8. Energy Conservation in Glass Industry

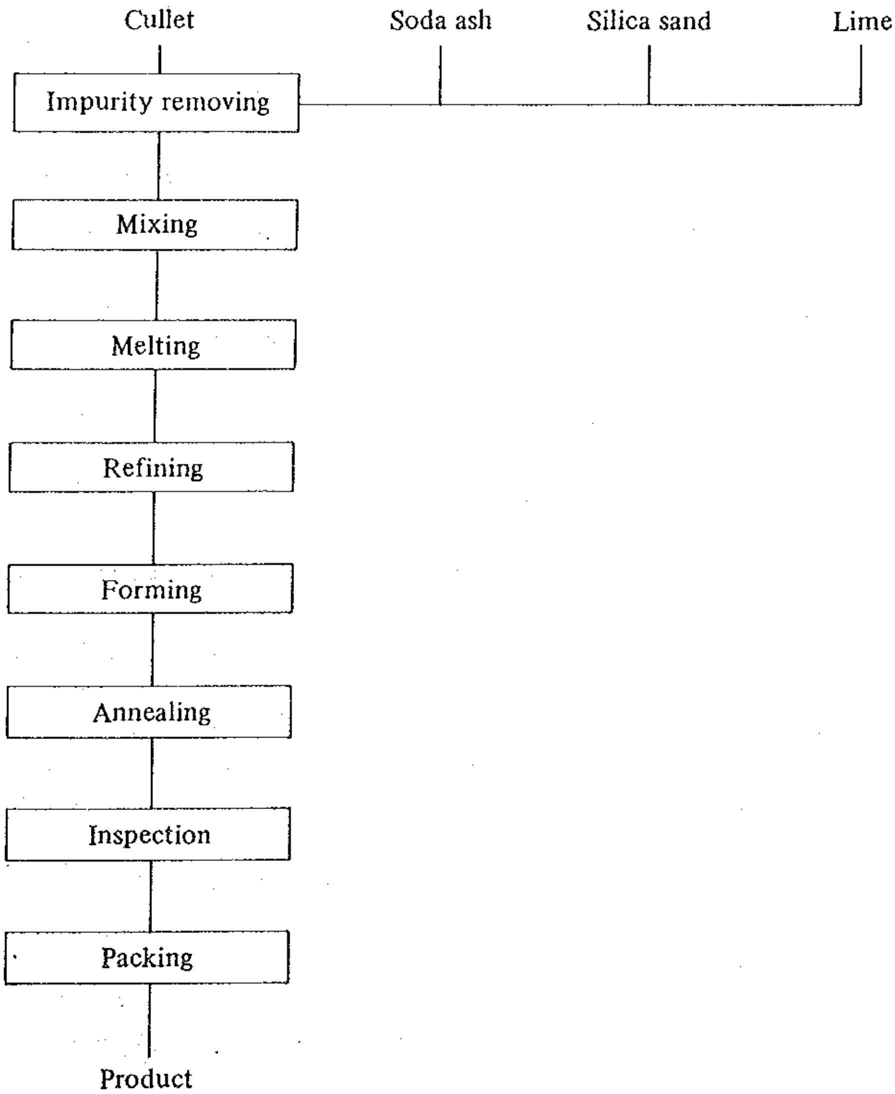
8. GLASS

8.1 Characteristics of Use of Energy

8.1.1 Manufacturing Process and Main Equipment

The manufacturing process of bottles and glassware is relatively simple as shown in Figure 8.1.

Figure 8.1 Manufacturing Process



The composition of glass varies from one application to another. Bottles and tableware are made of soda ash glass of the composition shown in Table 8.1.

Table 8.1 Composition of Glass for Vessel

Components	Contents
SiO_2	70 ~ 74 %
Al_2O_3 Fe_2O_3	1.5 ~ 2.0
CaO MgO	8 ~ 12
Na_2O K_2O	13 ~ 16

(1) Manufacturing process

According to the glass composition required for the manufacturing process, silica sand, soda ash, limestone, dolomite, etc. are mixed, and small amounts of auxiliary materials, such as clarifier, colorant, and decolorant, as well as an appropriate amount of cullet, are blended with the mixture into a composite material.

The composite material is charged into the furnace (see Figure 8.2) that is kept at about 1,500 °C, where the material is heated and melted by the radiating heat of flames in the upper space. Then the molten material is clarified and its bubbles are separated. The center part of the furnace is kept higher in temperature than the rest so that unmolten or low-temperature material in the furnace will not flow out to the working hearth.

The molten, clarified glass runs through the throat to the working hearth, from which it is supplied through the forehearth to the forming machines. When the molten glass is in the working hearth and forehearth, its temperature is adjusted to suit the molding of products according to their weights and shapes. There, the material is heated by a number of small burners or directly by applying electricity.

Except for some cases in which glass is formed by manual blowing, individual section machines are generally used for mass production.

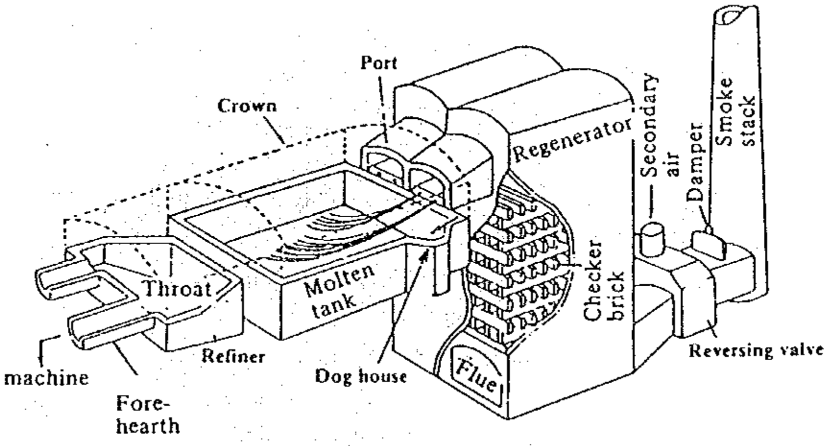
Formed products are annealed in an annealing furnace so that there will be no thermal strain left in the products. Annealing temperature and time vary depending on the glass composition, product wall thickness, etc. Generally, however, formed products are gradually cooled from 500 °C – 550 °C to abut 400 °C at a speed of 1 °C to 5 °C per minute. Although batch furnaces are also used for annealing, a continuous, tunnel furnace with a mesh belt, called lehr, is mostly used.

After annealing, the products are checked and packed.

(2) Main equipment

There are two types of furnace for melting glass material: the tank furnace that is suited to continuous, mass production, and the pot furnace for producing a variety of kinds in small quantities. Figure 8.2 shows a typical, medium-sized tank furnace.

Figure 8.2 Outline Sketch for Middle-Size Tank Furnace (End Port Type)



A high temperature of about 1,500 °C is necessary to melt glass so that combustion air must be preheated by heat exchange with combustion exhaust gas. A regenerator or recuperator such as shown in the figure is used for this preheating. Instead of heating with fuel, or as a complementary means, an electrode may be directly inserted into molten glass to directly heat it with electricity.

The melting furnace is lined with erosion-resistant electrocast bricks of $ZrO_2 - Al_2O_3 - SiO_2$ in the lower part which is exposed to molten glass, and with silica bricks in the upper part.

The burners are arranged in the axial direction of the furnace (end port type) except for large-sized furnaces. A furnace that has a regenerator uses an even number of burners, alternately operating a half of the burners every specific time, usually every 15 to 20 minutes.

The regenerator is divided into two rooms. The one on the side of the operating burners is used to preheat combustion air, and the other heats the checker bricks through combustion exhaust gas to store the heat in the bricks. Generally, the regenerator type has a higher rate of heat recovery than the recuperator.

8.1.2 State of Use of Energy

In glass factories, energy is consumed as shown in the table below.

Figures 8.3 and 8.4 show an average ratio of energy consumption by purpose of use at some glass bottle factories. As is clear from these figures, energy conservation is important for the melting and other furnaces.

Figure 8.3 Share of Total Energy Consumption

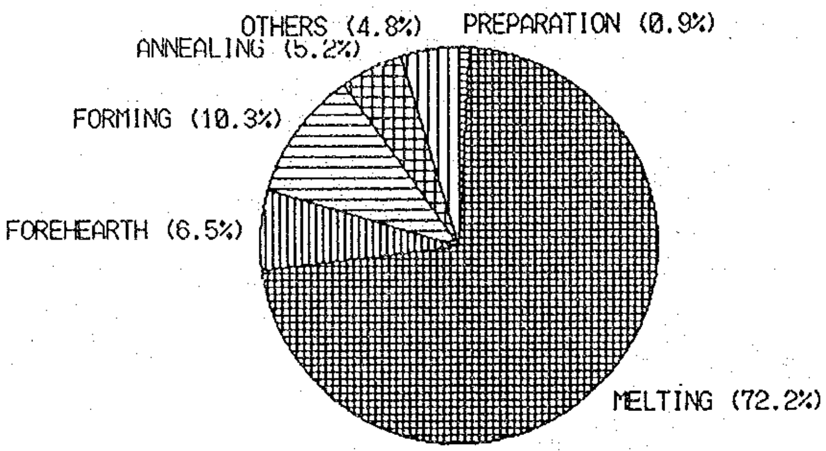
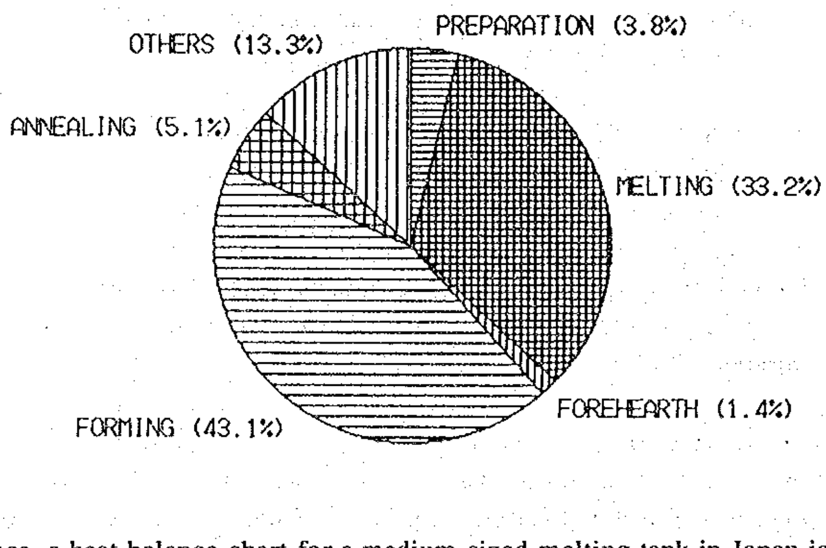
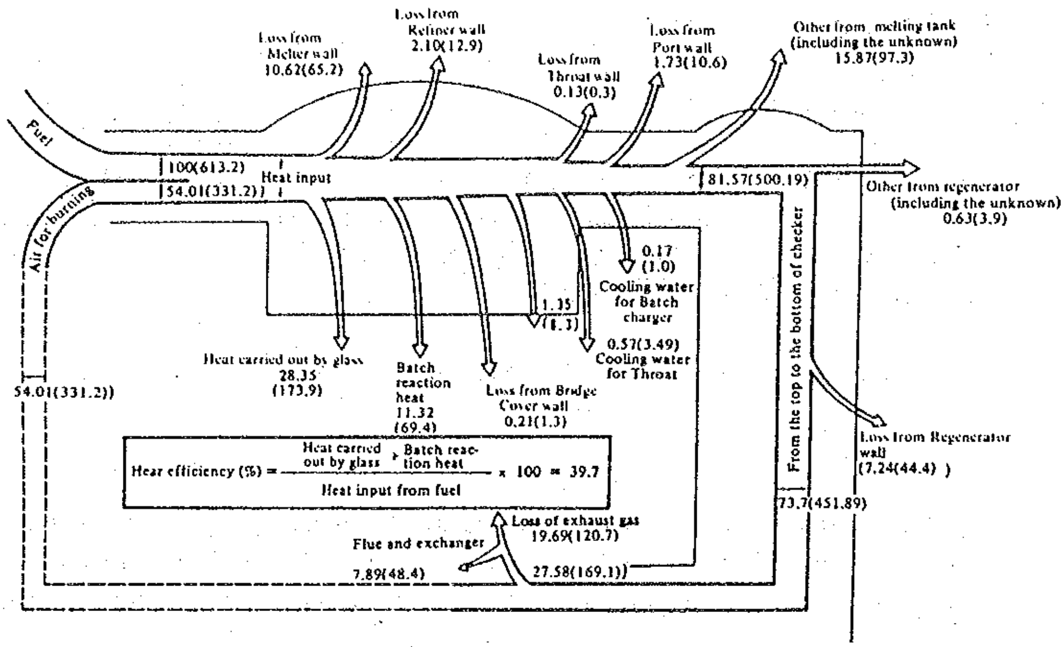


Figure 8.4 Share of Electricity Consumption



For your reference, a heat balance chart for a medium-sized melting tank in Japan is shown in Figure 8.5. This furnace has a thermal efficiency of about 40 %, and heat loss is mainly from the furnace walls except that about 20 % of the heat is lost in the combustion exhaust gas.

Figure 8.5 Heat Balance Chart for Glass Melting Tank



Energy consumption rate, including power consumption, for the production of glass bottles cannot be simply compared because it varies depending on the kind of glass, whether a printing process is involved, and other factors. The example in Japan for your reference reveals that the mean energy consumption rate was about 2,500,000 kcal/ton, improving by about 30 % over the reference year of 1974 when it was about 3,500,00 kcal/ton.

A glass bottle factory with new furnace of the highest efficiency (200 tons/day) showed an energy consumption rate of 1,820,000 kcal/ton, of which energy consumption for melting was 950,000 kcal/ton. By kind of energy, fuel consumption was 1,310,000 kcal/ton and electricity consumption 510,000 kcal/ton.

A breakdown of electricity consumption at a glass bottle factory in Japan is shown below.

Table 8.2 Purpose of Electric Power Consumption

Facilities	Purpose	Ratio
Large-size fan	Cooling of kiln wall, feeding of air for burning	28%
Compressor	Drive and cooling of bottle manufacturing machine	27%
Electric booster	Melting	21%
Other motors		21%
Illumination		3%

8.2 Rationalization of Use of Heat Energy

8.2.1 Melting Furnace

(1) Optimization of air ratio

Glass is melted at a high temperature of about 1,500 °C, and heat is conducted predominantly by radiation at such a high temperature. The quantity of heat, Q, radiated from an object T_1K in absolute temperature to another object T_2K in absolute temperature can be expressed by the following equation.

$$Q = 4.88\varepsilon\left\{\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right\} \text{kcal}/\text{m}^2\text{h}$$

where ε is the emissivity.

It is known from the above equation that the amount of heat transferred increases as flame temperature rises. Because flame temperature lowers as excess air increases, however, the air ratio must be lowered within a range in which incomplete combustion will not occur.

It is also important to decrease the amount of exhaust gas because it still has a temperature of about 500 °C after waste heat recovery.

If the actual amount of exhaust gas is G, the theoretical amount of exhaust gas G_0, the theoretical amount of combustion air A_0, and the ratio m,

$$G = G_0 + (m - 1)\, A_0\ \text{Nm}^3/\text{kg}(\text{Nm}^3)\ \text{fuel}$$

As expressed above, lowering the air ratio will help reduce the amount of exhaust gas. Although G_0 and A_0 should be calculated from the composition of the fuel, they can be approximately calculated from the lower heating value of the fuel by the equation (Rosin's equation) of Table 8.3.

If the amount of exhaust gas decreases from G_1 to G_2 by improving the air ratio, the decreased exhaust gas loss will reduce the amount of fuel to further decrease the amount of exhaust gas. In this case, the percentage of fuel saving can be expressed by the following equation.

$$\text{Fuel saving } (\%) = \frac{100R(1-\frac{G_2}{G_1})}{100-RG_2/G_1}$$

(there R is the percentage of exhaust gas loss before the improvement.)

Table 8.3 Relationship between Low Calorific Value $H\ell$ and G_0, A_0 (By Rosin)

Fuel	G_0	A_0
Solid fuel ($H\ell$: kcal/kg fuel)	$\frac{0.89\,H\ell}{1{,}000} + 1.65$ Nm³/kg fuel	$\frac{1.01\,H\ell}{1{,}000} + 0.5$ Nm³/kg fuel
Liquid fuel ($H\ell$: kcal/kg fuel)	$\frac{1.11\,H\ell}{1{,}000}$ Nm³/kg fuel	$\frac{0.85\,H\ell}{1{,}000} + 2.0$ Nm³/kg fuel
Low calorific value gaseous fuel ($H\ell$ = 500 to 3,000 kcal/Nm³ fuel)	$\frac{0.725\,H\ell}{1{,}000} + 1.0$ Nm³/Nm³ fuel	$\frac{0.875\,H\ell}{1{,}000}$ Nm³/Nm³ fuel
High calorific value gaseous fuel ($H\ell$ = 4,000 to 7,000 kcal/Nm³ fuel)	$\frac{1.14\,H\ell}{1{,}000} + 0.25$ Nm³/Nm³ fuel	$\frac{1.09\,H\ell}{1{,}000} - 0.25$ Nm³/Nm³ fuel

The results of actually measuring a tank furnace in Japan showed that fuel consumption was least in the range of m = 1.07 to 1.16.

An amount of combustion air cannot be directly measured because, apart from preheated air for combustion, there is air entering through the openings. Thus, it is determined by measuring the concentration of oxygen or CO_2 in the exhaust gas and calculating the material balance. If fuel has only small nitrogen content, burns completely, and if the nitrogen content of combustion air is 79 %, air ratio can be calculated by the following equation.

$$m = \frac{21}{21-(O_2)+0.5(CO)}$$

where (O_2) is the concentration of oxygen in exhaust gas (%).
(CO) is the concentration of CO in exhaust gas (%).

Or,

$$m = \frac{1-(CO_2)-1.5(CO)}{\frac{1-(CO_2)max}{0.79} \times \frac{(CO_2)+(CO)}{(CO_2)max}} + 0.21$$

where (CO_2) is the concentration of carbon dioxide gas in exhaust gas (%); theoretical dry exhaust gas (%).
(CO_2) max, the maximum concentration of carbon dioxide gas in theoretical dry exhaust gas (%)

$$(CO_2)\ max = \frac{1{,}867 . C}{G_0} \times 100\ \%\ \text{(solid/liquid fuel)}$$

$$G_0\ ' = G_0 - (11.2 \cdot h + 1.244\ W)\ Nm^3/kg$$

where h is hydrogen content (kg) in 1 kg fuel;
W, water content (kg) in 1 kg fuel;
C, carbon content (kg) in 1 kg fuel.

In the case of gas fuel, the same can be calculated from analyzed values of the components.

The following values may also be used for (CO_2).

Coal (18.5 %); fuel oil (15.7 %); natural gas (12 %); LPG (14.5 %)

To keep the air ratio appropriate, the following must be borne in mind.

a. In the case of liquid fuel, observe the following.

a-1 Preheat it to an appropriate level of viscosity.

a-2 Remove solids from the fuel using a filter.

a-3 Keep the burner tips clean.

a-4 Adjust atomizing steam or air to appropriate pressure.

There was an instance in which fuel consumption was reduced by 2 or 3 % by atomizing natural gas instead of air.

b. Preventing air infiltration

Air sucking through the dog house, around the burners, sightholes, etc. will not only increase the amount of exhaust gas but also lower the temperature inside the furnace because that air is cool.

- It is necessary to take the following steps in order to reduce air sucking to a minimum.

- Make the openings as small as possible by, for example, completely sealing the joints, using water-cooled burners to narrow the clearances around the burners, or sealing the dog house with batch.

- Adjust the damper to maintain the correct furnace pressure.

c. Control

Control the amount of secondary air in proportion to the amount of fuel. In cases, a computer is employed for more accurate control, involving compensation for changes in crown temperature, O_2 concentration in exhaust gas, and secondary air temperature, and shortening of switching time.

(2) Improving flame emissivity

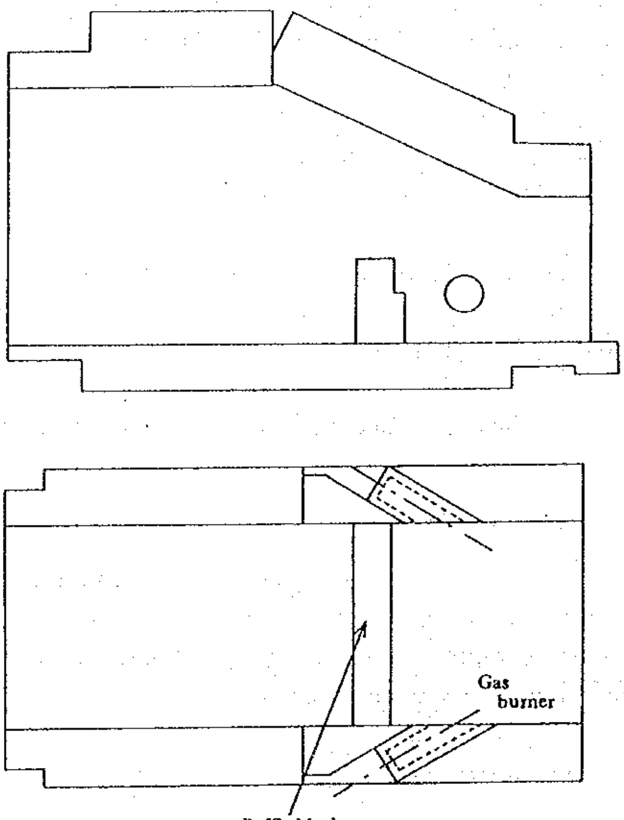
In gas combustion, heat is transferred mainly by radiation from the clear flames of high-temperature carbon dioxide gas, water vapor, and other triatomic gas.

In fuel oil combustion, heat is transferred by luminous flame radiation, and solid radiation from the suspended carbon particles that are generated in the flames during combustion plays an important role.

Emissivity ε of radiation heat transfer differs between fuel oil (0.5 – 0.6) and gas (0.1 – 0.2) in the initial phase of combustion. In actual furnaces, the effect will be less because there is re-radiation from the furnace walls in addition to radiation from the flames, but gas has less amount of radiation heat transfer than fuel oil.

Figure 8.6 shows an instance, in which a baffle is provided in the port. Fuel gas is injected in back of it to be burnt in a state of rather insufficient air so that fine carbon particles will be generated and they will be burnt into luminous flames in secondary combustion.

Figure 8.6 Baffle Block in the Port

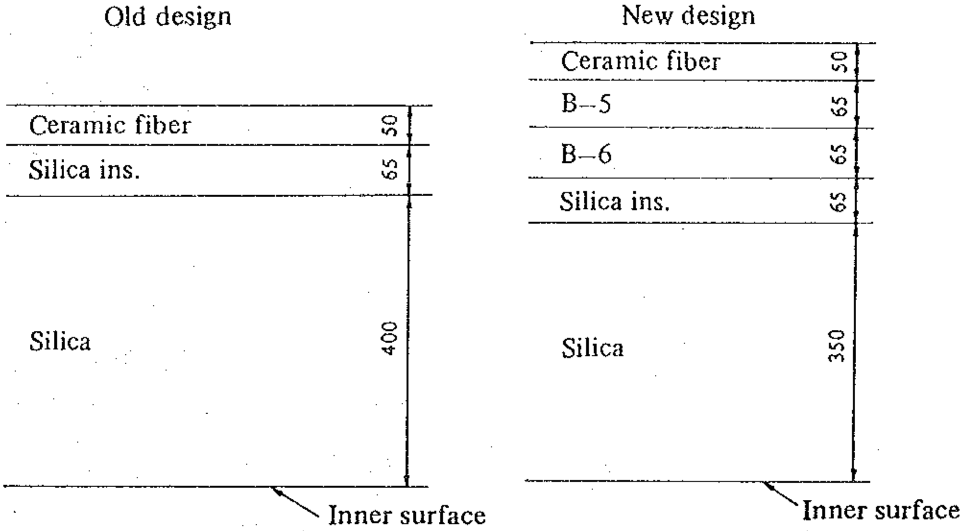


(3) Reinforcing heat insulation

The refractories of the melting furnace are exposed to very severe conditions in terms of temperature and corrosion by the glass. Consequently, they had not been sufficiently heat-insulated, and the outer surface of wall of molten glass level was cooled by air. As is clear from the heat balance chart, heat radiation from the furnace walls accounts for a large percentage of heat loss, so the furnace was being improved in heat insulation using high-grade refractories. Specifically, the furnace crown was lined with super-duty silica bricks having small alkali or alumina content; the tank block and bottom were lined with electrocast bricks of alumina, zirconium, silica inside and with refractory bricks, insulating bricks, or ceramic fiber outside.

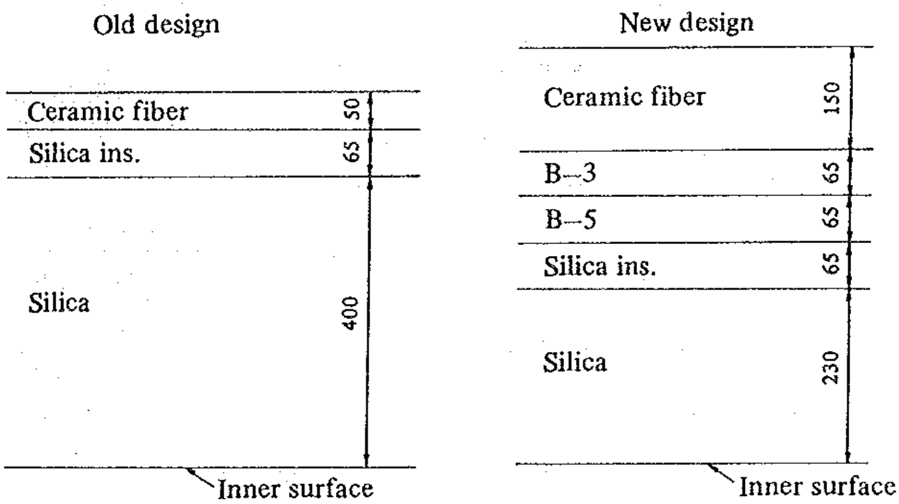
Figures 8.7 to 8.15 show the bricks lining various parts of the old and new furnaces, and the difference in their heat radiation.

Figure 8.7 Heat Insulation of Melting Furnace Crown



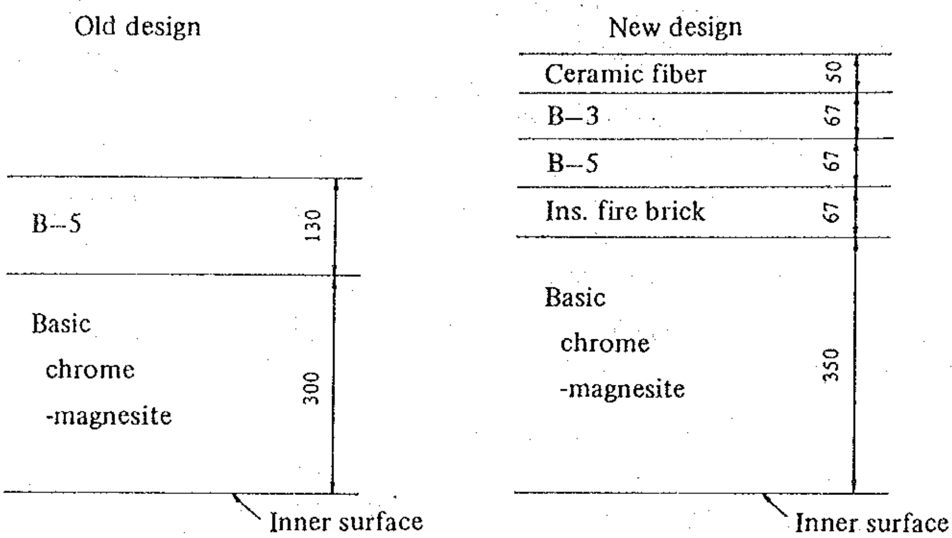
	Old design	New design
Inner surface temperature	1550 °C	1550 °C
Outer surface temperature	109.6 °C	83.4 °C
Amount of heat radiation	1505 kcal/m²·h	1046 kcal/m²·h

Figure 8.8 Heat Insulation of Working Hearth Crown



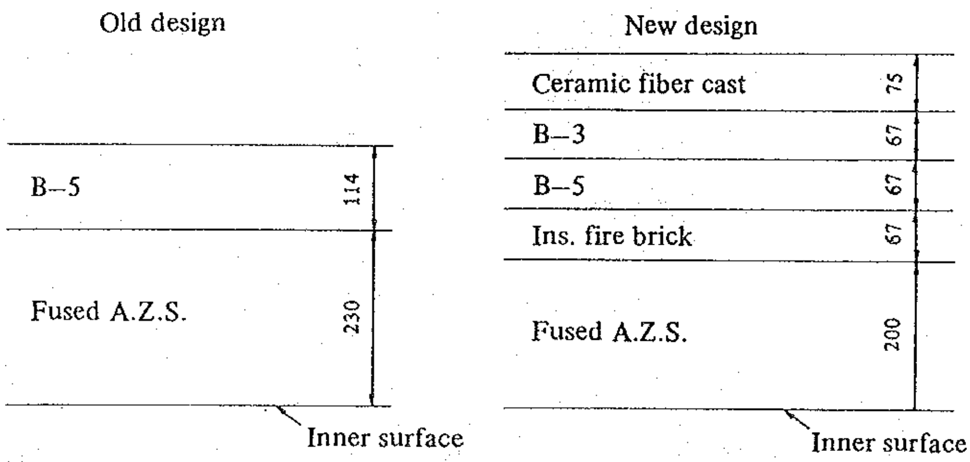
	Old design	New design
Inner surface temperature	1250 °C	1250 °C
Outer surface temperature	85.4 °C	43 °C
Amount of heat radiation	1078 kcal/m²·h	463 kcal/m²·h

Figure 8.9 Heat Insulation of Regenerator Crown



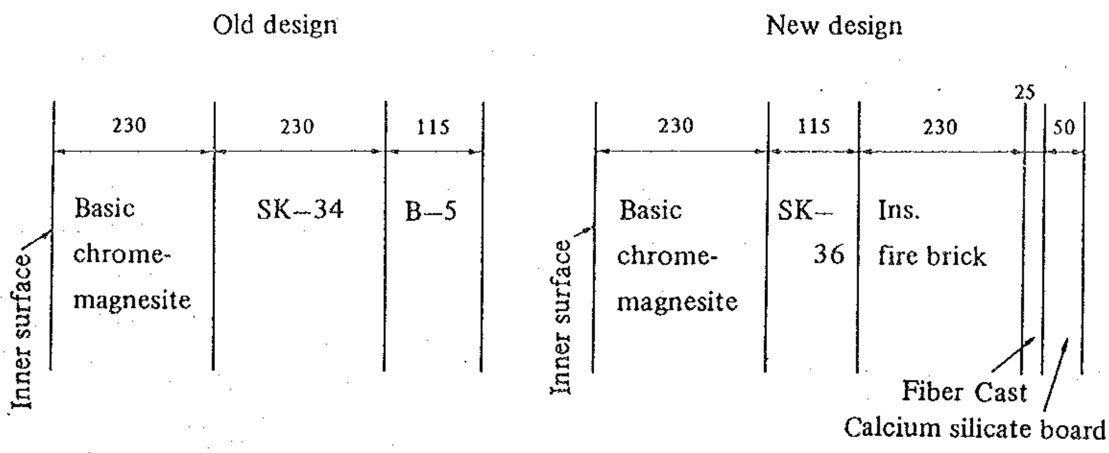
	Old design	New design
Inner surface temperature	1450 °C	1450 °C
Other surface temperature	128.4 °C	75.2 °C
Amount of heat radiation	1900 kcal/m²·h	919 kcal/m²·h

Figure 8.10 Heat Insulation of Port Crown



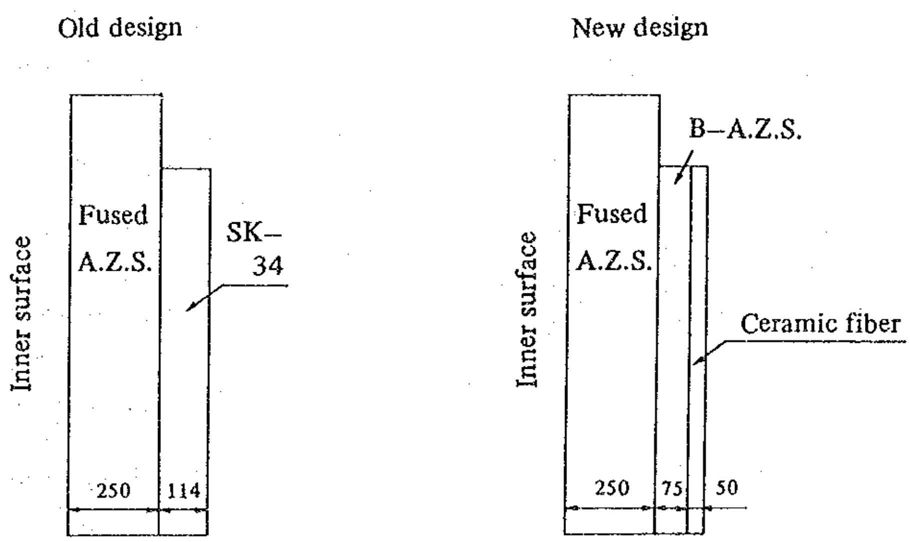
	Old design	New design
Inner surface temperature	1500 °C	1500 °C
Outer surface temperature	164 °C	86.6 °C
Amount of heat radiation	2778 kcal/m²·h	1097 kcal/m²·h

Figure 8.11 Heat Insulation of Regenerator Sidewalls (Upper Part)



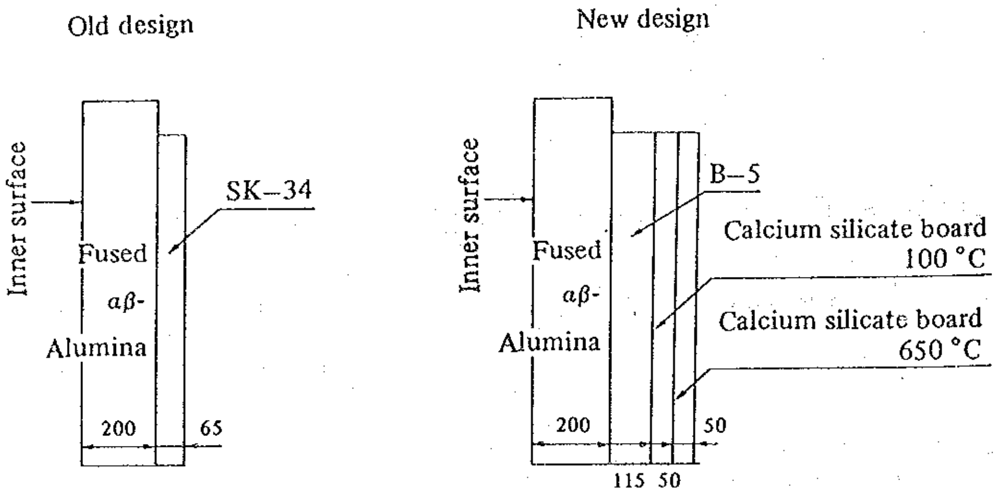
	Old design	New design
Inner surface temperature	1450 °C	1450 °C
Outer surface temperature	122.2 °C	81.2 °C
Amount of heat radiation	1554 kcal/m²·h	814 kcal/m²·h

Figure 8.12 Heat Insulation of Melting Tank Block



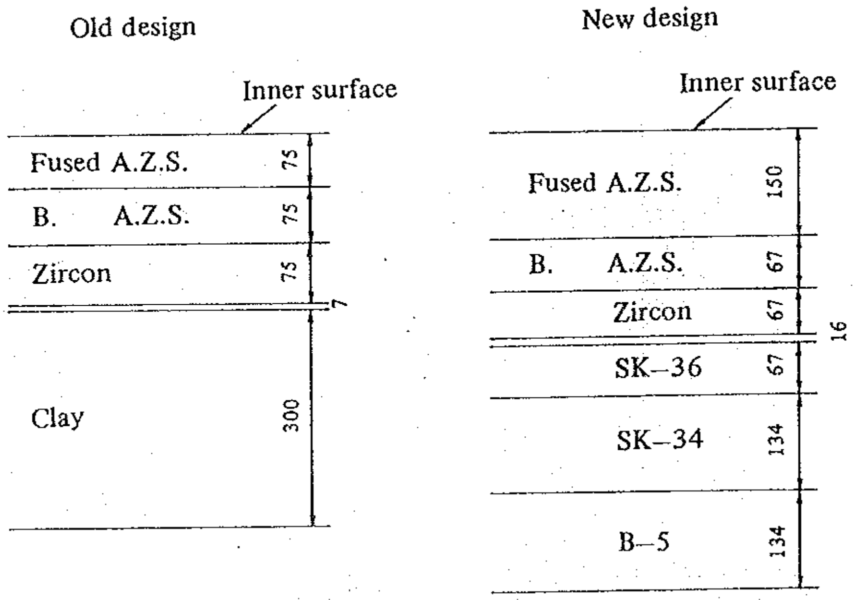
	Old design	New design
Inner surface temperature	1350 °C	1350 °C
Outer surface temperature	231.6 °C	141 °C
Amount of heat radiation	6102 kcal/m²·h	2017 kcal/m²·h

Figure 8.13 Heat Insulation of Working Hearth Tank Block



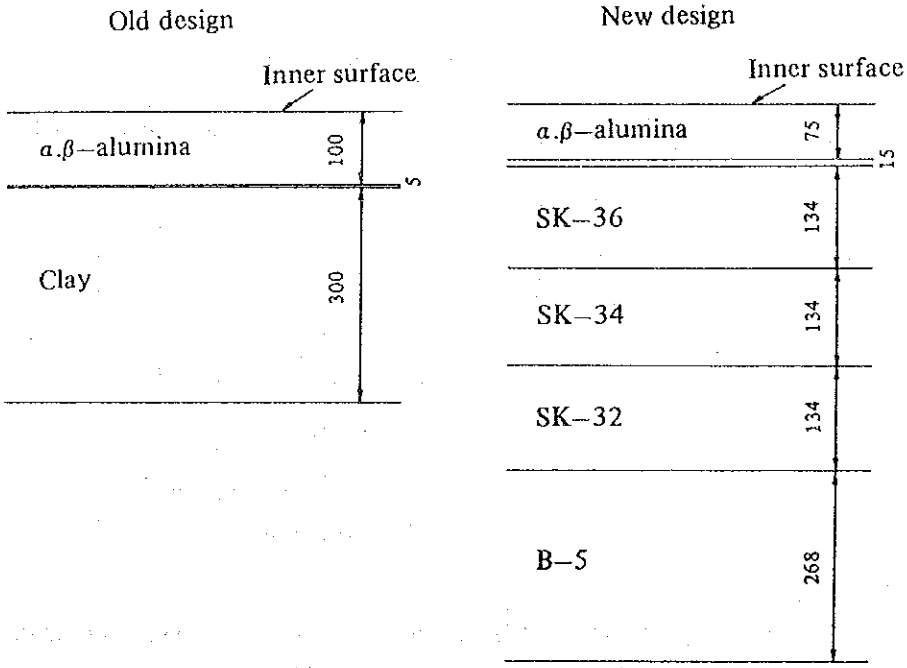
	Old design	New design
Inner surface temperature	1200 °C	1200 °C
Outer surface temperature	251.6 °C	74.2 °C
Amount of heat radiation	7624 kcal/m²·h	717 kcal/m²·h

Figure 8.14 Heat Insulation of Melting Tank Bottom



	Old design	New design
Inner surface temperature	1350 °C	1350 °C
Outer surface temperature	187 °C	114 °C
Amount of heat radiation	3240 kcal/m²·h	1381 kcal/m²·h

Figure 8.15 Heat Insulation of Working Hearth Bottom



Inner surface temperature	1100 °C	1150 °C
Outer surface temperature	181.8 °C	63.4 °C
Amount of heat radiation	3070 kcal/m²·h	631 kcal/m²·h

(4) Waste heat recovery

Because a melting furnace requires high temperature, the waste heat of burnt exhaust gas is recovered to preheat secondary air. Either a regenerator or recuperator is used as a waste heat recovery unit. Generally, a regenerator is used except for small-sized furnaces.

The heat recovery ratio of the regenerator can be improved by decreasing the thickness of checker bricks, increasing the velocity of exhaust gas running through the checker bricks, and raising the height of the regenerator and thus increasing the amount of checker bricks. (See Figures 8.16 and 8.17.) Normally, secondary air is preheated to about 1,250 °C – 1,300 °C. The checker bricks cause breaking down by reaction with the dust in exhaust gas over years of use, clogging up the gaps and reducing the heat exchange area. Therefore, high-grade bricks of high corrosion resistance have come to be used to last as long as the melting furnace itself.

Figure 8.16 Relationship between Height of Checker and Air Preheating Temperature

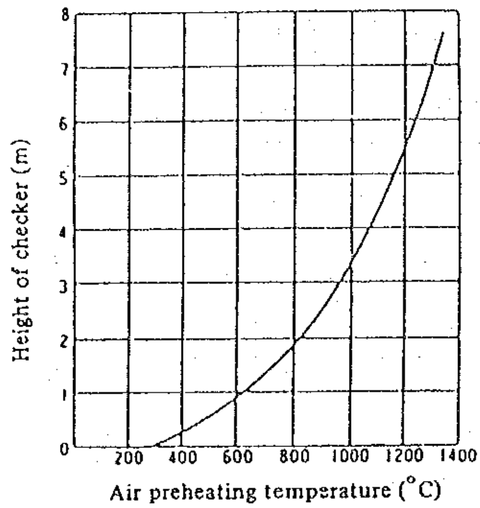
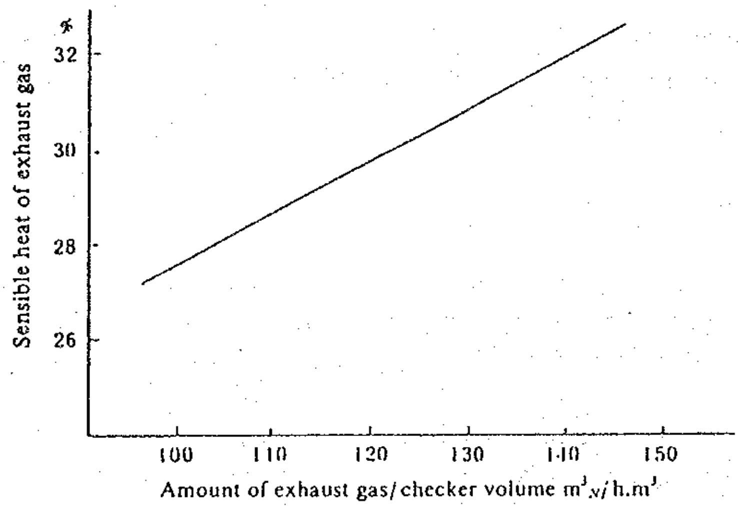


Figure 8.17 Relationship between Amount of Exhaust Gas/Checker Volume and Sensible Heat of Exhaust Gas



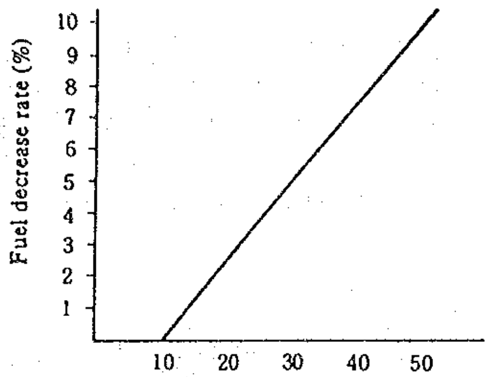
As for recuperator, the radiating type recuperator which is free of clogging with dust is mostly used, but a multiple ceramic tube recuperator is also used. There is also a type which withstands exhaust gas temperatures of up to about 1,500 °C, but its heat recovery ratio is low because preheated air temperature is up to about 800 °C. However, it is used for small-sized furnaces for reasons that it costs low to install and does not require much floor space.

To make maximum use of preheated air, it is necessary to reduce the entry of air of normal ambient temperature through the openings.

(5) Material mixing

The energy used for melting can be reduced if cullet and limestone are mixed in a larger percentage, provided that product quality will not be adversely affected by their increased percentage. The relationship between the percentage of cullet and required heat is shown in Table 8.4 and Figure 8.18.

Figure 8.18 Consumption Rate for Cullet and Fuel Saving Rate



Consumption rate for cullet (against the weight of finished product) (%)
Based on the consumption percentage of 10% for cullet.

Table 8.4 Heat Requierd for Production of Various Kinds of Glass at 1,400 °C and Pull Temeratures (Theoretical Value)

Kind of glass	Temperature °C	Heat required for melting glass (kcal/kg glass) Cullet addition rate %					
		0	20	40	60	80	100
Tableware glass	1,400	576	543	510	477	444	411
	1,250	530	497	464	431	398	365
Sheet glass	1,400	666	615	563	512	460	409
	1,150	571	520	468	417	365	314
Laboratory appliances	1,400	508	482	455	429	402	376
	1,300	477	451	424	398	371	345
Lead glass	1,400	496	472	448	424	400	376
	1,100	391	367	343	319	295	271

For your reference, the percentage of cullet used in producing glass bottles in Japan was 58 percent in 1992. Because impurities cannot be removed in the melting furnace, they must be removed from cullet beforehand. The cullet quality standard and processing method are shown in an item of the report of the factory survey.

Use of a clarifing agent will shorten the clarifying time, and result in saving energy. A type and quantity of clarifing agent must be selected to suit the furnace conditions.

(6) Electric melting

This method uses an electrode inserted into the melting furnace to directly apply electricity to glass which becomes electro-conductive at about 800 °C. If it is used in a fuel-heating furnace as an auxiliary means to increase the amount of pull and adjust the temperature inside the furnace, it is called booster. About 100 kW of electricity is required to increase quantity by 3 tons or more per day. If the efficiency of conversion from fuel oil to electricity is 35 % and if the fuel consumption rate is 175 liters or more per ton, energy can be saved by using a booster.

Table 8.5 Heat Output Ratio of Electric Melting Furnace

	Heat output (kcal/h)	Ratio (%)
Heat release from ceiling	28	(0.07)
Heat release from furnace bottom	5,883	
Heat release from throat side wall	5,200	
Other walls	7,850	
Total	18,961	44.1
Loss by water cooling for electrode	10,455	24.3
For glass heating	13,584	31.6

(Capacity 750 kg. pull quantity 400 kg/day)

	Heat output (kcal/h)	Ratio (%)	
Ceiling	1,800	2	30
Side wall	10,700	15	
Bottom	9,300	13	
Cooling water for electrode	1,400	2	2
Calorific value required for vitrification	2,200	3	68
Soaring temp. of glass	46,600	65	
Total	72,000	100	100

(Pull quantity 60 t/day)

8.2.2 Forehearth

The forehearth is used to adjust the glass temperature to suit bottle production. In the case of using fuel in the forehearth control of the air ratio and improved heat insulation will be as important items of energy conservation measures as for the melting furnace.

8.2.3 Lehr

(1) Increase in the heat carried in

Formed products still have a temperature of over 600 °C, so if they are taken into the lehr without losing this heat, heating should be theoretically unnecessary, provided that the following conditions are met.

- To shorten the distance between the forming machine and lehr
- To charge formed products from the forming machine into the lehr as quickly as possible.

(2) Preventing heat radiation

While the glass is still at high temperature, it must be gradually cooled. For this purpose the following conditions must be met.

- Heat insulation of the high-temperature parts and prevention of hot air leakage
- Controlling cold air leakage into the lehr through the charging port
- A lehr sectional shape suited to product dimensions and production
- Shortening spaces of charged products

(3) Use of direct heating method

In case of using fuel oil, the indirect heating method using muffles or radiant tubes was usually employed to prevent the burning gas from directly touching the products and possibly making their surfaces cloudy.

However, the lehr has a heating temperature range of less than 600 °C, and radiation heat transfer by indirect heating is inefficient. For this reason, direct heating comes, common when using gas as fuel.

(4) Lowering of mesh belt heat capacity

The example shown below indicates that the quantity of heat required to heat the mesh belt is larger than normally expected.

Product processing rate : 630 kg/h

Average specific heat of products : 0.252

Product temperature before entering lehr: 400 °C

Annealing temperature : 550 °C

In this case, the quantity of heat Q_1 required to heat the products can be calculated as follows:

$$Q_1 = 0.252 \times (550 - 500) \times 630 = 23814 \text{ (kcal/h)}$$

Suppose that the products are conveyed on a 1,500 mm width belt into the lehr.

Belt weight : 20 kg/m²

Belt speed : 380 mm/min

Temperature before entering lehr : Normal temperature 15 °C

Maximum heating temperature of belt in lehr: 550 °C

Average specific heat : 0.132

In this case, the quantity of heat Q_2 required to heat the belt will be:

$$Q_2 = 0.132 \times (550 - 15) \times 20 \times 0.38 \times 1.5 \times 60 = 48304 \text{ (kcal/h)}$$

As shown, more than twice as much heat is consumed to heat the belt as to heat the products Possible measures to reduce this heat include decreasing belt wire diameter, increasing wire pitch, and thus reducing belt weight per unit area.

Further, the mesh belt may be preheated by exhaust gas on the return way.

The heat consumption rate of the lehr varies largely depending on the charging temperature of the products, their shape, wall thickness, the number of times these parameters change, operating time, processing quantity, and the type of lehr. For your reference, some of the lehrs used in Japan show a heat consumption rate ranging from 380 to 830 kcal/kg in most cases, and some large ones show an extremely low heat consumption rate of 50 kcal/kg.

8.2.4 Product Weight Reduction

Reducing the quantity of glass required to produce a specific quantity of bottles helps decrease the energy used for production. To maintain the required bottle strength using a limited quantity of glass material, it is necessary to improve form design and wall thickness distribution, and enforce strict control on surface treatment and manufacturing conditions.

8.2.5 Productivity Improvement

Glass bottle production requires high temperature and consumes much heat even during temporary suspensions of production. Therefore, it is necessary to prevent mechanical trouble from interrupting work, shorten the time of changing molds in the forming machines, and decreasing the frequency of changing the molds.

The glass melting furnace has a high percentage of fixed heat loss, and its fuel consumption rate lowers as the amount of pull increases. It is also necessary, therefore, to try increasing the amount of pull while preventing quality deterioration by better stirring the material in the furnace.

8.2.6 Preventing Rejects

If products are defective and must be returned as rejects into the material, it means loss of all energy consumed for them. Efforts must be made to enforce better control on material quality, working conditions in each of the manufacturing processes, and equipment maintenance so that there will be no rejects on the production line.

9. Energy Conservation in Boiler Operation

9. ENERGY CONSERVATION IN BOILER OPERATION

9.1 Classification

Now, boilers used universally can be classified by structure as shown in Table 9.1.

Table 9.1 Classification of Boiler

Type	Model
Cylindrical boiler	Vertical boiler Flue boiler Smoke tube boiler Tube boiler
Water tube boiler	Natural circulation water tube boiler Forced circulation water tube boiler Once-through boiler
Others	Sectional boiler etc.

9.1.1 Cylindrical boiler

Cylindrical boiler is mainly composed of a large diameter cylinder and unsuitable for a high pressure and a larger capacity due to its structure. It has been used as a boiler of less than 10 bar and 8 t/h in evaporation.

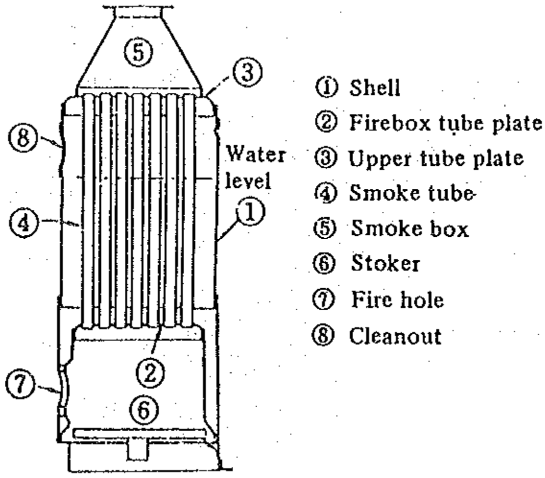
Since the cylindrical boiler has a larger water retaining volume per capacity compared with water-tube boiler, it demands much time to start up but a pressure fluctuation due to loading change is small.

a. Vertical boiler

As shown in Figure 9.1, vertical boiler has a vertical cylinder and a combustion chamber in the bottom section. There are two systems of horizontal tube type and multi-tube type. Because it can not be provided with large heating surface area, the capacity is limited to 1 t/h or less.

It can do with a small floor area and can be set simply up, but it is hard to check and clean because of its small size. Because of the small surface area, entrainment contained in the generated steam tends to be too much.

Figure 9.1 Vertical Boiler (multitubular type)



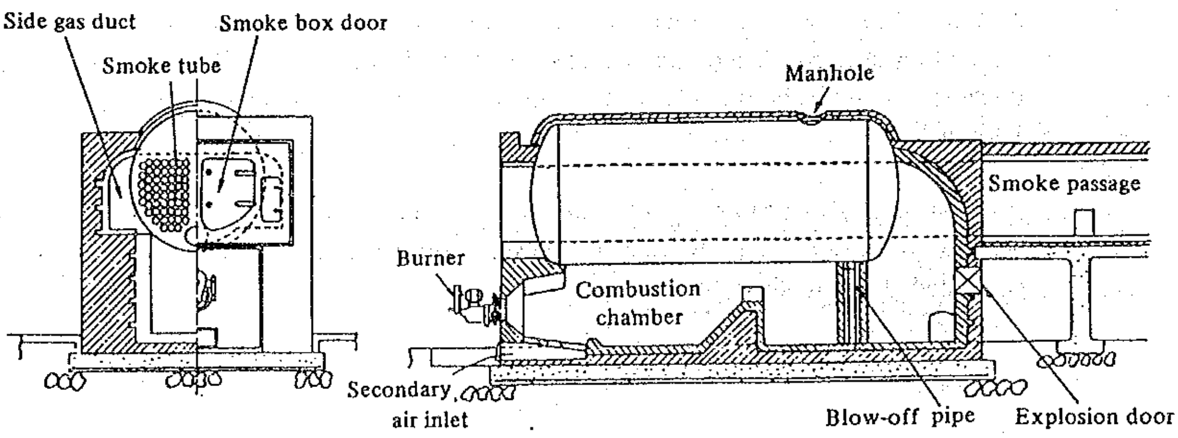
b. Flue boiler

The flue boiler is provided with one or two flues through shell and the burners are equipped in the flue. One flue type is called a Cornish boiler and two flues type is referred to as a Lancashire boiler. Since the boiler has a small heating surface area and has lower efficiency, recently it has been scarcely manufactured.

c. Smoke tube boiler

As shown in Figure 9.2, a smoke tube boiler is equipped with a combustion chamber formed with brick laying beneath the cylinder and arranged with a number of smoke tubes in the shell. The combustion gas heats the lower section of shell and then heats again the side surface of shell after passing the smoke tubes. As the heat loss through the brick wall is large in case of outside combustion chamber, some boiler is equipped with the combustion chamber in a part of the flue.

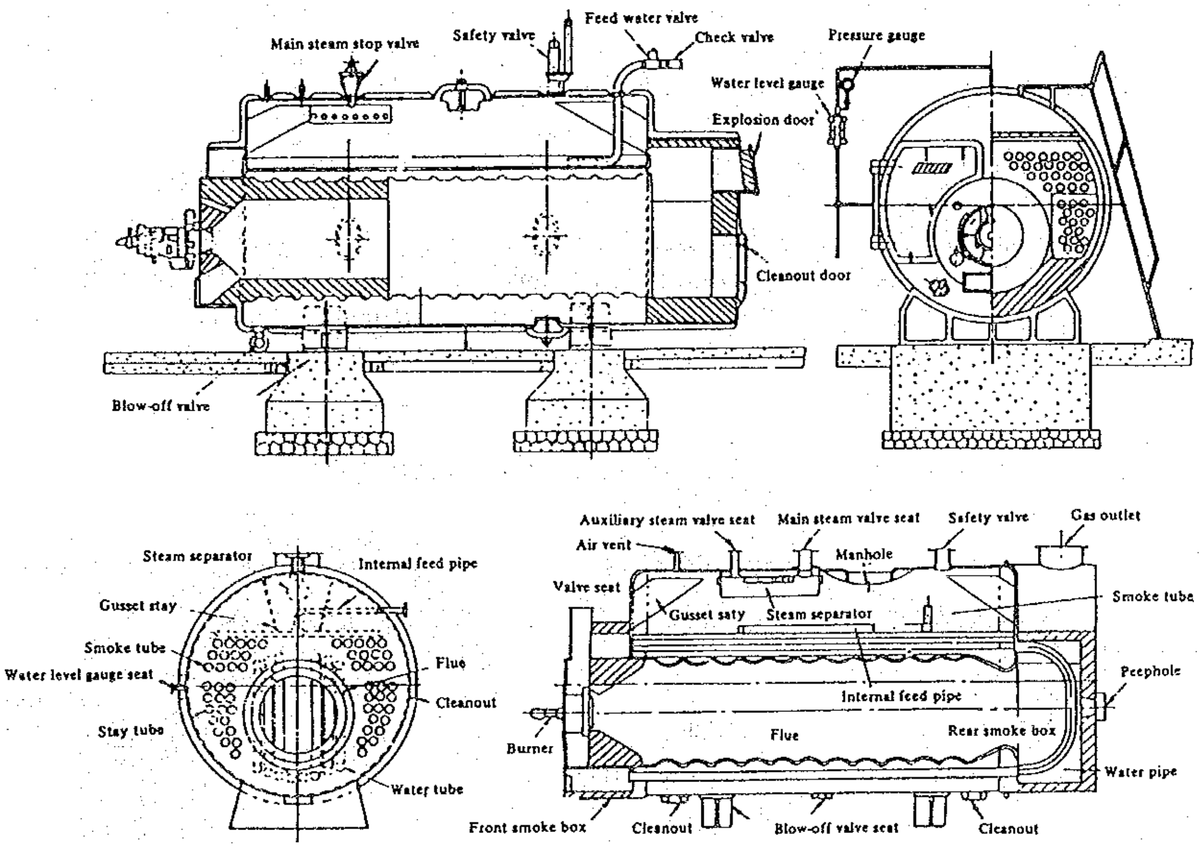
Figure 9.2 Externally Fired Horizontal Smoke Tube Boiler



d. Flue smoke tube boiler

As shown in Figure 9.3, a flue smoke tube boiler is an internally fired boiler equipped with both of flue and smoke tubes in the shell. The boiler is generally used as a package boiler with characteristics of a relatively larger heating surface area of high efficiency even in a small capacity and has easy installation and handling. The boiler is limited to 15 bar in pressure and 25 t/h in capacity. An efficiency of 85 to 92 % is obtainable. On the other hand, the structure is complex, check and cleaning in the inside are difficult and feed water is required to be high quality.

Figure 9.3 Flue Smoke Tube Boiler



9.1.2 Water-Tube Boiler

As shown in Figure 9.4, a water-tube boiler is composed of a drum for steam and water separation and a number of water tubes formed with a heating surface, and is designed to make evaporate feed water in the water tubes. Accordingly, since the heating surface can be made larger through increasing the number of water tubes, the boiler is suitable even for a large capacity and is able to obtain easily a high pressure. The features of water-tube boilers are as follows:

a. Because the combustion chamber is able to be made in any size, the combustion is in good condition and various fuels can be adapted easily.

b. The thermal efficiency is higher because of a larger heating surface area.

c. The start-up time is shorter because of the small amount of retaining water per heating surface area. While a fine regulation is required since the pressure and water levels are prone to fluctuate with a loading variation.

d. Consideration should be given to feed water and boiler water treatment.

The water-tube boiler has two systems: a natural circulation system, which utilizes the differences of the specific gravities between steam and water, and forced circulation, which uses a pump (see Figure 9.5). A high pressure boiler is required to adopt a forced circulation system because of the density difference between steam and water is small.

Figure 9.4 Bending Water Tube Boiler

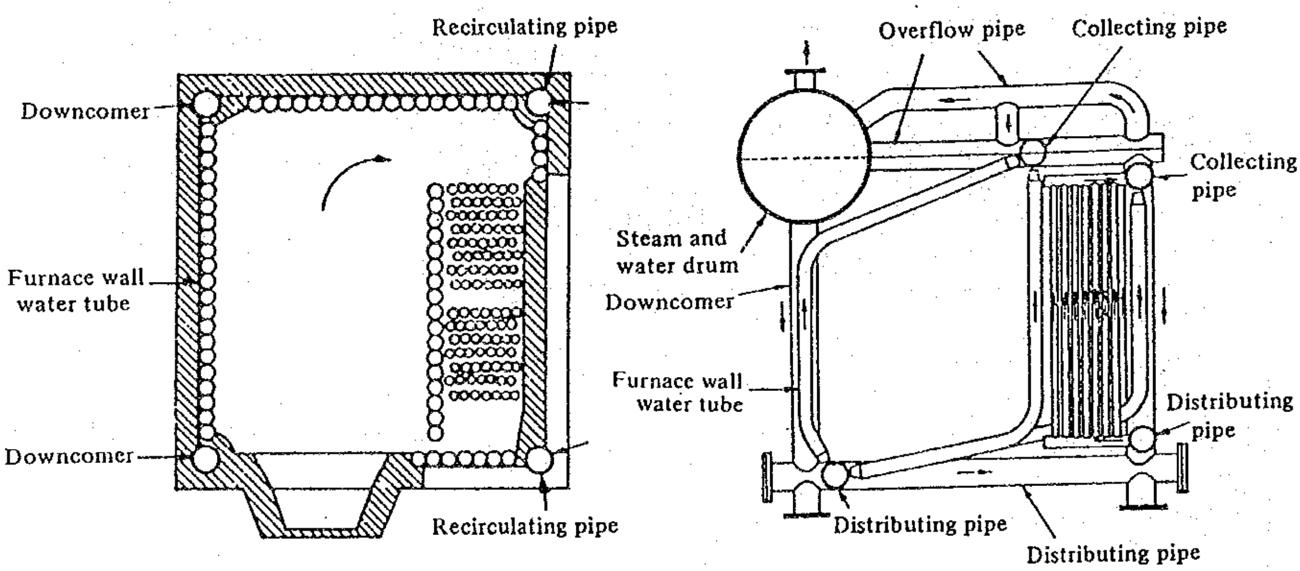
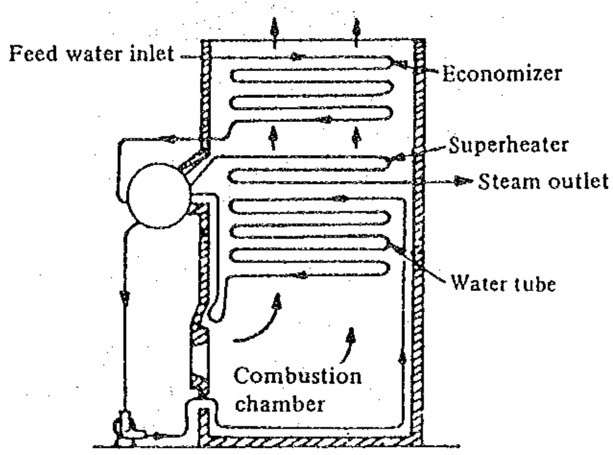
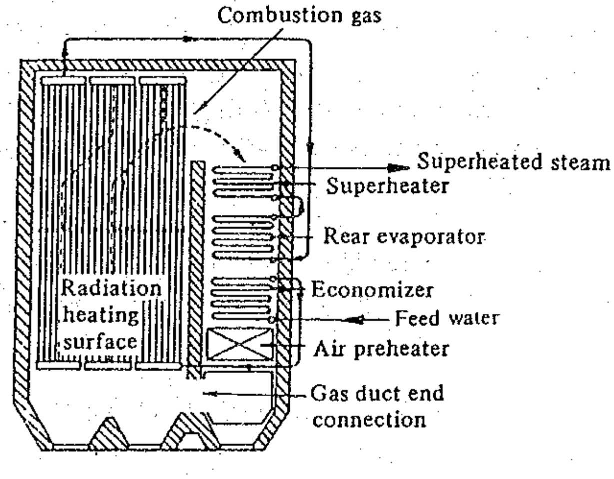


Figure 9.5 Forced Circulation Boiler



A one-through boiler only composed of a series of long water tubes is designed so that feed water is pushed into the tube by a pump from the end of the tube, by turn temperature is raised, evaporated, superheated and taken out as superheated steam from another end of the tube. Accordingly boiler water is not circulated (see Figure 9.6).

Figure 9.6 Schematic Flow Diagram of Benson Boiler



The features of this one-through boiler are as follows:

- Suit a high pressure boiler because there is no steam drum.
- Able to be designed compactly.
- Start-up time is short because the retaining water is extremely small amount per heating surface area.
- Require an automatic control device with good response since a loading change is prone to cause large pressure fluctuation.
- Require a feed water of good quality because all the feed water evaporates in the tube.

With such characteristics, the one-through boiler has been applied in a wide variety from a supercritical pressure boiler to a small scale boiler.

9.1.3 Other boilers

There is a boiler combined with a cast iron section which is used as a low pressure or hot water boiler, a waste heat boiler or a boiler for special fuel and so on.

9.2 Boiler Trouble Prevention

A boiler is an equipment which deals with a high temperature and a high pressure steam. If trouble occurs, the human body and the facilities may suffer damage on a large scale and it is related to a long-term production stop. Then, the continuing effort for energy conservation may be rendered futile. To take prudential measures for boiler trouble is essential for energy conservation.

The operation necessary to prevent boiler trouble is closely related with energy conservation. For example, a feed water treatment prevents damage due to local heating and also serves for improvement of heat transfer.

Most boiler troubles are caused by a lower water level (no load combustion), explosion in combustion chamber, crack of cast iron boiler or burst due to local overheating.

The points remarked to prevent trouble are as follows:

9.2.1 Preparation of operation and inspection manuals and training

The standards on boiler operation and check-and-servicing should be prepared and be observed by the employee through sufficient training.

9.2.2 Safety device

The boilers should pass a predetermined inspection and be equipped with a relief valve, a high and low water level alarm, a flame detector as a necessary instrument and a safety device. Furthermore, the boilers should be designed to operate fail-safely against misoperation through automation. These must be inspected periodically. Table 9.2 shows the routine check items for boilers.

Table 9.2 Daily Inspection of Boiler (1/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Constant inspection	1. Pressure of boiler	O				1. Reading. Pointer movement	1. Smooth moving without catching.
					O	2. Surface temperature. Leakage	
				O		3. Initial and stop temperatures of pressure controller.	3. No disorder. See item 9.
					O	4. Particularly take care to popping pressure at operation of the safety valve.	4. Check disorder by comparison with pressure gages of three or more.
	2. Water level of boiler	O				1. Movement of water level of a water gage.	1. A little movement of the water level is normal. If the hole is clogged, the movement becomes dull. Compare the water levels of two water gages which height changes.
			O			2. Normality of water level at start and stop of the feed water pump.	2. A detection by bellows varies with the level and the operation range by fluctuation of pressure. When the pressure goes to higher, the level goes to down and the operation range comes to wider. Check the operation level and range in an average pressure.
					O	3. Special care must be taken to the working at a lower and higher level alarm.	3. Find out the cause and take a countermeasure. (See items 5 and 6.)

Table 9.2 Daily Inspection of Boiler (2/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Constant inspection	3. Combustion state	O				1. Change of burning sound.	1. Take care to abnormal sound at the start of combustion and during the switching from low to high.
			O			2. Shape and color of flame.	2. Proper flame without touch to furnace and with no rough particle.
		O				3. Generation of smoke and its time.	3. Check the internal pressure of furnace, exhaust gas analysis and the quantity of air and oil. Care must be used to a long time operation under a low load.
Daily inspection	4. Gage glass	O				Check of gage glass.	1. Make sure the open and close condition and any leakage of each cock. Clean the inside.
					O	Open a drain cock, close a steam cock and blow out boiler water sufficiently. And then close the water cock, open the steam cock, check the steam side, then close the drain cock, open the water cock and watch forcible rising of water level.	2. Repair to any leakage from the out of glasses. Check a disorder of the mounting core of the upper and lower cocks and the length of glass.
			O				3. Clean the glass. Use a predetermined length of glass if exchanged. Use care not to tighten too much the glass. Namely, first, open the drain cock to warm with steam and close the drain cock. Open the water cock and open fully the steam cock. After using a little, do retightening.
	5. Water column (floatless)		O			1. Drain water in the column and remove sludge and scale.	1. Make sure the open and close condition of the interconnecting line and clean the inside.
					O	2. Built-in water level detector. Inspect the electric wiring terminal, any contamination of the insulation of the electrode holder, contamination and crack of the electrode.	2. Check the electric wiring (heat resistance wiring). Measuring of insulation resistance—remove the wiring for the electrode holder and the resistance between the electrode and the earth shall be more than 100 MΩ. Cleaning of electrode. Clean contamination of the electrode holder, check any crack or exchange it.

Table 9.2 Daily Inspection of Boiler (3/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection – Automatic equipment (accessory of the body)	6. Automatic feed water adjustable device. Low level breaker. High and low water level alarm.		O			1. Purge scale and sludge in the interconnecting pipe.	1. Make sure the open and close condition of the interconnecting line. Clean the inside (blow enough) in a condition of lower pressure if possible.
			O			2. Make sure the operation with lowering of the water level by blowing.	2. Make sure the operation with blowing. If impossible to blow, remove the electric wire to make sure the operation (burner cut).
					O	3. Check the internal mercury switch and bellows.	3. Check a scattering of mercury and balance. Check leakage from the bellows.
					O	4. Check the electric wiring.	4. Check damage due to heat. Rewire with a heat resistance wire.
					O	5. Check a wrong operation due to vibration.	5. Mount a stay in a change orientation.
					O	6. Check contamination, crack and leakage of the electrode holder.	6. Replace the cracked and leaking insulator with a new one and clean the electrode. Insulation shall be move than 100 MΩ.
	7. Automatic feed water adjustable device (single element type)			O		1. Discharge scale and sludge in the interconnecting pipe of the thermostat.	1. Make sure the open and close condition of the valve in the connecting pipe and clean the inside.
				O		2. Make sure and adjust each interconnecting place.	2. Make sure the specified position of the slide sprocket weight.
			O			3. Adjust the water level due to a boiler load.	3. The level lowers by loosening the adjustable nut of the heel piece of thermostat until the valve lever comes to horizontal position.

Table 9.2 Daily Inspection of Boiler (4/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessory of the body) 8. Flame detector			O		1. Make sure fire going-out, no ignition and burner cut.	1. Stop an ignition fuel for detection of the pilot and make sure not to transfer to the main. For detection of the main, remove the cap or the detector and make sure no ignition. A flame response delays for 2 to 4 seconds.
					O	2. Check the degree of fatigue of a detector.	2. Measure the current by a microammeter, test by a false flame.
					O	3. Defect of electric wiring. Influence of induced current of power.	3. Change to the shield wire or a single wire.
					O	4. Detection of false flame. Self-discharge. Check by a protect relay, no ignition.	4. Check mistake to detect red heat refractory and change the position of installation. Inferior tube shall be replaced.
				O		5. Contamination of lens and glass tube and mounting position.	5. Cleaning of contamination.
					O	6. Check + or – phase of the electric wiring and loosening of connection.	6. Change the wiring and tighten it.
					O	7. Check the amplifier and the flame relay.	7. Replace the defective. If current is normal in measuring current by a microammeter but fire is not ignited, the amplifier or the flame relay is defective.

Table 9.2 Daily Inspection of Boiler (5/14)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessory of the body)	9. Pressure restriction device				O	1. Check the operation stop pressure and the setting of differential gap.	1. Clean and check the siphone pipe, meter cock and the detective part of the bellows. Change the setting of differential gap.
						O	2. Check leakage and concave in the bellows of the detector. Check the mounted position and orientation.	
						O	3. Check the two step setting values for control of high- and low-off.	
						O	4. Check damage of the electric wire.	4. Check and replacement.
		10. Pressure controller				O	1. Check the width of proportional band.	1. Change the width of proportional band.
						O	2. Check inferior contact, contamination and disconnection of resistance of the potentiometer.	2. Check, clean and replace it.
						O	3. Check clogging of the detecting part.	
		11. Wind pressure switch				O	1. Check the setting value.	1. Set to a proper value.
						O	2. Check clogging and leakage of the pipe.	2. Disassembly, check and cleaning.
		12. Oil temperature switch				O	1. Check the setting value.	1. Set to a proper oil temperature.
						O	2. Check contamination and installing dimension of the heat sensitive cylinder and the detecting part.	2. Clean contamination. Investigate the length and replace. Investigate the installing location.
						O	3. Check the configuration of detecting part.	

Table 9.2 Daily Inspection of Boiler (6/14)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessory of the body)	13. Latch switch. Low and high interlock, damper lock and burner lock				O	1. Check the settings of each latch switch.	1. Check that it is set in a proper position.
						O	2. Check loosening of the setting of installed position.	2. Check and adjustment.
						O	3. Check a normal operation of the interlock.	3. Check the operation, inspect and repair.
		14. Control motor			O		1. Check the movement.	
						O	2. Check an inferior contact of the balancing relay.	2. Check arc and clean the contact. Investigate the installing position not to be influenced by vibration.
						O	3. Check contamination and contact defect of the potentiometer.	3. Inspection and cleaning.
	Firing equipment	15. Pilot burner			O		1. Check the gas pressure.	
						O	2. Check a deterioration of the ignition transformer.	2. Check a spark between the electrode and the earth to be 7 to 8 mm in atmosphere.
						O	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
						O	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper low combustion.
						O	5. Check the clearance between the nozzle and the electrode.	5. Adjust an interval suitable.
		16. Electric pilot firing device				O	1. Check an electric spark state.	1. Blue color is normal. If reddish, cleaning is necessary. Short spark is a narrow interval.
						O	2. When a frequent cleaning is required, inferior electrode setting.	2. If the electrode is set within the jetting angle, the electrode is wetted with oil and don't spark. The electrode should be set to the setting value.
						O	3. Transformer insulation defect. Deteriorated lead	3. Check the transformer and clean the insulator. Check any damage of the lead.

Table 9.2 Daily Inspection of Boiler (7/14)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Firing equipment	17. Burner			○		1. Remove carbon and sludge.	1. Check and repair the burner tile.
					○		2. Check the atomizing cap and the shape of tip bleeding part. Clean contamination.	
						○	3. Clean the shaft and the lubricating pipe.	3. Remove sludge and oil.
						○	4. Apply grease to the bearing. Check seal leakage.	4. Apply grease and check the bearing.
					○		5. Check any damage of the diffuser and carbon deposit.	5. Cleaning and adjustment of the interval.
						○	6. Gun type burner. Check and clean the chip and strainer.	6. Disassembly and cleaning. Check the chip hole.
						○	7. Check the gun type electrode insulator.	7. Clean and set the specified dimension.
					○		8. Check abnormal sound and overcurrent.	8. Research of its cause and assembly servicing. Replace the bearing.
						○	9. Oil leakage	9. Repair leaking place.
						○	10. Burner belt	10. Replace cracked burner.
		18. Fuel cutout valve (main valve)			○		1. Check leakage of the cutout valve.	1. A fire is extinguished entirely after cutout.
					○		2. Make sure cutout due to a low level and no ignition.	
						○	3. Check the electric wiring.	3. Check damage due to heat.
		19. Oil pump			○		1. Check the oil pressure.	1. Set to a proper oil pressure.
						○	2. Clean the strainer.	2. Drain and remove sludge.
						○	3. Check oil leakage.	3. Repair the leaking place. Replace the oil seal.
						○	4. Check overheat and overcurrent.	4. Replace the bearing.

Table 9.2 Daily Inspection of Boiler (8/14)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Firing equipment	20. Oil preheater			O		1. Check a proper oil temperature.	1. Adjustment of the thermostat. Check a gasification by the air chamber.
						O	2. Drain	2. Drain and remove sludge.
						O	3. Check oil leakage.	3. Repair the leaking place.
						O	4. Check the sheath heater.	4. Sludge removing.
		21. Service tank. Storage tank.			O		1. Make sure the oil level control.	1. Make sure the operation of the float switch and other controller.
						O	2. Temperature control. Operation of the control valve and the steam solenoid valve.	2. Check leakage and operation.
						O	3. Clean the oil strainer.	
					O		4. Check the receiving quantity and the residual quantity.	
						O	5. Check a leakage and the piping line.	
						O	6. Drain and remove sludge.	
		22. Oil meter		O			1. Check the oil meter indication record.	1. Disassemble and clean the meter and replace the parts.
						O	2. Grasp the oil temperature passing through the meter.	2. Since the efficiency calculation is based on the specific gravity at passing through the meter, the oil temperature should be roughly grasped.
		23. Oil quantity controller			O		1. Check the link mechanism to the controller.	1. Adjust the link mechanism compared with the air volume, check loosening and play.
						O	2. Check the oil quantity by a meter measurement. (Every load)	2. Check by operation and oil quantity and disassemble and clean it.

Table 9.2 Daily Inspection of Boiler (9/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection — Firing equipment	24. Oil strainer			O		1. In autocleaner, turn the handle. In a change type strainer, a prepared one should be always cleaned.	
					O	2. Remove drain and sludge. Grasp a good rating of cleaning by a differential pressure between the inlet and the outlet.	
	25. Forced draft fan			O		1. Check abnormal sound and overcurrent.	1. If abnormal, disassemble and service it, and replace the bearing.
					O	2. Check foreign matter in the suction port.	2. Mount a wire gauze not to suck foreign matter.
						3. Check vibration. Check and replace the belt.	3. Loosening of installed bolts. Loosening of the runner. Remove any deposit to the runner. Replace the bearing.
	26. Damper			O		1. Check the link mechanisms of the primary and main dampers.	1. The damper should be adjusted to be opened slowly.
				O		2. Check the opening of damper.	2. Check distortion or loosening.
					O	3. Adjust the damper draft in the outlet of boiler.	3. 0 ± 2 mm Aq in a pressurized combustion of rated operation.
					O		
					O		
	27. Internal pressure gage of boiler			O		1. Make sure the indication of internal pressure gage of boiler.	1. Check a clogging in lead pipe. Check the opening and closing of valve cock. Check and repair a leaking point due to corrosion.

Table 9.2 Daily Inspection of Boiler (10/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	28. Smoke indicator			○		1. Check a difference between the indication and the smoke concentration.	1. Cleaning of glass. Adjust a floodlamp and a light receiver. Blow air from a compressor.
						2. Adjust the Zero point.	2. Set the zero point.
	29. Exhaust gas analyzer					1. Make sure the operation of pointer.	1. Check a clogging and leakage in the lead. Cleaning or replacement of the filter and tightness test of the lead.
					○	2. Adjustment.	2. Adjustment of the water quantity in aspirator. Comparison of a normal operation through passing air to the transmitter with the Orsat analyzed value.
	30. Flue and stack				○	1. Check leakage and corrosion.	1. Inspection and repairing.
					○	2. Remove soot in the flue and the stack.	
					○	3. Discharge of rain water.	
	31. Water softening equipment			○		1. Check of the water pressure. 1.5 to 2 bar	
					○	2. Check of hardness. Check in the secondary side.	2. Check from 70 to 80 % of cycle.
					○	3. Leakage from the perforated valve.	3. Use care to leak from the fitting part of the packing.
					○	4. Care must be taken to leak during a stop of the pump operation.	

Table 9.2 Daily Inspection of Boiler (11/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	32. Feed water tank		○			1. Check of the level gage.	
			○			2. Make sure the operation of low level alarm lamp.	2. Test in an actual level drop or test by an electric wiring.
			○			3. Make sure the level control.	3. Make sure a manual operation of controller.
			○			4. Check of temperature.	4. Check of abnormality of trap.
					○	5. Check the painting on the tank inside and corrosion. Clean the inside.	5. Check, repair and cleaning.
	33. Chemicals pouring device			○		1. Check a proper chemicals pouring.	1. Check contamination in the tank and the flow rate.
				○		2. Check a linkage to the feed water pump.	2. Check the operation.
					○	3. Check leakage or clogging.	3. Inspection and repair.
	34. Feed water pump			○		1. Check overcurrent.	1. Adjust the valve.
					○	2. Check leakage from the ground.	2. Replace and tighten a packing.
					○	3. Check an oil servicing.	3. Apply oil and grease.
					○	4. Check play to the coupling.	4. Repair and replacement.
	35. Injector				○	1. Check a normal operation.	1. Impossible to feed when the steam pressure lowers, the feed water temperature rises, air is sucked, the feed water pressure is too much higher.
					○	2. Check the check valve. Attachment of scale.	2. Check, disassemble and clean.
					○		
	36. Water flow meter strainer		○			1. Check the operation.	1. Record, check operation.
					○	2. Check clogging in the strainer.	2. Disassemble and clean.
	37. Feed water check valve				○	1. Check back flow.	1. Water hammer. Hand touch feels hot to the feed water pipe. Overhaul or replacement.

Table 9.2 Daily Inspection of Boiler (12/14)

Type of inspection	Place of inspection	Cycle				Inspection item	Procedure
		Constantly monitoring	One hour	A week or a day	At any time		
	38. Feed water internal pipe				O	1. Check clogging in the internal pipe.	1. Insufficient feed water quantity. Overhaul.
					O	2. Inferior or falling of the gasket for installation of the internal pipe.	2. Water hammer. Replace the gasket.
	39. Relief valve			O		1. Check leakage of steam.	1. Repair the leaked place and overhaul.
					O	2. Check the popping and blowdown pressures in operation.	
						3. Check the popping volume.	3. When the pressure rising in a rated combustion is 6 % or more, it is not acceptable.
					O		
	40. Blow off valve			O		1. Check leakage. Check heat by hand touch.	1. Overhaul or replacement.
				O		2. Blow off as a quick opening valve in the body side and as a slow opening valve in the secondary side.	2. For 10 bar or more, two valves.
						3. Check the discharge port.	3. Check the size of pit. Should do arresting measure and water control.
	41. Manhole			O		1. Check leakage from the manhole.	1. Tightening, replacement of gasket.
					O	2. Keep a mating surface of the gasket in no contamination.	2. Apply graphite to facilitate a replacement.
	42. Casing for insulation					1. Check gas leakage.	1. Gas leakage should be checked and repaired as soon as possible.
						2. Check discolored place.	2. Find out the cause of overheat, check and repair.
	43. Refractory material				O	1. Check damage, falling and abnormality.	1. Repair the refractory materials as soon as possible.
					O	2. Check gas leakage and short pass.	2. Repairing.

Table 9.2 Daily Inspection of Boiler (13/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	44. Inspection port. Cleaning port. Mounting part of accessory.				O	1. Check leakage of steam and water.	1. Repair the leaked place. Tightening, replacement of gasket.
	45. Explosion door			O		1. Check gas leakage.	1. Repair the leaking place.
					O	2. Check the spring.	2. Inferior springs due to leakage or heat should be replaced. Check an impossible opening and closing due to rust.
	46. Magnet switch and contactor				O	1. Check the contact of relay.	1. Replace the contact and relay.
					O	2. Check loosening of the terminal.	2. Tighten the terminal.
					O		
	47. Timer. Time limit relay.				O	1. Check the setting of the timer.	1. Y-Δ starting. Starting current. Change to Δ after dropping to rated value by Y.
					O	2. Check the setting of the cam mechanism.	2. Check by sequence.
	48. Actuation lamp Indicator lamp			O		1. Check a disconnection and luminosity.	1. Replace the lamp.
					O	2. Inferior contact.	2. Tightening.
	49. Spare. Fuse lamp				O	1. Check the spare parts.	1. Supplement of fuse and lamp spare.
	50. Protect relay (Timer motor)			O		1. Check the operation.	1. Check the sequence. Replace if inferior.
					O	2. Check the fixing and tightening of relay and the contact.	2. Check the operation.
					O	3. Check voltage drop.	3. Check the voltage in the operating circuit.
	51. Terminal				O	1. Check loosening of the terminal.	1. Tightening. Apply a detent paint if possible.
					O	2. Cleaning.	2. Suck dust by a vacuum cleaner.

Table 9.2 Daily Inspection of Boiler (14/14)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
	52. Insulation resistance				O	1. Measuring by 500 V megger. Measure in a removing condition of a low voltage equipment.	1. If panel and secondary side has resistance less than 5 MΩ, inspection or repair is required.
	53. Electric wiring				O	1. Check overheat, damage and discoloration.	1. Check the wiring.
					O	2. Check damage of coating.	2. Use care to a discolorization of the wiring around the terminal.
					O	3. Check of phase.	

9.2.3 Consideration on operation

(1) Igniting operation

If fire is put in the furnace under a mixture of air and gas or oil vapor, combustion occurs explosively. It is a danger of accident occurrence. Prior to ignition, prepurge must be done for five minutes or more in Cold Start or for about one minute in Hot Start to send completely out combustible gases of the combustion chamber and flue. If ignition becomes a failure, the operation should be halted without hesitation and done over again from the prepurge step.

Heating just after ignition is done to make temperature rise gently over about two hours to prevent differential expansion of the body and leakage from the joint parts.

(2) Monitor of water level

Keeping the water level in a boiler to a certain range is the most important task of a boiler operator and should be monitored at all times.

Therefore, the water level gauge should be cleaned usually so that observation is easily made. For the following cases, a function test should be performed and a check should be done to indicate a regular water level.

a. After the boiler is started.

b. When the operators are shifted.

c. When the reads of two or more water level gauges are different.

d. When some foaming occurs in the boiler water.

Where an automatic feed water control device is equipped, its performance should be checked periodically by lowering the water level in the boiler.

(3) Water treatment and blow

The purposes of water treatment to boiler feed water are classified in the following three items:

a. Prevention of corrosion due to dissolved oxygen and corrosive substances.

b. Prevention of scale formation due to deposition of hardness components and dissolved solids in the feed water.

c. Prevention of foaming due to accumulation of dissolved solid and oily matter in the boiler water.

Since the thermal conductivity of scale is only 1/100 of mild steel, the thermal efficiency becomes extremely worse due to adhesion of scale and the local heating decreases the mechanical strength of the heating tube which leads to bursting trouble not standing against the boiler pressure. The steel surface, on which sludge deposits, is more easily corroded.

For prevention of the trouble mentioned above, Japanese Industrial Standard (JIS) has provided the standard value for water quality as shown in Table 9.3 and Table 9.4.

The treatment methods of boiler water are classified in a boiler external treatment and a boiler internal treatment.

In the boiler external treatment, there is elimination of suspended solid by sedimentation and filtration and salt elimination by ion exchange resin and a deaeration. For a low pressure boiler of 20 bar or less, a simple softener using cation exchange resin—a lower investment cost and an easy operation—is often applied. On the operation of the softener, extreme caution should be exercised to the impurity elimination in the salt for regeneration, establishment and its observation of the standard for flow rate, regeneration time and back washing amount, based on analysis of water, and a supplement or replacement of resin once a year.

The recovery of condensate is a reasonable method to make the load on the softener reduce and to plan an effective use of the heat. But, on the way of recovery, O_2, CO_2 or iron produced by corrosion may sometimes be contained into the condensate.

In such a case, the condensate should be passed through a filter and a deaerator prior to return to feed water and thus, care must be used not to cause new corrosion due to an accumulation of these impurities.

The boiler internal treatment is a method which treats water by addition of a conditioner, a softening agent, a scale inhibitor and a foaming inhibitor. The compound contained with these components is on the market.

To prevent an accumulation of the impurities in the boiler water, the blow is an important operation. A continuous blow with linking an amount of feed water is preferably economical owing to an easier adjustment of the amount and possibility of heat recovery compared with a periodic blow-down. The blow amount can be obtained by the following equation from the feed water quantity and the boiler water standard shown in Tables 9.3 and 9.4.

Table 9.3 Quality of Feed Water and Boiler Water for Circulating Boiler

Classification	Type of boiler	Cylindrical boiler									Water-tube boiler							
Classification	Max. servicing pressure bar	Below 10					From 10 to 20	From 20 to 30	From 30 to 50	From 50 to 75	From 75 to 100		From 100 to 125		From 125 to 150		From 150 to 200	
Classification	Max. servicing pressure (MPa)	Below 1					From 1 to 2	From 2 to 3	From 3 to 5	From 5 to 7.5	From 7.5 to 10		From 10 to 12.5		From 12.5 to 15		From 15 to 20	
Classification	Rate of evaporation of heating surface (bar·h)	Below 30[1]	From 30 to 60	Over 60	Below 50	Over 50	—	—	—	—	—		—		—		—	
Feed water	pH (25 °C)	7 ~ 9	7 ~ 9	7 ~ 9	7 ~ 9	7 ~ 9	7 ~ 9	7 ~ 9	8 ~ 9.5	8.5 ~ 9.5[9]	8.5 ~ 9.5[9]		8.5 ~ 9.5[9]		8.5 ~ 9.5[9]		8.5 ~ 9.5[9]	
Feed water	Hardness ($mgCaCO_3/\ell$)	Below 60	Below 2	Below 1	Below 1	Below 1	Below 1	0	0	0	0		0		0		0	
Feed water	Fat and oil (mg/ℓ)	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.		Maintain zero as much as possible.		Maintain zero as much as possible.		Maintain zero as much as possible.	
Feed water	Dissolved oxygen (mgO/ℓ)	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Below 0.5	Below 0.1	Below 0.03	Below 0.007	Below 0.007		Below 0.007		Below 0.007		Below 0.007	
Feed water	Total iron ($mgFe/\ell$)	—	—	—	—	—	—	—	Below 0.1	Below 0.05	Below 0.03[10]		Below 0.03[10]		Below 0.02[11]		Below 0.02[11]	
Feed water	Total copper ($mgCu/\ell$)	—	—	—	—	—	—	—	Below 0.05	Below 0.03	Below 0.02		Below 0.01		Below 0.01		Below 0.005	
Feed water	Hydrazine[3] (mgN_2H_4/ℓ)	—	—	—	—	—	—	Over 0.2	Over 0.06	Over 0.01	Over 0.01		Over 0.01		Over 0.01		Over 0.01	
Feed water	Electrical conductivity (25 °C) (μS/cm)	—	—	—	—	—	—	—	—	—	—		—		Below 0.3[12]		Below 0.3[12]	
Boiler water	Treatment method	Alkali treatment							Alkali treatment or phosphating		Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment
Boiler water	pH (25 °C)	11.0 ~ 11.8	11.0 ~ 11.8	11.0 ~ 11.8	11.0 ~ 11.8	11.0 ~ 11.8	10.8 ~ 11.3	10.5 ~ 11.0	9.4 ~ 11.0[13]	9.2 ~ 10.8[13]	9.0 ~ 9.8	8.5 ~ 9.5	8.7 ~ 9.7	8.5 ~ 9.5	8.5 ~ 9.5	8.5 ~ 9.5	8.5 ~ 9.5	8.5 ~ 9.5
Boiler water	M-Alkalinity[4] ($mgCaCO_3/\ell$)	100 ~ 800	100 ~ 800	100 ~ 800	100 ~ 800	100 ~ 800	Below 600	Below 150	—	—	—	—	—	—	—	—	—	—
Boiler water	Alkalinity[5] ($mgCaCO_3/\ell$)	80 ~ 600	80 ~ 600	80 ~ 600	80 ~ 600	80 ~ 600	Below 500	Below 120	—	—	—	—	—	—	—	—	—	—
Boiler water	Total solids (mg/ℓ)	Below 4000	Below 3000	Below 2500	Below 3000	Below 2500	Below 2000	Below 700	Below 500	Below 300	Below 100	Below 20	Below 30	Below 5	Below 20	Below 3	Below 10	Below 2
Boiler water	Electrical conductivity (μS/cm)	Below 6000	Below 4500	Below 4000	Below 4500	Below 4000	Below 3000	Below 1000	Below 800	Below 500	Below 150	Below 60[12]	Below 60	Below 20[12]	—	—	—	—
Boiler water	Chloride ion ($mgCl^-/\ell$)	Below 600	Below 500	Below 400	Below 500	Below 400	Below 300	Below 100	Below 80	Below 50	Below 10	—	Below 3	—	—	—	—	—
Boiler water	Phosphate ion[6] ($mgPO_4^{3-}/\ell$)	20 ~ 40	20 ~ 40	20 ~ 40	20 ~ 40	20 ~ 40	20 ~ 40	5 ~ 15	5 ~ 15	3 ~ 10	2 ~ 6	(14)	1 ~ 5	(14)	0.5 ~ 3	(14)	0.5 ~ 3	(14)
Boiler water	Sulfite ion[7] ($mgSO_3^{2-}/\ell$)	10 ~ 20	10 ~ 20	10 ~ 20	10 ~ 20	10 ~ 20	10 ~ 20	5 ~ 10	5 ~ 10	—	—	—	—	—	—	—	—	—
Boiler water	Hydrazine[8] ($mg N_2H_4/\ell$)	0.1 ~ 0.5	0.1 ~ 0.5	0.1 ~ 0.5	0.1 ~ 0.5	0.1 ~ 0.5	0.1 ~ 0.5	—	—	—	—	—	—	—	—	—	—	—
Boiler water	Silica ($mgSiO_2/\ell$)	—	—	—	—	—	—	Below 50	Below 20	Below 5	Below 2		Below 0.5		Below 0.3		Below 0.2	

Notes (1) Apply it when using live steam and using constantly make-up water in a cast iron boiler.
(2) It means hexane extract (see JIS B 8224).
(3) Apply it when hydrazine may be poured in the feed water as an oxygen scavenger.
(4) It means an acid consumption (pH 4.8).
(5) It means an acid consumption (pH 8.3).
(6) Apply it when phosphate may be poured in water.
(7) Apply it when sulfite may be poured in water as an oxygen scavenger.
(8) Apply it when hydrazine may be poured as an oxygen scavenger in a cylindrical boiler or a water-tube boiler in a pressure less than 20 bar (2 MPa) of the maximum servicing pressure.
(9) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.
(10) It is desirable to maintain below 0.02 mgFe/lit.
(11) It is desirable to maintain below 0.01 mgFe/lit.
(12) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.
(13) The pH lower limit indicates a lower limit when a phosphating is applied and shall be taken as a pH corresponding to the lower limit of the PO_4^{3-} concentration of boiler water. (See paragraph 1.3.1 of the description).
(14) If hardness components and pH lowering components are leaked in the boiler water due to see water leakage from the sample vessel, some type and quantity of phosphate required to the emergency treatment against the leaked components and quantity should be poured.

Remarks

1. The concentration unit of mg/lit. shall be regarded as the same as ppm.
2. For a make-up water to a water-tube boiler of the maximum servicing pressure of 20 bar, desalted water shall be applied.
3. Hydrazine or sulfite as an oxygen scavenger, as a rule, either one of them shall be poured.

Table 9.4 Quality of Feed Water for Once-through Boiler

Classification	Max. servicing pressure bar	Below 25	From 75 to 100	From 100 to 125	From 125 to 150	From 150 to 200	Over 200
	(MPa)	Below 2.5	From 7.5 to 10	From 10 to 12.5	From 12.5 to 15	From 15 to 20	Over 20
Feed water	pH (25 °C)	10.5 ~ 11.0	8.5 ~ 9.5 (2)	8.5 ~ 9.5 (2)	8.5 ~ 9.5 (2)	8.5 ~ 9.5 (2)	9.0 ~ 9.5
	Hardness ($mgCaCO_3/\ell$)	Below 1*	0	0	0	0	0
	Dissolved oxygen (mgO/ℓ)	Below 0.5	Below 0.007	Below 0.007	Below 0.007	Below 0.007	Below 0.007
	Total iron ($mgFe/\ell$)	—	Below 0.03 (3)	Below 0.03 (3)	Below 0.02 (4)	Below 0.02 (4)	Below 0.01
	Total copper ($mgCu/\ell$)	—	Below 0.01	Below 0.01	Below 0.005	Below 0.003	Below 0.002
	Hydrazine (1) (mgN_2H_4/ℓ)	—	Below 0.01	Below 0.01	Below 0.01	Below 0.01	Below 0.01
	Silica ($mgSiO_2/\ell$)	—	Below 0.04 (5) Below 0.02 (6)	Below 0.04 (5) Below 0.02 (6)	Below 0.03 (5) Below 0.02 (6)	Below 0.02	Below 0.02
	Total solids (mg/ℓ)	Below 700	—	—	—	—	—
	Electrical conductivity (25°C) ($\mu S/cm$)	Below 1,000	Below 0.3 (7)	Below 0.3 (7)	Below 0.3 (7)	Below 0.3 (7)	Below 0.25 (7)
	Phosphate ion ($mgPO_4^{3-}/\ell$)	20 ~ 40	—	—	—	—	—

Notes (1) The concentration of hydrazine shall be limited with a concentration not exceeded the upper limit of pH.

(2) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.

(3) It is desirable to maintain below 0.02 mgFe/lit.

(4) It is desirable to maintain below 0.01 mgFe/lit.

(5) It is applied to a boiler with separator.

(6) It is applied to a boiler without separator.

(7) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.

Remarks 1. Since the concentration of the total solids in the feed water for a high pressure once-through boiler is very low and can not be nearly measured, the measured value of electrical conductivity should be used to estimate a concentration of soluble solids in the total solids.

2. The maximum servicing pressure of 25 bar (2.5 MPa) or less shall be applied to an once-through boiler returned by 30 % of the boiler water into the feed water. Since the water returned from the boiler is added into the feed water is again fed to the boiler with addition of some chemicals, the water quality shall be controlled by the method similar to it for a circulating boiler.

The mark of * shall be applied to the feed water prior to addition of a returned water.

y: Blow amount
k: Blow rate (%)
x: Evaporation
a: Impurity concentration in feed water
b: Impurity concentration standard in boiler water

$$a(x+y)=by$$

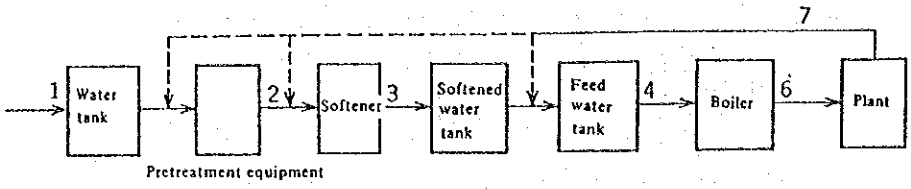
$$\therefore y=\frac{a}{b-a}$$

$$k=\frac{a}{b-a}\times 100$$

Although an M-alkalinity, total solids, silica and chloride ion are taken as the control subject, the analyses of those are not easy in practice and the electrical conductivity is sometimes taken as a good measure. It is desirable to control through premeasurement of a relation between the chloride ion concentration and the electrical conductivity.

Table 9.5 is a standard of the water quality measuring frequency shown as reference in JIS.

Table 9.5 Standard for Water Quality Measuring Frequency



Sampling location	1		2		3		4		5		6		7	
Item / Check division	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals	Irregular intervals	Periodical intervals
Appearance		D		D				D		D				D
pH	n		n		n			D		D	n			D
P-alkalinity										D				
M-alkalinity	n				n					D				
Chloride ion	n							W		D				D
Free chlorine	n		n											
Phosphate ion										D				
Electric conductivity		D						D		D				
Hydrazine								2W						
Sulfite ion								2W						
Total solid	n				n				n		n		n	
Silica										M				
Total hardness	n		n			D		D	n				n	
Total iron									n					
Turbidity	n				n				n				n	
Organic matter(COD)	n												n	

Remarks: D: Once per day, W: Once per week, 2W: Twice per week, M: Once per month,
n : According to demand

9.3 Expression of Boiler Capacity

An expression of boiler capacity has two ways of rated evaporation and an equivalent evaporation.

9.3.1 Rated evaporation

The rated evaporation is expressed as an evaporation per unit hour under the maximum load possible to operate continuously and should be described together with evaporation pressure, evaporation temperature and feed water temperature.

9.3.2 Equivalent evaporation

The equivalent evaporation facilitates comparison of capacity through conversion of the above-mentioned condition to a certain reference. This value is that net heat per hour required to generate a steam from feed water is divided by a heat of vaporization of 539 kcal/kg at temperature of 100 °C.

If G is taken as an actual evaporation kg/h, h_1, h_2 as a specific enthalpy (kcal/kg) of the feed water and the produced steam, the equivalent evaporation G_e can be obtained by the following equation:

$$G_e = \frac{G(h_2 - h_1)}{539} (kg/h)$$

In addition, the boiler capacity may sometimes be expressed by a heating surface area (m²) based on the combustion side. A small sized boiler in U.S. and British has been often expressed by boiler horse power. This expression was established in 1876 and was based on the value which was taken as one horse power per 30 lb/h of saturated steam in 70 lb/in² of gauge pressure. Nowadays this is not familiar with the actual specification. The equivalent evaporation of 15.65 kg/h corresponds to one horse power.

9.4 Heat Balance of Boilers

In Japan, a heat balance system of boilers is specified by Japanese Industrial Standard (JIS B8222). Its outline will be described below.

The heat balance is carried out as the result of an operation in one or more hours under a steady-state on consideration of atmospheric temperature as a reference temperature. In this operation, no blow or no soot blow is done.

At the start, a limit of heat balance should be fixed as shown in Figure 9.7. The heat balance shall be performed on heat output and heat input across the battery limit. If equipped with waste heat recovery equipment, take care not to mistake the measuring points.

The specification of equipment for a subject boiler should be examined according to the items shown in Table 9.6 and the operation record should be described on the items of Table 9.7. The results of the heat balance should be entered into the formula of Table 9.8. Referred items are indicated for calculation below.

Figure 9.7 Standard Range of Boiler Heat Balance

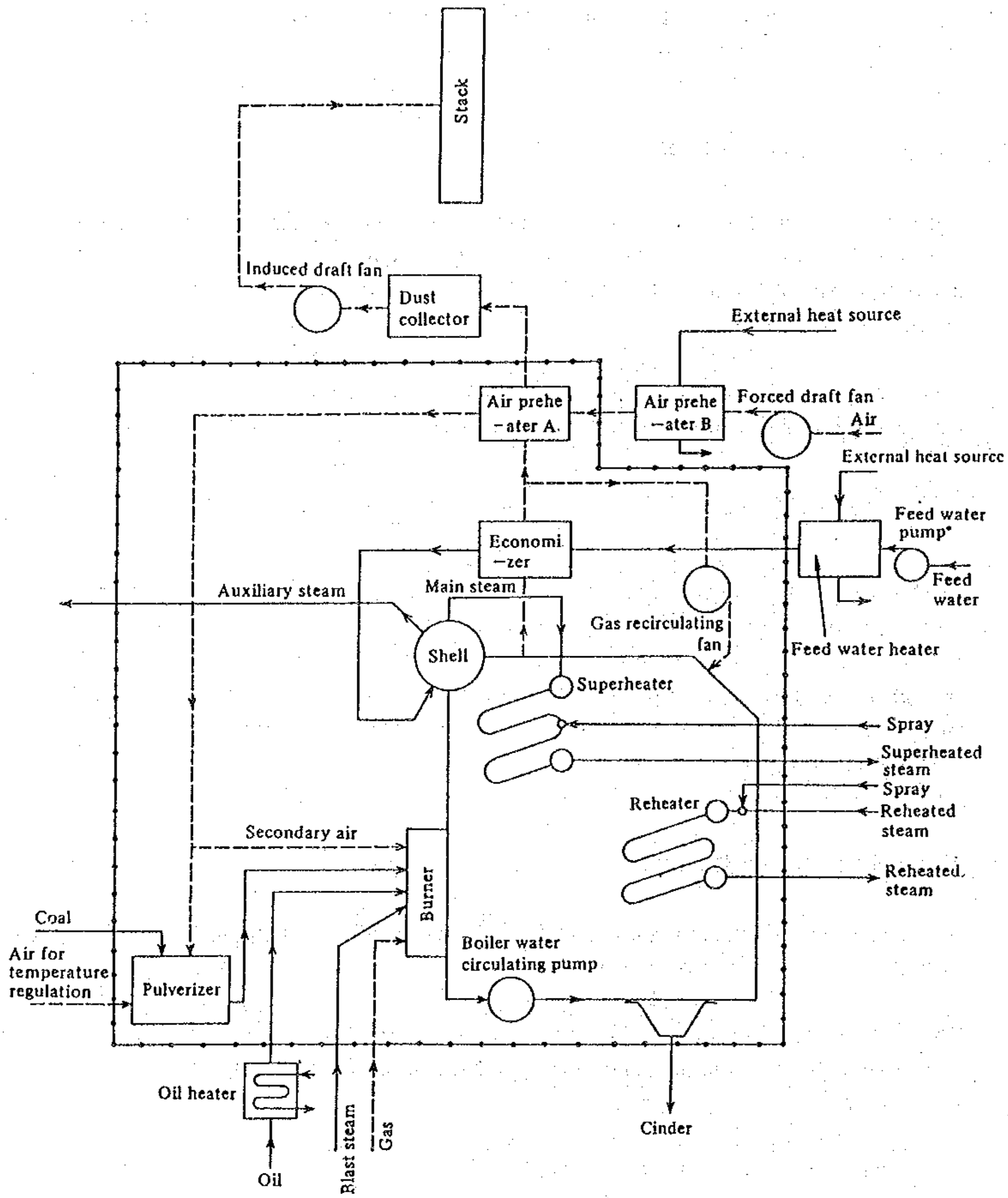


Table 9.6 Outline of Equipment

Outlines of the installation shall be indicated as follows.

Name of plant, Address				
Name of boiler maker				
Number of boiler, date of manufacture				
Boiler proper	Kind•Type			
	Maximum continuous evaporation		t/h	
	Maximum working pressure (1)		bar	
	Normal operating pressure (1)		bar	
	Superheated (reheated) temperature		°C	
	Calorific value of standard fuel		kcal/kg(m_n^3)	
	Heating surface area	Boiler	m^2	
		Water wall	m^2	
		Total	m^2	
Superheater	Type			
	Heating surface area		m^2	
Reheater	Type			
	Heating surface area		m^2	
Economizer	Type			
	Heating surface area		m^2	
Air preheater	Type			
	Heating surface area		m^2	
Firing equipment	Type (1)			
	Burner capacity, number and grate area		kg(m_n^3)/h, m^2	
Combustion chamber	Furnace volume		m^3	
	Standard heat generation		kcal/m^3h	
Control device	Pressure			
	Water level			
	Superheating temp.			
	Others			
Drafting equipment	Drafting			
	Forced fan	Type		
		Capacity	m^3/min(°C)	
		Pressure	mmAq	
	Induced fan	Type		
		Capacity	m^3/min(°C)	
		Pressure	mmAq	
	Other fan	Type		
		Capacity	m^3/min(°C)	
		Pressure	mmAq	
	Chimney	Size (diameter × height)	m × m	
		Name and number of common use		
Water feeding equipment	Kind			
	Capacity, number		t/h	
	Kind and capacity of feed water treating device			
	Quality of feed water			
	Name and quantity of chemical use			
Preparing condition at test starting				

Note(1) The pressure is a gage pressure.

Table 9.7 Results of Measurement (1/2)

The test results shall be indicated as follows.

Category	Item	Sub-item	Unit	Remarks
	Date and time of test			
	Personnel in charge			
	Weather, atmospheric pressure, wind velocity		°C	
	Ambient temperature, dry bulb and wet bulb temperatures		°C	
	Duration of test		h	
	Load factor		%	
Fuel	Brand and characteristic of fuel			
	Mixing ratio			
	Temperature as used		°C	
	Total moisture		%	
	Proximate analysis	Analysed value	%	
		As used	%	Correct by moisture.
	Ultimate analysis	Analysed value	%	
		As used	%	Correct by moisture.
	Lower calorific value of fuel used (high)	Analysed value	kcal/kg(m_n^3)	Measure a high combustion heat by a calorimeter and obtain a low combustion heat by calculation. Correct by moisture.
		As used	kcal/kg(m_n^3)	
	Fuel consumption Total		kg(m_n^3)	
	Fuel consumption per hour		kg(m_n^3)/h	
	Firing quantity per burner		kg(m_n^3)/h	
	Combustion chamber heat generation		kcal/m³h	
	Condition of firing equipment			
	Condition of control device			
	Condition of drafting equipment			
	Condition of water feeding equipment			
Feed water	Quantity of feed water	Total (corrected value)	kg	
		Per hour	kg/h	
		Per unit volume of fuel	kg/kg(m_n^3)	
	Temperature	Economizer inlet	°C	
		Boiler proper inlet	°C	
	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum	bar	
		Superheater outlet	bar	
		Reheater inlet	bar	
		Reheater outlet	bar	
	Temperature	Superheated outlet	°C	
		Reheater inlet	°C	
		Reheater outlet	°C	
	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (i.e. 98%)
	Evaporation	Total (corrected value)	kg	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
		Per hour	kg/h	
		Equivalent evaporation per hour	kg/h	
Steam jetting into furnace	Source of steam			
	Quantity of steam		kg/h	If impossible to measure, use an approximate figures.
	Pressure and temperature		bar, °C	
Air for combustion	Air quantity per 1 kg of fuel		m_n^3/kg(m_n^3)	Calculate from the composition of fuel and combustion gas.
	Temperature and pressure	Air preheater inlet	°C, mmAq	
		Air preheater outlet	°C, mmAq	
		Outlet of forced draft fan	°C, mmAq	
		Inlet of chamber	°C, mmAq	

Table 9.7 Results of Measurement (2/2)

Air for combustion	Air ratio	Outlet of boiler proper Outlet of economizer Outlet of air preheater		
Exhaust (combustion) gas	Exhaust gas quantity per unit volume of fuel		$m_n^3/kg(m_n^3)$	
	Temperature and pressure	Furnace inside Outlet of boiler proper Economizer inlet Economizer outlet Air preheater inlet Air preheater outlet Induced fan suction Induced fan delivery	°C, mmAq °C, mmAq °C, mmAq °C, mmAq °C, mmAq °C, mmAq °C, mmAq °C, mmAq	
	Gas analysis	Outlet of boiler proper (CO_2, O_2, CO) Outlet of economizer (CO_2, O_2, CO) Outlet of air preheater (CO_2, O_2, CO)	% % %	
	Unburned component Refuse quantity per unit volume of fuel		% kg/kg	Calculate from the fuel consumption, ash in fuel, unburned fuel in cinder.
Condition of smoke				
Auxiliary	Steam consumption Electric power consumption		kg kWh	
Remark				

Remarks

1. The values entered to this sheet, such as analysis data of the refuse and exhaust gas, pressures, temperatures and etc. of the steam, air and gas shall be the averages.

2. Load factor shall be as follows.

$$\text{Load factor} = \frac{\text{Actual evaporation}}{\text{Maximum continuous evaporation}} \times 100\%$$

3. Condition of firing equipment means as follows.

Hand firing	method and interval of feeding coal, damper opening
Stoker firing	speed of stoker or coal feeder, thickness of coal layer, damper opening, etc.
Pulverizer coal firing	working number and speed of coal feeders, pulverizers, exhausters and fans, damper opening, working number and condition of burners
Oil firing	oil pressure, and working number and condition of burner
Gas combustion	gas pressure. Number and condition of operating burners

4. Condition of water feeding equipment means as follows.

Intermittent feeding	number of feeding per hour, etc.
Continuous feeding	working number, revolution, valve opening, etc. of pumps

5. Condition of drafting equipment means revolution, regulating valve opening, damper opening, etc. of fans.

Table 9.8 Heat Balance Table (1/2)

Heat input	kcal/kg(m_n^3)	%	
(1) Calorific value of fuel	H_l[3]		(2) Mean specific heat of fuel × (Fuel temp. after heating – ambient temp.)
(2) [2] Sensible heat of fuel	Q_1		(3) Air quantity (including moisture) per 1 kg (m_N^3) of fuel × Mean specific heat of air × (Air temp. after heating – ambient temp.)
(3) [2] Sensible heat of air	Q_2		(4) Blast steam quantity per 1 kg (Nm^3) of fuel × (Enthalpy of steam – Enthalpy of steam in ambient temp.) (Only in case of steam from another source)
(4) [2] Carrying heat of furnace blast steam	Q_3		
Total	H_l[3] + Q	100	

Note [2] (2), (3) and (4) are due to the external heat source.

[3] In case of a high heating value basis, it shall be taken as H_h(H_h').

	Heat input	kcal/kg(m_n^3)	%	
Effective heat	(1) Heat content of generated steam			(1) (a) Feed water quantity per 1 kg (m_N^3) of fuel × (Enthalpy of steam in outlet of boiler – Enthalpy in outlet of economizer)
	(a) Heat absorbed at the boiler proper	Q_b		(b) Feed water quantity per 1 kg (m_N^3) of fuel × (Enthalpy of feed water in outlet of economizer – Enthalpy of feed water)
	(b) Heat absorbed by economizer	Q_{ec}		(c) Feed water quantity per 1 kg (m_N^3) of fuel × (Enthalpy of steam in outlet of superheater – Enthalpy of steam in outlet of boiler) + Spray quantity per 1 kg (m_N^3) of fuel × (Enthalpy of steam in outlet of superheater – Enthalpy of spray water).
	(c) Heat absorbed by superheater	Q_{sh}		
	(2) Heat absorbed by reheater	Q_{rh}		(2) Steam quantity in inlet of reheater per 1 kg (m_N^3) of fuel × (Enthalpy of steam in outlet of reheater – Enthalpy of steam in inlet of reheater) + Spray quantity per 1 kg (m_N^3) of fuel × (Enthalpy of steam in outlet of reheater – Enthalpy of spray water)
	Subtotal	Qs		
Heat loss	(1) Heat loss in exhaust gas	L_{1l}[4]		(1) Actual exhaust gas quantity (including moisture) per 1 kg (m_N^3) of fuel × mean specific heat of exhaust gas × (Temp. of exhaust gas – ambient temp.)
	(2) Heat loss due to furnace blast steam	L_2		See item (f)
	(3) Heat loss due to incomplete burning exhaust gas	L_3		See item (g)
	(4) Heat loss due to combustible in refuse	L_4		See item (h)
	(5) Heat loss due to release	L_5		See item (i)
	(6) Heat loss due to others	L_6		See item (j)
	Subtotal	L_l [4]		
	Total		100	

Note [4] In case of a high heating value basis L_{1l}{L_{1l}'} shall be taken as L_{1h} {L_{1h}'} and L_l { L_l'} be taken as shall be taken as L_h {L_h'}.

Table 9.8 Heat Balance Table (2/2)

Boiler efficiency	%
(1) Input-and-output heat method $\eta_1 = \frac{Q_5}{H_1 + Q} \times 100,$	
(2) Heat loss method $\eta_2 = \left(1 - \frac{L_1 - L_6}{H_1 + Q}\right) \times 100,$	

a. Method to obtain lower combustion heat from higher combustion heat.
Solid fuel and liquid fuel: $H_\ell = H_h - 5.9\ (9h + w)$ kcal/kg Fuel

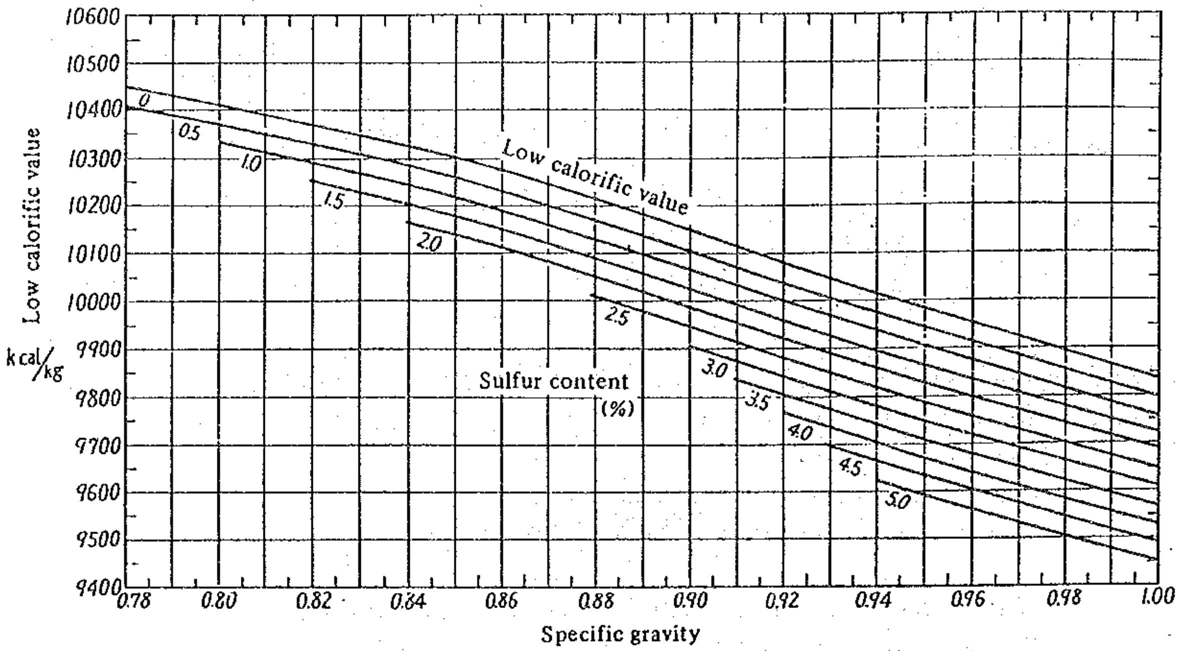
Here, h : Hydrogen content in service condition (wt%)
w : Moisture content in service condition (wt%)

When omitting elementary analysis, h shall take the following value.
Kerosene, light oil, crude oil and fuel oil A; h = 13%
Fuel oil B: h = 12%
Fuel oil C: h = 11%

Apart from this, on petroleum fuel, the graph and chart which show the relation between specific gravity and calorific value have been published. (See Figure 9.8). When a specific gravity measured at t°C is d_t, the specific gravity d_{15} at 15 °C can be obtained by the following equation.

$$d_{15} = d_t + 0.00065\ (t - 15)$$

Figure 9.8 Relation between Calorific Value (Low) and Specific Gravity of Petroleum Fuel



Even if the following equation is applied, error is not so much. (See Table 9.9)

Gaseous fuel: $H_l = 25.7\,(H_2) + 30.2\,(CO) + 85.5\,(CH_4)$
$+ 14.3\,(C_2H_4) + 154\,(C_2H_6) + 211\,(C_3H_6)$
$+ 224\,(C_3H_8) + 272\,(C_4H_8)$
$+ 295\,(C_4H_{10})$ kcal/m^3_N Fuel

Here, (H_2) etc. are taken as the vol.% of each component.

Table 9.9 Specific Gravity, Sulfur Content and Mean Calorific Value of Petroleum Fuel

	Specific gravity	Sulfur content (%)	Mean calorific value (low)
Kerosene	0.79 ~ 0.85	0.5 or Below	kcal/kg 10,400
Light oil	0.82 ~ 0.86	1.2 or Below	10,300
Whole fuel oil			9,850
A fuel oil	0.84 ~ 0.86	0.5 ~ 1.5	10,200
B fuel oil	0.88 ~ 0.92	0.5 ~ 3.0	9,900
C fuel oil	0.90 ~ 0.95	1.5 ~ 3.5 (Over)	9,750

b. Specific heat of fuel and air

Coal: 0.25 kcal/(kg. °C)
Fuel oil: 0.45 kcal/(kg. °C)
Natural gas: 0.38 ~ 0.42 kcal/(kg · °C)
LPG: 0.7 ~ 1.0 kcal/($m^3{}_N$°C)
Air: 0.31 kcal/(m^2 · °C) (Influence of humidity in air can be neglected.)

c. Air amount

The theoretical air (A_0) can be obtained by calculation from the component of fuel. In solid and liquid fuels, if the contents of carbon, hydrogen, oxygen and sulfur in the fuel are taken as c, h, o and s%, respectively, A_0 is represented by the following equation.

$$A_0 = \frac{1}{100}\left[8.89c + 26.7\left(h - \frac{o}{8}\right) + 3.33s\right] \text{ m}^3{}_N\text{/kg Fuel}$$

If an elementary analysis of fuel is not done, A_0 is able to calculate using the approximate expression from its calorific value. This standard adopts Boie's equation.

Case of coal

$$A_0 = 1.01\frac{H_\ell}{1,000} + 0.56\,m^3_N/kg\ Fuel$$

Case of fuel oil

$$A_0 = 12.38\frac{H_\ell}{10,000} - 1.36\,m^3_N/kg\ Fuel$$

Case of gaseous fuel

$$A_0 = 11.20\frac{H_\ell}{10,000}\,m^3_N/m^3_N\ Fuel$$

(Case of hydrocarbon-mixed gas)
The actual air input (A) can be obtained by the following equation.

$$A = mA_0\,(1 + 1.61\,z)\ m^3_N/kg\ Fuel$$

m: Air ratio
z: Absolute humidity of atmosphere kg/kg Dry air

The value of z can be obtained from Figure 9.9.

$$\text{Quantity of water vapor in air} = \frac{\text{Specific volume of water vapor } m^3_N / kg}{\text{Specific volume of dry air } m^3_N / kg} \times z = 1.61\,z\ m^3_N/m^3_N\ (\text{dry air})$$

The air ratio can be obtained by calculating the material balance through measuring the oxygen concentration or the CO_2 concentration in the exhaust gas. If the nitrogen content in the fuel is small, if the nitrogen content in the dry combustion exhaust gas can be assumed as 79 %, and if complete combustion can be assumed, the air ratio can be obtained by the following equation.

$$m = \frac{21}{21-(O_2)}$$

(O_2): Oxygen concentration (%) in the exhaust gas

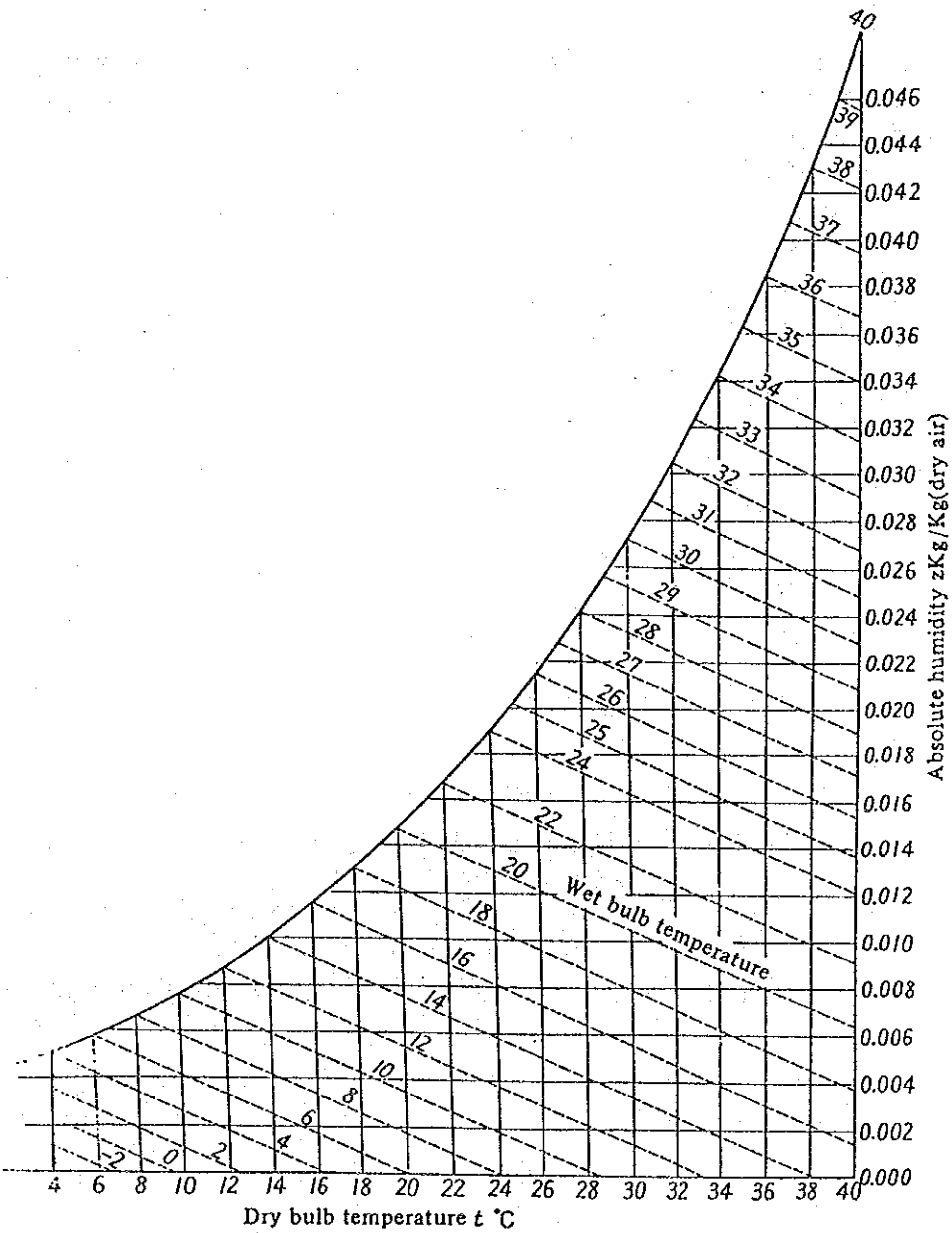
When there is little hydrogen in the fuel:

$$m = \frac{(CO_2)\ \text{max}}{(CO_2)}$$

(CO_2): Carbon dioxide concentration (%) in the exhaust gas
(CO_2) max: Max. carbon dioxide concentration in theoretical dry exhaust gas

The following values may be used for the value of CO_2 max: Coal: 18.5 %, fuel oil: 15.7 %, natural gas: 12 %, LPG: 14.5 %.

Figure 9.9 Absolute Humidity of Air



d. Heat absorbed by generated steam

The heat absorbed by the generated steam is shown by the value that subtracts the sensible heat of feed water from the retaining heat of generated steam. If water is sprayed at a superheater, the heat absorbed by the sprayed water is added to this.

If a reheater is used, the heat obtained by the steam and the sprayed water is added to it. The enthalpy of steam is shown in Tables 9.10 and 11.

e. Exhaust gas loss

The average specific heat of combustion exhaust gas is 0.33 kcal/($m^3{}_N$°C) from the result obtained in the range of 0 to 300 °C in a temperature and 1.0 to 1.3 in an air ratio (1.5 for a solid fuel).

The theoretical wet combustion exhaust gas quantity is calculated from the material balance similar to the theoretical air or can be obtained from the fuel calorific value according to the Boie's approximate expression.

Case of coal

$$G_1 = \frac{0.904\,H_\ell}{1{,}000} + 1.67 \text{ m}^3{}_N\text{/kg Fuel}$$

Case of fuel oil

$$G_1 = \frac{15.75\,H_\ell}{10{,}000} - 3.91 \text{ m}^3{}_N\text{/kg Fuel}$$

Case of gaseous fuel

$$G_1 = \frac{12.25\,H_\ell}{10{,}000} \text{ m}^3{}_N \text{ Fuel}$$

(Case of hydrocarbon-mixed gas)

Actual exhaust gas quantity is as the following equation.

$G = G_1 + (m - 1)\,A_0$ + water vapor quantity due to moisture in air

The water vapor quantity due to moisture in the air may usually be neglected.

Table 9.10 Thermodynamic Properties of Saturated Water and Saturated Steam (Temperature reference)

Temperature		Saturation pressure	Specific volume (m³/kg)		Specific enthalpy (kJ/kg)			Specific entropy (KJ/(kg·K))	
t (℃)	T (K)	P_s (MPa)	v'	v''	h'	h''	$r=h''-h'$	s'	s''
0.00	273.15	0.0006108	0.0010002	206.3	−0.04	2501.6	2501.6	−0.0002	9.1577
0.01	273.16	0.0006112	0.0010002	206.2	0.00	2501.6	2501.6	0.0000	9.1575
2	275.15	0.0007055	0.0010001	179.9	8.39	2505.2	2496.8	0.0306	9.1047
4	277.15	0.0008129	0.0010000	157.3	16.80	2508.9	2492.1	0.0611	9.0526
6	279.15	0.0009345	0.0010000	137.8	25.21	2512.6	2487.4	0.0913	9.0015
8	281.15	0.0010720	0.0010001	121.0	33.60	2516.2	2482.6	0.1213	8.9513
10	283.15	0.0012270	0.0010003	106.4	41.99	2519.9	2477.9	0.1510	8.9020
12	285.15	0.0014014	0.0010004	93.84	50.38	2523.6	2473.2	0.1805	8.8536
14	287.15	0.0015973	0.0010007	82.90	58.75	2527.2	2468.5	0.2098	8.8060
16	289.15	0.0018168	0.0010010	73.38	67.13	2530.9	2463.8	0.2388	8.7593
18	291.15	0.002062	0.0010013	65.09	75.50	2534.5	2459.0	0.2677	8.7135
20	293.15	0.002337	0.0010017	57.84	83.86	2538.2	2454.3	0.2963	8.6684
22	295.15	0.002642	0.0010022	51.49	92.23	2541.8	2449.6	0.3247	8.6241
24	297.15	0.002982	0.0010026	45.93	100.59	2545.5	2444.9	0.3530	8.5806
26	299.15	0.003360	0.0010032	41.03	108.95	2549.1	2440.2	0.3810	8.5379
28	301.15	0.003778	0.0010037	36.73	117.31	2552.7	2435.4	0.4088	8.4959
30	303.15	0.004241	0.0010043	32.93	125.66	2556.4	2430.7	0.4365	8.4546
32	305.15	0.004753	0.0010049	29.57	134.02	2560.0	2425.9	0.4640	8.4140
34	307.15	0.005318	0.0010056	26.60	142.38	2563.6	2421.2	0.4913	8.3740
36	309.15	0.005940	0.0010063	23.97	150.74	2567.2	2416.4	0.5184	8.3348
38	311.15	0.006624	0.0010070	21.63	159.09	2570.8	2411.7	0.5453	8.2962
40	313.15	0.007375	0.0010078	19.55	167.45	2574.4	2406.9	0.5721	8.2583
42	315.15	0.008198	0.0010086	17.69	175.81	2577.9	2402.1	0.5987	8.2209
44	317.15	0.009100	0.0010094	16.04	184.17	2581.5	2397.3	0.6252	8.1842
46	319.15	0.010086	0.0010103	14.56	192.53	2585.1	2392.5	0.6514	8.1481
48	321.15	0.011162	0.0010112	13.23	200.89	2588.6	2387.7	0.6776	8.1125
50	323.15	0.012335	0.0010121	12.05	209.26	2592.2	2382.9	0.7035	8.0776
55	328.15	0.015741	0.0010145	9.579	230.17	2601.0	2370.8	0.7677	7.9926
60	333.15	0.019920	0.0010171	7.679	251.09	2609.7	2358.6	0.8310	7.9108
65	338.15	0.02501	0.0010199	6.202	272.02	2618.4	2346.3	0.8933	7.8322
70	343.15	0.03116	0.0010228	5.046	292.97	2626.9	2334.0	0.9548	7.7565
75	348.15	0.03855	0.0010259	4.134	313.94	2635.4	2321.5	1.0154	7.6835
80	353.15	0.04736	0.0010292	3.409	334.92	2643.8	2308.8	1.0753	7.6132
85	358.15	0.05780	0.0010326	2.829	355.92	2652.0	2296.5	1.1343	7.5454
90	363.15	0.07011	0.0010361	2.361	376.94	2660.1	2283.2	1.1925	7.4799
95	368.15	0.08453	0.0010399	1.982	397.99	2668.1	2270.2	1.2501	7.4166
100	373.15	0.10133	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
110	383.15	0.14327	0.0010519	1.210	461.32	2691.3	2230.0	1.4185	7.2388
120	393.15	0.19854	0.0010606	0.8915	503.72	2706.0	2202.2	1.5276	7.1293
130	403.15	0.27013	0.0010700	0.6681	546.31	2719.9	2173.6	1.6344	7.0261
140	413.15	0.3614	0.0010801	0.5085	589.10	2733.1	2144.0	1.7390	6.9284
150	423.15	0.4760	0.0010908	0.3924	632.15	2745.4	2113.2	1.8416	6.8358
160	433.15	0.6181	0.0011022	0.3068	675.47	2756.7	2081.3	1.9425	6.7475
170	443.15	0.7920	0.0011145	0.2426	719.12	2767.1	2047.9	2.0416	6.6630
180	453.15	1.0027	0.0011275	0.1938	763.12	2776.3	2013.1	2.1393	6.5819
190	463.15	1.2551	0.0011415	0.1563	807.52	2784.3	1976.7	2.2356	6.5036
200	473.15	1.5549	0.0011565	0.1272	852.37	2790.9	1938.6	2.3307	6.4278
210	483.15	1.9077	0.0011726	0.1042	897.74	2796.2	1898.5	2.4247	6.3539
220	493.15	2.3198	0.0011900	0.08604	943.67	2799.9	1856.2	2.5178	6.2817
230	503.15	2.7976	0.0012087	0.07145	990.26	2802.0	1811.7	2.6102	6.2107
240	513.15	3.3478	0.0012291	0.05965	1037.6	2802.2	1764.6	2.7020	6.1406
250	523.15	3.9776	0.0012513	0.05004	1085.8	2800.4	1714.6	2.7935	6.0708
260	533.15	4.6943	0.0012756	0.04213	1134.9	2796.4	1661.5	2.8848	6.0010
270	543.15	5.5058	0.0013025	0.03559	1185.2	2789.9	1604.6	2.9763	5.9304
280	553.15	6.4202	0.0013324	0.03013	1236.8	2780.4	1543.6	3.0683	5.8586
290	563.15	7.4461	0.0013659	0.02554	1290.0	2767.6	1477.6	3.1611	5.7848
300	573.15	8.5927	0.0014041	0.02165	1345.0	2751.0	1406.0	3.2552	5.7081
310	583.15	9.8700	0.0014480	0.01833	1402.4	2730.0	1327.6	3.3512	5.6278
320	593.15	11.289	0.0014995	0.01548	1462.6	2703.7	1241.1	3.4500	5.5423
330	603.15	12.863	0.0015615	0.01299	1526.5	2670.2	1143.6	3.5528	5.4490
340	613.15	14.605	0.0016387	0.01078	1595.5	2626.2	1030.7	3.6616	5.3427
350	623.15	16.535	0.0017411	0.008799	1671.9	2567.7	895.7	3.7800	5.2177
360	633.15	18.675	0.0018959	0.006940	1764.2	2485.4	721.3	3.9210	5.0600
370	643.15	21.054	0.0022136	0.004973	1890.2	2342.8	452.6	4.1108	4.8144
374.15	647.30	22.120	0.00317		2107.4		0.0	4.429	

1[Mpa]= 10.197kg/cm²　　　　1kJ=0.2389 kcal

Table 9.11 Thermodynamic Properties of Saturated Water and Saturated Steam (Pressure reference)

Pressure	Saturation temperature		Specific volume (m^3/kg)		Specific enthalpy (kJ/kg)			Specific entropy	(KJ/(kg·K))
P (MPa)	t_s (℃)	T_s (K)	v'	v''	h'	h''	$r=h''-h'$	s'	s''
0.001	6.9828	280.1328	0.0010001	129.20	29.34	2514.4	2485.0	0.1060	8.9767
0.002	17.513	290.663	0.0010012	67.01	73.46	2533.6	2460.2	0.2607	8.7246
0.003	24.100	297.250	0.0010027	45.67	101.00	2545.6	2444.6	0.3544	8.5785
0.004	28.983	302.133	0.0010040	34.80	121.41	2554.5	2433.1	0.4225	8.4755
0.005	32.898	306.048	0.0010052	28.19	137.77	2561.6	2423.8	0.4763	8.3960
0.006	36.183	309.333	0.0010064	23.74	151.50	2567.5	2416.0	0.5209	8.3312
0.007	39.025	312.175	0.0010074	20.53	163.38	2572.6	2409.2	0.5591	8.2767
0.008	41.534	314.684	0.0010084	18.10	173.86	2577.1	2403.2	0.5925	8.2296
0.009	43.787	316.937	0.0010094	16.20	183.28	2581.1	2397.9	0.6224	8.1881
0.010	45.833	318.983	0.0010102	14.67	191.83	2584.8	2392.9	0.6493	8.1511
0.02	60.086	333.236	0.0010172	7.650	251.45	2609.9	2358.4	0.8321	7.9994
0.03	69.124	342.274	0.0010223	5.229	289.30	2625.4	2336.1	0.9441	7.7695
0.04	75.886	349.036	0.0010265	3.993	317.65	2636.9	2319.2	1.0261	7.6709
0.05	81.345	354.495	0.0010301	3.240	340.56	2646.0	2305.4	1.0912	7.5947
0.06	85.954	359.104	0.0010333	2.732	359.93	2653.6	2293.6	1.1454	7.5327
0.08	93.512	366.662	0.0010387	2.087	391.72	2665.8	2274.0	1.2330	7.4352
0.10	99.632	372.782	0.0010434	1.694	417.51	2675.4	2257.9	1.3027	7.3598
0.101325	100.00	373.15	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
0.12	104.81	377.96	0.0010476	1.428	439.36	2683.4	2244.1	1.3609	7.2984
0.14	109.32	382.47	0.0010513	1.236	458.42	2690.3	2231.9	1.4109	7.2465
0.16	113.32	386.47	0.0010547	1.091	475.38	2696.2	2220.9	1.4550	7.2017
0.18	116.93	390.08	0.0010579	0.9772	490.70	2701.5	2210.8	1.4944	7.1622
0.2	120.23	393.38	0.0010608	0.8854	504.70	2706.3	2201.6	1.5301	7.1268
0.3	133.54	406.69	0.0010735	0.6056	561.43	2724.7	2163.2	1.6716	6.9909
0.4	143.62	416.77	0.0010839	0.4622	604.67	2737.6	2133.0	1.7764	6.8943
0.5	151.84	424.99	0.0010928	0.3747	640.12	2747.5	2107.4	1.8604	6.8192
0.6	158.84	431.99	0.0011009	0.3155	670.42	2755.5	2085.0	1.9308	6.7575
0.7	164.96	438.11	0.0011082	0.2727	697.06	2762.0	2064.9	1.9918	6.7052
0.8	170.41	443.56	0.0011150	0.2403	720.94	2767.5	2046.5	2.0457	6.6596
0.9	175.36	448.51	0.0011213	0.2148	724.64	2772.1	2029.5	2.0941	6.6192
1.0	179.88	453.03	0.0011274	0.1943	762.61	2776.2	2013.6	2.1382	6.5828
1.2	187.96	461.11	0.0011386	0.1632	798.43	2782.7	1984.3	2.2161	6.5194
1.4	195.04	468.19	0.0011489	0.1407	830.08	2787.8	1957.7	2.2837	6.4651
1.5	198.29	471.44	0.0011539	0.1317	844.67	2789.9	1945.2	2.3145	6.4406
1.6	201.37	474.52	0.0011586	0.1237	858.56	2791.7	1933.2	2.3436	6.4175
1.8	207.11	480.26	0.0011678	0.1103	884.58	2794.8	1910.3	2.3976	6.3751
2.0	212.37	485.52	0.0011766	0.09954	908.59	2797.2	1888.6	2.4469	6.3367
2.2	217.24	490.39	0.0011850	0.09065	930.95	2799.1	1868.1	2.4922	6.3015
2.4	221.78	494.93	0.0011932	0.08320	951.93	2800.4	1848.5	2.5343	6.2690
2.5	223.94	497.09	0.0011972	0.07991	961.96	2800.9	1839.0	2.5543	6.2536
2.6	226.04	499.19	0.0012011	0.07686	971.72	2801.6	1825.0	2.5831	6.2315
2.8	230.05	503.20	0.0012088	0.07139	990.48	2802.0	1811.5	2.6106	6.2104
3.0	233.84	506.99	0.0012163	0.06663	1008.4	2802.3	1793.9	2.6455	6.1837
3.5	242.54	515.69	0.0012345	0.05703	1049.8	2802.0	1752.2	2.7253	6.1228
4.0	250.33	523.48	0.0012521	0.04975	1087.4	2800.3	1712.9	2.7965	6.0685
4.5	257.41	530.56	0.0012691	0.04409	1122.1	2797.7	1675.6	2.8612	6.0191
5.0	263.91	537.06	0.0012858	0.03943	1154.5	2794.2	1639.7	2.9206	5.9735
5.5	269.93	543.08	0.0013023	0.03563	1184.9	2789.9	1605.0	2.9757	5.9309
6.0	275.55	548.70	0.0013187	0.03244	1213.7	2785.0	1571.3	3.0273	5.8908
6.5	280.82	553.97	0.0013350	0.02972	1241.1	2779.5	1538.4	3.0759	5.8527
7.0	285.79	558.94	0.0013513	0.02737	1267.4	2773.5	1506.0	3.1219	5.8162
7.5	290.50	563.65	0.0013677	0.02533	1292.7	2766.9	1474.2	3.1657	5.7811
8.0	294.97	568.12	0.0013842	0.02353	1317.1	2759.9	1442.8	3.2076	5.7471
9	303.31	576.46	0.0014179	0.02050	1363.7	2744.6	1380.9	3.2867	5.6820
10	310.96	584.11	0.0014526	0.01804	1408.0	2727.7	1319.7	3.3605	5.6198
11	318.05	591.20	0.0014887	0.01601	1450.6	2709.3	1258.7	3.4304	5.5595
12	324.65	597.80	0.0015268	0.01428	1491.8	2689.2	1197.4	3.4972	5.5002
13	330.83	603.98	0.0015672	0.01280	1532.0	2667.0	1135.0	3.5616	5.4408
14	336.64	609.79	0.0016106	0.01150	1571.6	2642.4	1070.7	3.6242	5.3803
15	342.13	615.28	0.0016579	0.01034	1611.0	2615.0	1004.0	3.6859	5.3178
16	347.33	620.48	0.0017103	0.009308	1650.5	2584.9	934.3	3.7471	5.2531
17	352.26	625.41	0.0017696	0.008371	1691.7	2551.6	859.9	3.8107	5.1855
18	355.96	630.11	0.0018399	0.007498	1734.8	2513.9	779.1	3.8765	5.1128
19	361.43	634.58	0.0019260	0.006678	1778.7	2470.6	692.0	3.9429	5.0332
20	365.70	638.85	0.0020370	0.005877	1826.5	2418.4	591.9	4.0149	4.9412
21	369.78	642.93	0.0022015	0.005023	1886.3	2347.6	461.3	4.1048	4.8223
22	373.69	646.84	0.0026714	0.003728	2011.1	2195.6	184.5	4.2947	4.5799
22.12	374.15	647.30	0.00317		2107.4		0.0	4.4429	

f. Heat loss due to furnace blast steam

Steam is used to atomize fuel. In use of the steam generated in the boiler, the heat loss is according to the following equation.

Heat loss due to blow-in steam = Blow-in steam quantity per 1 kg of fuel × (Enthalpy of steam at exhaust gas temperature) – (Enthalpy of feed water)

In use of steam in another line, the enthalpy of steam at ambient temperature is taken as basis, and an output heat and input heat are calculated in enthalpies in each condition.

g. Heat loss due to incompletely burning gas

It is calculated according to the following equation.

$$\text{Heat loss} = 30.5\ [G_0 + (m - 1)\ A_0]\ (CO)\ \text{kcal/kg}\ (m^3_N)\text{-Fuel}$$

(CO) is a carbon monoxide content (%) in dry exhaust gas, G_0 is theoretical dry exhaust gas quantity.

h. Heat loss due to combustible refuse in cinder

A combustible carbon (C)% content can be obtained by the following equation.

$$c = au/(100 - u)$$

here, a: Ash content % in fuel
u: Average unburned content % in cinder

Heat loss is 81 kcal/kg Fuel.

i. Heat loss due to heat release

Although it may be obtained by measuring the heat release in each part, in Japanese Industrial Standards, heat loss is taken as a value multiplied by the fuel calorific value by heat release loss %.

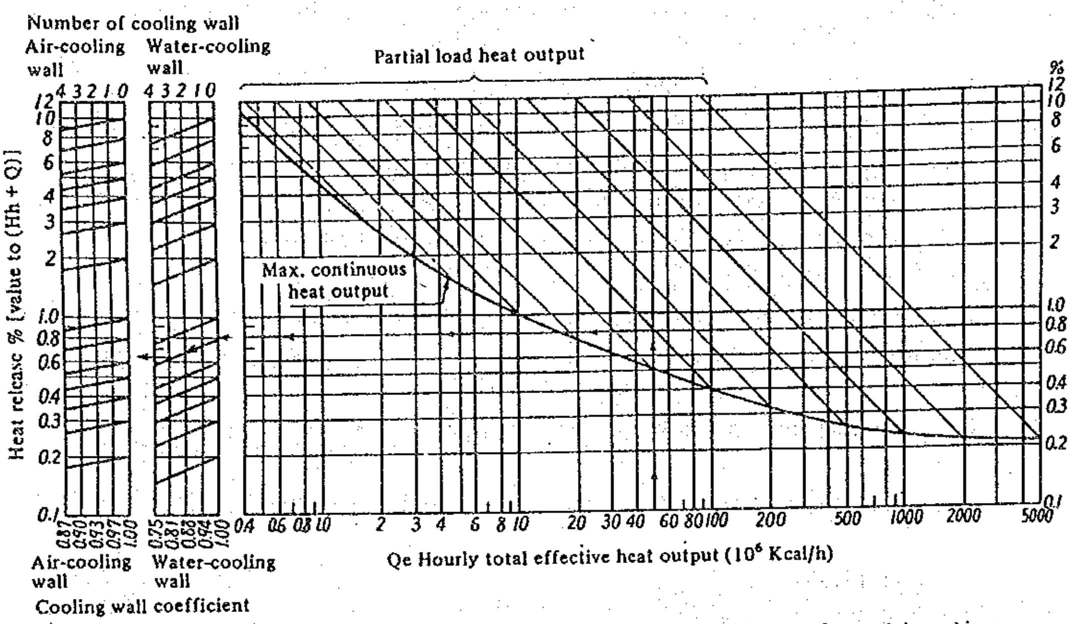
The following values are shown as round figures for heat loss. (Table 9.12)

For reference, the diagram shown in the Power Test Code of the ASME (American Society of Mechanical Engineering) is shown in Figure 9.10. This diagram is a case of the difference between the temperature of the warm surface and the ambient temperature is 28 °C and the air flow velocity on the surface is 0.5 m/s. For other conditions, it should be corrected by a multiple of Figure 9.11. This diagram is for a high calorific value. For a low calorific value it should be multiplied by Hh/Hℓ.

Table 9.12 Radiant Heat Loss

Boiler capacity t/h	5	10	50	100	500	1000
Radiant heat loss%	2.0	1.4	0.8	0.5	0.3	0.2

Figure 9.10 Heat Loss Chart (From ABMA chart in power test code of ASME)

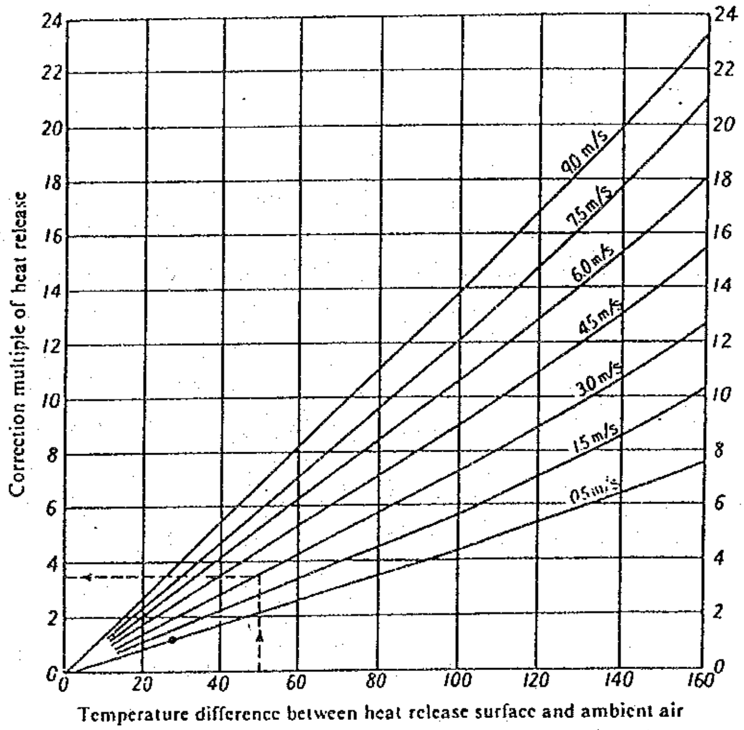


(The figure shows the case that the temperature difference between the heat release surface and the ambient air is 28°C and the wind velocity on the heat release surface is 0.5 m/s. Correction multiples in other condition are based on it of Fig. 9.11.)

Note: So far as a water-cooling wall occupies 1/3 or more of the projected area in a combustion chamber, reduction of heat loss is permitted to be done. For an air-cooling wall, the reduction of heat loss should be restricted to a case of utilization to combustion of the cooling air.

Example: In a boiler having the maximum continuous load of 100×10^6 Kcal/h, when the partial load is 5×10^6 Kcal, h and the number of water-cooling wall is 3, the heat loss rate results in 0.65%.

Figure 9.11 Correction Multiple of Temperature Difference and Air Velocity to Figure 9.10



j. Other heat losses

They are error terms.

9.5 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 9.8 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^2h) 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 (kcal/m^3h) in the combustion chamber which is divided by the total input heat by the volume of the combustion chamber.

9.6 Consideration in Installation Steps

9.6.1 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 9.12). And various systems are considered as follows.

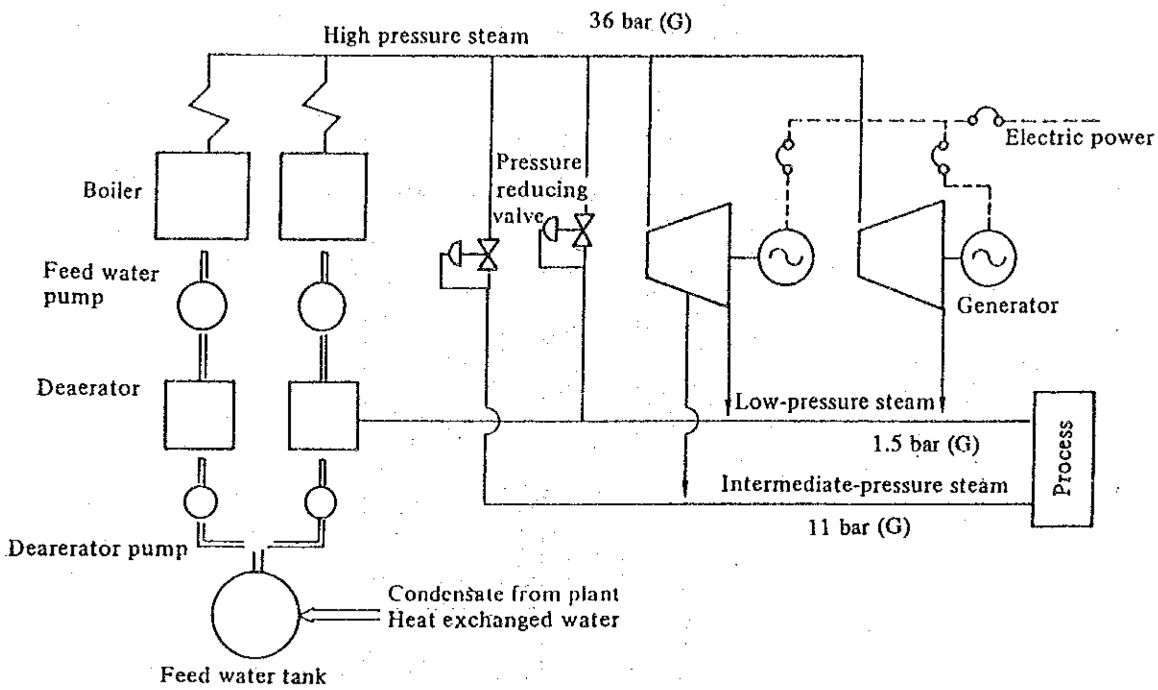
(1) (Gas turbine power generation) + (Steam turbine power generation)

(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 30 bar or more and it is almost 100 bar. 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 9.12 An Example of Cogeneration System



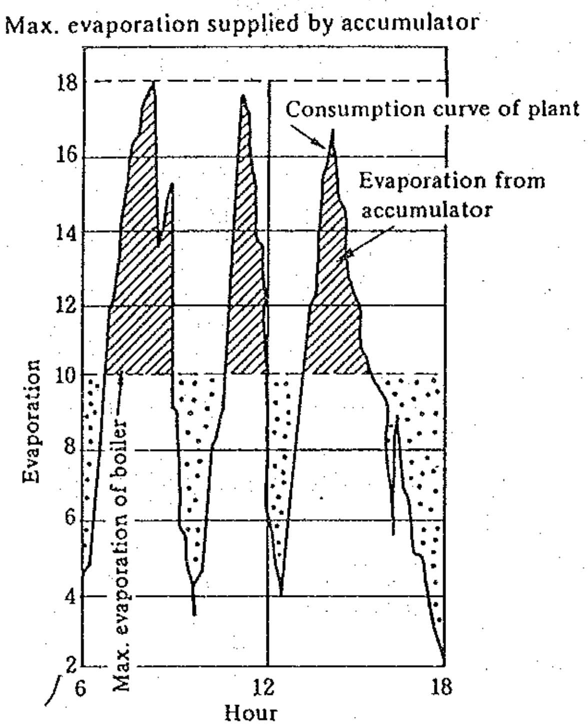
9.6.2 Coping with steam demand variation

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 9.13). If an accumulator is accompanied when the boiler is installed, a boiler of the capacity near to the average load is able to cover sufficiently the demand.

Figure 9.13 Effect of Steam Accumulator



In another method, several small size one-through boilers which are quick start-up are installed and the operating number of boilers is controlled automatically according to load (see Figure 9.14). Since this method increases the efficiency in a lower load compared with the case of a single boiler (see Figure 9.15), 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 9.14 Operation Number Control

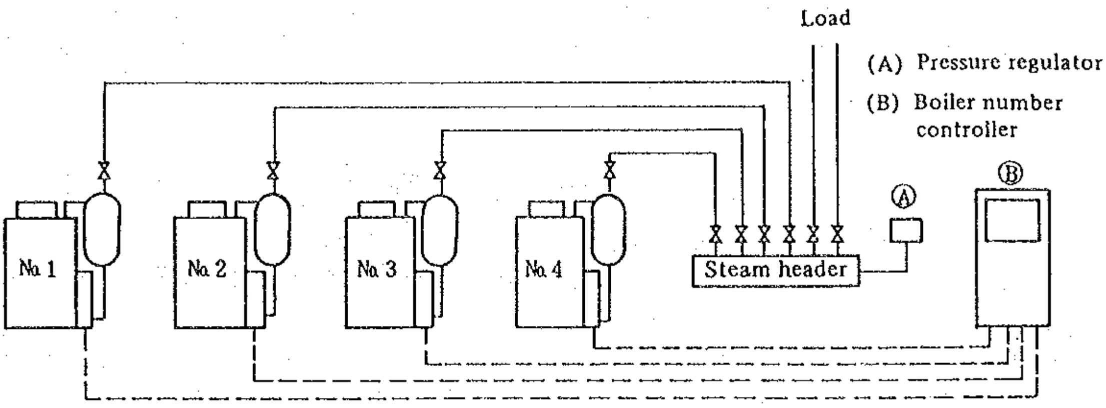
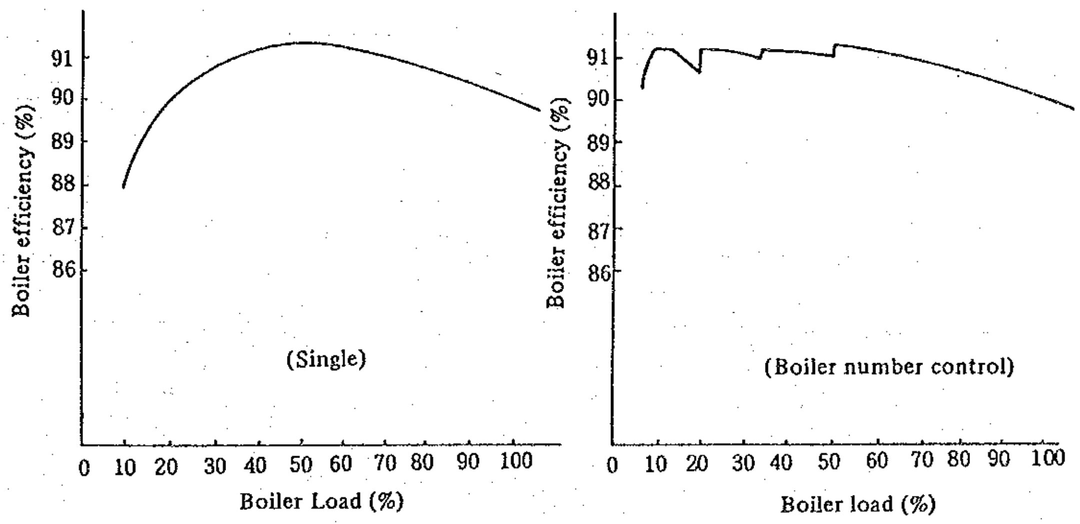


Figure 9.15 Boiler Efficiency Improvement by Operation Number Control



9.6.3 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.

9.7 Energy Conservation Measure of Boilers

There are various items for the energy conservation in the boilers as shown in Figure 9.16, the characteristic factor chart. The important points of these items are described below.

9.7.1 Air Ratio

The largest heat loss of boilers is an exhaust gas loss (see Figure 9.17). The exhaust gas loss is decided by an exhaust gas volume and an exhaust gas temperature. A proper air ratio must be kept to minimize the exhaust gas volume.

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

Figure 9.16 Energy Conservation Items of Boiler

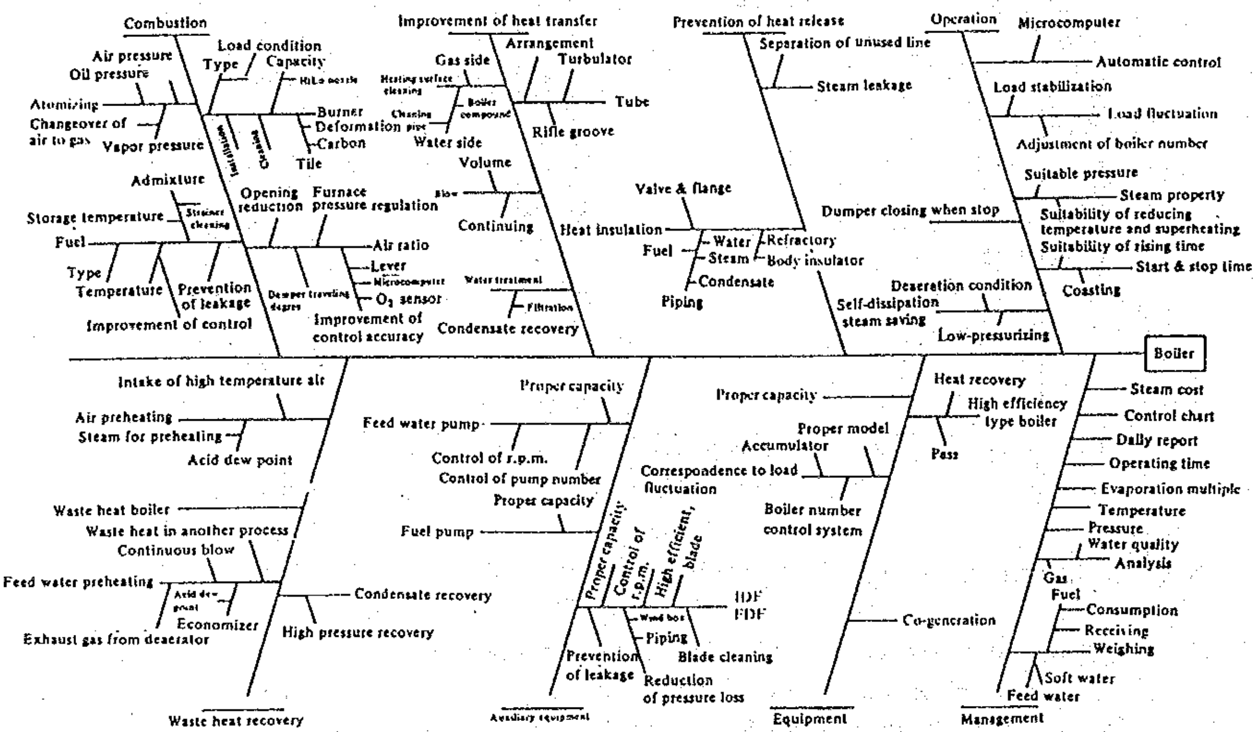
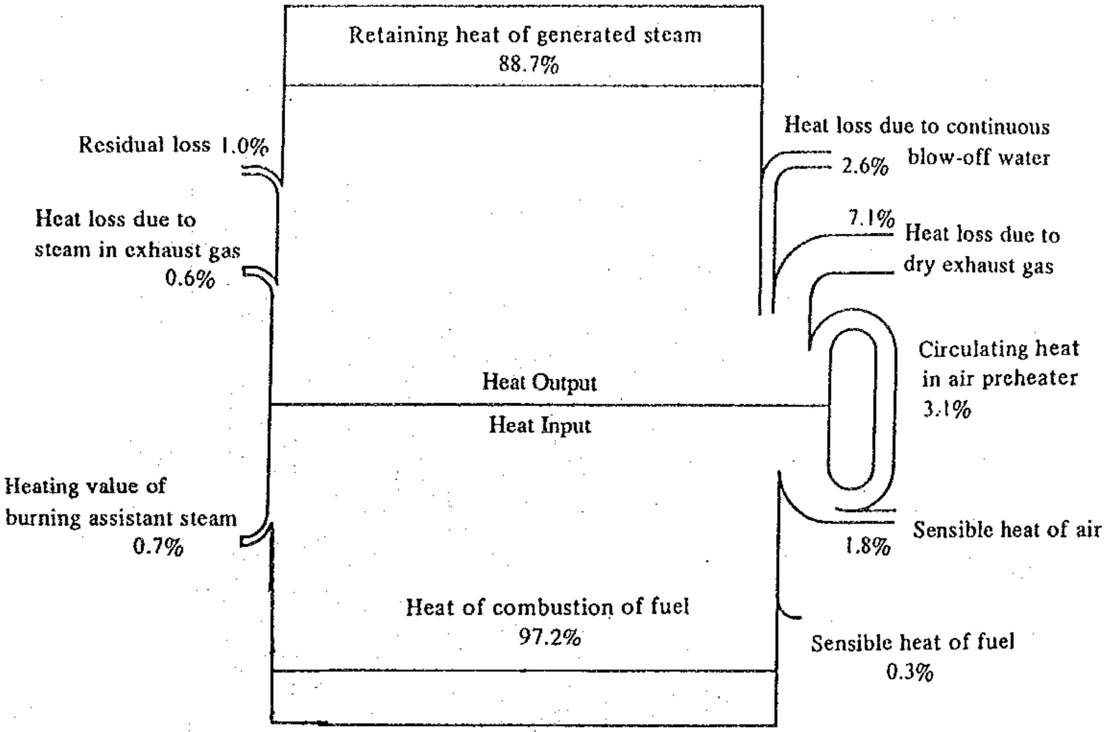


Figure 9.17 Example of 20 T/H Boiler Heat Balance



$$\text{Evaporation multiple} = \frac{13.67 \text{ kg}}{1 \text{ kg} \times 0.93 \text{ kg/lit.}} \times 1000 = 14.7 \text{ ton/kl.}$$

(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 9.18).

(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. The characteristics of oil burners should be referred to Table 9.13.

(4) Prevention of air invasion

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

Figure 9.18 Viscosity of Fuel Oil

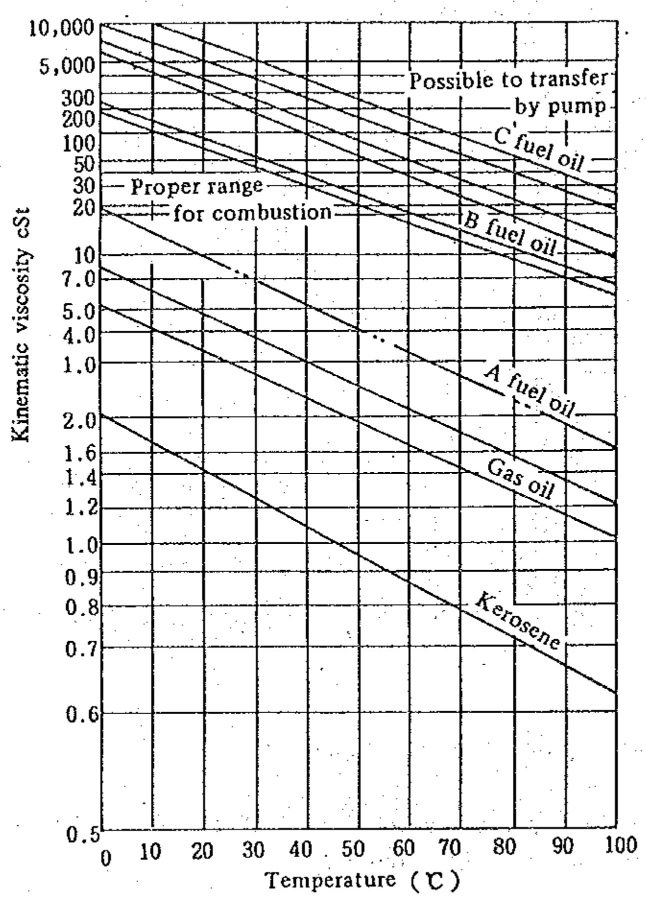


Table 9.13 Characteristics and Application of Oil Burner

		Low pressure air system		High pressure atomizing system		Oil pressure system		Rotary burner
		Interlocking type	Non-interlocking 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	10 ~ 300
Oil pressure	bar	0.4 ~ 1	0.1 ~ 0.3	2 ~ 9	0.2 ~ 1	5 ~ 40	5 ~ 70	0.5 ~ 10
Atomizing pressure		mm H_2O (400 ~ 2,000)	mm H_2O (400 ~ 2,000)	3 ~ 10 bar	2 ~ 8 bar	—	—	1 ~ 3 bar
Atomizing medium amount	A Nm^3/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			Air, rotation of cup
Combustion air pressure	mm H_2O	400 ~ 2,000	100 ~ 2,000	0 ~ 250	0 ~ 50	100	100	0 ~ 100
Combustion regulation range		4 ~ 6 : 1	4 ~ 8 : 1	8 : 1	6 : 1	3 : 1	3 : 1	2 ~ 10 : 1
Flame characteristic		Short flame	Slightly short flame, Long flame	Short flame, Long flame	Slightly long flame	Short flame	Short flame	Short flame
Merit		Possible for proportional control by one lever. Low cost of installation and operation	Easy handling. Same as left.	Good atomizing. Small clogging	Same as left	Low combustion noise. Low cost of operation	Same as left	Low cost, Easy handling
Weakness		Blower required	Same as left	Power cost required	Power cost required	Not respond to load fluctuation High pressure pump required	Same as left	Result in large size
Boiler application	Flue smoke tube	○	○	○	○	○	○	○
	One-through			○	○	○	○	
	Vertical	○	○		○			○
	Water-tube	○		○	○	○	○	○

(5) Regulation of air

The air ratio is able to make sure 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 spy 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 a 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 9.19 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 9.20 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 9.21.

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 9.22 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.

Figure 9.19 Boiler Air Ratio Controller (1)

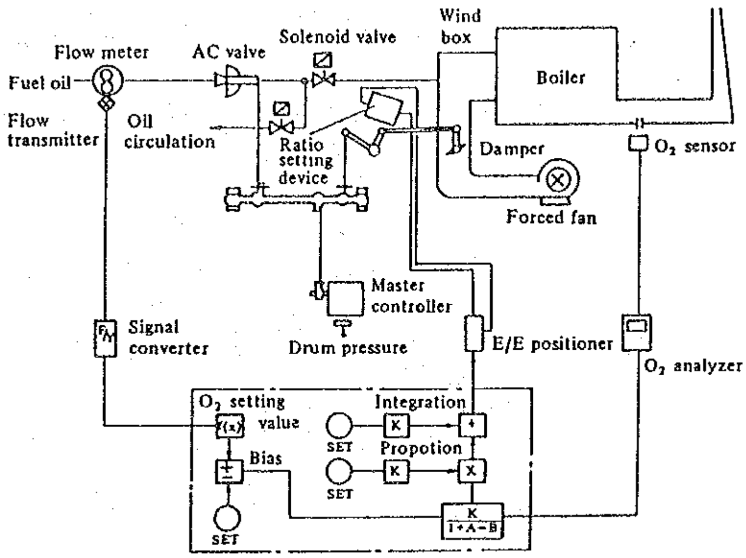


Figure 9.20 Boiler Air Ratio Controller (2)

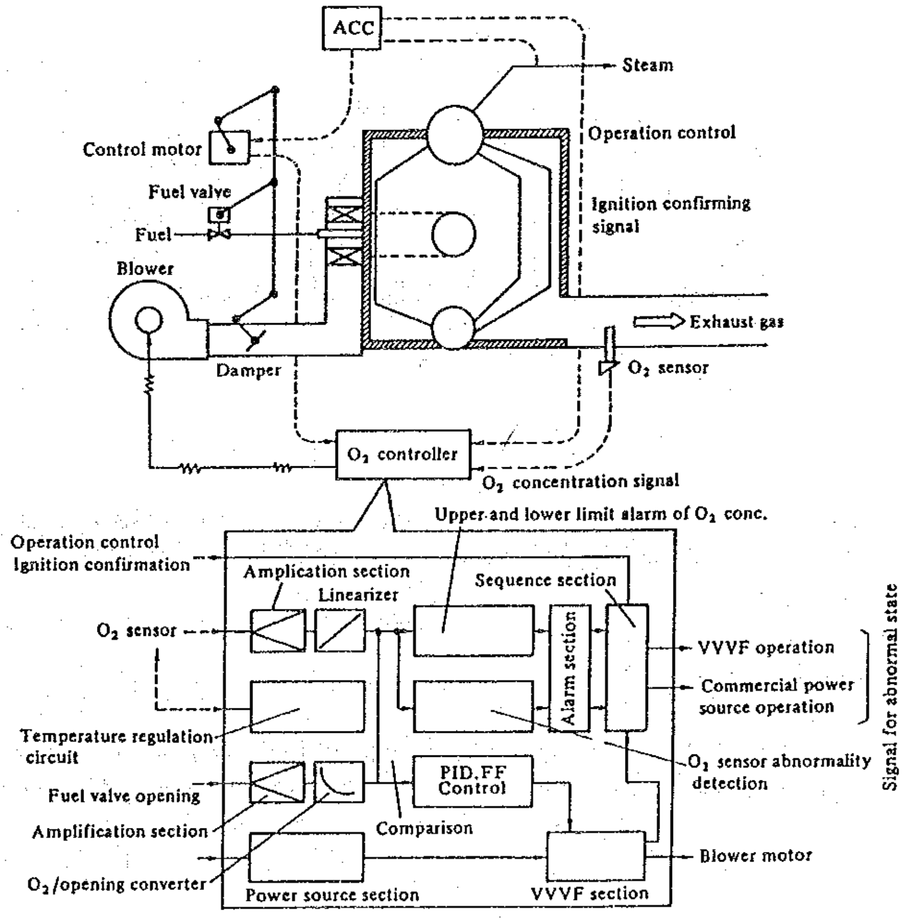
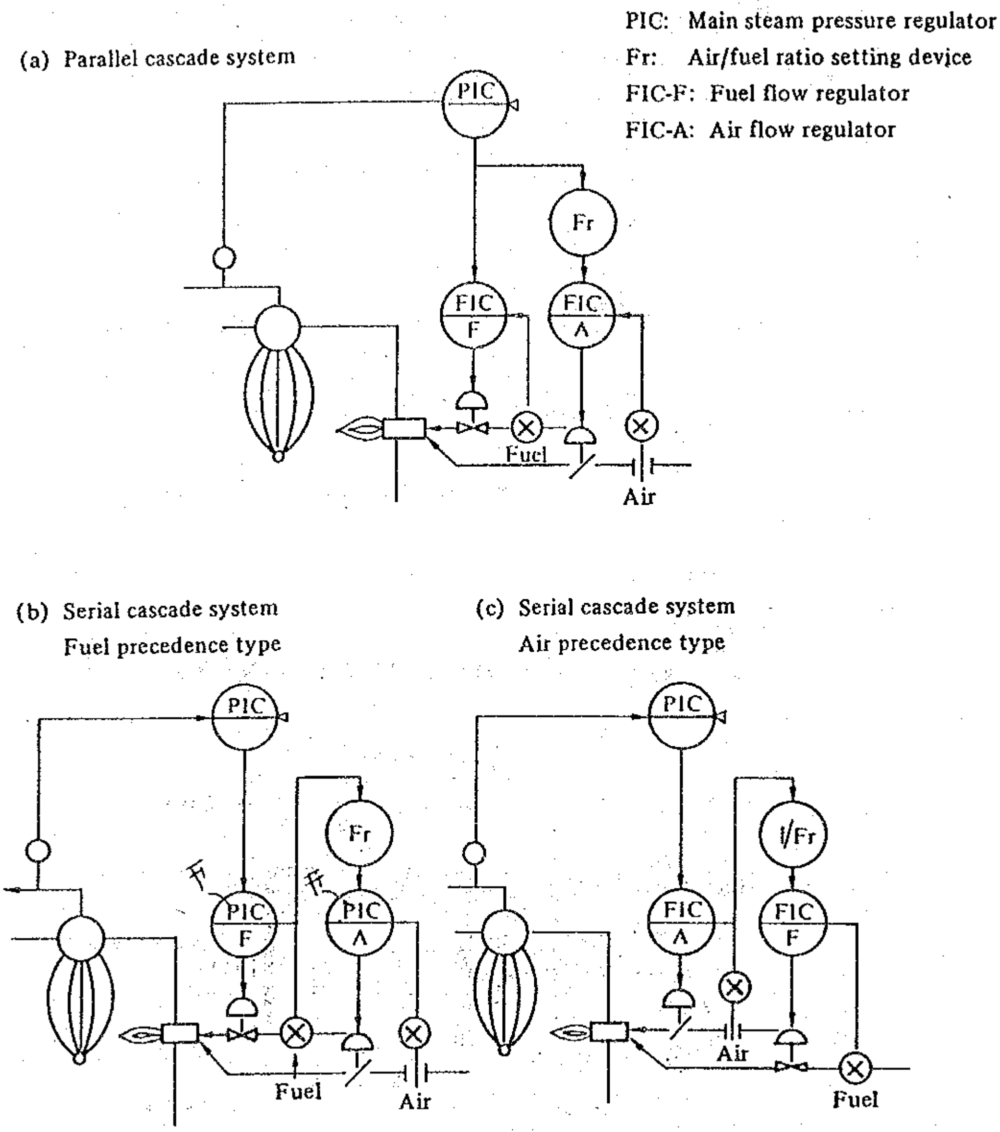


Figure 9.21 Basic Combustion Control System

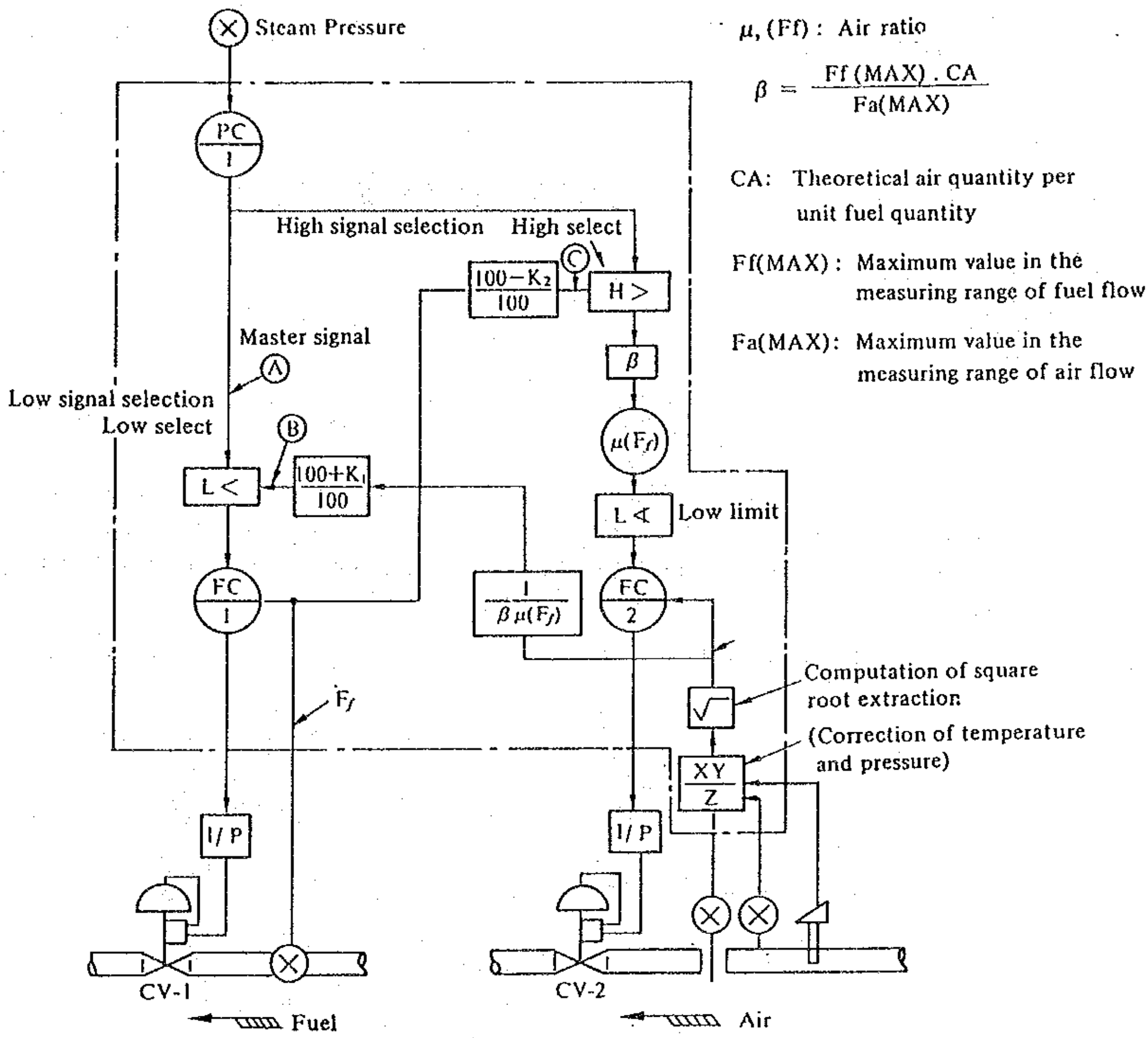


When the fuel component fluctuates, there are some cases in which air flow is controlled more exactly through transmitting the signal to the controller from the O_2 analyzer in exhaust gas.

(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 9.14 as reference.

Figure 9.22 Block Diagram of Single Cross Limit Combustion Control System



PC-1 : Main Steam pressure regulation

PC-1 : Fuel oil flow control

PC-2 : Air flow control

Table 9.14 Standard Air Ratio of Boiler

Classification of evaporation	Solid fuel Fixed bed	Solid fuel Fluidized bed	Liquid fuel	Gas fuel	By-product gas
Large-sized boiler for electric utilities	—	—	1.05 - 1.2	1.05 - 1.1	1.2
Other boilers					
30 t/h or more	1.3 - 1.45	1.2 - 1.45	1.1 - 1.25	1.1 - 1.2	1.2 - 1.3
10 to 30 t/h	1.3 - 1.45	1.2 - 1.45	1.2 - 1.3	1.2 - 1.3	—
5 to 10 t/h	—	—	1.3	1.3	—
< 10 t/h	—	—	1.3	1.3	—

These values shall be applied to the operations of load factor in the range shown in the Table and to steady operation. In a solid fuel, this is the case of pulverized coal of $H\ell \geq 5{,}000$ kcal/kg.

9.7.2 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 9.15. Accordingly, these deposits make the thermal efficiency of boilers decline remarkably similar to some insulation on the heating surface (see Figure 9.23 and Figure 9.24).

Table 9.15 Thermal Conductivity of Scale and Other Substance

Scale and other substance	Thermal conductivity (kcal/mh°C)
Soot	0.06 ~ 0.1
Oily matter	0.1
Scale as main component of silicate	0.2 ~ 0.4
Scale as main component of carbonate	0.4 ~ 0.6
Scale as main component of sulfate	0.6 ~ 2
Mild steel	40 ~ 60

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 9.2.3.

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 9.7.7).

(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 contained with 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.

Figure 9.23 Example of Fuel Loss due to Soot on Heating Surface

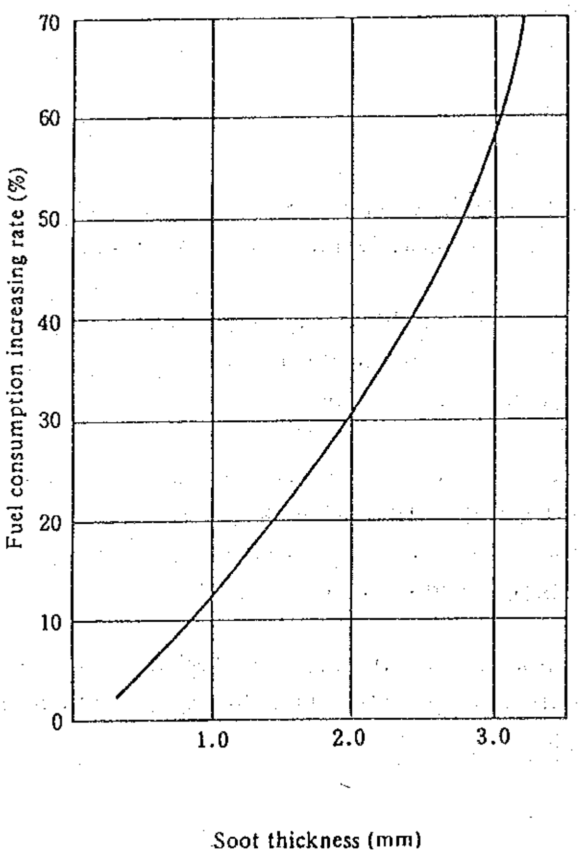
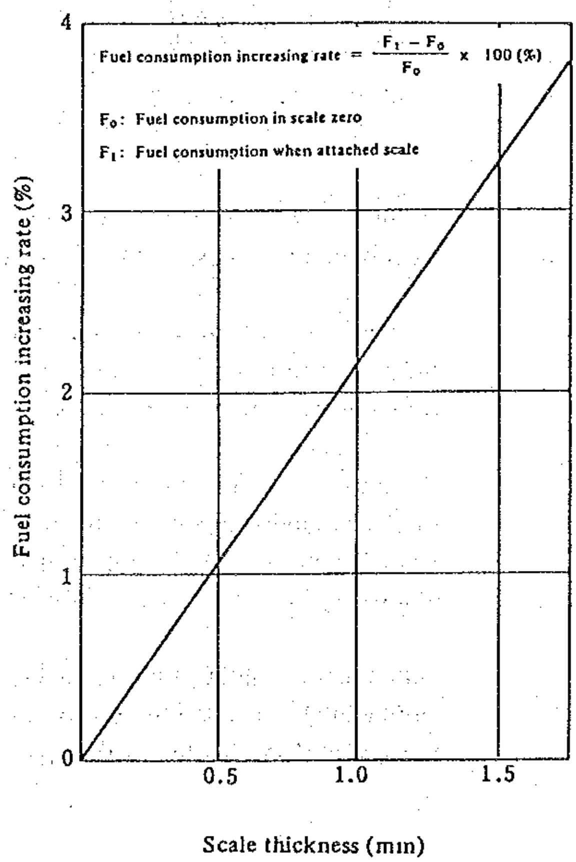


Figure 9.24 Example of Relation between Scale Thickness and Fuel Loss



The relation between the sulfur content in fuel and the SO_2% in exhaust gas is shown in Figure 9.25, the conversion of SO_2 to SO_3 is shown in Figure 9.26 and the relation between the SO_3 concentration and the dew point of acid is shown in Figure 9.27. 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 9.25 Relation between Sulfur Content in Fuel and SO_2 Content in Fuel Gas

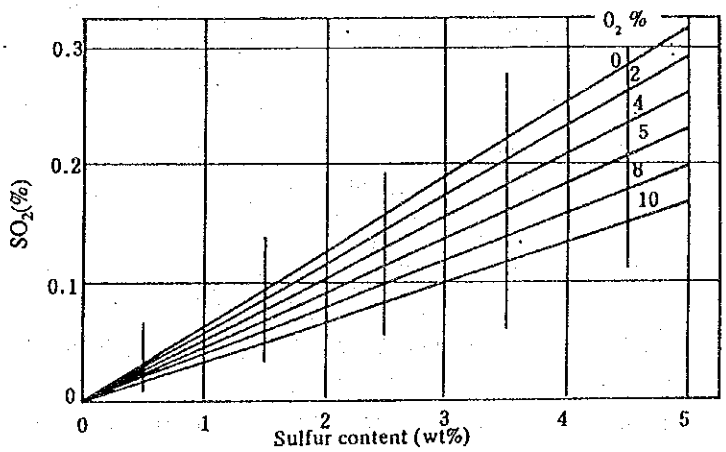


Figure 9.26 Relation between Sulfur Content in Fuel and Conversion Ratio from SO_2 to SO_3

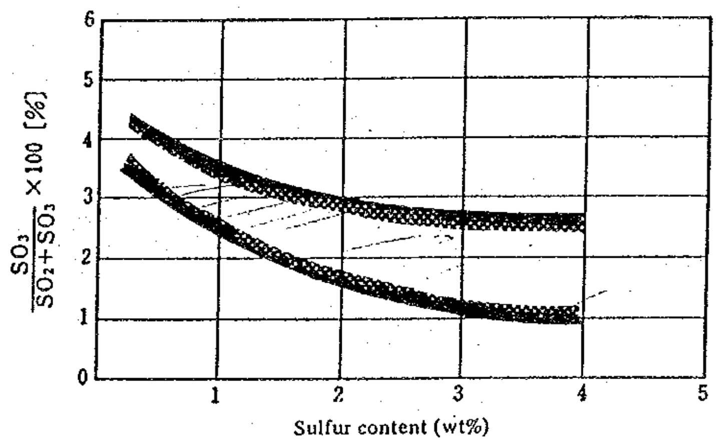
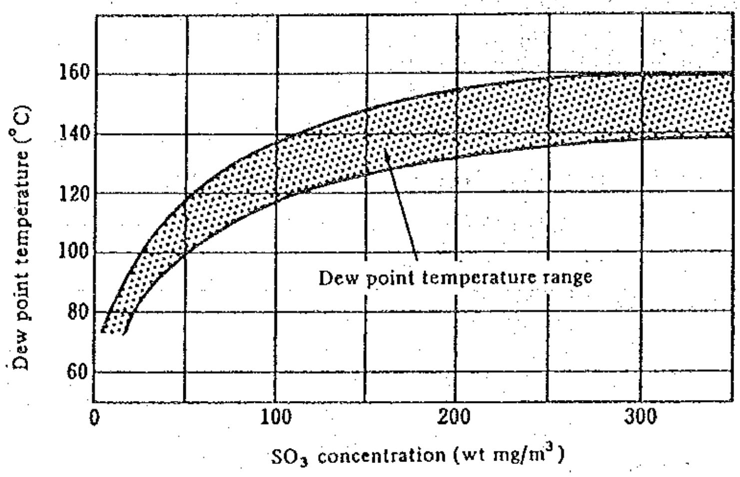


Figure 9.27 Relation between SO_3 Concentration in Exhaust Gas and Dew Point Temperature



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 9.7 of paragraph 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	kcal/kg Fuel
P:	Carrying-in heat of the preheated air	kcal/kg Fuel
F:	Calorific value of fuel	kcal/kg Fuel
H:	Available heat and required heat = F – Q	kcal/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 kcal/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:

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

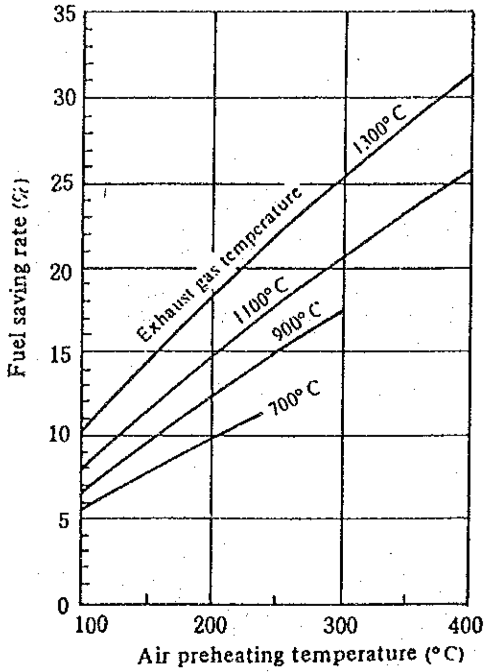
The fuel saving rate in case of 1.2 in the air ratio is shown in Figure 9.28.

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 9.28 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 9.16.

Table 9.16 Standard Exhaust Gas Temperature of Boiler (unit: °C)
(Load factor: 100% at the outer temperature of 20 °C)

Classification of evaporation	Solid fuel Fixed bed	Solid fuel Fluidized bed	Liquid fuel	Gas fuel	By-product gas
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.

9.7.3 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. (See Chapter of Steam.)

9.7.4 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 contraction 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.

9.7.5 Operation

If the use of steam is limited to only day time, a one-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.

9.7.6 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 9.1.5), 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 9.17 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 9.17 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 bar	Feed water temperature °C	Feed water quantity: Meter reading	Feed water quantity: Consumption lit.	Fuel oil quantity: Consumption lit.	Fuel oil quantity: Meter reading	Fuel oil temp.: Service tank °C	Fuel oil temp.: Heater outlet °C	Oil pressure: Primary bar	Oil pressure: Secondary bar	Exhaust gas temperature °C	Exhaust gas %CO_2	Furnace pressure mmAq	WB static pressure mmAq	Outlet static pressure mmAq
				(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				
Daily inspection	Water gage blowing				
Daily inspection	Automatic feedwater regulator				
Daily inspection	Low water Level Governor 1st step 2nd step 3rd step				
Daily inspection	Flame detector				
Daily inspection	Combustion state				
Daily inspection	Firing equipment				
Daily inspection	Feedwater device				
Daily inspection	Automatic controller				
Daily inspection	Control interlocking devices				
Total	Feedwater quantity (A)			ℓ/d	
Total	Fuel oil quantity (B)			ℓ/d	
Total	Evaporation multiple A/B			ℓ/ℓ	
Total	Boiler efficiency			%	
Total	Operating time			h	
Fuel	Carry-over			ℓ	
Fuel	Today receiving quantity			ℓ	
Fuel	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

Chemicals pouring device		
Previous day	Today	Pour

Water softener		
Previous meter reading		ℓ
Today's meter reading		ℓ
Treating water quantity		ton
Basic cycle		ton
NaCl quantity		kg
Hardness analysis		Good or no

Boiler water		
Sampling	Pressure bar	State of boiler Before and after blowing
Yes		
No		

Water quality test	Item		Unit
Feed water	pH		—
Feed water	Conductivity		μΩ/cm
Feed water	Chloride ion		ppm
Feed water	Hardness		ppm
Boiler water	pH		—
Boiler water	Conductivity		μΩ/cm
Boiler water	Chloride ion		ppm
Boiler water	Hardness Phosphate ion		ppm

Description:

9.7.7 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	90%
• Exhaust gas loss	5%
• 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 2.5 % of the conventional O_2% limit to 0.6 %. As a result, O_2 has been reduced to 1.0 %

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.

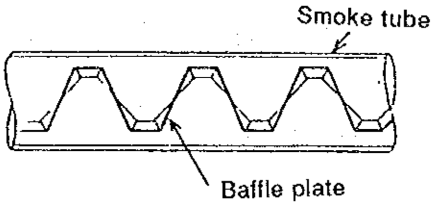
Since the opening of the damper for the forced draft fan was a low degree of 10 to 20 %, the revolution control by inverter was carried out.

As a result, fuel oil was reduced by 37.5 kℓ /1 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.

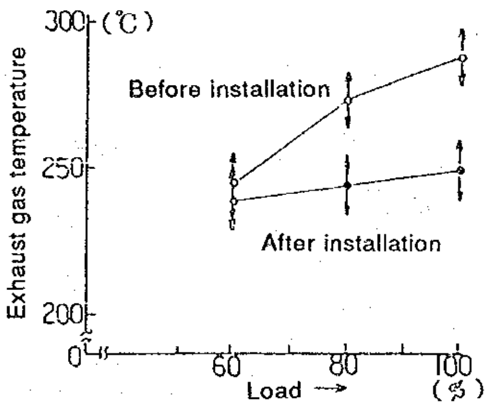
(3) Heat transfer improvement of smoke tube (See Figure 9.29)

A special steel turbulator was inserted in the smoke tube of a flue smoke tube boiler (6 bar, 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 9.29 Turbulator Insertion Effect



(a) Load – exhaust gas temperature



(b) Load – efficiency