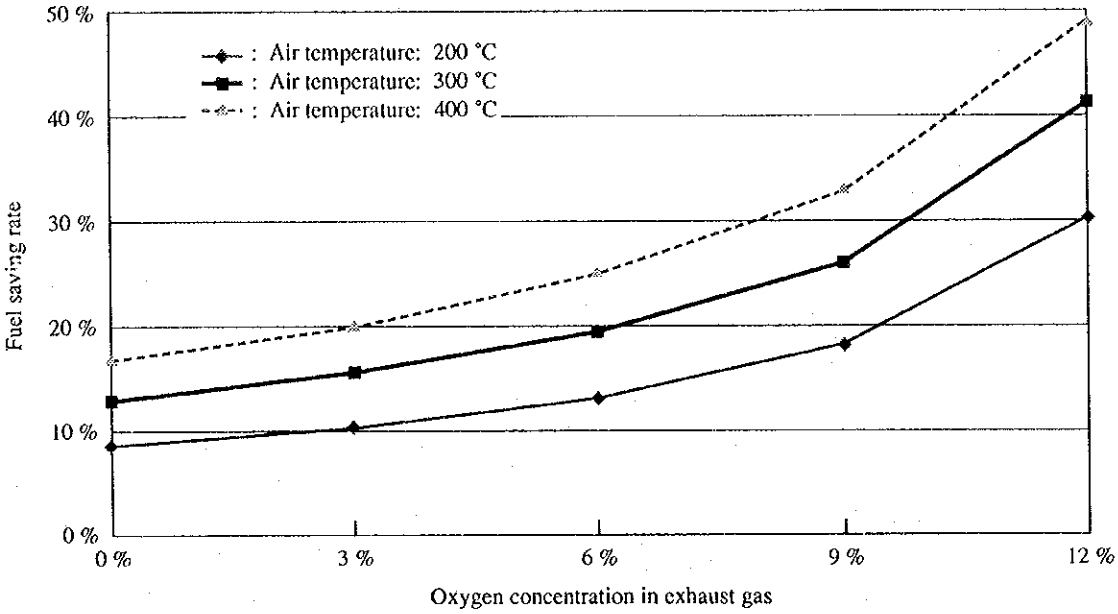


Figure 12.16 Fuel Saving by Air Preheating (Exhaust gas temperature before preheating: 800 °C)



12.2.2 Standard for Exhaust Heat Recovery Rate in Japan

The judgment criteria provided in Energy Conservation Law present the exhaust heat recovery rates for industrial furnaces. See Table 12.3.

Table 12.3 Standard and Target Values of Waste Heat Recovery Rate for Furnaces

Exhaust gas temperature (°C)	Capacity class	Exhaust heat recovery rate Standard (%)	Exhaust heat recovery rate Target (%)	(Reference for target) Waste gas temperature (°C)	(Reference for target) Preheated air temperature (°C)
500 & under	A & B	25	30	300	165
500 & over, under 600	A & B	25	30	365	200
600 & over, under 700	A	35	35	400	270
	B	30	30	435	230
	C	25	25	470	195
700 & over, under 800	A	35	35	460	310
	B	30	30	505	265
	C	25	25	545	220
800 & over, under 900	A	40	40	480	395
	B	30	35	525	345
	C	25	30	575	295
900 & over, under 1,000	A	45	50	430	550
	B	35	40	535	440
	C	30	35	590	385
1,000 & over	A	45	50		
	B	35	40		
	C	30	35		

Notes: A: Rating capacity of over 20 Gcal/h.
B: Rating capacity of 5 to 20 Gcal/h.
C: Rating capacity of 1 to 5 Gcal/h.

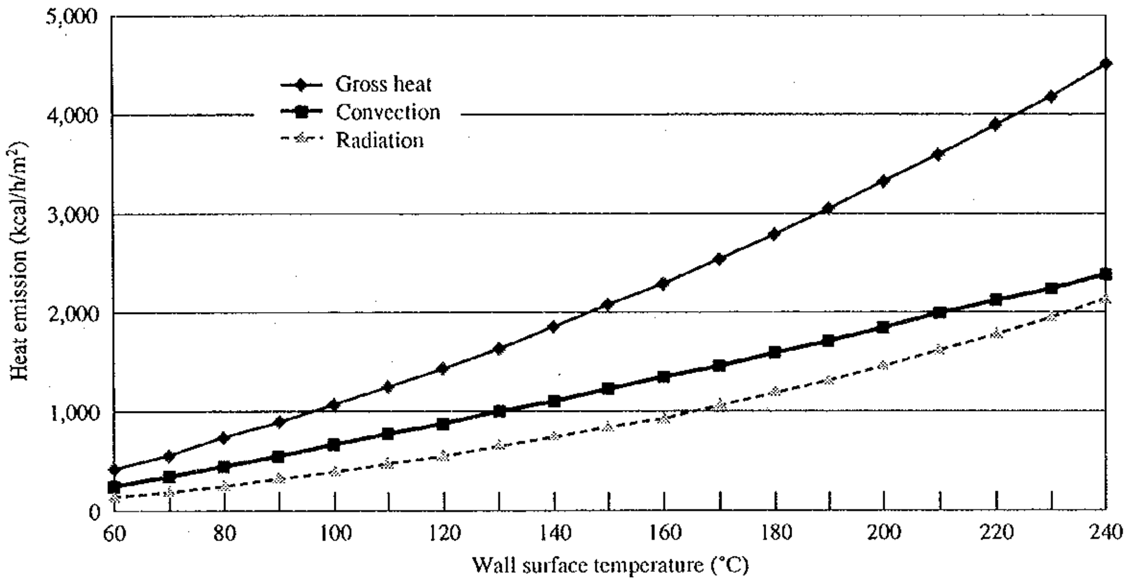
12.3 Reduction in Heat Loss from Furnace Wall and Cooling Water

12.3.1 Heat Loss due to Radiation from Furnace Wall

The furnace wall constituting the heating furnace is composed of bricks, etc. As the surface temperature of the furnace wall is higher, heat radiation loss from the furnace wall increases. Heat loss from the surface consists of two factors; heat transfer by air convection and heat loss due to radiation from the furnace wall.

For the coefficient of heat transfer by convection, several experimental formulas are proposed, and for heat radiation, a physical formula is available. By using these formulas, heat loss from the furnace wall can be calculated by using the furnace wall temperature. The calculation sheet for the furnace wall heat radiation is also available as a heat calculation sheet. Figure 12.17 shows the wall surface temperature and the amount of heat emission as an example.

Figure 12.17 Heat Emission from Furnace Wall
(Emissivity 0.7, vertical wall on natural convection)



As shown in this figure, heat radiation consists of the convection portion and radiation portion. The latter increases its percentage as the surface temperature rises.

12.3.2 Reinforcing the Heat Insulation for the Furnace Wall

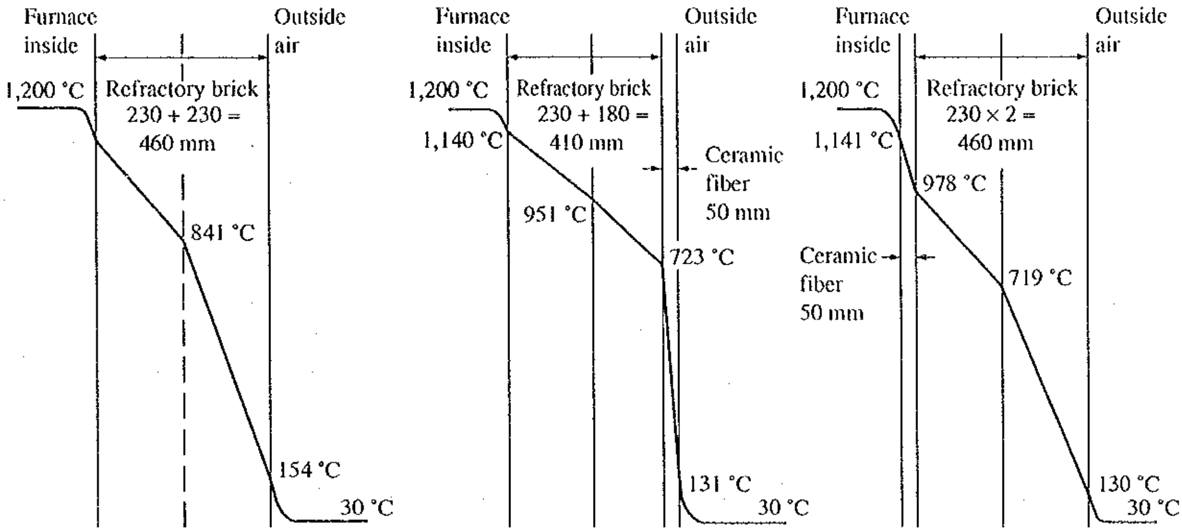
-Some recent furnaces may use ceramic fiber as the heat insulation material for the furnace wall. Since ceramic fiber has an excellent heat insulation effect, heat loss from the furnace wall can be reduced. Also, ceramic fiber stores a small volume of heat, it is effective for reducing the loss of heat storage in the body of a furnace operating on a batch basis. Table 12.4 and Figure 12.18 show calculation of the effect on reduction of heat emission by lining the furnace with ceramic fiber in comparison with an existing furnace with the wall made of bricks.

Table 12.4 Trial Calculation for Reinforcing the Heat Insulation of the Furnace Wall by Ceramic Fiber

Furnace wall structure		Case 1 Insulating refractory brick	Case 2 Lining the external wall with ceramic fiber	Case3 Lining the internal wall with ceramic fiber
Furnace internal temperature		1,200	1,200	1,200
Furnace internal wall temperature		1,120	1,140	1,141
First layer	Heat insulating material	Insulating firebrick Class 3	Insulating firebrick Class 3	Ceramic fiber blanket No. 3
		3	3	
	Insulation thickness mm	230	230	50
	Average heat conductivity	1.321	1.464	0.364
Inter-layer temperature		841	951	978
Second layer	Heat insulating material	Insulating firebrick Class 2	Insulating firebrick Class 2	Insulating firebrick Class 3
		2	2	3
	Insulation thickness mm	230	180	230
	Average heat conductivity	0.537	0.947	1.058
Inter-layer temperature		154	723	719
Third layer	Heat insulating material		Ceramic fiber blanket No. 3	Insulating firebrick Class 2
				2
	Insulation thickness mm		50	230
	Average heat conductivity		0.1013	0.4639
External wall temperature		154	131	130
Ambient temperature		30	30	30
Amount of heat emission	kcal/m²h	1,604	1,200	1,188
Heat emission rate		100	75	74

Unit of heat conductivity: kcal/m/h

Figure 12.18 Trial Calculation for Reinforcing the Heat Insulation of the Furnace Wall by Ceramic Fiber



Case 1 Refractory brick
Q = 1,604 kcal/m²/h

Case 2 Refractory brick + ceramic fiber for external lining
Q = 1,200 kcal/m²/h

Case 3 Refractory brick + ceramic fiber for internal lining
Q = 1,188 kcal/m²/h

In this case, the lining decreases the surface temperature on the outer surface of the furnace wall, which means that the heat emission amount of the furnace wall drops by approximately 25 %.

12.4 Energy Conservation for Rolling Continuous Reheating Furnace for Steel-making

12.4.1 Hot Charging and Low-temperature Extraction of Hot Billets

Great energy conservation can be achieved if high-temperature slabs (billets or blooms) are charged into the heating furnace by using the residual heat in the preceding process. In the iron and steel industry, hot charge in which continuously-cast billets of high-temperature are charged into the heating furnace and direct feed rolling in which continuously-cast billets are maintained at a high temperature to be fed directly to the rolling mill are available to achieve a substantial energy conservation effect.

In the rolling process in which the plastic machining heat is generated in the process, low-temperature extraction is also available for the purpose of extraction from the reheating furnace at a temperature which is as low as possible.

Extension of the furnace length and quenching in the preheating zone:

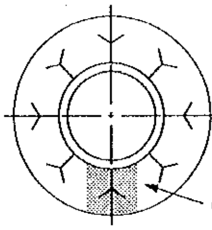
The effective means of improving the heat efficiency of the reheating furnace include optimization of the air ratio that reduces the exhaust gas volume, extension of the furnace length and also quenching in the preheating zone that are useful for dropping the exhaust gas temperature. Additionally, if the reheating furnace consists of the preheating zone, heating zone, and soaking zone, the amount of heat input in each zone is re-assessed according to the heat load and the so-called heat pattern is improved to decrease the exhaust gas temperature, thereby reducing the exhaust gas loss.

12.4.2 Reducing the Heat Loss from Water-cooled Skid

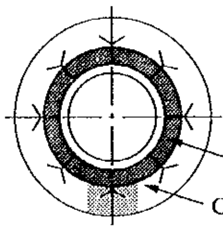
In a continuous reheating furnace, heat loss from the water-cooled skid (i.e. water-cooled beam supporting a steel product in the furnace) is largest next to the exhaust gas loss along with heat emission loss from the furnace body. Reducing the heat loss from the water-cooled skid allows reduction of the cooling water volume as well as fuel reduction.

Figure 12.19 shows the two-layer heat insulation system that reduces the heat loss from the skid.

Figure 12.19 Heat Insulation of a Water-cooled Beam



One-layer heat insulation



Two-layer heat insulation

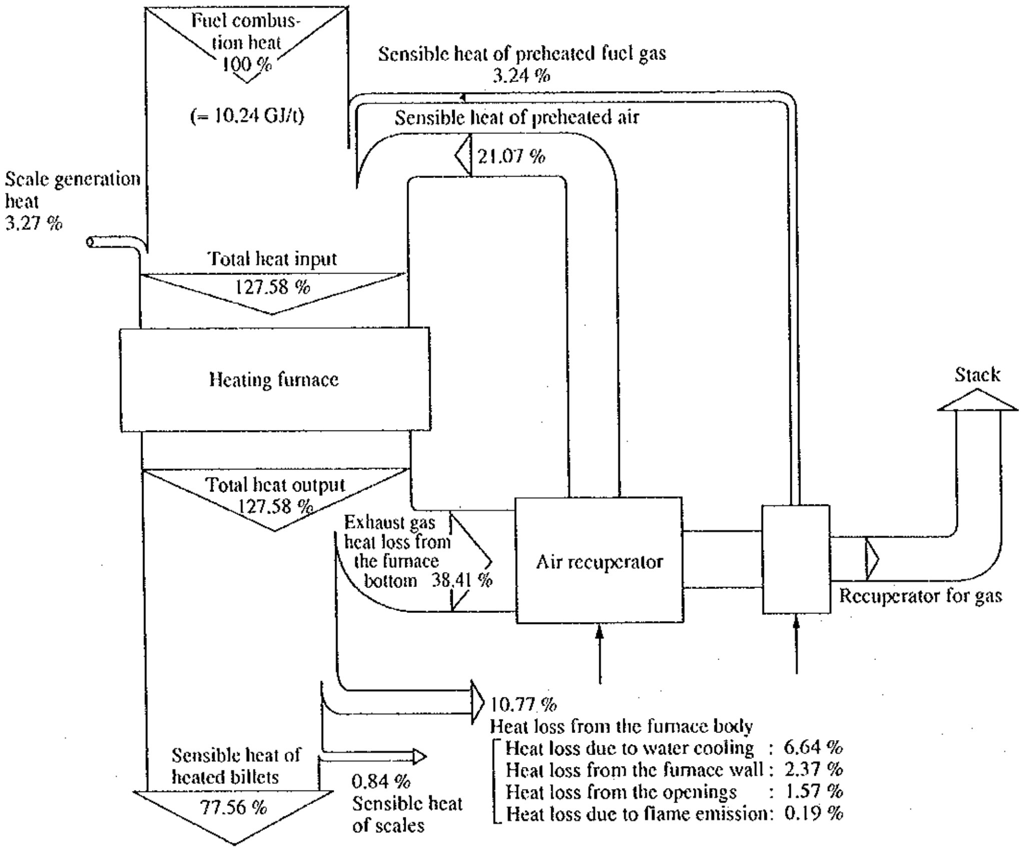
It is said that this two-layer heat insulation can reduce 40 % of the water cooling loss compared with one-layer heat insulation. However, since the outside diameter of the skid becomes larger for two-layer heat insulation, the shadow effect becomes larger in heat transfer to steel products. Therefore, the skids should be arranged properly based on this fact.

12.4.3 Heat Balance for Continuous Reheating Furnace

In heat balancing for the heating furnace, heat loss can be grasped quantitatively by obtaining details on the heat input and heat output to identify the important points in the countermeasures. In Japan, heat balancing method is specified in the standard (JIS).

Figure 12.20 shows an example of heat balance for the steel product continuously heating furnace to which the recent energy conservation measure has been applied.

Figure 12.20 Heat Balance Diagram of WB Type Heating Furnace



1. Heating capacity: 300 t/h
2. Billet (slab or bloom) to be heated: 250 T × 1,200 W × 12,000 L
3. Effective length of a furnace: 38 m
4. Load on the furnace floor: 700 kg/m²·h
5. Heating temperature: 30 °C → 1,200 °C
6. Fuel: Mix gas
7. Excess air ratio: 5 %
8. Preheated air temperature: 620 ° (before the burner)
9. Preheated gas temperature: 250 ° (before the burner)
10. Exhaust gas from the furnace bottom: 800 °C
11. Amount of reduction due to burning: 0.6 %
12. Fuel intensity: 10.24 GJ/t

Source: Handbook for Industrial Furnaces
(Published by The Energy Conservation Center, Japan)

Tables 12.5 and 12.6 list the heat contents in various steel products and the iron oxidization reaction heat as values specific to heat balance for the steel product heating furnace.

Table 12.5 Heat Content in Steel Products (Source: JIS 1995 edition)

Amount of heat required for heating a steel product starting from 0 °C (kJ/kg)

Type of steel / Temperature °C	Killed steel 0.08 % C	Mild steel (low carbon steel) 0.23 % C	Medium carbon steel 0.4 % C
0	0.0	0.0	0.0
50	23.44	23.44	23.44
100	47.72	47.72	47.72
150	72.84	72.84	72.84
200	98.79	98.79	98.37
250	126.00	125.58	124.74
300	153.63	153.21	152.37
350	182.09	182.09	180.84
400	211.81	211.81	210.14
450	243.21	243.21	240.70
500	276.28	276.28	273.35
550	311.02	311.44	307.67
600	348.28	348.69	343.25
650	387.62	388.04	379.67
700	430.32	430.32	418.18
750	487.25	501.90	497.30
800	535.39	549.62	528.27
850	578.51	586.46	553.81
900	619.11	618.69	581.02
950	651.76	651.34	612.41
1,000	684.41	683.57	643.39
1,050	717.48	716.22	675.20
1,100	750.55	748.46	706.60
1,150	783.62	781.53	738.83
1,200	816.69	814.60	771.48
1,250	849.76	848.50	804.97
1,300	883.25	882.83	839.29

Remarks: The values listed in the table above are adopted from the Physical Constants of Some Commercial Steels at Elevated Temperatures, 1953 (The British Iron and Steel Research Association). It should, however, be noted that the values for the temperature range from 0 to 50 °C are those estimated by extrapolation based on "Experiment on heat transfer in continuous slab heating furnaces and the calculation method", 1970 (The Iron and Steel Institute of Japan).

Table 12.6 Iron Oxidization Reaction Heat and Sensible Heat of Scales (Source: JIS 1995 edition)

Reaction	Reaction heat kJ/kg	kJ/kg
$Fe + \frac{1}{2}O_2 = FeO$	268.954	4.8140 (Fe)
$2Fe + \frac{3}{2}O_2 = Fe_2O_3$	817.117	7.3172 (Fe)
$3Fe + 2O_2 = Fe_3O_4$	1,117.257	6.6684 (Fe)

Remarks: These values are adopted from Anhaltszahlen für Energieverbrauch (5th edition)

The formulas for the heat generated by scale formation and scale sensible heat are shown below.

(Heat generated by scale formation)

Heat generated by scale formation is as follows:

Amount of Fe reduced by heating per ton of steel product (kg) × Heat of scale formation [kJ/kg·Fe] kJ/t of steel product

Heat generated by scale formation per kg of Fe is obtained from the following formula.

[Heat of FeO formation (kJ/kg·Fe) × 0.777 × FeO (%) + Heat of Fe_2O_3 formation (kJ/kg·Fe) × 0.700 × Fe_2O_3 (%) + Heat of Fe_3O_4 formation (kJ/kg) × 0.724 × Fe_3O_4 (%)] ÷ *T*. Fe (%) kJ/kg·Fe

However, if scale analysis is not performed, the heat generated is 5,588.4 kJ/kg·Fe.

(Sensible heat of scales)

Scale sensible heat is as follows:

Amount reduced by heating per ton of steel product (kg) × $\frac{100}{T.\text{Fe}\ (\%)}$ × Average specific heat of scale [kJ/kg°C] × [Surface temperature at extraction (°C) – Outside air temperature (°C)] kJ/ton of steel product

The specific heat of scale is assumed to be 0.900 kJ/kg °C. If scale analysis is not performed, *T*.Fe can be 75.5 %.

JIS also provides the calculation formula for the amount of heat loss for each of the following cases in addition to these tables:

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

Citation from JIS is shown below.

(1) Heat emitted from the furnace body and the flue

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

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

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

$$q_r\ (kJ/m^2h) = \varepsilon \times 20.428 \times \left[\left(\frac{T_w}{100} \right)^4 - \left(\frac{T_a}{100} \right)^4 \right]$$

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

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

where

ε : Emissivity of the furnace body surface
T_w: Outer wall temperature (K)
T_a : Ambient temperature (K)
ΔT: $T_w - T_a$ (K)

b. Heat loss due to radiation from the furnace hearth

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

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

Heat balancing time (h) × furnace hearth area (m^2) × heat loss through the furnace hearth (kJ/m^2h) / mass of steel product (t) kJ/ton-steel

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

$$Q = 3.599 \times S \cdot C \cdot \frac{T_h - T_a}{D} \quad (kJ/m^2h)$$

where

- S : Coefficient determined based on the shape of the furnace hearth: 4.1 for the circular floor, 4.5 for the square floor, and 3.8 for the long rectangular floor
- C : Heat conductivity of the furnace hearth material (W/mK)
- T_h: Temperature of the furnace hearth surface (K)
- T_a: Ambient temperature (K)
- D : Furnace width between the inner walls (m)

The formula shown above assumes that the wall thickness is $\frac{D}{6}$. For $\frac{D}{4}$, heat loss is 95 % of the value given by the above equation. For $\frac{D}{8}$, heat loss is 110 %. In other cases, the presumed value should be obtained based on the relationship shown above.

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

Furnace opening time (h) during heat balancing × amount of emitted flame gas (m^3_N/h) × [average specific heat of emitted flame gas (kJ/m^3_NK) × temperature of emitted flame gas (K) – average specific heat of emitted flame gas of reference temperature (kJ/m^3_NK) × reference temperature (K)] / mass of product steel (t) kJ/ton-steel

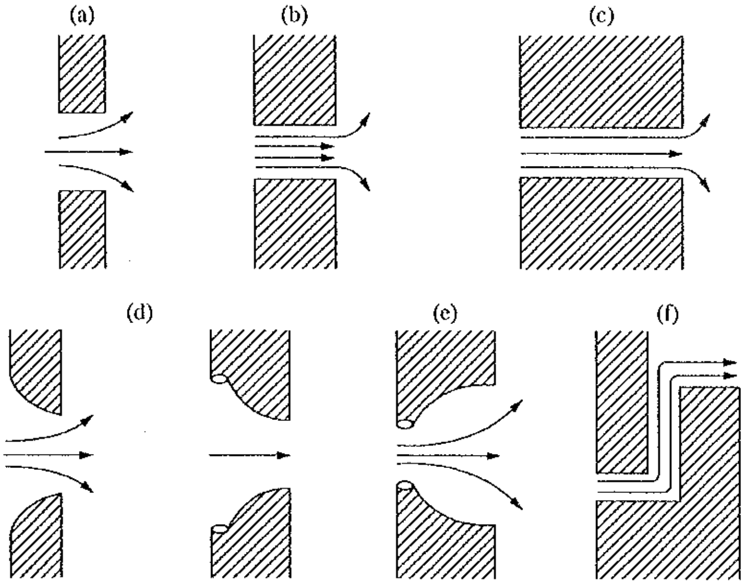
The amount of emitted flame gas is obtained from the following formula:

$$G = \alpha \times 4,467 \times \sqrt{\frac{273}{T_g}} \times \sqrt{\Delta p} \times A \quad (m^3{}_N/h)$$

where

- α : Coefficient determined by the shape of the outlet. If the friction resistance coefficient is f, $\alpha = \frac{1}{1+f}$
- Δp: Furnace inside pressure at the opening (Pa)
- T_a : Temperature of emitted flame gas (K)
- A : Area of the opening (m^2)

Remark: α is determined based on the following criteria:



(a) $\alpha = 0.38$ ($f = 1.6$) if the wall thickness is half the diameter of the opening (diameter for a circle, and hydraulic diameter for other cross sections) or smaller

(b) $\alpha = 0.67$ ($f = 0.5$) if the wall thickness is 2.5 to 3 times larger than the diameter of the opening.
If the wall thickness is 0.5 to 2.5 times larger, α is an intermediate value between the values in (a) and (b).

(c) If the wall thickness is 3 or more times larger than the diameter of the opening, f for the wall thickness up to the initial 3 times should be 0.5. For the wall thickness larger than that, calculation is performed based only on the friction loss of the wall surface at the opening. Therefore, $\alpha < 0.67$.

(d) $\alpha = 0.9$ to 0.95 ($f = 0.1$ to 0.05) if the gas inlet is open. $\alpha = 0.9$ ($f = 0.1$) if molten material is adhered as shown on the right in (d).

(e) An intermediate value between the values in (a) and (b).

(f) For general door gaps, the pressure loss of the bending corner is added to (b) or (c).

(3) Heat loss due to radiation from the furnace opening

Furnace opening time (h) during heat balancing × area of the opening (m^2) × ϕ ×

$$20.428 \times \left\{ \left(\frac{T_f}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4 \right\} \text{ / mass of steel product (t)} \quad \text{kJ/ton-steel}$$

where

ϕ : Coefficient determined by the shape of the furnace opening
T_f: Furnace inside temperature (K)
T_a: Ambient temperature (K)

Table 12.7 Emissivity by Shapes of Furnace Openings

Shape of the opening	(Diameter or shortest side) ÷ (Wall thickness)							
	0.01	0.1	0.2	0.5	1	2	4	6
Circular	0.02	0.10	0.18	0.35	0.52	0.67	0.80	0.86
Square	0.02	0.11	0.20	0.36	0.53	0.69	0.82	0.87
Rectangular (2:1)	0.03	0.13	0.24	0.43	0.60	0.75	0.86	0.90
Very slender and long	0.05	0.22	0.34	0.54	0.68	0.81	0.89	0.92

12.4.4 Heat Balance Table Formats

For reference, Tables 12.8 to 12.11 show the heat balance table formats according to JIS.

Table 12.8 Equipment Overview List

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

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

Table 12.9 Long-term Operation Result List

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

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

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

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

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

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

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

Table 12.10 Measurement Result List

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

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

Table 12.11 Heat Balance List

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

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

12.5 Actual Examples of Energy Conservation

12.5.1 Actual Cases of Energy Conservation

The Energy Conservation Center, Japan has collected improvement cases from factories throughout Japan every year and convened a presentation convention since 1975. "Heating furnaces" are searched through the cases in recent years (1984 to 1998) to find 103 cases. Figure 12.21 shows their distribution in business categories, Figure 12.22 shows the motivations for those energy conservation activities, and Figure 12.23 categorizes the activities for energy conservation.

Figure 12.21 Number of Cases Presented for Reheating Furnaces (1984 to 1998)

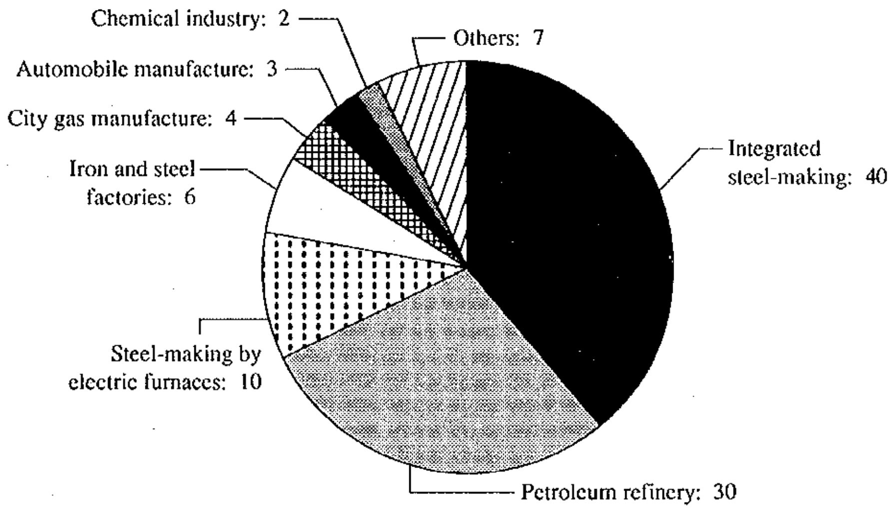


Figure 12.22 Motivations for Energy Conservation

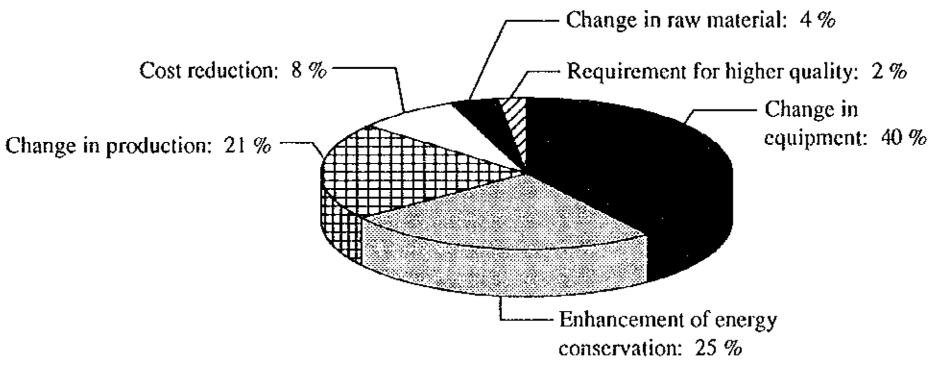
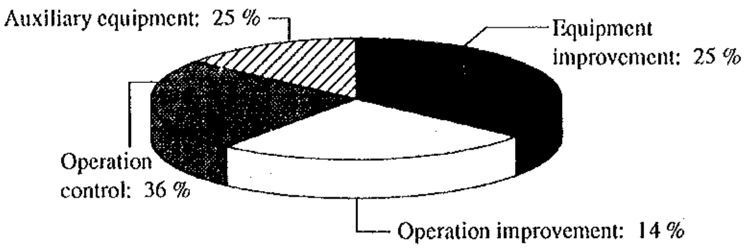


Figure 12.23 Patterns of Energy Conservation



These cases of energy conservation are mainly the results of small-group activities by operators in factories and most improvements are intended for operation of existing equipment. Table 12.12 briefly describes the content of improvements.

Table 12.12 Examples of Energy Conservation (heating furnace) (1/5)

Year	ID/ECC	Industrial categories	Process 1	Process 2	Motivation	Pattern	Improvements	Title for presentation
1996	FE96064	Petroleum refinery	Naphtha hydrogenation desulfurizer	Stabilizer heating furnace	Promotion of energy conservation	Auxiliary equipment	Optimum control; devised by operators	Energy conservation for the naphtha-hydrogenation desulfurizer by fuzzy control (for optimum operation)
1996	FE96045	Integrated steel making	Motors for blowers	Large-size motors: 3 locations	Promotion of energy conservation with a focus placed on electricity consumption	Auxiliary equipment	VVVF control, renewal of heating furnace heat exchanger, etc.	Audit activities for energy conservation and power-saving measures for rotary machines
1996	FE96036	Integrated steel making	Large-size shape steel factory	Heating furnace	Operating system (Blast furnace to be shut down)	Operation control	AI intake control	Establishment of the energy-saving operation method for the continuous heating furnace
1996	FE96009	Integrated steel making	Steel plate factory	Heating furnace	Small-lot multi-item production	Auxiliary equipment	Overheat prevention linked with the process computer	Reduction of the fuel intensity for the steel plate heating furnace
1996	FE96001	Petroleum refinery	Factory as a whole		Global environment as the corporate's goal	Operation control	A heat exchanger was newly installed.	Example of energy conservation investment practice by creation of a heat emission loss map
1995	FE95147	City gas manufacture	Naphtha cracking gas manufacture		Raw oil quality change	Operation control	Review associated with material change (from coal gas to naphtha)	Energy conservation for the city gas manufacturing equipment
1995	FE95090	Iron and steel factories	Steel tube galvanizing	Blowing the steam for removal of the excessive zinc	Frequent occurrence of troubles	Auxiliary equipment	Introduction of heat exhaust gas to eliminate steam condensate troubles	Energy conservation by stabilizing operation of the zinc recovery equipment
1995	FE95089	Integrated steel-making	Hot rolling works	Heating furnace	Operating system (Blast furnace: 1)	Operation control	Optimization of heat holding fuel distribution during shutdown	Review of the heating furnace heat holding/raising method for the work shift day
1995	FE95085	Steel-making by an electric furnace	Heating furnace		Promotion of energy conservation	Operation control	Decreasing the setting temperature during hot-charging	Energy conservation by improving the operating method for the preheating/heating furnace
1995	FE95082	Petroleum refinery	Fluid catalytic cracking	Catalytic regenerator	Promotion of energy conservation	Operation control	Running conditions for exhaust gas pressure recovery turbine	Unceasing effort for power recovery
1995	FE95080	Petroleum refinery	Tower light oil desulfurizer	Air fin cooler	Promotion of energy conservation	Operation control	Examination of the rise of the outlet temperature by a dynamic simulator	Further efforts for energy conservation
1995	FE95077	Petroleum refinery	Vacuum light oil desulfurizer	Distiller fuel oil heating furnace	Fuel quality change	Operation control	Air ratio control according to the change in the fuel gas	Reinforced effort for energy conservation for the heating furnace
1995	FE95076	Petroleum refinery	Atmospheric distillation unit		Improvement of performance	Operation control	Computerized forecasting of dirt in the heat exchanger and optimization of cleaning	Energy conservation by computer technology
1995	FE95044	Integrated steel-making	Hot rolling factory	Heating furnace	Process change	Operation control	Process information such as the extraction order and enhancement of slab temperature control	Reduction of the fuel intensity for the No.2 heating furnace in the hot rolling plant
1995	FE95018	Integrated steel-making	Hot rolling factory	Heating furnace	Promotion of energy conservation	Operation control	Optimization during hot charge	Improvement of the fuel intensity for the heating furnace
1995	FE95001	Steel-making by an electric furnace	Coke oven gas refinery	Heat exchanger	Promotion of energy conservation	Operation control	Hydrogenation washing	Improvement measures for light oil heat exchanger efficiency
1994	FE94112	Automobile manufacture	Engine manufacture	Cam shaft die casting	Introduction of new equipment	Operation control	Heat-insulated cover for the molten metal, refractory lining, and tapping nozzle material	Energy/resource saving by die casting
1994	FE94099	Automobile parts manufacture	Electric furnace		Increasing the production	Equipment improvement	Modification of the furnace body for increasing production	Reduction of the electricity intensity by modifying the furnace body for the high-frequency induction heating furnace
1994	FE94078	Integrated steel-making	Heating furnace for seamless steel pipe		Small-lot multi-item production	Operation improvement	Optimization of the charging method and setting temperature by making the rolling length longer	Reduction of the fuel intensity for the small-diameter tube heating furnace
1994	FE94070	Petroleum refinery	Raw oil heating furnace		Raw oil quality change	Equipment improvement	Additional installation and reinforcement of heat exchangers to cope with the change in the quality of the processed raw oil	Energy conservation by rearrangement of the raw oil preheating heat exchangers
1994	FE94065	Chemistry	Raw material heating equipment		Promotion of energy conservation	Equipment improvement	Two materials separately heated are put in series heating	Energy conservation for the NP manufacturing process
1994	FE94047	Integrated steel-making	Hot rolling factory	Heating furnace	Promotion of energy conservation	Auxiliary equipment	Coping with minimum operation, countermeasures against air invasion, and installation of a partition wall in the preheating zone	Measures for fuel intensity reduction for the hot roll heating furnace
1994	FE94035	Integrated steel-making	Hot rolling factory	Heating furnace	Retrofitting the furnace	Equipment improvement	Full-ceramic furnace body	Reduction of the fuel intensity by renewing the heating furnace for the hot rolling factory
1994	FE94032	Integrated steel-making	Hot rolling factory	Heating furnace	Retrofitting the furnace	Equipment improvement	Furnace shape improvement, fuel/air preheating, and reducing the number of operating burners	Energy conservation for the steel product heating furnace
1994	FE94008	Petroleum refinery	Fuel oil desulfurizer	Raw oil heating furnace	Worsening of the energy intensity	Operation control	Removal of scales on the inner surface of the intermediate section based on heat balance results	Limitless energy conservation for the heating furnace
1994	FE94002	Petroleum refinery	Atmospheric distillation unit	Raw oil heating furnace	Promotion of energy conservation	Operation control	Raising the raw oil storage temperature and improvement of heat exchange process	Energy conservation activities for the atmospheric distillation equipment (Effort for improvement of the process heat efficiency)
1993	FE93102	Integrated steel-making	Steel plate factory	Heating furnace	Inconsistency in process control	Operation control	Making the charging order variable	Effort toward 200,000 kcal/t of heat intensity in the continuous heating furnace

Table 12.12 Examples of Energy Conservation (heating furnace) (2/5)

Year	ID/ECC	Industrial categories	Process 1	Process 2	Motivation	Pattern	Improvements	Title for presentation
1993	FE93100	Integrated steel-making	Pipe manufacture factory	Heating furnace	Small-lot multi-item production	Operation control	Improvement of heating pattern and the temperature rise/drop pattern during lunch break	Reduction of the fuel intensity in the heating furnace in the small diameter tube manufacturing plant
1993	FE93095	Integrated steel-making	Hot rolling factory	Heating furnace	Furnace retrofitting/hot charging	Auxiliary equipment	Improvement of furnace setting temperature and the finishing stand water drainage	Effort toward 250,000 kcal of fuel intensity for the reheating furnace
1993	FE93052	Rubber products	Raw rubber refining process	Natural rubber heating process	Seasonal adjustment	Equipment improvement	Changing the heating source from steam to microwave	Energy conservation by heating rubber with microwave
1993	FE93021	Iron and steel factories	Heating furnace for seamless steel pipe		Trouble in furnace pressure control	Auxiliary equipment	Countermeasures against air invasion into the flue, recuperator, charging/extraction parts	Energy conservation by reducing the load on the induced draft fan for exhaust gas
1993	FE93013	Integrated steel-making	Manufacture of forge-welded steel tubes	Heating furnace/transfer line	Improvement of yield	Equipment improvement	Two-layer atmosphere heating and N_2 sealed transfer	Total energy reduction by reducing the scale loss in the forge-welded steel tube manufacturing line
1992	FE92126	Automobile manufacture	Heat-treatment furnace		Energy conservation during non-operating time	Operation control	Reduction of furnace temperature and atmospheric gas supply	Energy conservation for the sintering furnace and continuous reheating furnace on holidays
1992	FE92107	Integrated steel-making	Steel product heating furnace	Skid button	Improvement of product quality	Auxiliary equipment	Skid button shape change/material improvement	Development of an energy conservation type high melting point skid button
1992	FE92104	Integrated steel-making	Hot rolling factory	Heating furnace	Promotion of energy conservation	Operation improvement	Holding monthly meetings with the process departments and both departments holding daily meetings	Reduction of the fuel intensity for the heating furnace by DHCR
1992	FE92092	Petroleum refinery	Heavy oil hydrogenation desulfurizer	Hydrogen manufacturing equipment	Important items to be implemented	Equipment improvement	A hydrogen film separating unit was newly installed to be used together with the existing equipment after being reformed.	Enhancing the efficiency of the hydrogen supply system
1992	FE92047	Automobile manufacture	Forge reheating furnace	High-frequency induction furnace	Promotion of energy conservation	Equipment improvement	The skid rail for transport was abolished and ceramic was used instead.	Using ceramic as the material for high-frequency induction heating furnace body
1992	FE92041	Integrated steel-making	Blooming mill	Heating furnace	Small-lot multi-item production	Auxiliary equipment	Burner modification and development of a device for removing the scales on the skid	Reduction of the fuel intensity for the heating furnace
1992	FE92031	Integrated steel-making	Hot rolling mill	Heating furnace	Promotion of energy conservation	Operation control	Reverse charging of rejected hot slab into the furnace's extraction hole	Combustion intensity reduction measures for the heating furnace
1991	FE91101	Iron and steel factories	Cast forging	Heating furnace	Promotion of energy conservation	Operation control	Heat pattern and burner were changed	Energy conservation for the walking beam type continuous reheating furnace
1991	FE91098	Steel-making by an electric furnace	Rolling mill	Large-size heating furnace	Annual target policy of the section	Operation control	Improvement of burner load distribution	Fuel intensity reduction for a large heating furnace
1991	FE91047	Integrated steel-making	Large-size shape steel factory	Heating furnace	Promotion of energy conservation	Operation control	Air ratio, furnace internal pressure, heat holding damper, heat pattern, and furnace wall ceramic	Thoroughgoing on-site analysis for combustion improvement
1991	FE91028	Petroleum refinery	Atmospheric distillation unit	Heating furnace	Raw oil quality change	Operation control	Naphtha lead pressure setting was based on the type of raw oil, and control of washing tower NaOH	Pursuit of energy conservation for atmospheric distillation equipment
1991	FE91011	Petroleum refinery	Vacuum light oil desulfurizer		Promotion of energy conservation	Equipment improvement	Two-stage distilling operation was integrated into a single stage.	Reduction of heating energy for the vacuum light oil desulfurizing equipment
1991	FE91001	Petroleum refinery	All processes		Promotion of energy conservation	Operation control	Development/display of management and control screens and setting of the standard for intermediate product quality	Energy conservation effort for shift-basis work system – Development and utilization of the management and control screens
1990	FE90147	Electric enterprises	Thermal power station	Boiler	Cost reduction	Operation control	Operation control of auxiliary machine/desulfurizer operation and temperature control of chamber gas	Reduction of DSS start-up losses
1990	FE90144	City gas manufacture	Coal tar distillation equipment	Heating furnace	Furnace retrofitting	Equipment improvement	Combustion volume distribution, tube layout in the convection section, and weighing/heat insulation material	Energy conservation measures for the coal tar distiller heating furnace
1990	FE90088	Petroleum refinery	Vacuum distillation, waste water treatment		Integration of formal organizations	Equipment improvement	Lowering reboiler pressure and modifying the gas turbine in order to adopt natural drafting	Energy conservation activity challenging the environmental changes with reinforced determination
1990	FE90087	Petroleum refinery	Naphtha catalytic reforming device	Waste heat boiler	Promotion of energy conservation	Equipment improvement	Advanced control of water supply distribution to three waste heat boilers based on temperature	Maximization of waste heat recovery through advanced control
1990	FE90086	Petroleum refinery	Heavy oil desulfurizer	Heating furnace	Promotion of energy conservation	Equipment improvement	Exhaust heat recovery was changed from the boiler to raw oil plus hydrogen	Waste heat recovery by improving the heating furnace for the heavy oil desulfurizing equipment
1990	FE90084	Petroleum refinery	Naphtha desulfurization reforming device	Stripper	Raw oil quality change	Operation control	Stripper temperature/pressure control according to the raw oil	Energy conservation by improving the stripper running method
1990	FE90082	Petroleum refinery	Pour point depressing unit	Raw oil heat exchanger	Improvement of maintenance	Operation control	Reduction of dirt in the heat exchanger through control of raw oil quality	Energy conservation by preventing dirt in the raw oil heat exchanger
1990	FE90038	Integrated steel-making	Sizing mill heating furnace		Changing the operation in the upstream process	Auxiliary equipment	Dual slab cutting torch, and roll cooling by spraying air/water	Further efforts for improvement of the continuous cast steel temperature

Table 12.12 Examples of Energy Conservation (heating furnace) (3/5)

Year	ID/ECC	Industrial categories	Process 1	Process 2	Motivation	Pattern	Improvements	Title for presentation
1990	FE90028	Steel tubes manufacture	Erhart tube manufacture	Heating equipment	Promotion of energy conservation	Auxiliary equipment	Air ratio, preheated air temperature, ceramic fiber, and variable flame	Reduction of the heating energy in the Erhart tube manufacturing process
1990	FE90020	Steel-making by an electric furnace	Heating furnace		Worsening of the energy intensity	Operation control	Temperature measuring position, combustion air temperature, and burner fuel distribution	Improvement measures for fuel oil intensity of the heating furnace
1990	FE90018	Steel-making by an electric furnace	Forging mill	High-frequency heating furnace	Development of equipment	Equipment improvement	Development of a vertical high-frequency heating furnace	Development of the vertical high-frequency heating furnace
1990	FE90013	Integrated steel-making	Hot rolling mill		Controlling the temperature of the material to be heated	Operation control	Charging schedule and operation improvement for empty furnace	Energy conservation activities by using a more efficient operation mode
1990	FE90011	Integrated steel-making	Steel plate factory	Heating furnace	Promotion of energy conservation	Operation control	High-temperature charging and lead time reduction	Improvement of the hot steel product charging temperature for steel plate manufacture
1990	FE90008	Petroleum refinery	Atmospheric/vacuum distillation unit		Reviewing the integration of processes	Equipment improvement	Development of an ideal heat recovery calculation program	Reduction measures for heating furnace intensity for the petroleum distillation equipment
1989	FE89143	City gas manufacture	Naphtha heating furnace		Promotion of energy conservation	Equipment improvement	Preheating the combustion air by using the waste heat from the furnace and exhaust heat from the air fin cooler	Energy conservation for the heating furnace through recovery of waste gas and hot air
1989	FE89093	Steel-making by an electric furnace	Roll heating furnace		Promotion of energy conservation	Equipment improvement	An air preheater was newly installed; DDC was adopted for instrumentation	Energy conservation measures for the continuous heating furnace
1989	FE89092	Steel-making by an electric furnace	Fuel oil tank	Tank preheating electric heater	Promotion of energy conservation	Auxiliary equipment	Switching from constant heating to oil supply temperature detection control	Fuel oil tank and heater temperature control
1989	FE89091	Steel-making by an electric furnace	High-frequency heating furnace		Promotion of energy conservation	Equipment improvement	Heating coil shape was changed	Reduction of the electricity intensity for the high-frequency heating furnace by improving the coil efficiency and eliminating minor stoppages
1989	FE89051	Steel-making by an electric furnace	Roll heating furnace		Small-lot multi-item production	Operation control	Heating temperature pattern and control standard	Acivities for improving the fuel intensity
1989	FE89047	Integrated steel-making	Hot rolling mill	Heating furnace	Promotion of energy conservation	Operation control	Pressure setting for the air blower according to the combustion volume	Improvement of the electricity intensity through automatic control of the combustion air pressure
1989	FE89033	Iron and steel factory	Tube manufacturing factory	Heating furnace	Cost reduction	Operation control	Changing the combustion gas route and temperature rise pattern	Improvement of heavy oil A intensity for the pipe in coil
1989	FE89032	Petroleum refinery	Distillator heating furnace		Promotion of energy conservation	Auxiliary equipment	Using a microcomputer for control of oxygen in the exhaust gas	Energy conservation by improving the heating furnace control system
1989	FE89027	Integrated steel-making	Tube manufacturing factory	Rotary furnace floor heating furnace	Worsening of energy intensity due to low production	Operation improvement	Burner distribution, temperature control standard, and door improvement	Reduction of the fuel intensity for the heating furnace in the medium-size tube plant
1989	FE89007	Petroleum refinery	Fuel oil desulfurizer		Change in demand	Auxiliary equipment	Controlling the number of exhaust gas damper impellers on a variable basis, setting it according to the combustion load, and burner control	High-efficiency operation of raw oil heating furnace implemented by a team — Energy conservation achieved by modifying the damper
1988	FE88142	Petroleum refinery	Atmospheric distillation unit	Raw oil heating furnace	Decline in production	Operation improvement	Dropping the air preheater dew point control temperature because of reduction of sulfur in the raw oil	Energy conservation by reviewing the air preheater control temperature
1988	FE88129	City gas manufacture	Naphthalene heating furnace		Promotion of energy conservation	Equipment improvement	A stud was installed on the heating pipe and heat pipe's heat exchanger was installed for air.	Energy conservation measures for the naphthalene heating furnace
1988	FE88094	Integrated steel-making	Large-size shape steel factory	Heating furnace	Decline in production	Operation improvement	Monthly meeting by related shops, furnace operation control, and temperature rise/extraction temperature suitable for holidays	Reduction of the fuel intensity for the heating furnace by the One by One activity
1988	FE88060	Integrated steel-making	Service water supply	Electric power for service water	Promotion of energy conservation	Operation improvement	Implementation of 100 items for energy conservation (with small investments), and control in terms of kWh/ton	Effort for service water electricity reduction of 1000 kW with zero investment
1988	FE88041	Integrated steel-making	Steel plate factory	Heating furnace	Promotion of energy conservation	Operation improvement	Control including that for the preceding process for hot charge improvement and use of the heating model	Reduction of the fuel intensity for the plate heating furnace — Efforts for continuous integrated operation from tapping to rolling
1988	FE88038	Integrated steel-making	Steel plate factory	Heating furnace	Promotion of energy conservation	Auxiliary equipment	Temperature unevenness was eliminated by developing a slab surface scale removing equipment	Energy conservation by removing scale from the charged slab
1988	FE88002	Petroleum refinery	Heating furnace	Steam line	To cope with the cold region conditions	Auxiliary equipment	Temperature control trap was adopted (to avoid freezing), and heat insulation of the heating furnace was enhanced	Energy conservation activity for the oil refinery equipment in cold districts
1987	FE87052	Petroleum refinery	Atmospheric distillation unit		Limit in the utilization of microcomputer	Operation improvement	Application of a computer and improvement of analysis meter accuracy	Energy conservation for the atmospheric distilling equipment by computer

Table 12.12 Examples of Energy Conservation (heating furnace) (4/5)

Year	ID/ECC	Industrial categories	Process 1	Process 2	Motivation	Pattern	Improvements	Title for presentation
1987	FE87036	Integrated steel-making	Steel plate factory	Heating furnace	With the newly modified heating furnace	Operation improvement	Hot charge was improved and oxygen load factor was controlled with Nox, fuel distribution	Reduction of the fuel intensity for the plate continuous heating furnace
1987	FE87033	Integrated steel-making	Steel plate factory	Heating furnace	Comparison with competing companies	Auxiliary equipment	Preventive maintenance was enhanced and a heat insulating cover was installed on the transfer table.	Effort for fuel intensity "250" for the plate continuous heating furnace
1987	FE87031	Iron and steel factories	Heating furnace		Promotion of energy conservation	Auxiliary equipment	Controlling the furnace internal atmosphere by installing an oxygen meter and prevention of oxidative atmosphere by LPG injection	Reduction of the butane gas intensity for the heating furnace by O_2 meter control
1987	FE87024	Integrated steel-making	Steel bar factory	Heating furnace	Frequent occurrence of troubles and shutdowns	Auxiliary equipment	A partition was installed on the top of the preheating zone to improve the gas flow and air ratio control during heat holding	Improvement of the bar steel heating furnace
1987	FE87016	Petroleum refinery	Vacuum distillation unit	Raw oil heating furnace	Frequent occurrence of burner troubles	Operation improvement	Optimization of atomizing and control of the register opening degree	Efforts for optimization of the heating furnace operation
1986	FE86116	Petroleum refinery	Vacuum distillation unit	Heating furnace	To achieve a substantial effect with a large-size furnace	Operation improvement	O_2 reduction, clearance joint caulking and red indication of the O_2 meter	Reduction of control values for the heating furnace of the vacuum distilling equipment
1986	FE86105	Petroleum refinery	Indirect desulfurizer	Heating furnace	A large fluctuation in O_2	Operation improvement	Improvement of the seal for the operating lever of the air register	Thorough implementation of O_2 control for the heating furnace
1986	FE86084	Integrated steel-making	Wire and steel rod rolling	Heating furnace	Energy conservation along with maintenance of high quality	Operation improvement	Setting of the furnace internal temperature distribution with consideration given to the decarbonized depth	Energy conservation by the computer control activity for the heating furnace
1986	FE86068	Integrated steel-making	Steel tube manufacture	Rotary heating furnace	Cost reduction	Auxiliary equipment	Reduction of extraction door opening/closing time by improving the hydraulic device	Energy conservation activity for the extraction zone of the rotary heating furnace
1986	FE86060	Integrated steel-making	Hot rolling mill	Heating furnace	Cost reduction	Equipment improvement	Recuperator was improved, an exhaust heat boiler and skid boiler were installed	Total exhaust heat recovery for the heating furnace in the hot rolling plant
1986	FE86021	Petroleum refinery	Reforming furnace for hydrogen manufacture		Promotion of energy conservation	Equipment improvement	Natural ventilation was introduced by stopping the forced draft ventilation fan when the load is small	Energy conservation by stopping the blower for the heating furnace
1985	FE85133	Chemistry	Manufacture of man-made fiber intermediate material	Thermal heating furnace	A large fluctuation in fuel consumption	Operation control	Making the load uniform at the heat medium consumers and improvement of fuel control valve sensitivity	Fuel reduction for the COG heating furnace
1985	FE85071	Integrated steel-making	Semi-finished steel product manufacturing factory	Semi-finished steel product heating furnace	Black smoke emitted at setting change	Operation control	Fuel/air control software was changed (to avoid extraction door's external disturbance)	Reduction of the fuel intensity by improving O_2 control in the heating furnace
1985	FE85069	Iron and steel factory	Rolling mill	Semi-finished steel product heating furnace	Review based on heat balance results	Equipment improvement	Prevention of leak from the recuperator and additional installation of recuperators	Improvement of the fuel intensity for the bar steel heating furnace
1985	FE85026	Petroleum refinery	Naphtha reforming unit	Hydrogenation desulfurizer	Cost reduction	Operation improvement	Cleaning of burners, adjustment of air registers, and O_2 reduction by preventing air invasion	Challenge of expanding the limit for reducing O_2 in the heating furnace
1985	FE85021	Integrated steel-making	Butt-welded steel tube manufacturing equipment	Heating furnace	Cost reduction	Equipment improvement	Adopting the air-cooled skid instead of water-cooled skid to recover hot air for use	Energy conservation measures for the forge-welded steel tube skelp heating furnace
1985	FE85010	Aluminum processing	Rolling mill	Ingot heating furnace	Promotion of energy conservation	Equipment improvement	Reduction of the rotational speed of the hot air circulation fan in the furnace	Energy conservation for the aluminum ingot heating furnace in the hot rolling plant
1985	FE85007	Integrated steel-making	Hot rolling mill	Heating furnace	Reinforcement of measurement control	Auxiliary equipment	Improvement of O_2 control during minimum combustion, and high selection of the pyrometer in the furnace	Reduction of the fuel intensity for the hot-rolled slab heating furnace by applying the functional control technique
1984	FE84096	Integrated steel-making	Steel bar factory	Heating furnace	Switching to by-product gas	Auxiliary equipment	Modification of the burner wall and control according to the LD gas holder level	Improvement of the fuel intensity for the heating furnace by using the converter gas
1984	FE84084	Steel-making by an electric furnace	Special steel tube manufacture	Batch heating furnace	Small-lot multi-item production	Equipment improvement	Fuel charging pattern was improved, and a recuperator was installed.	Reduction of fuel intensity for batch type heating furnace
1984	FE84075	Integrated steel-making	Steel bar factory	Heating furnace	Cost reduction	Auxiliary equipment	Flue damper was adjusted under low load.	Improvement of the downstream flue damper for the heating furnace
1984	FE84060	Integrated steel-making	Large-size shape steel factory	Heating furnace	Reinforcing the effort for energy conservation which has been less active	Operation improvement	Track time was reduced, and the recuperator's heating surface was expanded.	Reduction of the fuel intensity for the large heating furnace
1984	FE84058	Integrated steel-making	Small-diameter tube factory	Butt-welded tube heating furnace	Cost reduction	Auxiliary equipment	Modification of burners, and oxygen-enriched combustion	Energy conservation by raising the flame temperature of the forge-welded steel tube heating furnace

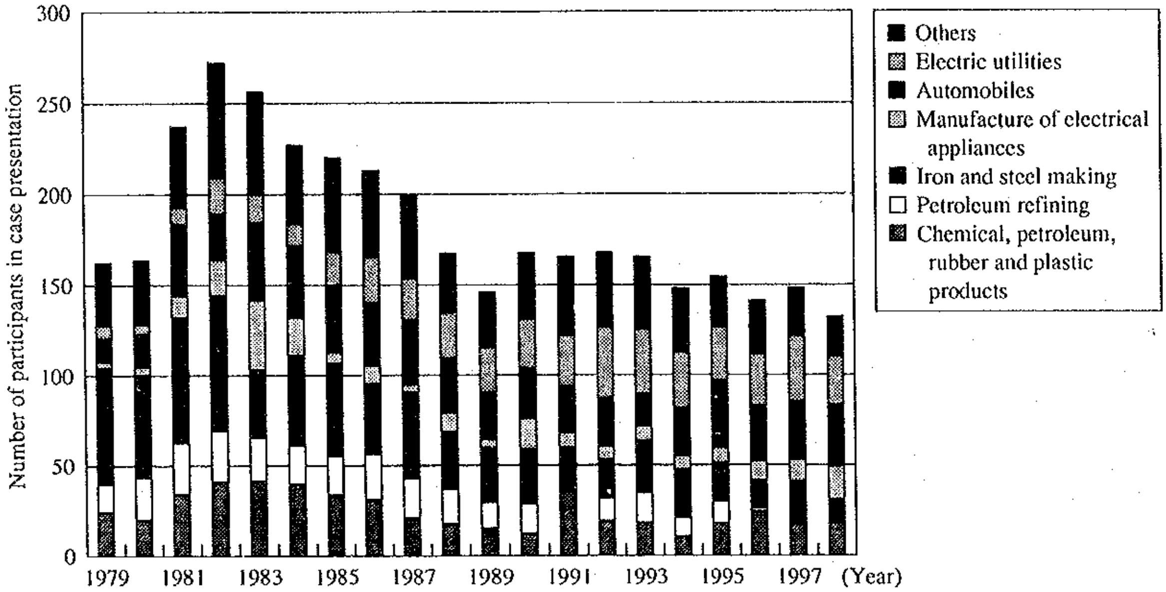
Table 12.12 Examples of Energy Conservation (heating furnace) (5/5)

Year	ID/ECC	Industrial categories	Process 1	Process 2	Motivation	Pattern	Improvements	Title for presentation
1984	FE84057	Integrated steel-making	Steel plate factory	Heating furnace	Cost reduction	Auxiliary equipment	Use of an electrical combustion fan damper, and automated control of air/fuel ratio	Energy conservation for the plate steel slab heating furnace
1984	FE84043	Integrated steel-making	Hot rolling factory	Heating furnace	Promotion of energy conservation	Operation improvement	Dual charging door, reduced flue, and a partition in the preheating zone	Improvement of the fuel intensity by preventing air invasion to the hot heating furnace
1984	FE84022	Integrated steel-making	Seamless steel pipe factory	Rotary heating furnace	Promotion of energy conservation	Equipment improvement	Energy conservation incorporated into the newly installed heating furnace	Effort toward No.1 ranking in the world with regard to the fuel intensity of the new heating furnace in the integrated tube plant
1983	FE83255	Brick burning	Refractory heating furnace	Heating furnace	Promotion of energy conservation	Equipment improvement	Use of ceramic fiber, utilization of sintering furnace exhaust, reinforcement of seal	Energy conservation for the refractory heating furnace by exhaust heat recovery
1983	FE83158	Construction heavy machinery manufacture	Electric heat-treatment furnace	Heating furnace	Promotion of energy conservation	Operation improvement	Weight reduction of jigs, stopping of cooling fans, and adjustment of the door opening degree	Energy conservation for the large electrical heating furnace by operation improvement
1983	FE83097	Integrated steel-making	Hot rolling factory	Heating furnace	Trouble with the exhaust gas analyzer	Operation improvement	Countermeasures against failures of the meters for the newly installed furnace, and clogging of sample tube	Reduction of the fuel intensity by stabilized operation of O_2 control for the continuous heating furnace
1983	FE83087	Integrated steel-making	Hot rolling factory	Heating furnace	Cost reduction	Auxiliary equipment	Measurement of in-furnace slab temperature, reduction of the soaking zone furnace floor, and semi-hot skid	Substantial reduction of the fuel intensity for the heating furnace in the hot roll plant — Challenge of expanding the limit based on a viewpoint from a different angle
1983	FE83057	Integrated steel-making	Steel plate factory	Heating furnace	Promotion of energy conservation	Operation improvement	Hot slab charge expansion, and heat pattern suitable for hot slab	Reduction of the fuel intensity for the heating furnace
1983	FE83056	Integrated steel-making	Steel pipe manufacture	Heating furnace	Promotion of energy conservation	Auxiliary equipment	Heat insulation boards on the furnace body (ceiling, side walls, and furnace floor)	Energy conservation for the roll heating furnace
1983	FE83037	Petroleum refinery	Atmospheric distillation and hydrogenation · desulfurizing	Heating furnace	Promotion of energy conservation	Auxiliary equipment	Prevention of air leak from the furnace floor, and damper control according to oxygen in the furnace	Effort toward reduction of exhaust gas O_2 in the heating furnace to 25 %
1983	FE83030	Integrated steel-making	Steel plate factory	Heating furnace	Improvement of computerized control	Operation improvement	Changing the control logic and mixing of hot and cold slabs	Improvement of the actual operation by application of computer control to the heating furnace

12.5.2 Convention for Presentation of Energy Conservation Cases

The first energy conservation improvement case presentation convention was convened in 1975. Up until 1998, totally 3,646 entries have been made. Figure 12.24 lists these entries along with business categories.

Figure 12.24 Entries to the Case Presentation Convention



Since member factories of The Energy Conservation Center, Japan mainly participate in the convention, most of these factories are large-scale factories.

Figure 12.22 shows the motivations for improvement. The production facility and operation always change from the initially planned situation. In other words, the product volume change, production quality change, advance of technologies for peripheral facilities, change of raw material, and so forth always take place. The presented cases show the results of pursuing optimization of energy conservation to cope with these changes.

Since such production environment changes are specific to each factory, application of a presented case to another factory may not always produce a good result. However, presented improvements cover a wide range and therefore these details may give tips for improvement in each factory.

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