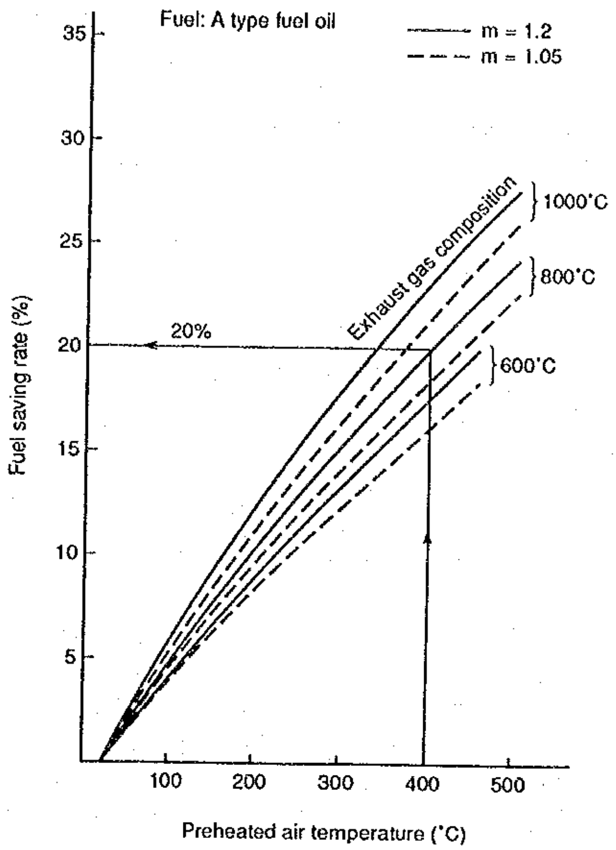


Figure 8.16 Preheated air temperature vs fuel conservation ratio

Furthermore, the coefficient of overall heat transfer of the recuperator drops as the time elapses due to contamination with deposit to the heating surface on the gas side. It is therefore necessary to clean the heating surface at every possible occasion.

The methods for cleaning include;

① to use wire brushes and compressed air

② to inject water under high pressure through a nozzle

Every method has both of advantages and disadvantages. Method ① is of good workability, but complete cleaning cannot be made. With method ②, sufficient cleaning is made but treatment of the wastewater is troublesome.

Typical cleaning effect obtained by injection of water under high pressure is shown in Table 8.11.

Table 8.11 Effect of recuperator cleaning

	Preheated air temp. [%]	Heat recovery rate [%]	Pressure drop of waste gas [mbar]
Before cleaning	240	27.0	2.65
After cleaning	380	44.5	0.88

b. Exhaust heat boiler

When the exhaust gas temperature after the recuperator is still high, recovery of steam can be made with a waste heat boiler installed after the recuperator. When fuel oil is used as the fuel, this scheme makes contribution to energy conservation of the reheating furnace because the recovered steam can be used for heating the fuel oil and for atomization at the burners. When gas is used as the fuel, however, this scheme does not lead to energy conservation of the reheating furnace itself, although contribution is made to steam supply in the factory, because no steam is required for the reheating furnace. When the merits of recovery of steam are small, therefore, provision of a gas preheater to be described in the next section should be examined.

In the case where a waste heat boiler is installed, examination of drafting capacity of the smokestack and of the exhaust blower is required because the exhaust gas resistance increases.

c. Gas preheater

When the exhaust gas temperature after the recuperator is still high, a heat exchanger for preheating the fuel gas is installed after the recuperator to preheat the fuel gas to several-100 [°C] at some occasions. Also in this case, the flame temperature rises, the heat pattern is improved and the exhaust gas temperature at furnace tail drops.

If leakage occurs at the heat exchanger, however, explosion may occur due to mixing of the fuel gas with the exhaust gas. Therefore, care such as implementation of heat exchange through liquid heat medium is required.

C) Combustion with low air ratio

When the air ratio of the combustion air decreases, the combustion gas flow decreases and the flame temperature rises in addition. Accordingly, the furnace internal heat transfer effect is enhanced, the exhaust gas temperature drops, and the energy conservation effect is outstanding.

Furthermore, ignition loss on slabs decreases because the oxygen concentration in the exhaust gas decreases as a result of combustion with low air ratio.

The optimum air ratio is as follows. Typical effect of improvement of air ratio in the case of fuel oil firing is shown in Table 8.12.

Case of fuel oil firing : 1.1 ~ 1.2

Case of fuel gas firing : 1.05 ~ 1.1

Table 8.12 Fuel conservation ratio for improving air ratio

(fuel: heavy oil, saving ratio; [%])

Waste gas temperature (°C)	Air ratio before improvement	Air ratio after improvement			
		1.30	1.20	1.10	1.00
700	1.40	3.76	7.27	10.5	13.5
	1.30		3.65	7.01	10.1
	1.20			3.48	6.74
	1.10				3.38
900	1.40	5.94	11.3	16.0	20.2
	1.30		5.66	10.7	15.2
	1.20			5.29	10.1
	1.10				5.06
1,000	1.40	9.43	17.3	23.8	29.4
	1.30		8.67	15.9	22.1
	1.20			7.91	14.7
	1.10				7.36
1,300	1.40	15.7	27.2	35.9	42.7
	1.30		13.7	23.9	32.1
	1.20			11.9	21.3
	1.10				10.7

D) Furnace internal pressure

When the furnace internal pressure is higher than the atmospheric pressure, the combustion gas in the furnace blows out to the exterior through furnace doors and other openings. When it is lower than the atmospheric pressure, on the other hand, suction of fresh air occurs through openings. The slabs and furnace internal gas at high temperature in the furnace are cooled and the exhaust gas flow increases, and the exhaust gas heat loss increases.

When the demerits of furnace internal pressure exerted over the operation are considered, the demerits during operation at negative pressure are larger, and therefore, control is made by the damper in the flue so that positive internal pressure is always kept at a reheating furnace.

The furnace internal pressure is usually measured in the soaking zone, and setup is made so that the pressure at the hearth line is 0.02 ~ 0.04 [mbar] that is slightly higher than the atmospheric pressure. In the case where an opening is located at a level lower than the hearth line, the furnace internal pressure is set at a higher level to prevent suction of fresh air from this point.

In the case where the furnace internal pressure detect position is not located at the hearth line but it is located on the ceiling, for instance, the influence of the buoyance of the combustion gas caused by the difference in the height between the hearth line and the detecting element should be taken into account. If it is assumed that the furnace gas temperature in the soaking zone is 1,300 [°C] and the fresh air temperature is 20 [°C], the buoyance per meter of height is 0.1 [mbar]. Therefore, the pressure obtained by adding the pressure that is equivalent to this buoyance to the suitable hearth line pressure is determined as the set value for the detecting element on the ceiling.

The heat loss caused by blow-out of the furnace internal gas through openings accompanying high furnace internal pressure can be calculated with the following equation.

$$Q = \alpha \times A \times 44{,}670 \times \{273/(273 + t)\}^{1/2} \times \Delta P^{1/2} \times C \times (t - t_r) \qquad (8\text{-}49)$$

where;

Q : Heat loss [kJ/h]

α : Coefficient determined by the form of the opening.
$\alpha = 1/(1+f)$ when the coefficient of friction is expressed as f.
$\alpha = 0.5$ when the thickness of the furnace wall is 0.5 ~ 2.5 times of the opening diameter.

A : Area of opening [m²]

ΔP : Furnace internal pressure [mbar]

C : Specific heat of furnace internal gas [kJ/(Nm³·°C)]

t : Flame gas temperature [°C]

t_r : Fresh air temperature [°C]

8.5.3 Cooling water heat loss

Cooling water heat loss is ranked next to the exhaust gas heat loss among heat loss factors of reheating furnaces. To reduce this heat loss provides a large effect for energy conservaiton.

Cooling water is also used for doors, door frames, furnace wall lintel, etc. But description is made below for the skid and walking beam, which occupy the majority of the consumption.

A) Strengthening of heat insulation of skid

Cooling water heat loss decreases as the thickness of the heat insulator for the skid increases. This relation is shown in Figure 8.17. However, there is a limit in the increase of the thickness in the aspects of workability, maintenance and influence over heating to the under side of slabs. Accordingly, dual layer heat insulation is adopted as what substitutes for single layer heat insulation.

A comparison between single layer heat insulation and dual layer heat insulation in the case where the pipe diameter is 140 [mm] is shown in Figure 8.18, and the effect in the case where the thickness of the dual layer heat insulator is fixed and the thickness of the heat insulator of the internal layer is changed is shown in Figure 8.19.

B) Management of water temperature

It is desirable that the temperature of the cooling water at outlet is as high as possible. But the water temperature should be managed with 50°C as the upper limit to reduce plugging caused by formation of scale in the cooling water pipes.

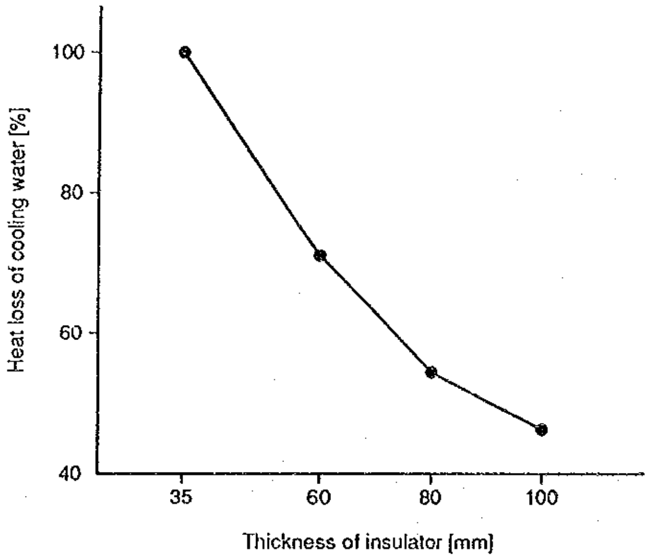


Figure 8.17 Heat loss of cooling water vs insulating thickness

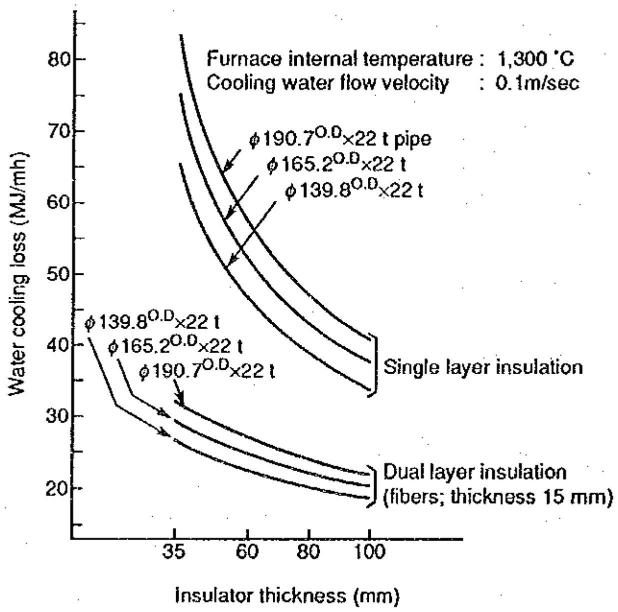


Figure 8.18 Comparison of 1-layer insulating & 2-layer insulating

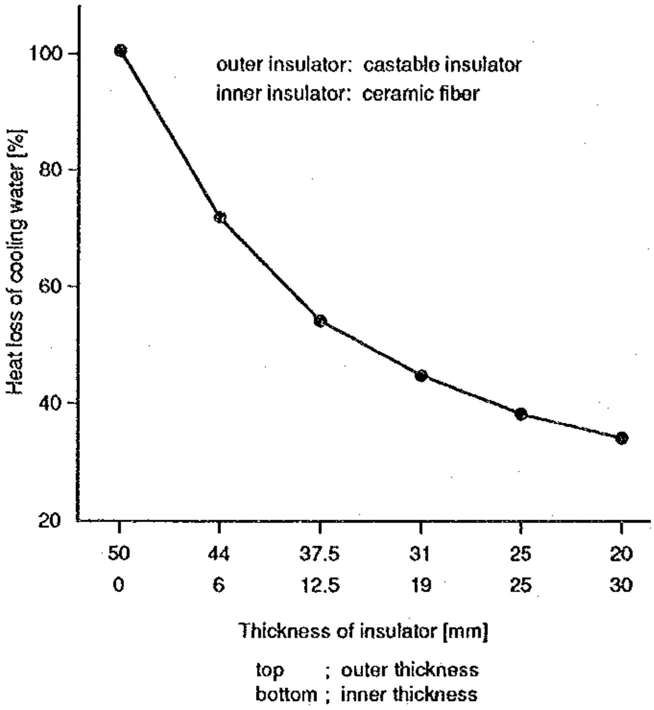


Figure 8.19 Heat loss vs inner layer thickness

8.5.4 Furnace proper radiation and accumulated heat loss

The heat loss from the furnace proper includes the heat radiation loss that occurs through the furnace walls and loss of heat accumulated in the furnace walls. The heat radiation loss and loss of accumulated heat can be calculated by the following equation.

① Heat radiation loss

In the steady state; $Q_1 = Q_2$ (8-50)

$$Q_1 = \lambda_1 / l_1 (t_i - t_1) = \lambda_2 / l_2 (t_1 - t_2) = \lambda_3 / l_3 (t_2 - t_0) \quad (8\text{-}51)$$

$$Q_2 = (h_c + h_r)(t_0 - t_a) \quad (8\text{-}52)$$

where;

Q_1 : Heat transfer rate through wall [kJ/(m²·h)]

Q_2 : Heat radiation rate [kJ/(m²·h)]

t_i : Internal wall temperature [°C]

t_1, t_2 : Boundary temperature [°C]

t_0 : External wall temperature [°C]

t_a : Fresh air temperature [°C]

$\lambda_1, \lambda_2, \lambda_3$: Thermal conductivity [kJ/(m·h·°C)]

l_1, l_2, l_3 : Thickness of furnace material [m]

h_c : Coefficient of convective heat transfer of external wall surface [kJ/(m·h·°C)]

h_r : Coefficient of radiant heat transfer of external wall surface [kJ/(m·h·°C)]

② Loss of accumulated heat

$$H = l_1 \times \rho_1 \times C_1 \times \{(t_i + t_1)/2 - t_{s1}\} + l_2 \times \rho_2 \times C_2 \times \{(t_1 + t_2)/2 - t_{s2}\} + l_3 \times \rho_3 \times C_3 \times \{(t_2 + t_0)/2 - t_{s3}\} \quad (8\text{-}53)$$

where;

H : Loss of accumulated heat [kJ/m²]

ρ_1, ρ_2, ρ_3 : Density of furnace material [kg/m²]

C_1, C_2, C_3: Specific heat of furnace material [kJ/(kg·°C)]

t_{s1}, t_{s2}, t_{s3} : Temperature of furnace wall before heating [°C]

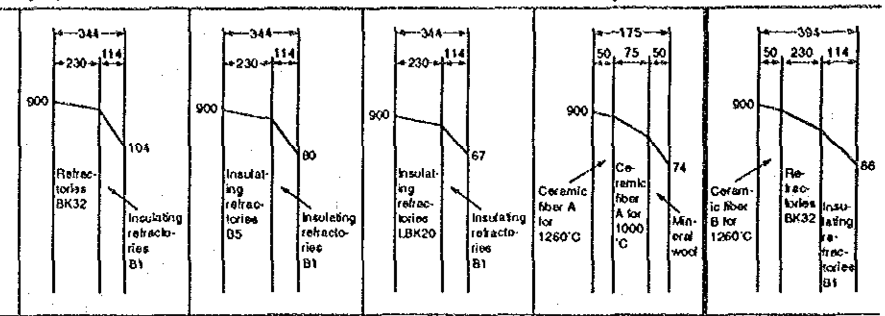
Therefore, to reduce the heat radiation loss and loss of accumulated heat through the furnace walls, it is recommended that the furnace walls are composed by effectively combining heat insulators of small thermal conductivity and small heat capacity.

Typical calculation of heat radiation loss and loss of accumulated heat at the time when various heat insulators are combined at furnace temperature 900 [°C], furnace temperature 1,100 [°C] and furnace temperature 1,300 [°C] is shown in Figure 8.20. With an actual reheating furnace, it is considered that these values are larger than these calculated values because heat radiation from joints, cracks, hardware, etc. is added besides the calorific value that runs through the furnace walls.

● Furnace inside wall temperature: 900 [°C] Fresh air temperature: 25°C, blackness: 0.85

Furnace wall composition

Furnace wall thickness: 344 [mm]

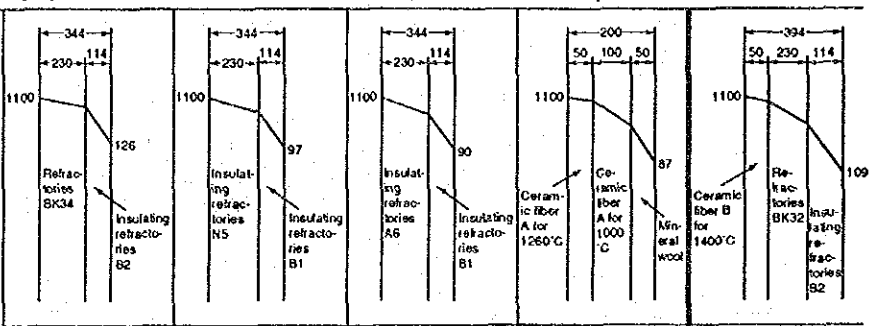


Radiated calorific value: Q [kJ/m²h]		3,634	2,252	1,591	1,947	2,575
Accumulated calorific value: [kJ/m²]		382,297	142,309	84,531	12,058	298,016
Continuous operation 6000 h/y	Radiated calorific value [10³kJ/m²y]	21,805	13,515	9,546	11,681	15,449
	Ratio [%]	100	61.8	56.6	63.6	72.6
* Batch operation 40 w/y	Total heat loss [10³kJ/m²y]	31,100	15,491	10,304	8,951	23,124
	Ratio [%]	100	53.6	44.5	29.1	88.4

● Furnace inside wall temperature: 1100 [°C] Fresh air temperature: 25°C, blackness: 0.85

Furnace wall composition

Furnace wall thickness: 344 [mm]



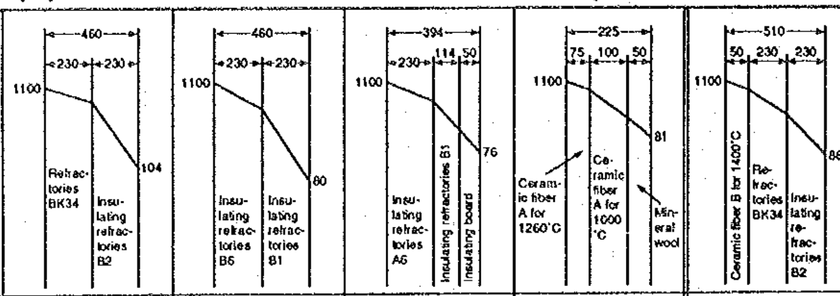
Radiated calorific value: Q [kJ/m²h]		4,974	3,228	2,834	2,608	3,961
Accumulated calorific value: [kJ/m²]		468,210	200,966	154,577	17,208	405,533
Continuous operation 6000 h/y	Radiated calorific value [10³kJ/m²y]	29,844	19,368	17,007	15,650	23,764
	Ratio [%]	100	64.9	57.0	52.4	79.6
* Batch operation 40 w/y	Total heat loss [10³kJ/m²y]	40,365	22,081	18,514	12,037	33,327
	Ratio [%]	100	54.7	45.9	29.8	82.4

Figure 8.20 Wall construction vs heat loss from wall & storage heat (1/3)

● Furnace inside wall temperature: 1100 [°C] Fresh air temperature: 25°C, blackness: 0.85

Furnace wall composition

Furnace wall thickness: 460 [mm]

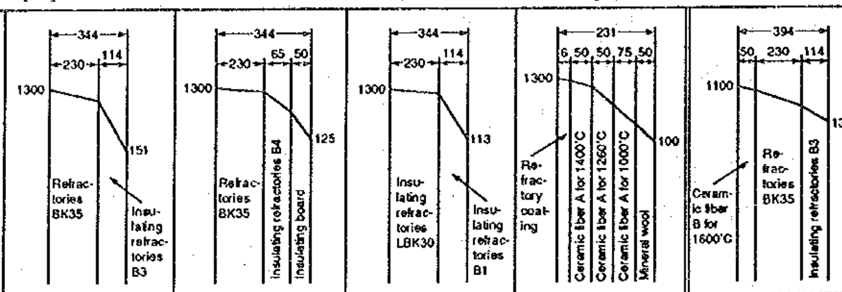


		(1)	(2)	(3)	(4)	(5)
Radiated calorific value: Q [kJ/m²h]		3,605	2,227	2,309	2,294	2,617
Accumulated calorific value: [kJ/m²]		533,314	253,469	190,290	19,636	487,595
Continuous operation 6000 h/y	Radiated calorific value [10³kJ/m²y]	21,629	13,364	12,234	13,766	15,700
	Ratio [%]	100	61.8	56.6	63.6	72.6
* Batch operation 40 w/y	Total heat loss [10³kJ/m²y]	37,015	19,829	16,483	10,768	30,886
	Ratio [%]	100	53.6	41.5	29.1	83.4

● Furnace inside wall temperature: 1300 [°C] Fresh air temperature: 25°C, blackness: 0.85

Furnace wall composition

Furnace wall thickness: 344 [mm]



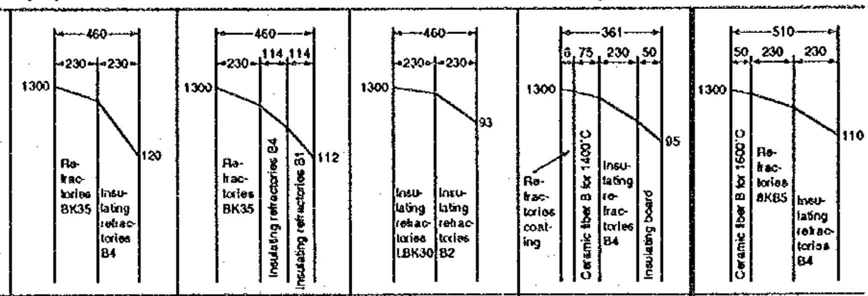
		(1)	(2)	(3)	(4)	(5)
Radiated calorific value: Q [kJ/m²h]		6,921	4,974	4,136	3,379	5,589
Accumulated calorific value: [kJ/m²]		511,108	579,914	240,950	45,971	480,519
Continuous operation 6000 h/y	Radiated calorific value [10³kJ/m²y]	41,525	29,844	24,819	20,272	33,536
	Ratio [%]	100	71.9	59.8	48.8	80.8
* Batch operation 40 w/y	Total heat loss [10³kJ/m²y]	52,151	44,832	27,633	16,583	43,534
	Ratio [%]	100	86.0	53.0	31.7	83.5

Figure 8.20 Wall construction vs heat loss from wall & storage heat (2/3)

● Furnace inside wall temperature: 1300 [°C] Fresh air temperature: 25°C, blackness: 0.85

Furnace wall composition

Furnace wall thickness: 460 [mm]



Radiated calorific value: Q [kJ/m²h]		4,605	4,124	2,956	3,107	3,986
Accumulated calorific value: [kJ/m²]		633,002	647,614	301,073	178,609	579,202
Continuous operation 6000 h/y	Radiated calorific value [10³kJ/m²y]	27,633	43,844	24,903	18,640	23,940
	Ratio [%]	100	89.5	64.2	67.5	86.6
* Batch operation 40 w/y	Total heat loss [10³kJ/m²y]	45,356	43,844	24,903	20,658	40,524
	Ratio [%]	100	96.7	54.9	45.5	89.4

Figure 8.20 Wall construction vs heat loss from wall & storage heat (3/3)

As is apparent from the table, ceramic fibers provide excellent heat insulation performance, and in addition, its accumulated calorific value is also small. Furthermore, the heat radiation loss can be reduced to a major extent only by execution of fiber veneering to adhere ceramic fibers to the inside walls of existing furnaces.

The temperature of refractories will rise when heat insulation is strengthened. Since the strength of refractories drops accompanying temperature rise in general, selection of refractories which correspond to the temperature conditions is important. When erroneous selection is made, drop in the furnace proper service life occurs. At the ceiling in particular, drop in the strength of the anchor bricks and hangers occurs. It is therefore necessary to adopt a working method that fully takes into account the heat resistance.

8.5.5 Opening heat loss

A) Strengthening of sealing

Provision of opening doors and complete sealing of doors are required to prevent blow-out of flames and entry of fresh air through openings of the furnace.

The charging door cannot be completely closed because the width and thickness of charged slabs are not fixed, and gaps always remain among door, charged slab and furnace wall. Modification to a dual type door having a sub door shown in Figure 8.21 is available as a method for reducing this opening to the minimum. Furthermore, it is desirable that a dual type door is adopted also at the extraction end where an extractor is used for extraction of slabs, in order to seal the opening of the extractor arm.

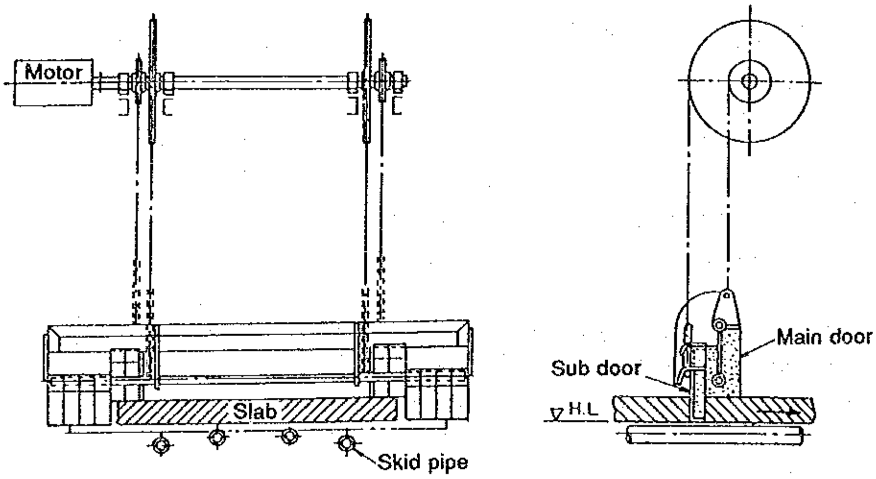


Figure 8.21 Furnace end door with sub-door

B) Reduction of openings

Even if no blow-out of flames occurs through openings of the furnace, radiation from furnace inside walls and radiation of furnace internal gas are present. Therefore, provision of openings should be limited to the minimum required level, and unnecessary openings should be filled with refractories. The heat radiation loss through openings can be calculated by the following equation and Figure 8.22.

$$Q = 4.88 \times \sigma \times A \times \{(t + 273)/100\}^4 \tag{8-54}$$

where;

Q : Heat radiation loss [kJ/h]

t : Furnace internal temperature [°C]

A : Area of openings [m²]

σ : Factor against entire heat radiation

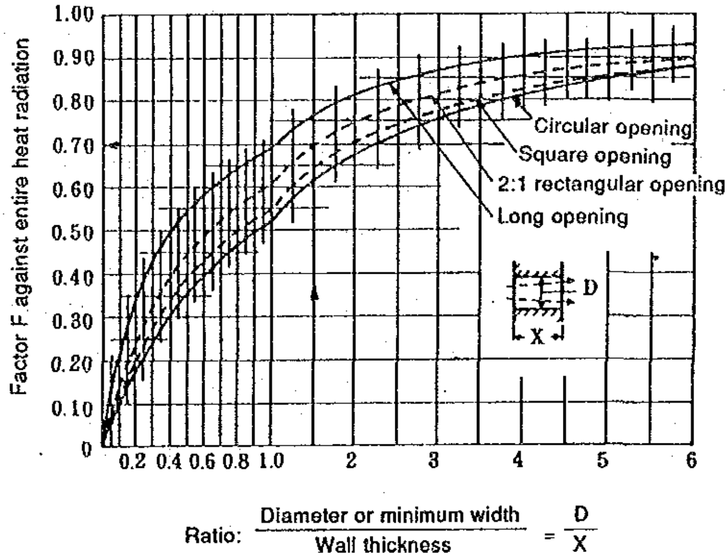


Figure 8.22 Correction factor; F for open hole

8.5.6 Keeping warm and heating up

To retain the heat in the heat pattern for usual heating operation when running of the rolling line is suspended is not desirable from the aspects of adverse effect over the slab quality such as overheat, burning and increase of scale as well as increase of loss of exhaust gas heat. Therefore, the furnace internal temperature should be changed in correspondence to the rolling suspension time.

In the case of suspension for a short time, keep the thermal state of the furnace before entry to the heat retaining state, and perform such heat retaining that permits return to the normal state within a short length of time at the time of recovery. Typical heat pattern setup is shown in Table 8.13.

Table 8.13 Example of heat pattern in temp. holding

Holding time	10 ~ 19'	20 ~ 39'	40 ~ 79'
Soaking zone	–30 [°C]	–50 [°C]	–80 [°C]
Heating zone (upper)	–40 [°C]	–70 [°C]	–100 [°C]
Heating zone (lower)	–40 [°C]	–60 [°C]	–100 [°C]
Preheating zone (upper)	–40 [°C]	Fuel cut	Fuel cut
Preheating zone (lower)	Fuel cut	Fuel cut	Fuel cut

In the case of heat retaining for a long time, keep the temperature as low as possible in the range that permits recovery of the soaking zone temperature within the heat-up time at the time of restart of operation, and reduce the heating zone temperature to around 800 [°C].

If the suspension time is even longer, put off the fire in all zones and fully close the charge door, extraction door and flue damper.

At the time of heat-up, increase the temperature at the rate of around 50 [°C/h] up to the transformation point, with spalling of refractories taken into account.

8.5.7 Recovery of exhaust heat

A) Recuperator (already described)

B) Exhaust heat boiler (already described)

C) Gas preheater (already described)

D) Skid boiler (hot cooling system)

Make recovery of steam using demineralized water for cooling the skid or the walking beam.

8.5.8 Instrumentation

Constant monitoring and adjustment of combustion, fuel flow rate in each zone, temperature at various points of the furnace, furnace internal pressure, etc. are required to perform energy conservation operation with suitable slab heating conditions maintained. Eye observation alone by operators is impossible to make quantitative judgment of these conditions. Furthermore, readjustment of various manipulated variables should be made to maintain the specified target values when heating conditions change accompanying changes in the operation. But considerable skill and continuous adjusting works are required to judge the quantity and rate of changes and to make stable and quick adjustment, and it is extremely hard for usual operators. Therefore, provision of measuring instruments and controllers which are matched with the objective of measurement and control is essential. It is impossible to expect heating quality of high level and minimum fuel cost at a reheating furnace without these instrumentation.

Typical instrumentation equipment are shown in Figure 8.23.

Computerized control is introduced to recent reheating furnaces as a part of instrumentation control that aims at full automation of the rolling mill, and the furnace temperature in each zone, fuel, air ratio, etc. are controlled. Furnace temperature control calculates such a heat pattern that satisfies heating restrictions such as slab surface temperature and soaking degree and that minimizes fuel consumption and adopts as the set values. Furthermore, a panelless system that permits entire monitoring and operation from CRT pictures is adopted.

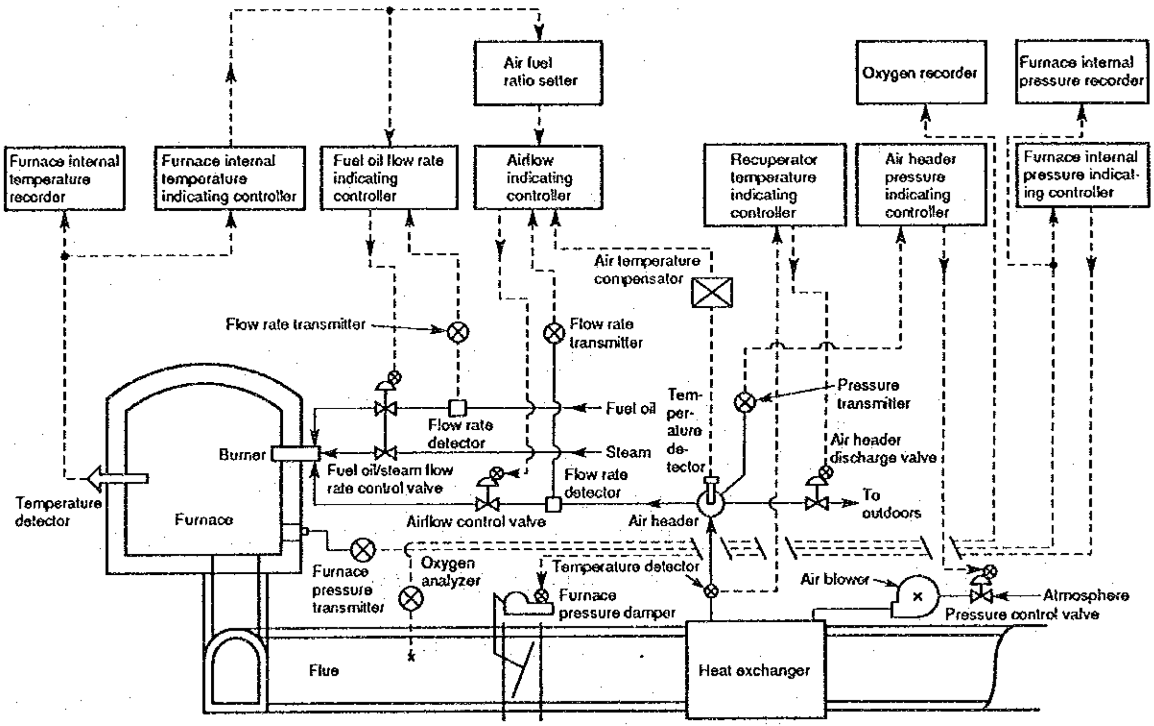


Figure 8.23 Example of furnace instrumentation

8.5.9 Estimation of effect of energy conservation measures

Approximate values were indicated for each item regarding the effect of measures. But these values indicate the effect of individual measures, and the propagation effect to be obtained at the time of implementation of measures is not taken into account. If the effect to be obtained at the time when multiple measures are taken as combined and when a waste heat recovery equipment is added is evaluated by the cumulative value of each effect by item, errors in the judgment may result.

A number of methods are available for estimation of the comprehensive effect. But a method using heat balance equation is introduced below.

a. The fuel flow rate V_F(Nm³/h) required for heating is given by equation (8-55) from the heat balance of the furnace proper.

$$V_F = (Q_C \times W_C + L(1) + L(2)) / (H + UV_A \times T_A(3) \times C_A(3) - UV_G \times T_G(2) \times C_G(2)) \quad (8\text{-}55)$$

Q_C = (1 − Ignition loss Fe weight])
× ([Heat content at extraction temperature]
− [Heat content at charging temperature])
+ [Ignition loss Fe weight] × 100/75.5 × [Mean specific heat of scale]
× ([Extraction temperature] − [Charging temperature]) − [Ignition loss Fe weight]
× [Scale formation heat]

$$UV_A = m \times A_0$$

$$UV_G = G + (m - 1) \times A_0 \ [\mathrm{Nm^3/Nm^3}]$$

where;

- V_F : Fuel flow rate [Nm³/h]
- Q_C : Heat input to slab [kJ/kg]
- W_C : Heated slab weight [kg/h]
- L(1) : Cooling water loss [kJ/h]
- L(2) : Furnace proper heat radiation loss [kJ/h]
- H : Fuel gas low calorific value [J/Nm³]
- UV_A : Air volume per unit fuel flow rate [Nm³/Nm³]
- m : Air ratio

A_0 : Theoretical airflow per unit fuel flow rate [Nm^3/Nm^3]

$T_A(3)$: Before burner preheated air temperature [°C]

$C_A(3)$: Specific heat of before burner preheated air [$kJ/(Nm^3 \cdot °C)$]

UV_G : Exhaust gas flow rate per unit fuel flow rate [Nm^3/Nm^3]

G : Theoretical wet combustion gas flow rate per unit fuel flow rate [Nm^3/Nm^3]

$T_G(2)$: Furnace tail exhaust gas temperature [°C]

$C_G(2)$: Specific heat of furnace tail exhaust gas [$kJ/(Nm^3 \cdot °C)$]

b. The heat Q [kJ/h] the slabs, skid and furnace walls receive from the combustion gas in the furnace is given by equation (8-56).

The overall heat transfer coefficient to the slabs, skid and furnace walls from the combustion gas and the heat receiving areas of the slabs, skid and furnace walls are different. But only slabs were selected as representative to simply implement calculation of heat transfer. Therefore, Ø is the apparent numeric value that corresponds to the representative area.

$$Q = Ø \times S(1) \times 4.88[\{(T_GM + 273) / 100\}^4 - \{(T_CM + 273) / 100\}^4] \qquad (8\text{-}56)$$

$$T_GM = \{T_G(1) + T_G(2)\} / 2$$

$$T_G(1) = \{H + UV_A \times T_A(3) \times C_A(3)\} / \{UV_G \times C_G(1)\} \qquad (8\text{-}57)$$

$$T_CM = [T_C(2) + T_C(1)\} / 2$$

where;

Q : Heat given to slabs, skid and furnace walls receive from combustion gas in the furnace [kJ/h]

Ø : Overall heat transfer coefficient [$kJ/(m^2 \cdot °C \cdot h)$]

S(1) : Slab surface area [m^2]

T_GM : Combustion gas mean temperature [°C]

$T_G(1)$: High temperature side combustion gas temperature [°C]; theoretical combustion gas temperature was adopted here

T_CM : Slab mean temperature

$T_C(2)$: Slab extraction temperature [°C]

$T_C(1)$: Slab charging temperature [°C]

$C_G(1)$: Specific heat of theoretical combustion gas [kJ/(Nm³·°C)]

c. The exhaust gas temperature $T_G(3)$ [°C] at the recuperator inlet is determined by equation (8-58) that takes into account the temperature drop by air suction from the furnace charging opening and the flue heat radiation loss.

$$T_G(3) = (V_F \times UV_G \times T_G(2) \times C_G(2) + V_AL \times T_A(1) \times C_A(1) - L(3)) \\ / ((V_F \times UV_G + V_AL) \times C_G(3)) \qquad (8\text{-}58)$$

where;

V_AL : Airflow entering through furnace charging opening [Nm³/h]

$T_A(1)$: Fresh air temperature [°C]

$C_A(1)$: Specific heat of fresh air [kJ/(Nm³·°C)]

L(3) : Heat radiation loss between furnace tail and recuperator [kJ/h]

$C_G(3)$: Specific heat of exhaust gas at recuperator inlet [kJ/(Nm³·°C)]

d. Also with the recuperator, the following equation establishes from heat balance and heat transfer rate.

$$V_F \times UV_G \times (T_G(3) - T_G(4)) \times C_G(3) \\ = V_F \times UV_A \times (T_A(2) - T_A(1)) \times C_A(2) + L(4) \qquad (8\text{-}59)$$

(Case of parallel flow)

$$V_F \times UV_A \times (T_A(2) - T_A(1)) \times C_A(2) = (\alpha \times S(2)) \times ((T_G(3) - T_A(1)) \\ - (T_G(4) - T_A(2))) / LN((T_G(3) - T_A(1)) \\ / (T_G(4) - T_A(2))) \qquad (8\text{-}60)$$

(Case of counter flow)

$$V_F \times UV_A \times (T_A(2) - T_A(1)) \times C_A(2) = (\alpha \times S(2)) \times ((T_G(3) - T_A(2)) \\ - (T_G(4) - T_A(1))) / LN((T_G(3) - T_A(2)) \\ / (T_G(4) - T_A(1))) \qquad (8\text{-}61)$$

Since the subject recuperator is of such a structure that fresh air enters from both ends of exhaust gas high temperature side and low temperature side of the recuperator and the preheated air makes outflows from the center, the following equation was adopted.

$$V_F \times UV_A \times (T_A(2) - T_A(1)) \times C_A(2)$$
$$= (\alpha \times S(2)) \times 1/2 \times ((T_G(3) + T_G(4)) - (T_A(2) + T_A(1))) \quad (8\text{-}62)$$

where;

α : Coefficient of overall heat transfer [kJ/(m^2·h·°C)]

$S(2)$: Heat transfer area [m^2]

$T_G(4)$: Exhaust gas temperature at recuperator outlet [°C]

$T_A(2)$: Air temperature at recuperator outlet [°C]

$C_A(2)$: Specific heat of air at recuperator outlet [kJ/(Nm^3·°C)]

$L(4)$: Heat radiation loss of recuperator proper [kJ/h]

The flowchart for calculation of the anticipated effect of energy conservation measures using the equations indicated above is shown in Figure 8.24.

9. Energy Conservation in Boiler Operation

9. ENERGY CONSERVATION IN BOILER OPERATION

9.1.1 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.

9.1.1.1 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.

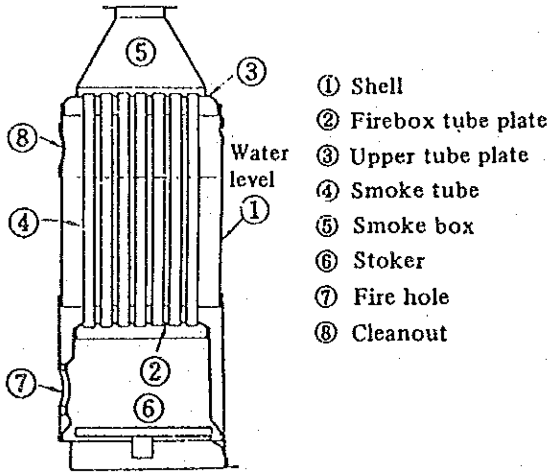


Figure 9.1 Vertical boiler (multitubular type)

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.

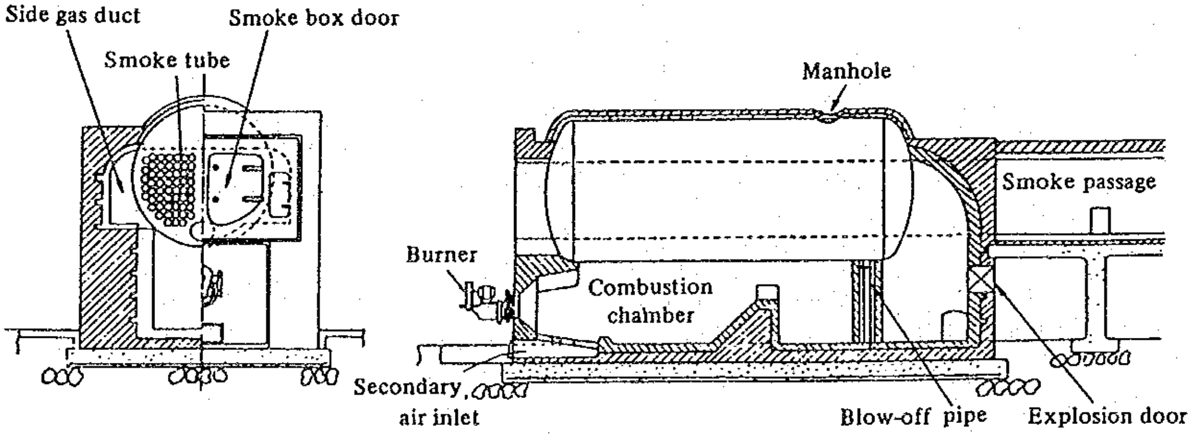


Figure 9.2 Externally fired horizontal smoke tube boiler

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.

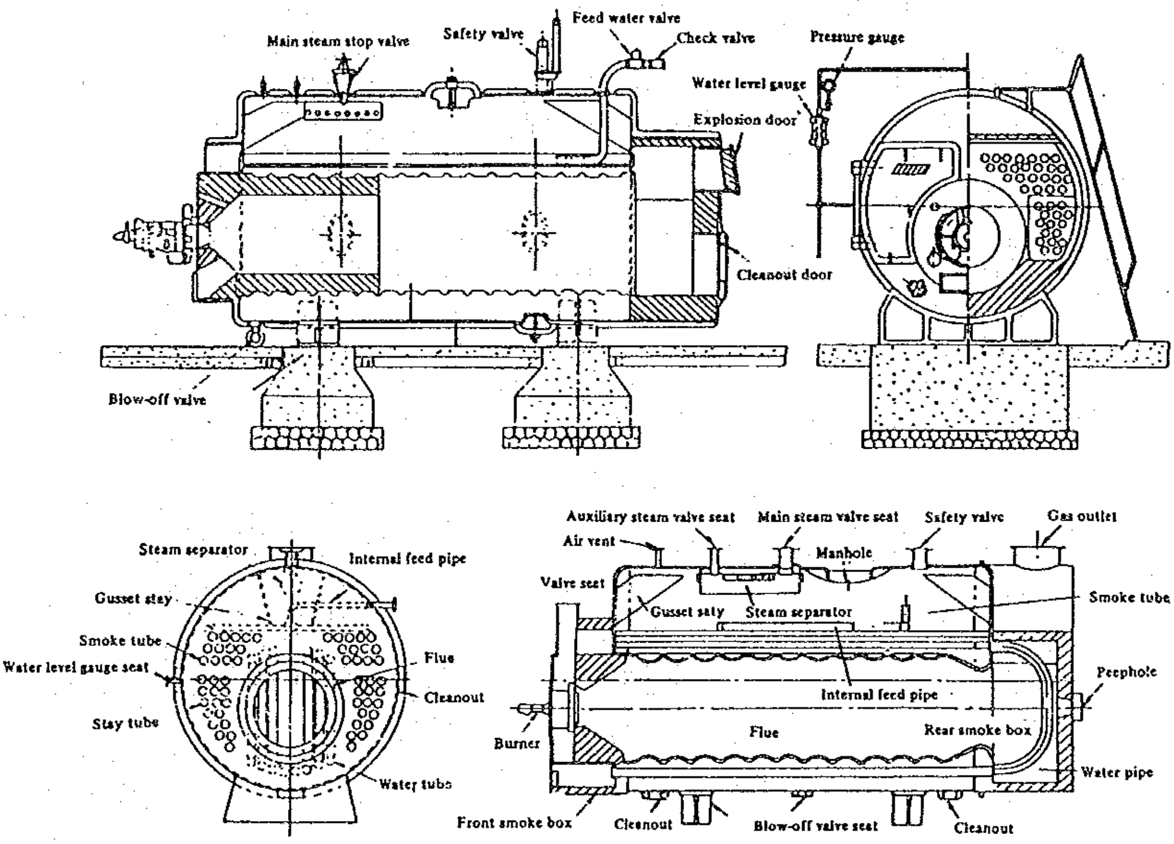


Figure 9.3 Flue smoke tube boiler

9.1.1.2 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.

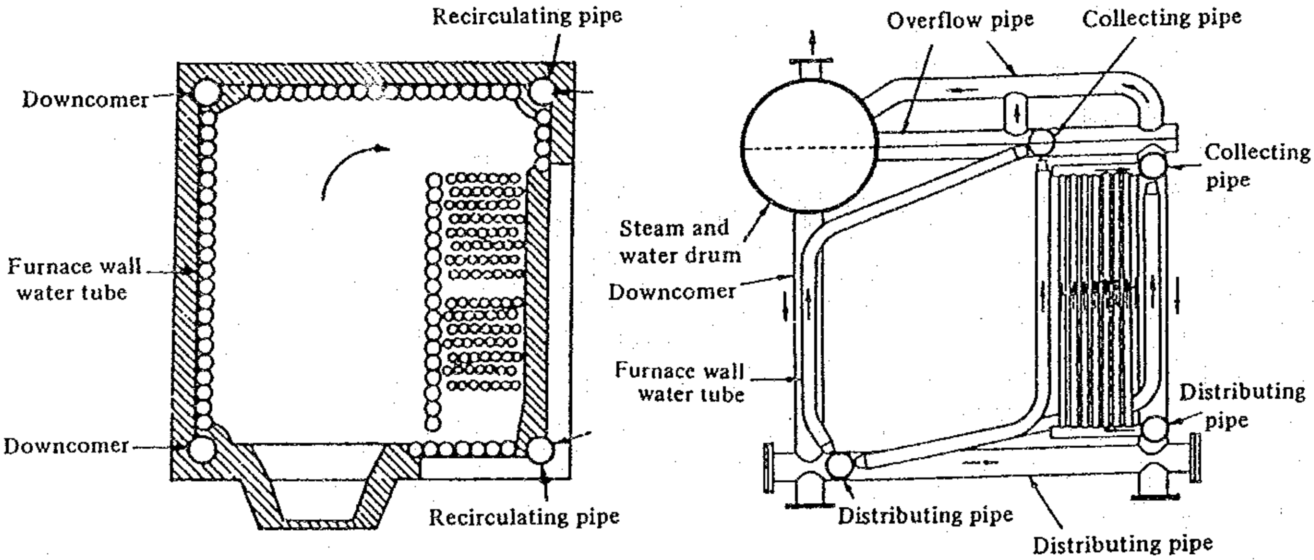


Figure 9.4 Bending water tube boiler

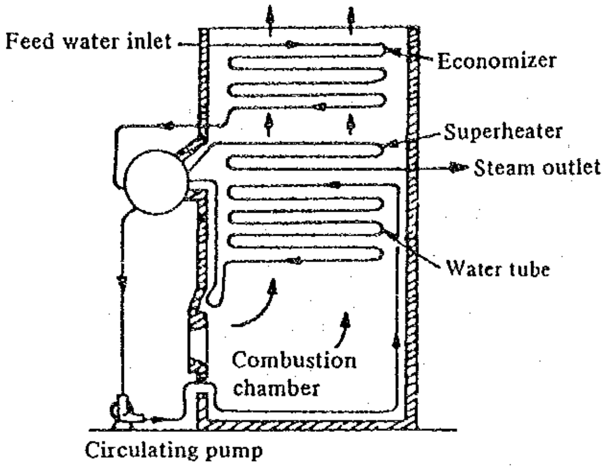


Figure 9.5 Forced circulation boiler

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

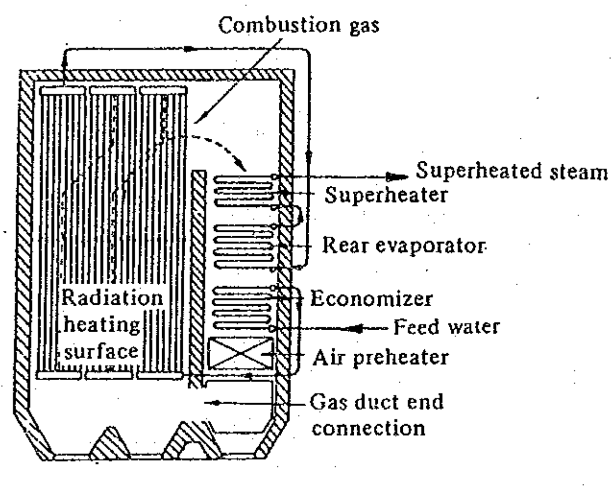


Figure 9.6 Schematic flow diagram of Benson boiler

- 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.

9.1.1.3 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.

9.1.2 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 case iron boiler or burst due to local overheating.

The points remarked to prevent trouble are as follows:

9.1.2.1 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.

9.1.2.2 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 the 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. Open a drain cock, close a steam cock and blow out boiler water sufficiently.	1. Make sure the open and close condition and any leakage of each cock. Clean the inside.
					O	And then close the water cock, open the steam cock, check the steam side, then close the drain cock, open the	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			water cock and watch forcible rising of water level.	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			○		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.
						○	2. Check the degree of fatigue of a detector.	2. Measure the current by a microammeter, test by a false flame.
						○	3. Defect of electric wiring. Influence of induced current of power.	3. Change to the shield wire or a single wire.
						○	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.
					○		5. Contamination of lens and glass tube and mounting position.	5. Cleaning of contamination. Stop down it when excessive current is detected (the life be shortened.)
						○	6. Check + or – phase of the electric wiring and loosening of connection.	6. Change the wiring and tighten it.
						○	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				○	1. Check the settings of each latch switch.	1. Check that it is set in a proper position.
						○	2. Check loosening of the setting of installed position.	2. Check and adjustment.
						○	3. Check a normal operation of the interlock.	3. Check the operation, inspect and repair.
		14. Control motor			○		1. Check the movement.	
						○	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.
						○	3. Check contamination and contact defect of the potentiometer.	3. Inspection and cleaning.
	Firing equipment	15. Pilot burner			○		1. Check the gas pressure.	
						○	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.
						○	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
						○	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper low combustion.
						○	5. Check the clearance between the nozzle and the electrode.	5. Adjust an interval suitable.
		16. Electric pilot firing device				○	1. Check an electric spark state.	1. Blue color is normal. If reddish, cleaning is necessary. Short spark is a narrow interval.
						○	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.
						○	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			O		1. Remove carbon and sludge.	1. Check and repair of burner tile.
					O		2. Check the atomizing cap and the shape of tip bleeding part. Clean contamination.	
						O	3. Clean the shaft and the lubricating pipe.	3. Remove sludge and oil.
						O	4. Apply grease to the bearing. Check seal leakage.	4. Apply grease and check the bearing.
					O		5. Check any damage of the diffuser and carbon deposit.	5. Cleaning and adjustment of the interval.
						O	6. Gun type burner. Check and clean the chip and strainer.	6. Disassembly and cleaning. Check the chip hole.
						O	7. Check the gun type electrode insulator.	7. Clean and set the specified dimension.
					O		8. Check abnormal sound and overcurrent.	8. Research of its cause and assembly servicing. Replace the bearing.
						O	9. Oil leakage	9. Repair leaking place.
						O	10. Burner belt	10. Replace cracked burner.
		18. Fuel cutout valve (main valve)			O		1. Check leakage of the cutout valve.	1. A fire is extinguished entirely after cutout.
					O		2. Make sure cutout due to a low level and no ignition.	
						O	3. Check the electric wiring.	3. Check damage due to heat.
		19. Oil pump			O		1. Check the oil pressure.	1. Set to a proper oil pressure.
						O	2. Clean the strainer.	2. Drain and remove sludge.
						O	3. Check oil leakage.	3. Repair the leaking place. Replace the oil seal.
						O	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			O		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.
					O	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				O	1. Check leakage and corrosion.	1. Inspection and repairing.
					O	2. Remove soot in the flue and the stack.	
					O	3. Discharge of rain water.	
	31. Water softening equipment			O		1. Check of the water pressure. 1.5 to 2 bar	
					O	2. Check of hardness. Check in the secondary side.	2. Check from 70 to 80% of cycle.
					O	3. Leakage from the perforated valve.	3. Use care to leak from the fitting part of the packing.
					O	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		O			1. Check of the level gage.	
			O			2. Make sure the operation of low level alarm lamp.	2. Test in an actual level drop or test by an electric wiring.
			O			3. Make sure the level control.	3. Make sure a manual operation of controller.
			O			4. Check of tempera-ture.	4. Check of abnormality of trap.
					O	5. Check the painting on the tank inside and corrosion. Clean the inside.	5. Check, repair and cleaning.
	33. Chemicals pouring device			O		1. Check a proper chemicals pouring.	1. Check contamination in the tank and the flow rate.
				O		2. Check a linkage to the feed water pump.	2. Check the operation.
					O	3. Check leakage or clogging.	3. Inspection and repair.
	34. Feed water pump			O		1. Check overcurrent.	1. Adjust the valve.
					O	2. Check leakage from the ground.	2. Replace and tighten a packing.
					O	3. Check an oil servicing.	3. Apply oil and grease.
					O	4. Check play to the coupling.	4. Repair and replacement.
	35. Injector				O	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.
					O	2. Check the check valve. Attachment of scale.	2. Check, disassemble and clean.
					O		
	36. Water flow meter strainer		O			1. Check the operation.	1. Record, check operation.
					O	2. Check clogging in the strainer.	2. Disassemble and clean.
	37. Feed water check valve				O	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: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	38. Feed water internal pipe				○	1. Check clogging in the internal pipe.	1. Insufficient feed water quantity. Overhaul.
					○	2. Inferior or falling of the gasket for installation of the internal pipe.	2. Water hammer. Replace the gasket.
	39. Relief valve			○		1. Check leakage of steam.	1. Repair the leaked place and overhaul.
					○	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.
					○		
	40. Blow off valve			○		1. Check leakage. Check heat by hand touch.	1. Overhaul or replacement.
				○		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			○		1. Check leakage from the manhole.	1. Tightening, replacement of gasket.
					○	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				○	1. Check damage, falling and abnormality.	1. Repair the refractory materials as soon as possible.
					○	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			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.	

9.1.2.3 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 (mgCaCO₃/l)	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/l)	—	—	—	—	—	—	—	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/l)	—	—	—	—	—	—	—	Below 0.05	Below 0.03	Below 0.02		Below 0.01		Below 0.01		Below 0.005	
Feed water	Hydrazine[3] (mgN₂H₄/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] (mgCaCO₃/l)	100~800	100~800	100~800	100~800	100~800	Below 600	Below 150	—	—	—	—	—	—	—	—	—	—
Boiler water	Alkalinity[5] (mgCaCO₃/l)	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⁻/l)	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] (mgPO₄³⁻/l)	20~40	20~40	20~40	20~40	20~40	20~40	5~15	5~15	3~10	2~6	[11]	1~5	[11]	0.5~3	[11]	0.5~3	[11]
Boiler water	Sulfite ion[7] (mgSO₃²⁻/l)	10~20	10~20	10~20	10~20	10~20	10~20	5~10	5~10	—	—	—	—	—	—	—	—	—
Boiler water	Hydrazine[8] (mg N₂H₄/l)	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 (mgSiO₂/l)	—	—	—	—	—	—	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 PO4 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 ($mgCaCO_3/l$)	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 ($mgFe/l$)	—	Below 0.03 (3)	Below 0.03 (3)	Below 0.02 (4)	Below 0.02 (4)	Below 0.01
	Total copper ($mgCu/l$)	—	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 ($mgSiO_2/l$)	—	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 ($mgPO_4^{3-}/l$)	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

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

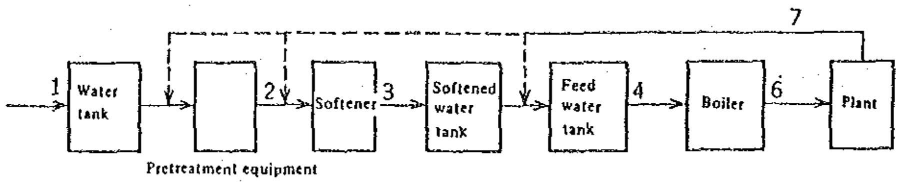
$$\therefore y=\frac{a}{b-a}$$

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

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

9.1.3 Expression of Boiler Capacity

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

9.1.3.1 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.

9.1.3.2 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 2,257 kJ/kg at temperature of 100°C.

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

$$G_e = \frac{G(h_2 - h_1)}{2257} (kg/h)$$

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.

9.1.4 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.

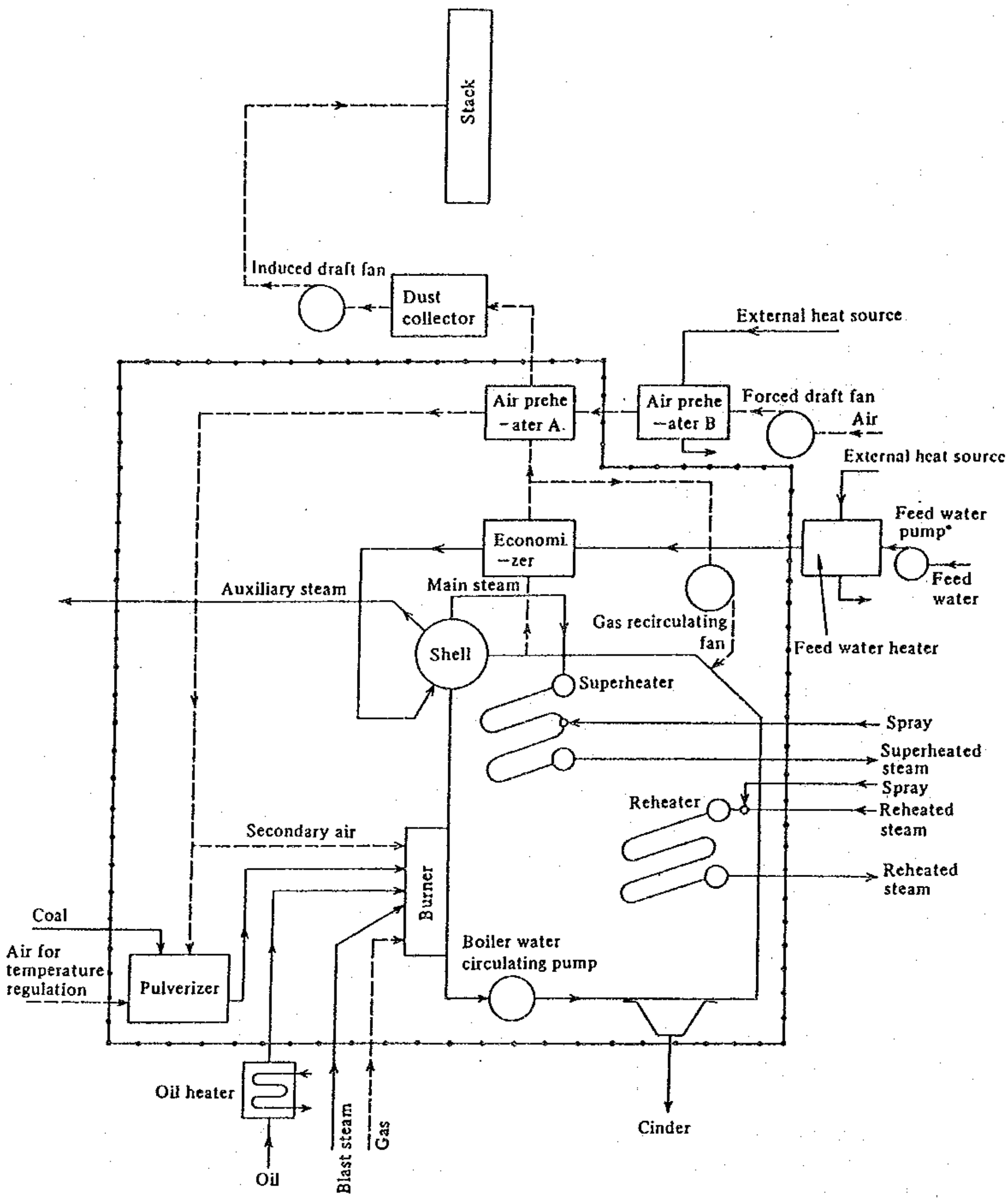


Figure 9.7 Standard range of boiler heat balance

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 $kJ/kg(m_n^3)$		
	Heating surface area	Boiler m^2 Water wall m^2 Total m^2	
Super-heater	Type Heating surface area m^2		
Reheater	Type Heating surface area m^2		
Econo-mizer	Type Heating surface area m^2		
Air pre-heater	Type Heating surface area m^2		
Firing equip-ment	Type (1) Burner capacity, number and grate area $kg(m_n^3)/h$, m^2		
Combu-sion chamber	Furnace volume m^3 Standard heat generation kJ/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 Ambient temperature, dry bulb and wet bulb temperatures Duration of test Load factor			 °C °C h %	
Fuel	Brand and characteristic of fuel Mixing ratio Temperature as used Total moisture		 °C %	
Fuel	Proximate analysis	Analysed value As used	% %	Correct by moisture.
Fuel	Ultimate analysis	Analysed value As used	% %	Correct by moisture.
Fuel	Lower calorific value of fuel used (high)	Analysed value As used	kJ/kg(m_n^3) kJ/kg(m_n^3)	Measure a high combustion heat by a calorimeter and obtain a low combustion heat by calculation. Correct by moisture.
Fuel	Fuel consumption Total Fuel consumption per hour Firing quantity per burner Combustion chamber heat generation		kg(m_n^3) kg(m_n^3)/h kg(m_n^3)/h kJ/m^3h	
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	
Feed water	Quantity of feed water	Per hour	kg/h	
Feed water	Quantity of feed water	Per unit volume of fuel	kg/kg(m_n^3)	
Feed water	Temperature	Economizer inlet	°C	
Feed water	Temperature	Boiler proper inlet	°C	
Feed water	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum Superheater outlet Reheater inlet Reheater outlet	bar bar bar bar	
Steam generated	Temperature	Superheated outlet Reheater inlet Reheater outlet	°C °C °C	
Steam generated	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (i.e. 98%)
Steam generated	Evaporation	Total (corrected value) Per hour Equivalent evaporation per hour	kg kg/h kg/h	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
Steam jetting into furnace	Source of steam Quantity of steam Pressure and temperature		 kg/h bar, °C	If impossible to measure, use an approximate figures.
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.
Air for combustion	Temperature and pressure	Air preheater inlet Air preheater outlet Outlet of forced draft fan Inlet of chamber	°C, mmAq °C, mmAq °C, mmAq °C, mmAq	

Table 9.7 Results of measurement (2/2)

Air for combus-tion	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 °C, mmAq Outlet of boiler proper °C, mmAq Economizer inlet °C, mmAq Economizer outlet °C, mmAq Air preheater inlet °C, mmAq Air preheater outlet °C, mmAq Induced fan suction °C, mmAq Induced fan delivery °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			
Auxil-iary	Steam consumption kg Electric power consumption 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		kJ/kg(mn3)	%	
(1) Calorific value of fuel (2) (²) Sensible heat of fuel (3) (²) Sensible heat of air (4) (²) Carrying heat of furnace blast steam	H_l(³) Q_1 Q_2 Q_3			(2) Mean specific heat of fuel × (Fuel temp. after heating – ambient temp.) (3) Air quantity (including moisture) per 1 kg (Nm³) of fuel × Mean specific heat of air × (Air temp. after heating – ambient temp.) (4) Blast steam quantity per 1 kg (Nm³) of fuel × (Enthalpy of steam – Enthalpy of steam in ambient temp.) (Only in case of steam from another source)
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		kJ/kg(mn3)	%	
Effective heat	(1) Heat content of generated steam (a) Heat absorbed at the boiler proper (b) Heat absorbed by economizer (c) Heat absorbed by superheater (2) Heat absorbed by reheater	 Q_b Q_{ec} Q_{sh} Q_{rh}			(1) (a) Feed water quantity per 1 kg (Nm³) of fuel × (Enthalpy of steam in outlet of boiler – Enthalpy in outlet of economizer) (b) Feed water quantity per 1 kg (Nm³) of fuel × (Enthalpy of feed water in outlet of economizer – Enthalpy of feed water) (c) Feed water quantity per 1 kg (Nm³) of fuel × (Enthalpy of steam in outlet of superheater – Enthalpy of steam in outlet of boiler) + Spray quantity per 1 kg (Nm³) of fuel × (Enthalpy of steam in outlet of superheater – Enthalpy of spray water). (2) Steam quantity in inlet of reheater per 1 kg (Nm³) of fuel × (Enthalpy of steam in outlet of reheater – Enthalpy of steam in inlet of reheater) + Spray quantity per 1 kg (Nm³) of fuel × (Enthalpy of steam in outlet of reheater – Enthalpy of spray water)
	Subtotal	Qs			
Heat loss	(1) Heat loss in exhaust gas (2) Heat loss due to furnace blast steam (3) Heat loss due to incomplete burning exhaust gas (4) Heat loss due to combustible in refuse (5) Heat loss due to release (6) Heat loss due to others	L_l'(4) L_2 L_3 L_4 L_5 L_6			(1) Actual exhaust gas quantity (including moisture) per 1 kg (Nm³) of fuel × mean specific heat of exhaust gas × (Temp. of exhaust gas – ambient temp.) See item (f) See item (g) See item (h) See item (i) See item (j)
	Subtotal	L_l(⁴)			
Total				100	

Note (⁴) In case of a high heating value basis $L_l l\{L_l l'\}$ shall be taken as L_{lh} $\{L_{lh}'\}$ 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 $\eta_1 = \frac{Q_5}{H_l + Q} \times 100,$			
(2) Heat loss method $\eta_2 = \left(1 - \frac{L_1 - L_6}{H_l + Q}\right) \times 100,$			

a. Method to obtain lower combustion heat from higher combustion heat.
Solid fuel and liquid fuel: $H_l = H_h - 25.12\ (9h + w)$ kJ/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.

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

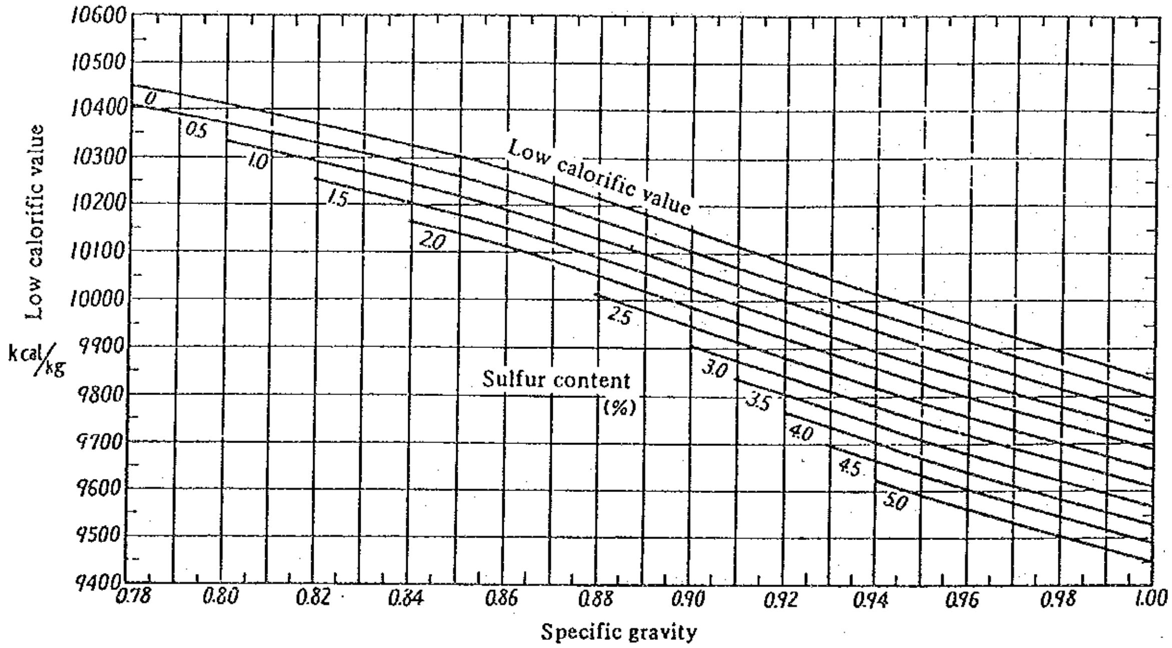


Figure 9.8 Relation between calorific value (Low) and specific gravity of petroleum fuel

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

Gaseous fuel: $H = 107.6\ (H_2) + 126.4\ (CO) + 357.9\ (CH_4)$
$+ 598.6\ (C_2H_4) + 644.6\ (C_2H_6) + 883.2\ (C_3H_6)$
$+ 937.7\ (C_3H_8) + 1{,}138.6\ (C_4H_8)$
$+ 1{,}234.9\ (C_4H_{10})\ kJ/m^3_N$ 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	kJ/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: 1.05 kJ/(kg. °C)
Fuel oil: 1.88 kJ/(kg. °C)
Natural gas: 1.59 ~ 1.76 ($kJ/m^3{}_N{}^\circ C$)
LPG: 2.93 ~ 4.10 ($kJ/m^3{}_N{}^\circ C$)
Air: 1.30 ($kJ/m^3{}_N{}^\circ C$) (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.

$$A_0 = \frac{1}{100}\,[8.89c + 26.7\,(h - \frac{0}{8}) + 3.33s]\ m^3{}_N/kg\ Fuel$$

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

$$A_0 = 0.241\frac{H_l + 2,302}{1,000} m^3_N/kg \text{ Fuel}$$

Case of fuel oil

$$A_0 = 2.957\frac{H_l - 4,605}{10,000} m^3_N/kg \text{ Fuel}$$

Case of gaseous fuel

$$A_0 = 2,676\frac{H_l}{10,000} m^3_N/m^3_N \text{ Fuel}$$

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

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

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

The value of z can be obtained from Figure 9.9.

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

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:

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

(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%.

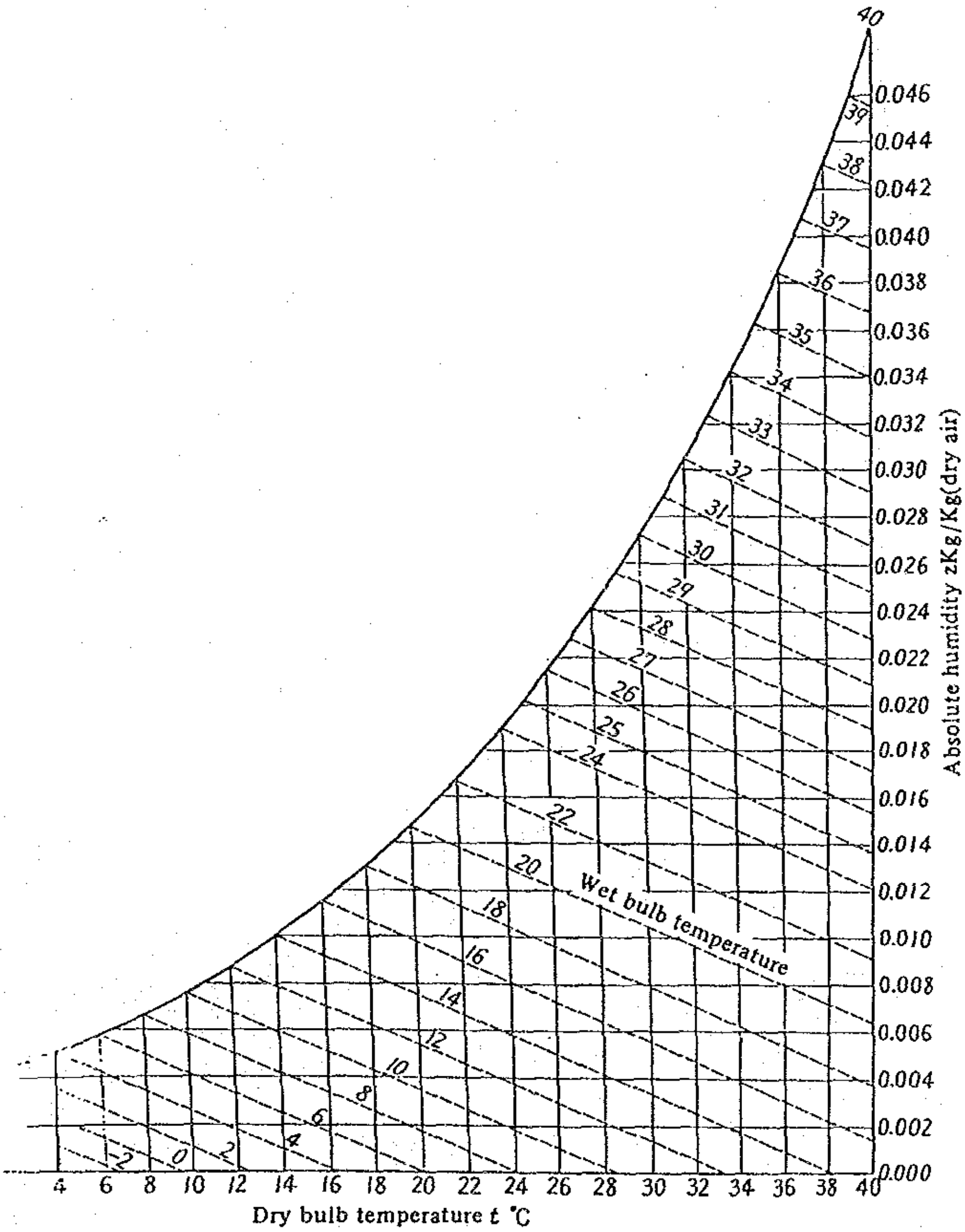


Figure 9.9 Absolute humidity of air

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 1.38 kJ/($m^3{}_N$°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

$$G_1 = \frac{0.216\,H_l}{1{,}000} + 1.67\ m^3{}_N/kg\ Fuel$$

Case of fuel oil

$$G_1 = \frac{3.762\,H_l}{10{,}000} - 3.91\ m^3{}_N/kg\ Fuel$$

Case of gaseous fuel

$$G_1 = \frac{2.926\,H_l}{10{,}000}\ m^3{}_N\ Fuel$$

(Case of hydrocarbon-mixed gas)

Actual exhaust gas quantity is as the following equation.

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

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

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.

$$\text{Heat loss} = 128\ [G_0 + (m - 1)\ A_0]\ (CO)\ \text{kJ/kg}\ (m^3{}_N)\text{-Fuel}$$

(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 339 c kJ/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 9.10 Thermodynamic properties of saturated water and saturated steam (Temperature reference)

Temperature		Saturation pressure	Specific volume (m^3/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	0.0010506	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	6.7476
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	

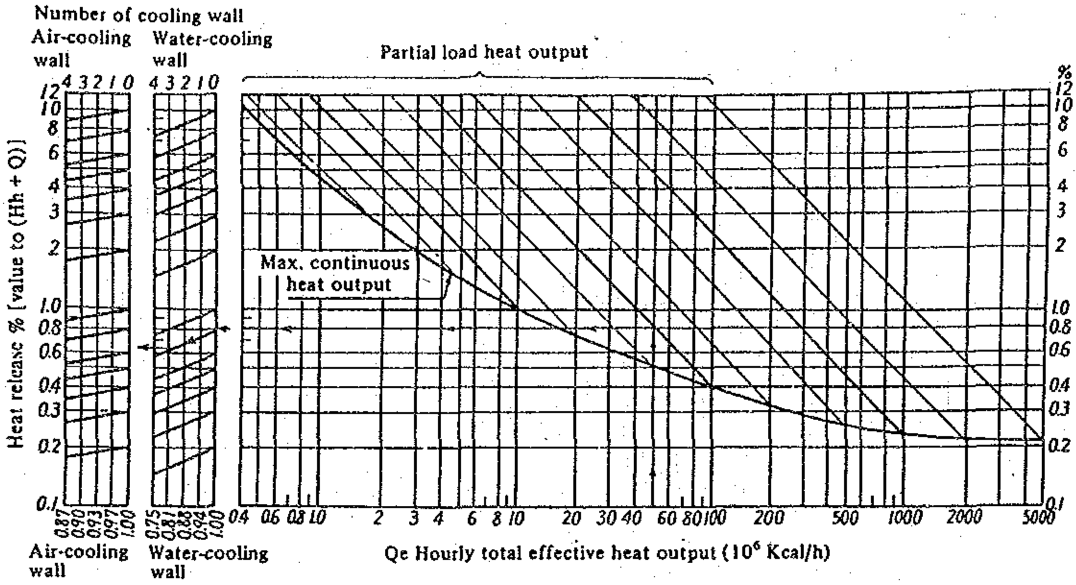
1[Mpa] = 10.197 kg/cm²　　　1 kJ = 0.2389 kcal

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	356.96	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	

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



(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 9.10 Heat loss chart (From ABMA chart in power test code of ASME)

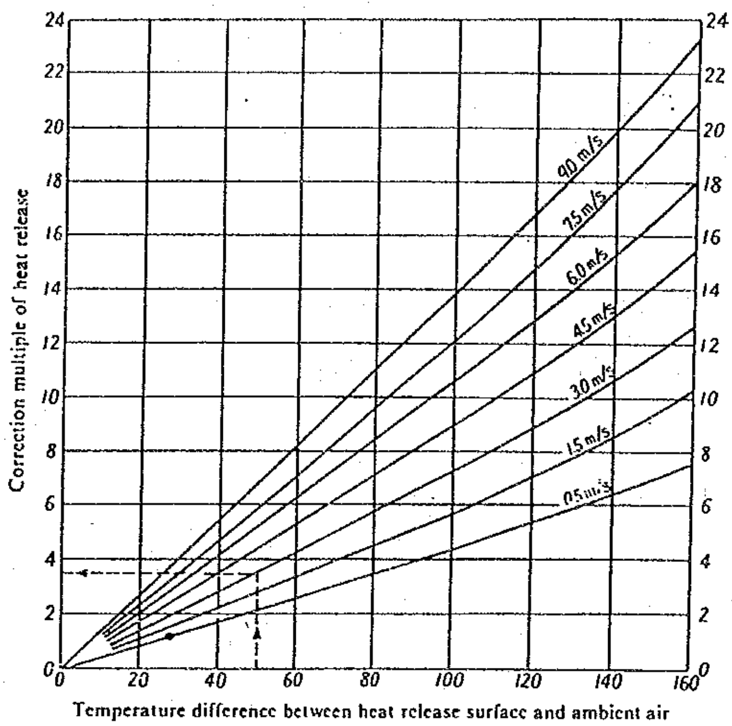


Figure 9.11 Correction multiple of temperature difference and air velocity to Figure 9.10

j. Other heat losses

They are error terms.

9.1.5 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 (kJ/m^3h) in the combustion chamber which is divided by the total input heat by the volume of the combustion chamber.

9.1.6 Consideration in Installation Steps

9.1.6.1 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.

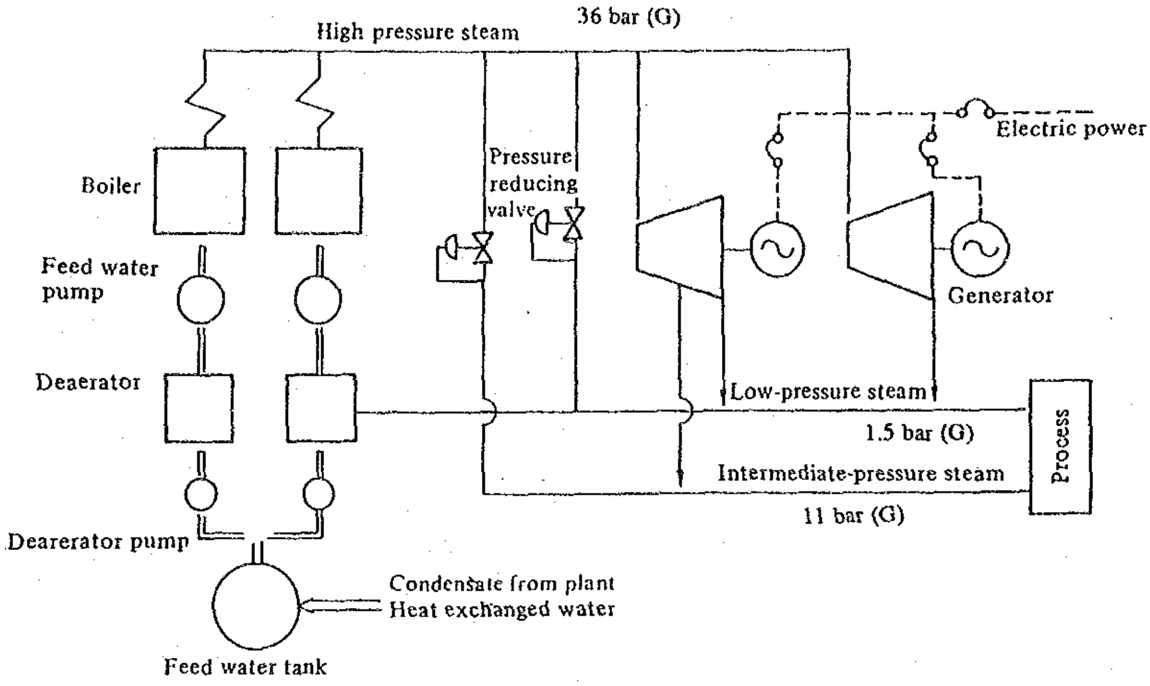


Figure 9.12 An example of cogeneration system

9.1.6.2 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.

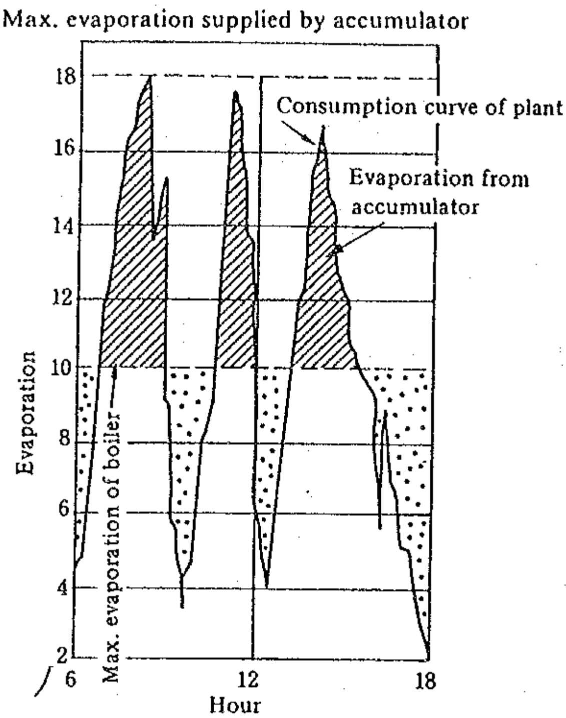


Figure 9.13 Effect of steam accumulator

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.

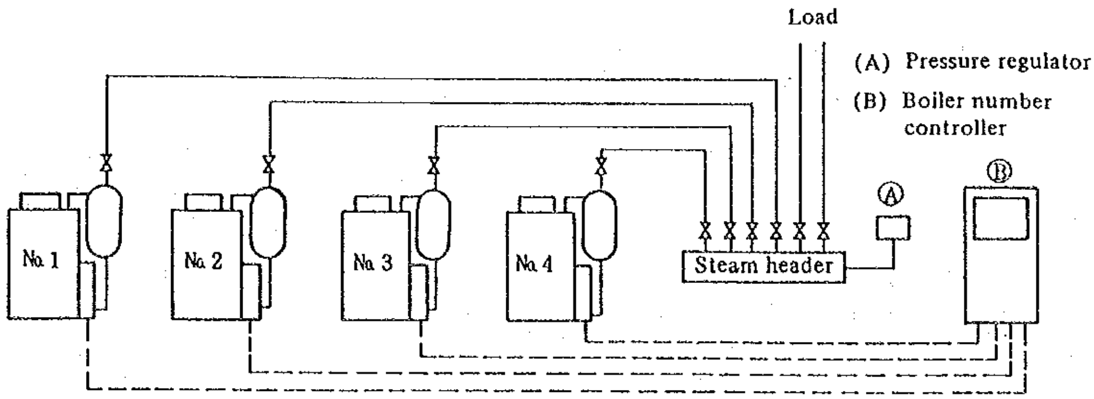


Figure 9.14 Operation number control

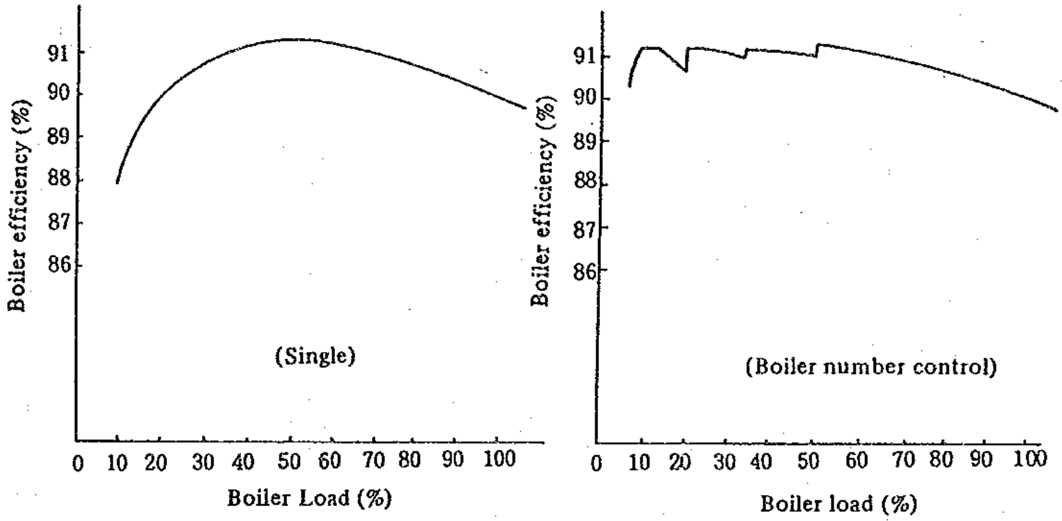


Figure 9.15 Boiler efficiency improvement by operation number control

9.1.6.3 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.

9.1.7 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.

9.1.7.1 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:

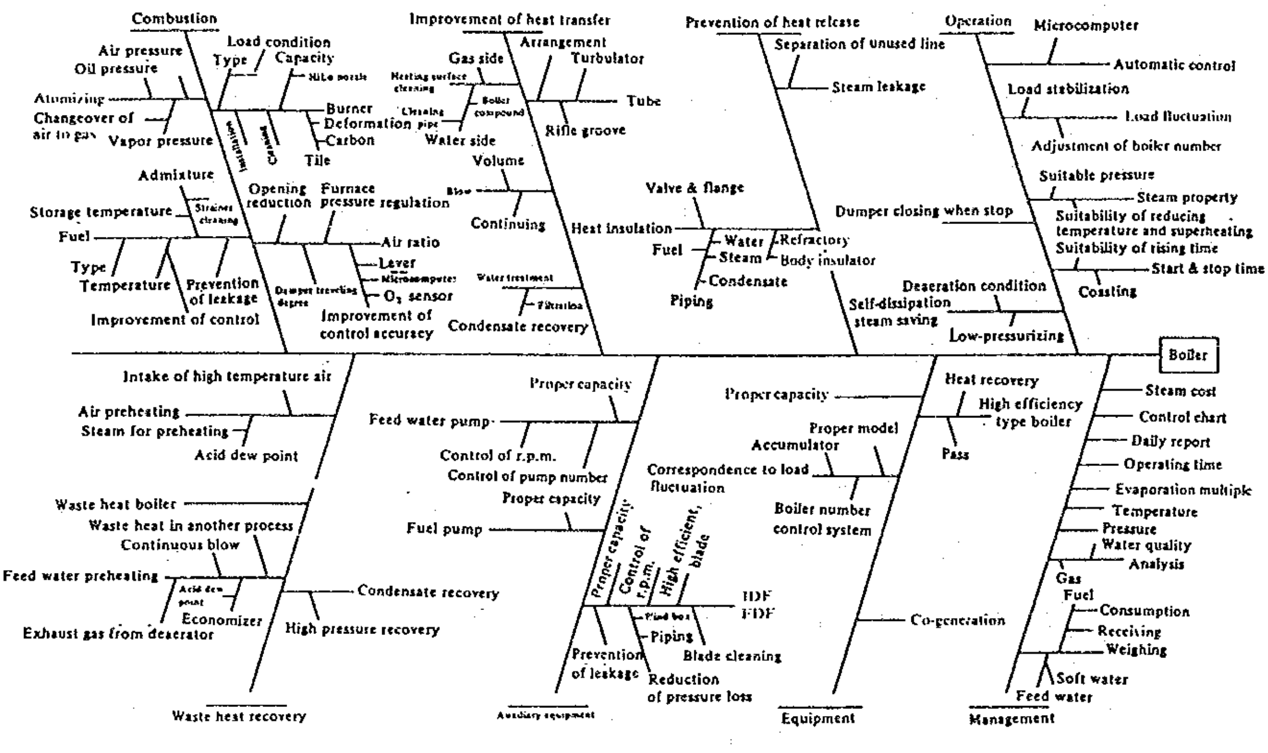
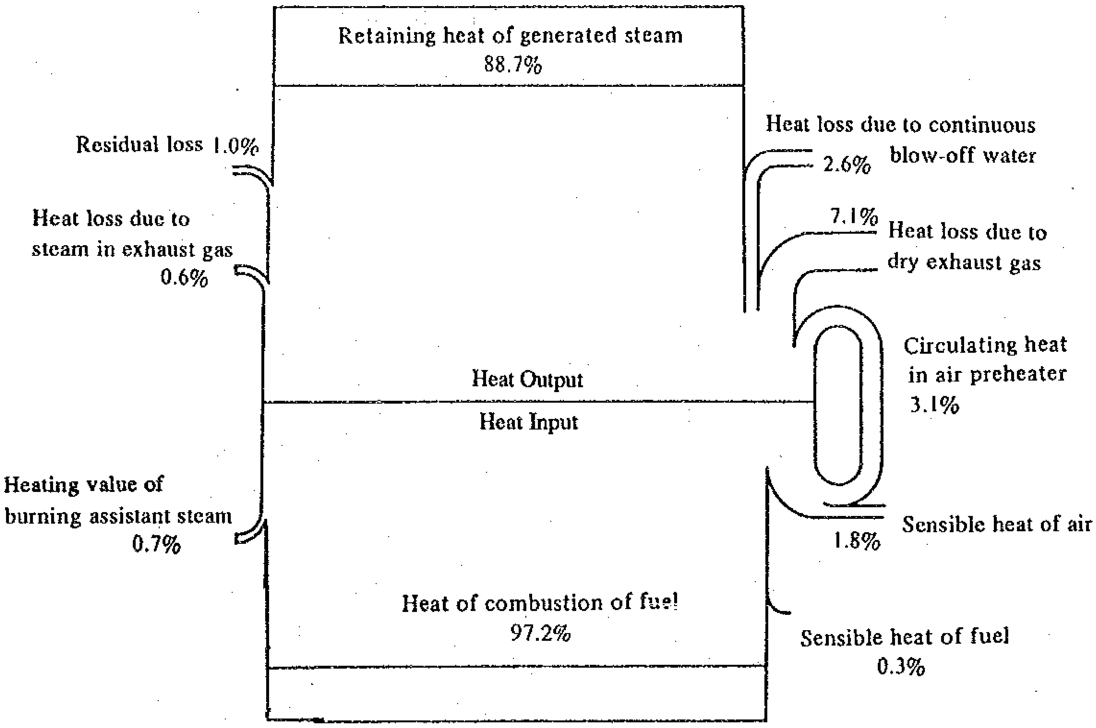


Figure 9.16 Energy conservation items of boiler



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

Figure 9.17 Example of 20 T/H boiler heat balance

(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.

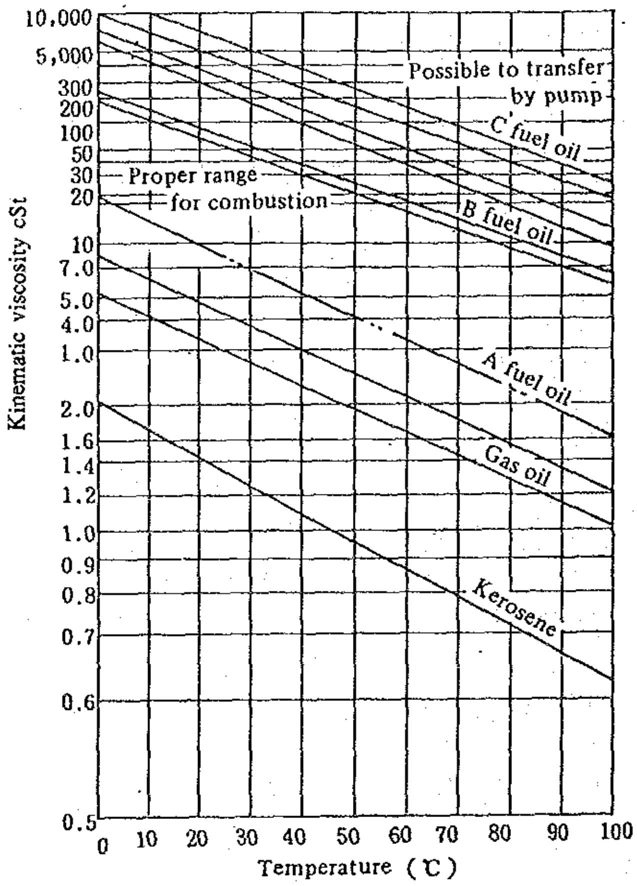


Figure 9.18 Viscosity of fuel oil

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	O	O	O	O	O	O	O
	One-through			O	O	O	O	
	Vertical	O	O		O			O
	Water-tube	O		O	O	O	O	O

(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.

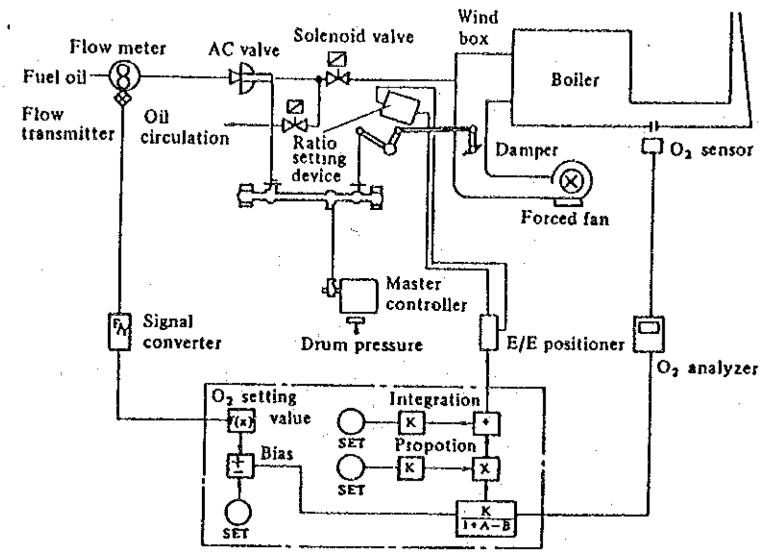


Figure 9.19 Boiler air ratio controller (1)

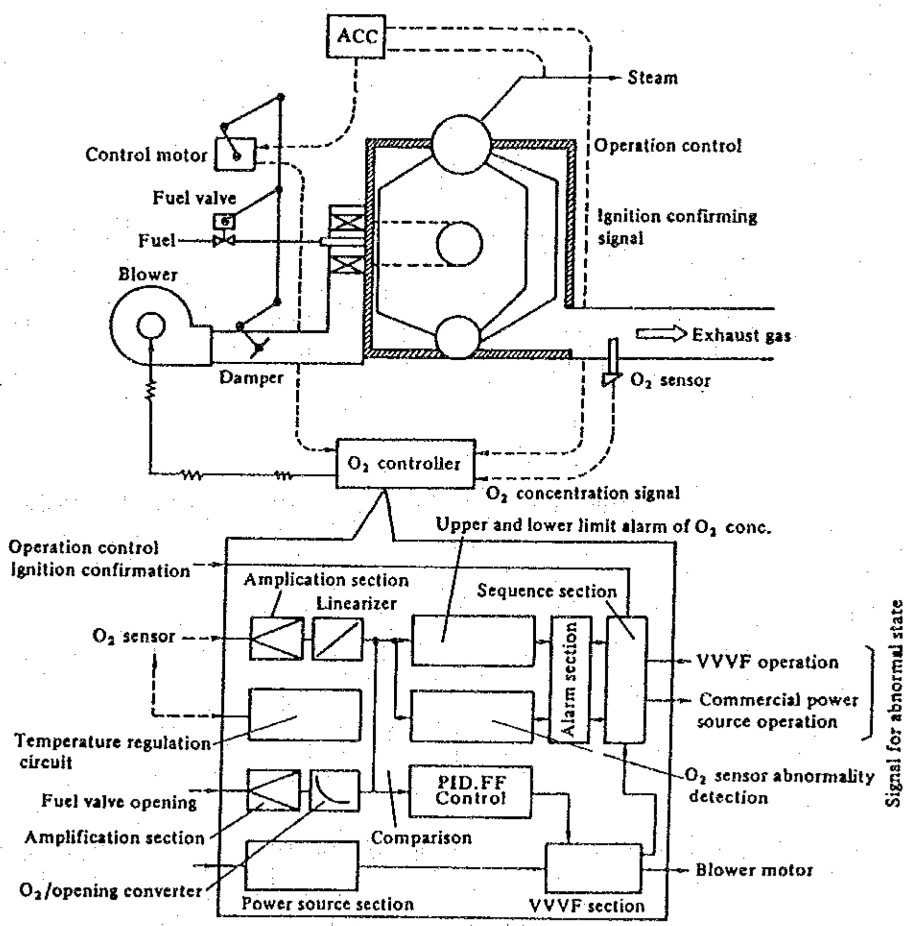


Figure 9.20 Boiler air ratio controller (2)

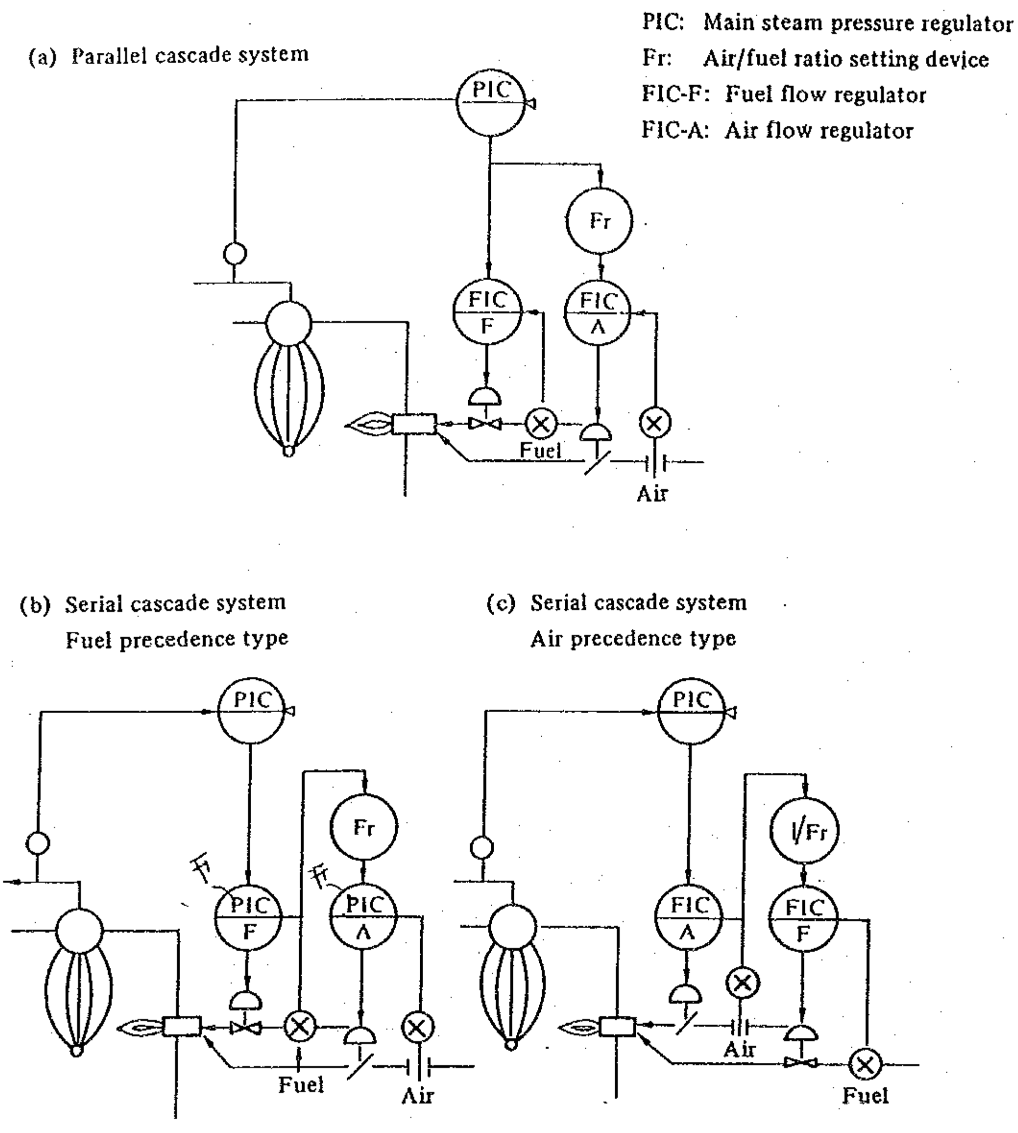
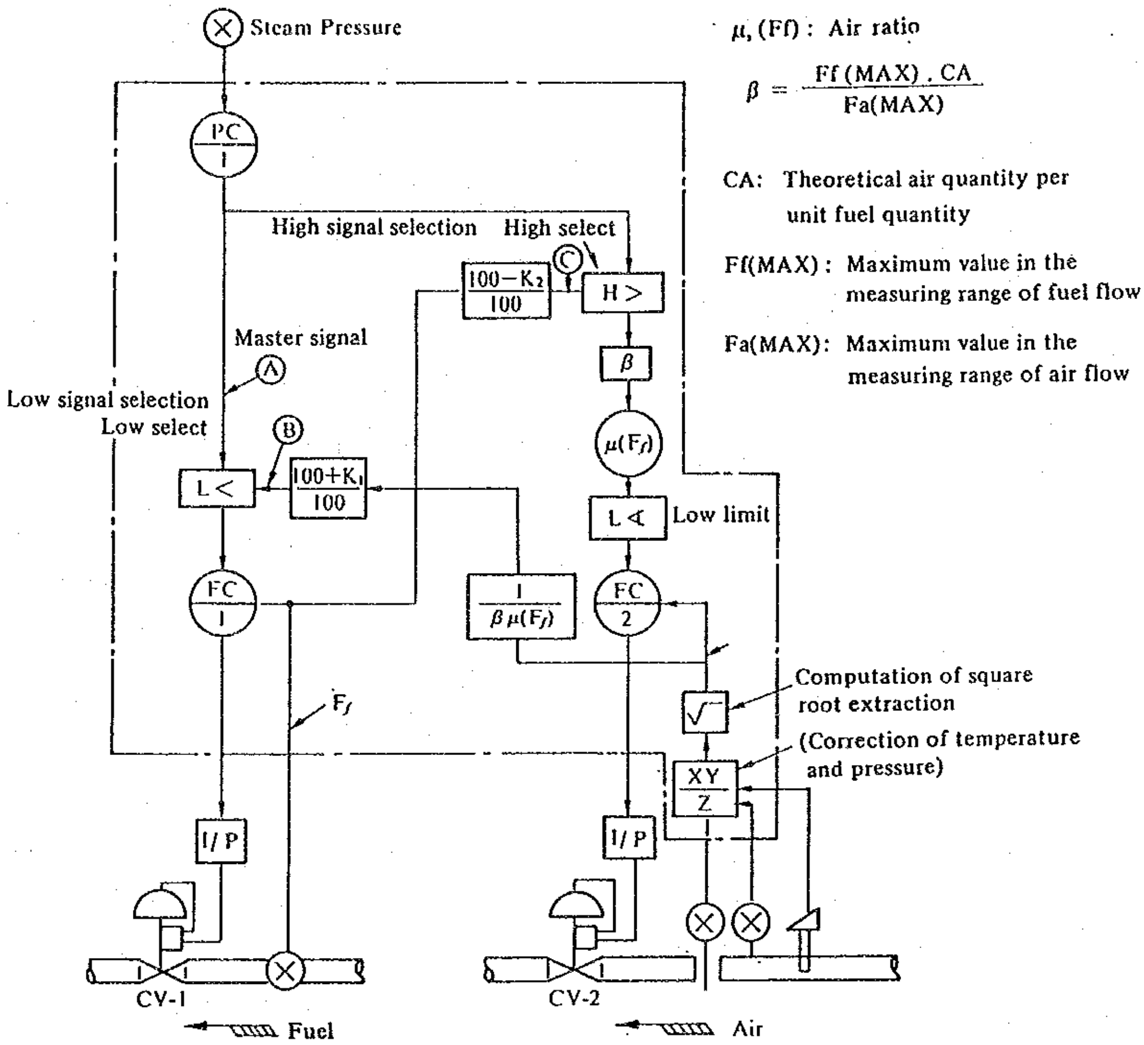


Figure 9.21 Basic combustion control system

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.



PC-1 : Main Steam pressure regulation

PC-1 : Fuel oil flow control

PC-2 : Air flow control

Figure 9.22 Block diagram of single cross limit combustion control system

Table 9.14 Standard air ratio of boiler

Division		Load rate (%)	Standard air ratio			
			Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other byproduced gas
For electric industry		75 ~ 100	1.2 ~ 1.3	1.05 ~ 1.1	1.05 ~ 1.1	1.2
Others	Evaporation: More than 30 t/h	75 ~ 100	1.2 ~ 1.3	1.1 ~ 1.2	1.1 ~ 1.2	1.3
	Evaporation: 10 to 30 t/h	75 ~ 100	—	1.2 ~ 1.3	1.2 ~ 1.3	—
	Evaporation: Less than 10 t/h	75 ~ 100	—	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 Hl ≥ 20 MJ/kg

9.1.7.2 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 1/100 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 (kJ/mh°C)
Soot	0.25 ~ 0.4
Oily matter	0.4
Scale as main component of silicate	0.8 ~ 1.7
Scale as main component of carbonate	1.7 ~ 2.5
Scale as main component of sulfate	2.5 ~ 8.4
Mild steel	170 ~ 250

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 9.1.2.3.

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 a 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 9.1.7.7).

(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.

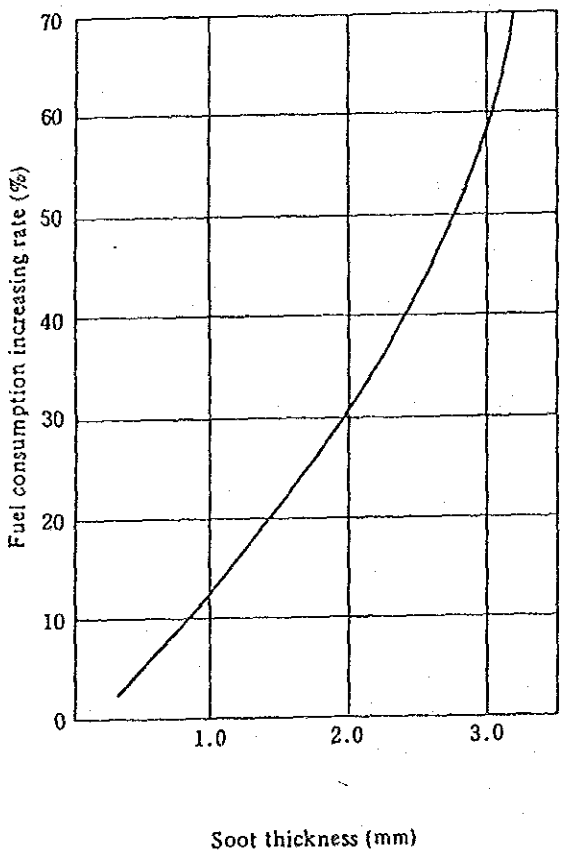


Figure 9.23 Example of fuel loss due to soot on heating surface

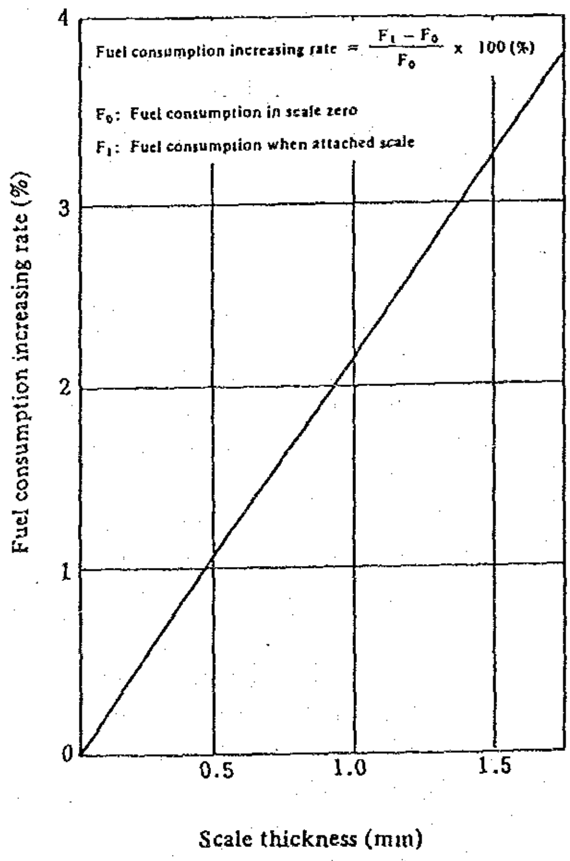


Figure 9.24 Example of relation between scale thickness and fuel loss

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.

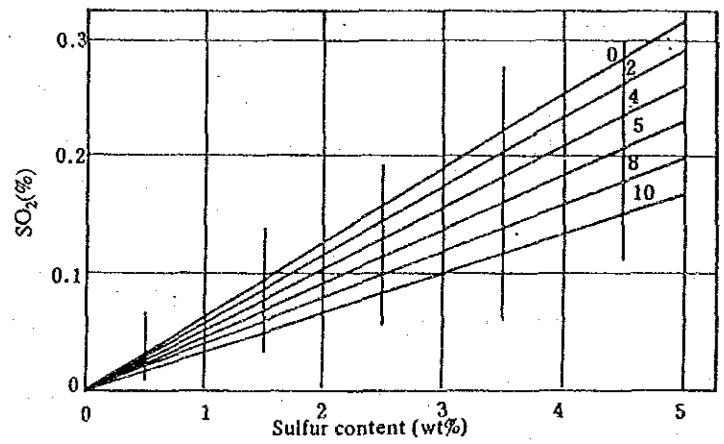


Figure 9.25 Relation between sulfur content in fuel and SO_2 content in fuel gas

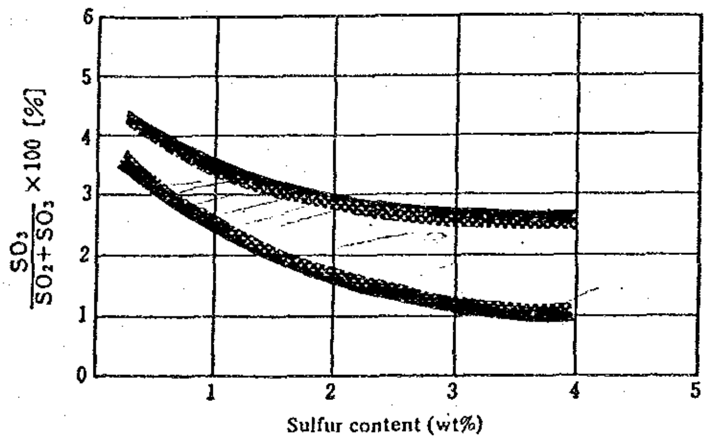


Figure 9.26 Relation between sulfur content in fuel and conversion ratio from SO_2 to SO_3

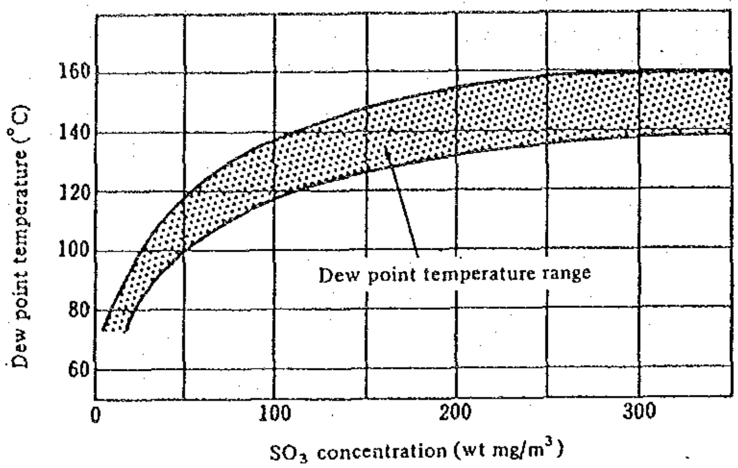


Figure 9.27 Relation between SO_3 concentration in exhaust gas and dew point temperature

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

In a case, where air is not preheated

$H_A = F - Q$

In a case of preheating air

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

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

$$\frac{X}{H_A} \text{ kg Fuel/h}$$

When air is preheated:

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

Accordingly, the fuel saving rate is as follows:

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

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

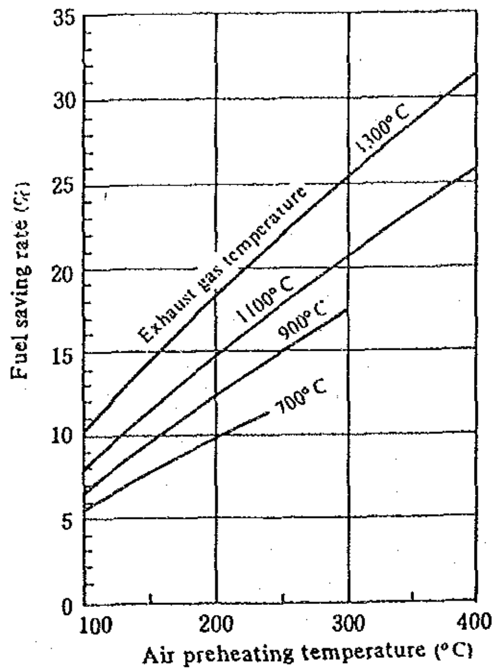


Figure 9.28 Fuel saving rate due to air preheating

(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

Division		Standard exhaust gas temperature (°C)			
		Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other byproduced gas
For electric industry		145	145	110	200
Others	Evaporation: More than 30 t/h	200	200	170	200
	Evaporation: 10 to 30 t/h	—	200	170	—
	Evaporation: Less than 10 t/h	—	200	300	—

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.

9.1.7.3 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.)

9.1.7.4 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.

9.1.7.5 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.

9.1.7.6 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				
	Water gage blowing				
	Automatic feedwater regulator				
	Low water Level Governor 1st step 2nd step 3rd step				
	Flame detector				
	Combustion state				
	Firing equipment				
	Feedwater device				
	Automatic controller				
	Control interlocking devices				
Total	Feedwater quantity (A)			lit./d	
	Fuel oil quantity (B)			lit./d	
	Evaporation multiple A/B			l/l	
	Boiler efficiency			%	
	Operating time			h	
Fuel	Carry-over			l	
	Today receiving quantity			l	
	Stock			l	

Boiler water blowdown	Blowing time	Pressure bar	Blowing quantity
	Continuing blow		
	Total blowing quantity		

Cleaning agent	Chemical name	Input g	Input hour
Chemicals putting device	Previous day	Today	Pour

Water softener		
Previous meter reading		/
Today's meter reading		/
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			
Feed water	PH		—
	Conductivity		μΩ/cm
	Chloride ion		ppm
	Hardness		ppm
Boiler water	PH		—
	Conductivity		μΩ/cm
	Chloride ion		ppm
	Hardness Phosphate ion		ppm

Description:

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

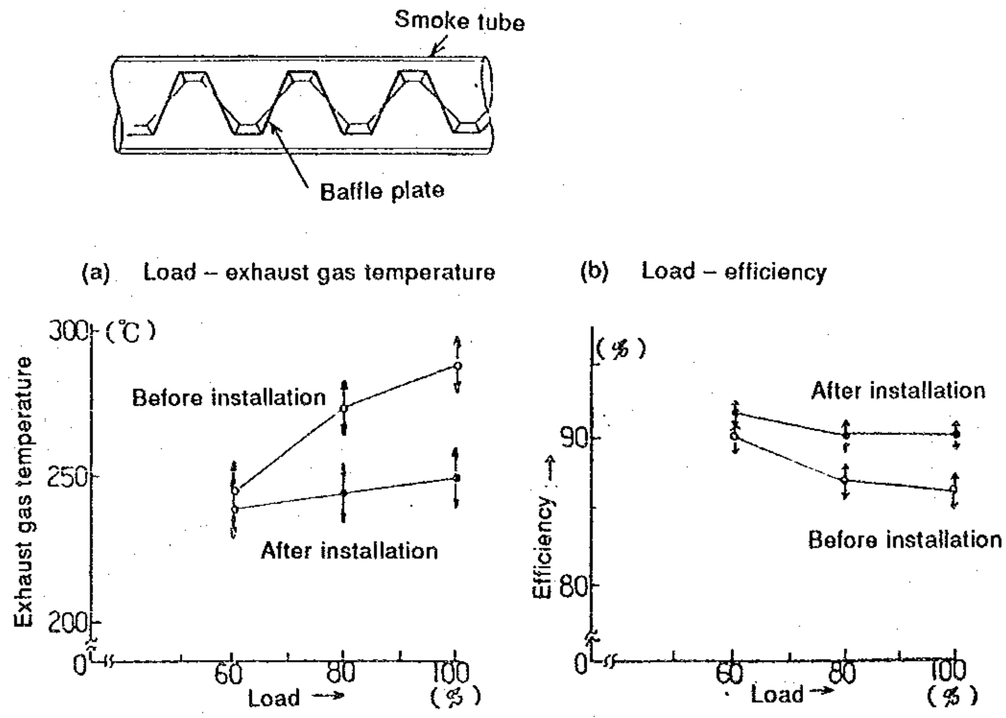


Figure 9.29 Turbulator insertion effect

10. Energy Conservation in the Utilization of Steam

10. ENERGY CONSERVATION IN THE UTILIZATION OF STEAM

10.1 Utilization of Steam

Steam is widely used in factories, buildings and so on as an energy source because of its excellent physical and chemical properties. Available utilization of steam with a thorough comprehension of its properties is related to an effective energy conservation.

The general characteristics of steam are as follows:

(1) Saturated steam is always in a constant relationship between the pressure and the temperature and by keeping steam in a constant pressure it is possible to set a constant temperature. (See Figure 10.1.)

(2) Steam has a large latent heat of evaporation and the temperature is kept constant during evaporation (or condensation).

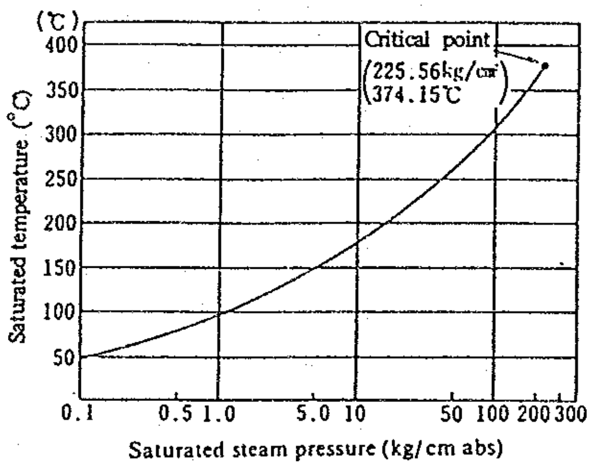


Figure 10.1 Relation between the saturated steam pressure and the saturated temperature

(3) The latent heat of evaporation of steam is larger with lower pressure and it is reduced as the pressure rises. (See Figure 10.2.)

(4) The heat transfer coefficient of steam in condensation is very large and so steam is particularly excellent as a heat transfer medium.

(5) Volume of the steam varies greatly after condensation and the specific volume of condensate is very small. Accordingly steam facilitates handling.

(6) Steam is chemically stable and is a harmless substance.

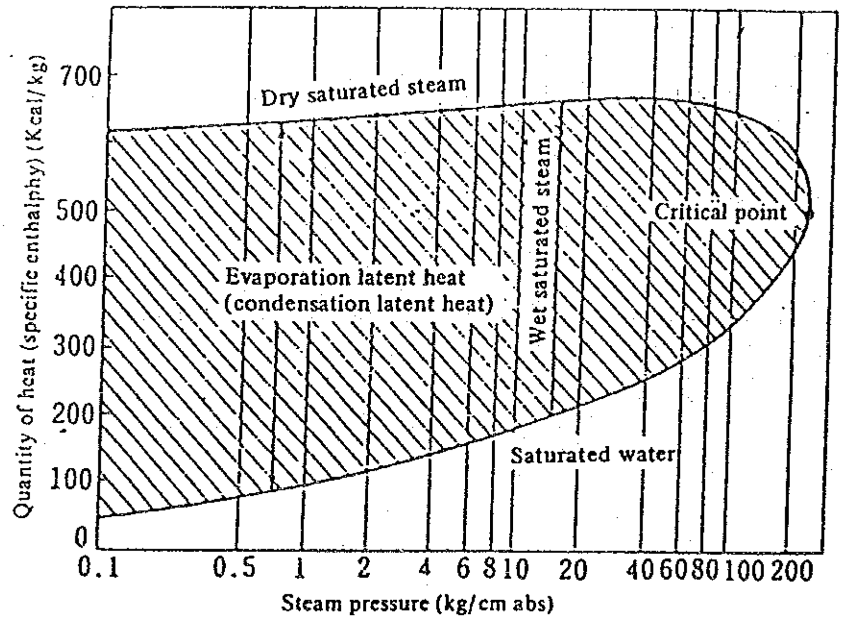


Figure 10.2 Relation between the saturated steam pressure and the quantity of heat

10.2 Effectiveness of Steam Setting Pressure

(1) Effectiveness of boiler steam pressure

When steam is used as indirect heating, the lower the steam pressure, the larger the heat quantity (latent heat of condensation) released when steam condensates is. Therefore, the use of lower pressure steam allows saving of the fuel.

In case of reduction of the steam pressure in an existing boiler, however, a proper pressure must be set in consideration of the limit of the minimum operating pressure of the boiler, the pressure loss of the steam piping and the capacity of the steam servicing equipment.

Example of fuel saving through the reduction of boiler steam pressure is shown as follows.

Table 10.1 Difference of steam effective heat by pressure

Steam pressure (bar G)	Saturation temperature (°C)	Specific enthalpy of steam (kJ/kg)	Condensation latent heat (kJ/kg)
7	170	2768	2047
5	159	2756	2085

If the steam pressure is reduced from 7 bar (G) to 5 bar (G), the latent heat of condensation rises to approximately 38 kJ/kg from Table 10.1. If an average steam consumption per month is taken as 5,400 metric tons, the steam consumption due to reduction of the steam pressure is

$$5,400 \times \frac{2,047}{2,085} \fallingdotseq 5,300 \text{ t/month}$$

If the calorific value of fuel is taken as 40 MJ/kg, the feed water temperature as 20°C and the boiler efficiency as 85%. The saving of the fuel due to the reduction of steam pressure is as follows:

$$\frac{5,400 \times 10^3 \times (2,768-84)}{40,000 \times 0.85} - \frac{5,300 \times 10^3 \times (2,756-84)}{40,000 \times 0.85} = 9,760 \text{ kg/month}$$

Through reduction of steam pressure, there is also a merit of energy conservation due to decreasing of the diffusion heat from the boiler body and decreasing of heat loss of the blow-off.

(2) Pressure reducing effect of steam

When the minimum operating pressure of the boiler is limited or the high pressure steam in some steam servicing equipment is necessary, the high pressure steam is often reduced by a pressure reducing valve at the front of the low pressure steam servicing equipment.

Since pressure reduction through a pressure reducing valve is a kind of the throttling adiabatic expansion, the enthalpy of steam due to throttling does not change. If a high pressure steam is reduced through a pressure reducing valve, the dryness increases and an energy per unit weight, that is, heat utilized effectively by increasing of latent heat increases. As a result of this, steam consumption can be saved.

An example of an increase of the heat quantity through pressure reducing is as follows:

If a steam 9 bar (G) of steam pressure and 0.95 of dryness is reduced to 2 bar (G), the latent heat of saturated steam before pressure reduction is

$$2{,}014 \times 0.95 = 1{,}913 \text{ kJ/kg}$$

and the enthalpy of wet steam is

$$763 + 1{,}913 = 2{,}676 \text{ kJ/kg.}$$

The latent heat after pressure reduction is

$$2{,}676 - 561 = 2{,}115 \text{ kJ/kg.}$$

Accordingly, the heat quantity due to pressure reduction is increased by

$$2{,}115 - 1{,}913 = 202 \text{ kJ/kg.}$$

In other words, the excessive heat quantity of $(202/1{,}913) \times 100 = 10.6\%$ is possible for utilization through pressure reduction. The dryness after pressure reduction results in the following:

$$2{,}676 = 561 + x \times 2{,}163$$
$$x = 0.98.$$

10.3 Steam Transport

A steam piping from the boiler to the servicing equipment is required to satisfy the condition of minimum distance, minimum pipe diameter, minimum heat loss and minimum pressure drop as far as possible.

(1) Piping plan

The steam servicing condition in steam consuming equipment should be defined by the following items.

a. Servicing time and hours

b. Batch or continuance

c. Servicing pressure and quantity (average quantity and peak quantity)

With a plant plan of piping, the relation between the yard piping and the plant piping should be defined. The yard piping system diagram is shown in Figure 10.3. Decision of either the example 1 or 2 should be taken into consideration for various factors such as the area of factory, the length of yard piping, the time of expansion plant, the operating process of each plant, the initial cost and the heat loss. It is also required to investigate for an exclusive piping for the daytime and the night time, and a separation of the high pressure line and the low pressure line.

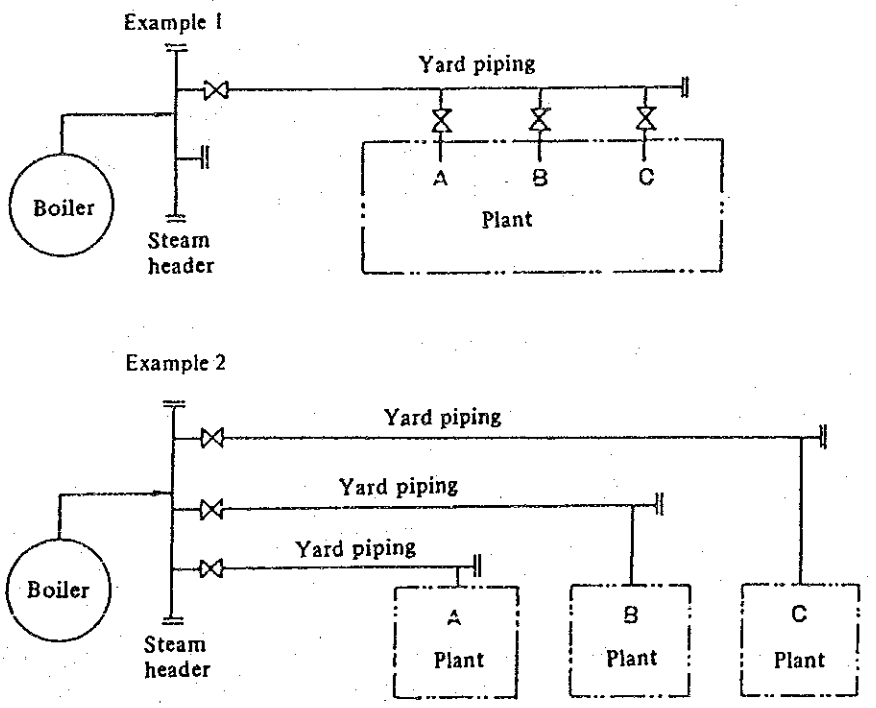


Figure 10.3 Yard piping system diagram

To take the piping from the yard piping into the plant, a main valve should be installed as shown in Figure 10.4 to lessen the influence on the work for the plant extension or to avoid heat loss by closing the main valve at a dead time. A pressure gauge and a flow meter must be installed. Also it is a method that a blind flange is mounted to some terminals of the heater for future usage.

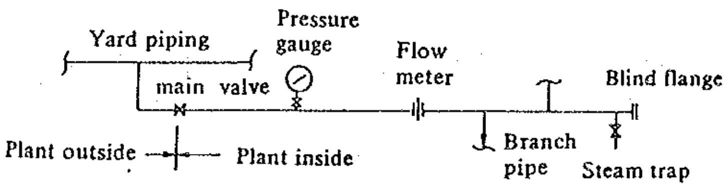


Figure 10.4 Plant battery limit schematic flow diagram

(2) Heat Insulation of steam piping

In steam transport, part of the steam does not contribute for consuming at steam servicing equipment by heat dissipation from the pipe and is discharged as condensate with a large energy loss. Accordingly, the steam piping should be given a proper heat insulation to reduce heat loss.

A) Type and selection of heat insulating materials

a. Properties required of heat insulating materials

Heat insulating materials are classified roughly into an organic and an inorganic material. Both materials of organic and inorganic contain air bubbles in porous portion by the sponge structure, and show the insulation effect.

The thermal conductivity of insulating materials is:

(1) increases generally with the density;

(2) increases with absorption of moisture;

(3) increases with raising of the temperature.

b. Type of insulating materials

The insulating material used for steam piping is mostly an inorganic materials. Table 10.2 shows the kinds and features of inorganic insulating materials.

c. Selection of heat insulating materials

Recently, as a heat insulation for the steam piping system, the calcium silicate, pearlite or rock wool is generally applied. The important points for selection are as follows:

(1) Low thermal conductivity

(2) Small specific weight

(3) Low water absorption

(4) High strength and durability

(5) Withstands sufficiently against servicing temperatures (but use below the safety servicing temperature.)

(6) Good workability

B) Heat insulation works

Although an excellent heat insulation material is used, an incomplete work allows the heat insulation to worsen through intrusion of rainwater and the energy loss due to heat dissipation cannot be neglected. Care must be exercised for works.

See Section 12 for heat radiation amount through heat insulator and the most economical thickness of insulator.

a. Works

(1) Use a molded product as far as possible.

(2) Consider the thermal expansion of pipes and the shrinkage of the heat insulating material.

The thermal expansion of piping and the shrinkage of the insulator cause some gasp. In case of two layers or more (if a required thickness is more than 75 mm, the works should be two layers as much as possible), the longitudinal and the lateral joints in each layer should be installed, in shifting, not to be put at the sample part, and the joint should be packed with a compressed fiber (Figure 10.5).

Table 10.2 Heat insulator type and its feature

Heat insulator	Raw material and manufacturing process	Product	Property	Safety service temp.
Rock wool insulator	• Andesite, basalt, igneous rock, serpentinite, peridotite, chlorite-schist, slag of nickel ore and manganese ore and limestone • Compound the above materials in a proper ratio, melt in a temperature of 1,500 ~ 1,600°C and form it to a thin fiber shape by blowing of compressed air/steam. SiO_2 : 40~50% Al_2O_3: 10~20% CaO : 20~30% MgO : 3~7% Fe_2O_3: 2~5%	• Attacked by weak acid but not weathered. • Various shape products such as plate, cylinder, band and bracket. • Blacket is formed by set metal on both sides of the stratified rock wool and sew up with a wire. Good acoustic absorption effect.	Density: < 0.3 g/cm³ Thermal conductivity (70°C): < 0.05 W/m.k	600°C or less
Glass wool insulator	• Manufactured by the similar manner to the rock wool.	• Plate, cylinder, bracket and band	Density: < 0.1 g/cm³ Thermal conductivity (70°C): < 0.05 W/m.k	400°C or less
Calcium silicate insulator	• Add asbestos fiber into silicate power (mainly diatom earth) and slaked lime to reinforce, allow it to swell enough and mold in a metal mold to allow produce calcium silicate by steaming.	• Put on the market for a high temperature from 1952 and standardized in JIS in 1955. • Low price, good workability and durability. • Typical insulator used not only piping but a general machine.	Density: less 0.22 g/cm³ Thermal conductivity (70°C): < 0.06 W/m.k	1000°C or less
Perlite insulator	• Calcinate ignition rock such as pearlite or obsidian at 800 ~ 1,200°C in kiln. • White or gray white color fine particle and very light particle having fine bubble. Not change in quality and not fade in the color. Not absorb moisture in atmosphere.	• Less 1 mm for moulding insulator • Blend asbestos fiber and inorganic adhesive, mold by press and dry. • Classified to 1st class and 2nd class. One of many excellent insulators.	Density: less 0.2 g/cm³ Thermal conductivity: < 0.07 W/m.k	900°C or less
Basic magnesium carbonate insulator (magnesium carbonate insulator)	• The conventional basic magnesium carbonate insulator has been compounded with basic magnesium carbonate of 85% and asbestos of 15%. The thermal conductivity is influenced by this ratio. The present insulator is blended with asbestos of 8% or more.	• Classified to magnesium carbonate water kneading insulator, plate and cylinder. • Convert to magnesium oxide by heating in a temperature of 300°C or more and shrink extremely • Almost same properties as those of calcium silicate except for heat resistance. As present not used too much.	Density: less 0.3 g/cm³ Thermal conductivity: < 0.07 W/m.k	250°C or less

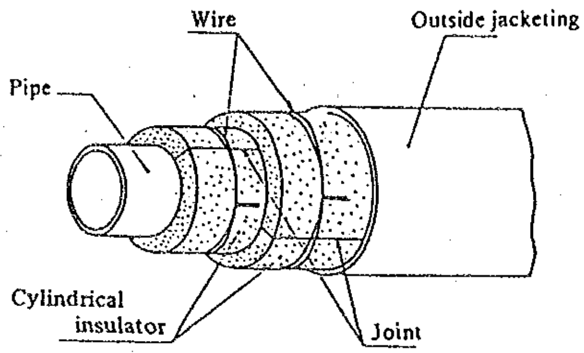


Figure 10.5 Case of cylindrical insulator

(3) The valves, the flanges, and hangers of pipes should be insulated.

The valve portions and the flange parts may sometimes not be insulated by reason of maintenance or inspection and complexity of the works, but these also should be insulated. Figure 10.6 shows the works of heat insulation for valves, Figure 10.7 shows the works of heat insulation for flange portions, and Figure 10.8 shows the works of a heat insulation for hangers.

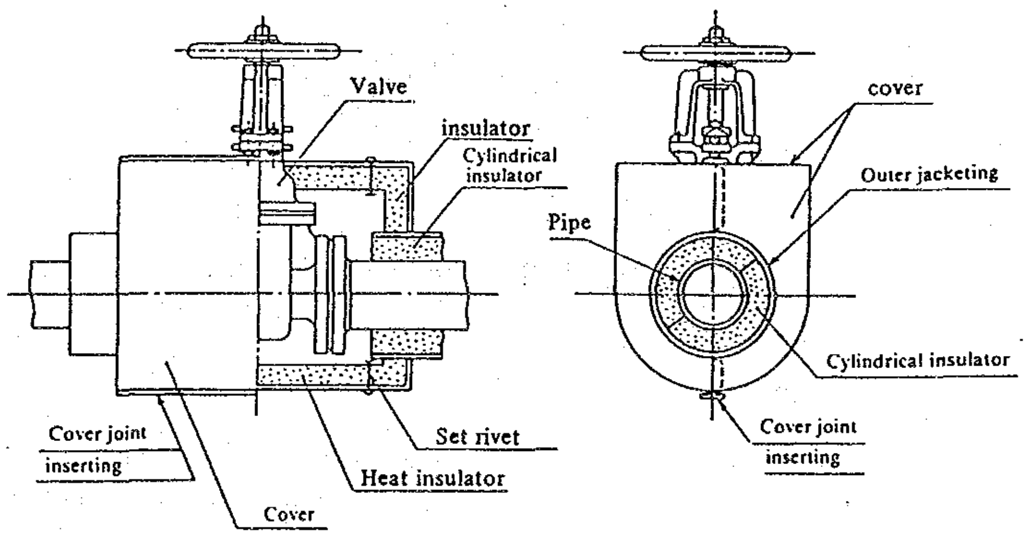


Figure 10.6 Insulation work of valve

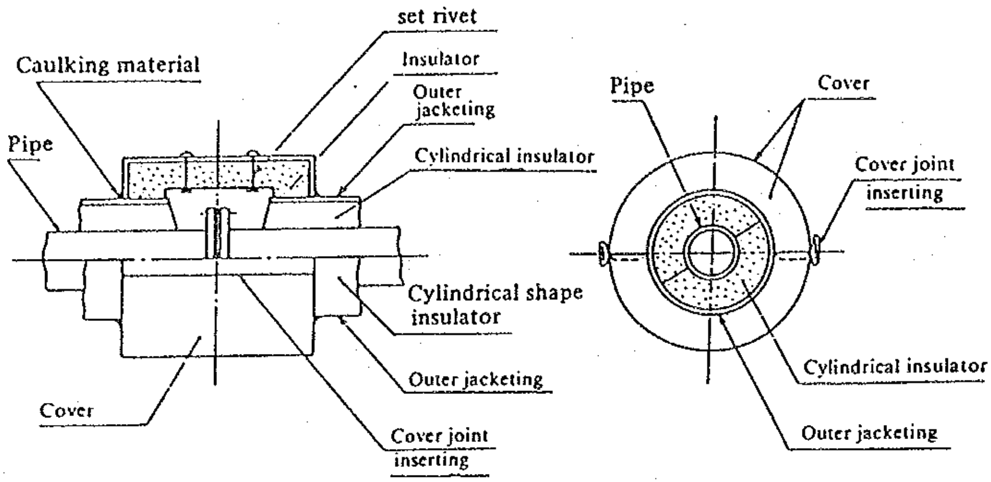


Figure 10.7 Insulation work of flange

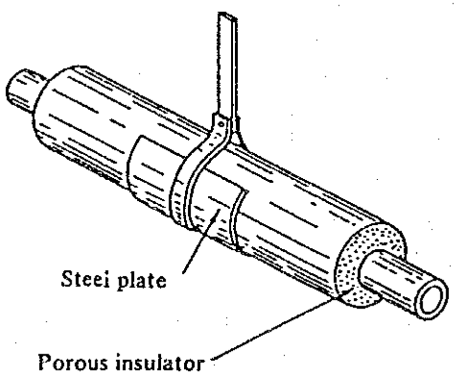


Figure 10.8 Installation work of hanger

(4) Consideration of vibration

For heat insulation on the piping installed to vibrating equipment, an antivibration heat insulation should be selected and a fibrous heat insulating material is suitable for vibration absorption.

(5) Consideration of rainwater resistance and chemical resistance

To prevent the heat insulation against rainwater or corrosive chemicals, the heat insulating material should be covered with steel sheet, aluminium sheet or mastic gum. When the heat insulating material absorbs moisture, because the thermal conductivity of water is approximately 2 kJ/mh°C which is larger by about 10 times than that of the insulating material, heat loss increases. Care must be taken against moisture. The mastic gum is a liquid or a paste containing asphalt or plastics as the main component and is excellent for workability, antirainwater and chemical resistance.

b. Maintenance and inspection of heat insulation

Since the heat-insulated sections deteriorate with age and are damaged, inspection is required. The inspection is sufficient by a visual check of the appearance and can be performed even in a daily inspection tour of the factory.

Special attention is as follows:

(1) Deformation and damage of the outerjacketing

(2) Decoloration of the outerjacketing and peeling of the painting

(3) Mark of steam leakage or falling of drops

(4) Shifting of the cover joint parts of outerjacketing or falling-off of the caulking.

(5) Gap between the hardware for hangers and supports and the outer jacketing for insulation.

If any abnormality is not found in the above points, the insulating performance is considered to be kept sufficiently.

If an abnormality is found, repairing is required at once.

c. Heat insulation thickness of steam piping, loss of release heat and heat insulation efficiency.

The heat insulation efficiency and heat loss after heat insulation are shown in Figure 10.9 to 10.14.