10.2 Heating System and Devices

This section introduces some actual cases of the heating system and devices.

10.2.1 Air-conditioning System for Large-scale Printing Factories

The configuration of a newspaper printing factory is described below.

- Fax plate pressing section : Prepares plates for printing
- Paper stock/paper feed section: Stocks and supplies the paper for newspaper
- Printing section : Performs printing.
- Shipping section : Sends the printed newspapers.
- Control system : Controls the above sections.

Among the above sections, the rotary presses installed in the printing section consume a large amount of electricity and cooling water. The newspaper printing tasks are carried out in the limited range of time, that is, during the evening newspaper printing and morning newspaper printing at nighttime. Thus, it is rather short in time zone. The shipping and paper feeding sections are also operated in conjunction with the operation of the rotary presses, and therefore the air-conditioning loads in these sections have a large fluctuation on a time basis.

On the other hand, the fax plate pressing and paper feeding sections generate a stable cooling load throughout the year though it is not so large.

The paper feeding section also operates on a 24-hour basis and requires good performance especially with regard to humidity.

(Air-conditioning equipment)

Newspaper printing factories require a large amount of electricity and cooling water. Figure 10.8 and Figure 10.9 show examples of changes on a time basis.

Figure 10.8 Power Consumption for the Principal Rotary Press

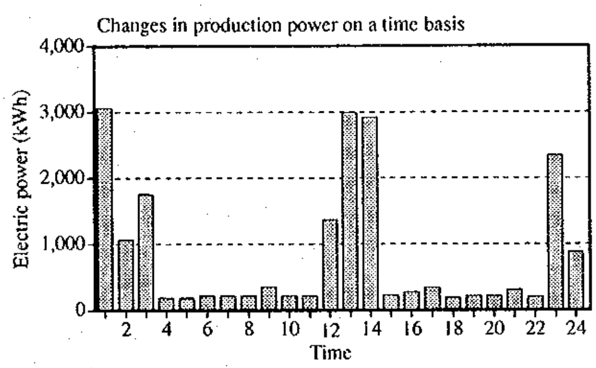
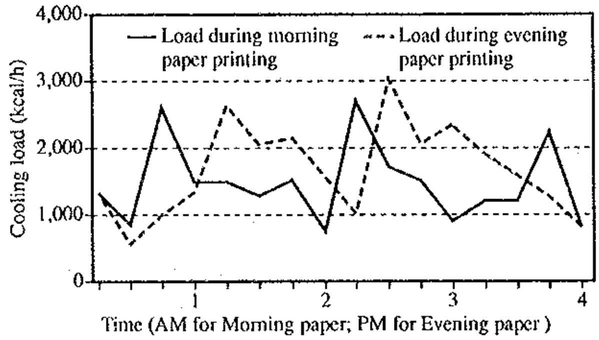


Figure 10.9 Cooling Water Loads during Newspaper Printing



It is not advisable to install a refrigerator in order to cope with such large fluctuations in the load because this means increasing the mechanical and electrical capacity. Thus, this factory has two 160m^3 heat storage tanks made of steel plate installed.

Table 10.3 shows an air-conditioning system in this factory.

Table 10.3 Air-conditioning Equipment

Heat source devices	Energy-saving turbo refrigerator	320USRt × 1
	Heat recovery type turbo refrigerator	290USRt × 2 (one unit: for standby)
	Air-cooled heat pump chiller	86USRt × 1
	Vertical type heat storage tank made of steel plate	160 m^3 × 2
System	Printing section	Single duct system for each zone
	General sections	Air-conditioner + fan coil system

The features of this system are described below.

(1) Reduction in the contract demand

The heat storage system was installed in order to reduce the power consumption by 30 % of that during the peak load. The reduction amount of contract demand was 257 kW.

(2) Heat storage tank

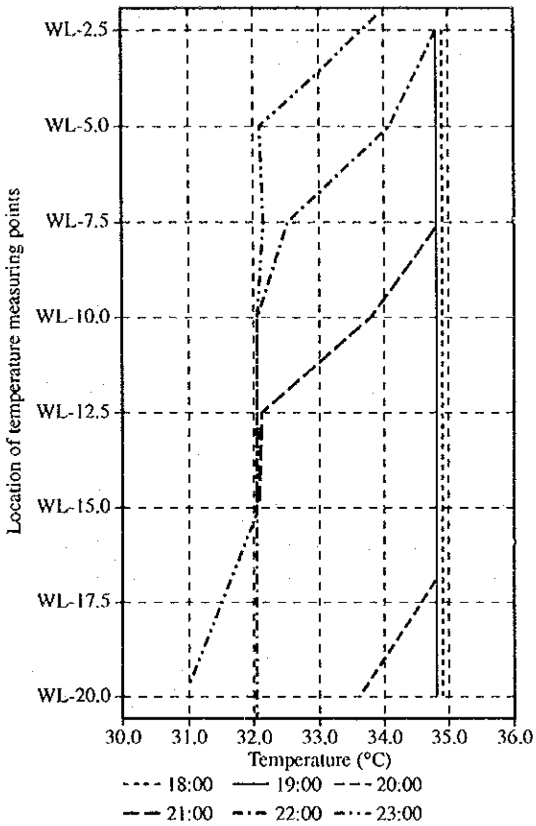
The closed type vertical heat storage tank employed this time has the following features as compared with the conventional flat type heat storage tanks.

a. A flat type heat storage tank forms an open piping network, whereas a vertical type is available in the closed form, thus allowing the reduction of the pump power by one-third to one-fifth.

b. The vertical type heat storage tank can utilize the stored heat effectively because of its thermal stratification effect.

Figure 10.10 shows the measured values of temperature distribution in the heat storage tank.

Figure 10.10 Temperature Distribution in the Heat Storage Tank (Hot water heat storage)



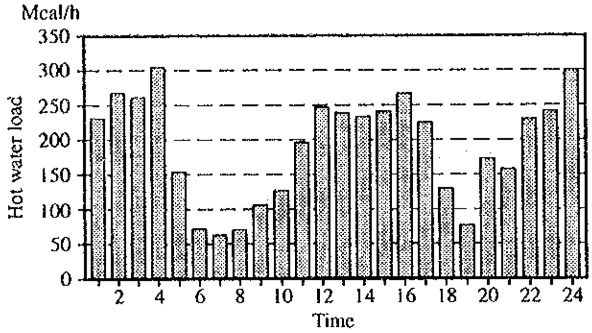
c. The installation area is small because of the tower shape, and the period of on-site installation is short because of factory fabrication.

d. Corrosion does not advance because the internal water does not come into contact with the air due to its closed type.

(3) Exhaust heat recovery system

In this factory, a large amount of heat generated by rotary presses, etc. is utilized with the circulating cooling water as a heat source for heating and hot water supply. Thus, no other heat sources are used. Figure 10.11 shows an example of heating load.

Figure 10.11 Changes in Heating Load

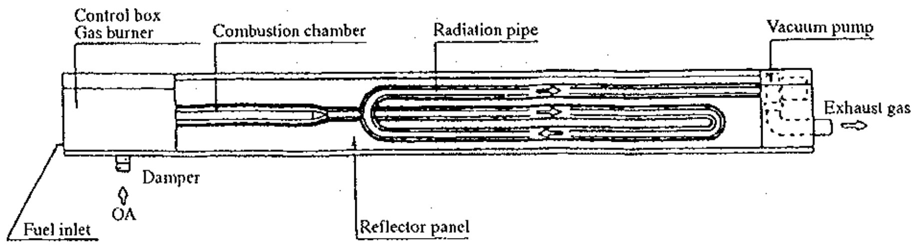


10.2.2 Kerosene-/gas-fired Far Infrared Heater

Unlike the conventional convection system where heating is conducted by heating the air, this far infrared heater heats a room by heat radiation from the internally heated circular tube.

Combustion gas is passed in the radiation pipe (heat-resistant and surface-treated to increase the performance of far infrared radiation) directly connected to the combustion section, and the pipe is heated until the surface temperature becomes 150 to 400 °C. This radiation pipe emits infrared rays of wavelength equivalent to the surface temperature. These rays are then radiated by the reflector plate without any interference of the air in the way and thereby directly heat the human body, floor surface, desk, wall surface, etc. in the zone to be heated. Figure 10.12 shows examples of devices.

Figure 10.12 Configuration Principle Diagram



This equipment uses primary energy, such as kerosene, city gas, and LPG, as heat sources. Therefore, the heat source cost is low compared with the cases where secondary energy, such as electricity, steam, and hot water, is used.

Heat loss due to heat radiation during the cold season is the largest of the heat losses from the human body. For heating, this heat radiation should be maintained at 50 kcal/h or less. To this end, it is important to heat the floor and outer circumferential wall, as well as the human body. Since the far infrared heater need not have the medium of air, it allows efficient heating of the open space and a large-space partial heating, which have not been easily accomplished by the conventional convection system.

10.2.3 Application Example of Infrared Heating

Standard classrooms in schools:

Infrared heating and convection heating by the use of boilers were actually compared in Watari-cho of Sendai City in the Tohoku district. The result showed that the fuel consumption for infrared heating is as small as 53.3 % of that for central heating.

Heating in the open system schools:

An elementary school in Yokohama City has a multi-purpose stairwell of 2- and 3-stories at the center of the school building. In such buildings as this one, no significant effect can be expected from convection heating by warm air, and thus the gas far-infrared heating system was employed.

Indoor sports facilities:

The occupied space requiring heating in a gymnasium, indoor swimming pool, audience seats, etc. is very small for the entire space. In this regard, a far infrared heater can directly heat the human body and floor without any medium of air, and thus it can work efficiently for partial heating of a high, wide, large space.

Optimum temperature control is made available in the arena by zoning according to the amount of motion.

Partial heating for the sitting audience is available in the ice skating rink.

Cold start which allows quick start is possible for large space, intermittent or short-time use only.

The indoor swimming pool requires the temperature to be 30 °C or higher at the pool side. In warm-air heating system with limitation in ventilation, the environment tends to be high in temperatures and humidity, and thus makes one feel uncomfortable. In contrast, far-infrared heating warms the human body and pool side floor surface as if by the sunlight and at the same time it can offer a comfortable heating effect since it generates no draft.

(1) Heating in factories and delivery centers

Factories generally involve many problems with the heating requirements.

a. The floor area is large and the ceiling is high for the occupied space. The heating zone accounts for only 5 to 30 % of the total space, and therefore partial heating (zoning) of this limited space is required.

b. The building is poor in air-tightness and heat insulating performance, the door outside the workplace is subjected to frequent opening/closing, and additionally forced ventilation is required for the maintenance of the environment. Thus, in general, heat loss due to ventilation is significant, accounting for as much as 30 to 50 % of the total heat loss. Therefore it is difficult to achieve energy conservation by convection heating.

c. The floor surface and space are limited in factories with traveling cranes or large-size machines, making it difficult to install heating equipment effectively because of such machines.

d. The semi-open spaces, such as delivery centers, distribution centers in the post office and automobile factories, are subject to much movement of air. For this reason, the convection system which first heats the air can hardly heat such semi-open spaces. The human body, floor, machines, etc. need to be directly heated to cover the reduction in persons' body temperatures due to draft.

(2) Far infrared radiation heating in large factories

In Japan, gas far infrared radiation heating equipment was first installed in an automobile factory in 1973. As an example of large factory, this heating equipment was installed in 1985 in the prototype manufacturing shop of an automobile factory, where robots are used. It was used for heating the entire area in this factory of floor area 3,600 m^2 (30 m × 120 m × 13mH) with a 30 m traveling crane. The result showed that the fuel consumption is about 40 % of that in the convection heating by the conventional heavy oil-fired boiler on the basis of heating value and that the necessary cost reduced to about 50 % even by using more expensive city gas than fuel oil.

Although most of the mail truck terminals for post offices have a roof, they are open in the surroundings. Because of the overnight (next-day) delivery system, the leaving and arriving of mail trucks are concentrated in the time zone from the midnight to the early morning when it is coldest in the day. Thus, heating constitutes a matter of great concern.

Far infrared heating was applied in these mail truck terminals, and the result disclosed that "operative temperature" (specified in ISO) in the non-heated zone dropped to as low as 2.9 °C, whereas "operative temperature" in the heated zone was maintained within the range of 15 °C to 20 °C. Thus, a heating effect could be verified. The heating effect has been proven sensibly as well. Additionally, the floor temperature in the non-heated zone was 4 °C at minimum, whereas that in the heated zone rose up to 27 °C, showing that the heating effect started at the foot.

(3) Characteristics of far infrared heating system

- Suitable for heating an open space or a large space.

- Allow partial heating of only the space which requires heating, and reducing the operating costs.

- High level of comfort because there is no need of air circulation which is required for convection heating.

(4) Safety of kerosene-, or gas-fired far infrared heaters

Vacuum combustion system is employed for these heaters to maintain the inside of the radiation pipe at negative pressure. Therefore, the combustion gas does not leak into the room. Safety here is ensured by combustion system based on "flame rod" and "flame eye", purging of incomplete combustion gas through the pre- and post-purging by protect relays, the vacuum switch which does not start combustion until the radiation pipe becomes vacuum, an overheating preventive device, etc.

Note:

ISO recommends adopting the concept of "Operative Temperature" as the reference for the heating effect which can satisfy 80 % or more people. "Operative Temperature" is calculated by obtaining the average radiation temperature and the ambient temperature from the globe temperature and multiplying these values by the velocity factor, etc.

10.2.4 Actual Cases of Factory Heating System

(1) Strip heater using steam as the fuel: Machine factory

Building overview:
Wall : Steel-framed corrugated galvanized sheet
Roof : Corrugated slate
Floor: Concrete

Scale: 25m Width × 91 m Length × 8.5 m Eaves height, Floor area: 2,275 m²

Category of industry: Manufacture of construction machine parts

Heating conditions:

Outside temperature	: 0 °C		
Globe temperature	: 16 °C		
Frequency of ventilation	: 3 times/hr		
Operating hours	: from 8:00 to 16:00		
Heat source	: Once-through boiler	:	1.5 t/h,
	Working steam pressure:		7 kg·cm²

Radiation panel:

Type	: Fin-tube type panel, Width: 750 mm
Total number of units	: 36
Total heat output	: 642,600 kcal/h

Figure 10.14 shows the overview of the heating system. Figure 10.13 shows the photograph of installation example.

Figure 10.13 System Diagram of Heating System

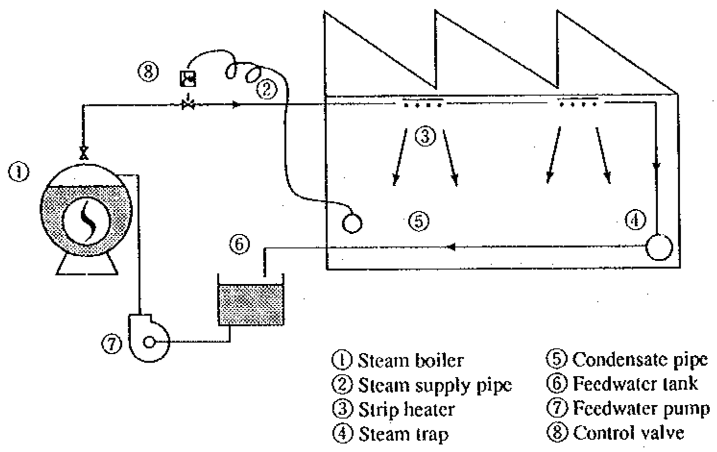


Figure 10.14 Example of Strip Heater Installation

In this factory, three direct-fired warm-air heaters were used; however, since the eaves height is 8.5 m and most of the heated air stayed long in the upper part, no heating effect could be obtained for the working area up to 2 m from the floor surface. Also horizontally, a large temperature difference was generated between the places near and away from the air heater and these air heaters were very inefficient for the total cost of fuel.

Thus, after comparative reviews of various heating systems to be employed as an improvement measure, it was determined in consideration of the following advantages that overhead radiation type heating equipment was to be used.

- Reduction of fuel consumption by 40 %
- Improvement of temperature distribution
- Full (100 %) availability of the floor surface as the working area.
- Combustion device (steam generator) is located at only one place to eliminate a flame source, resulting in securing of safety.

Figure 10.15 shows the temperature distribution on the floor surface, while Figure 10.16 shows an example of the temperature distribution in the vertical direction.

Figure 10.15 Operative Temperature Distribution by Radiation Heating (Globe temperature)

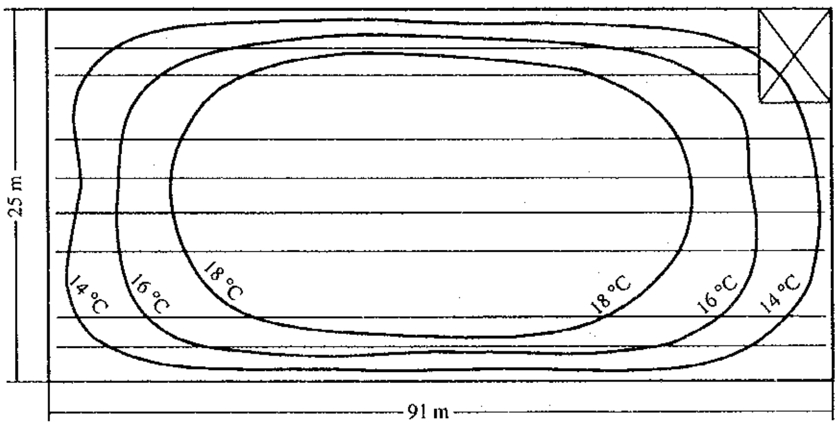
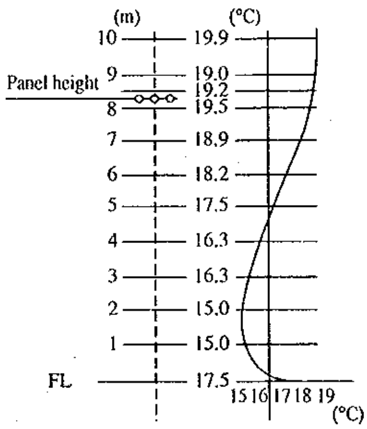


Figure 10.16 Changes in the Temperature in the Height Direction by Radiation Panel



The following comments were obtained from the workers after installation.

- There was no discomfort due to the heating turbulent airflow from the air heater.
- Partial heating is available during overtime work.
- There are no moving parts, such as motor and fan, thus eliminating noises from the inside of the factory.

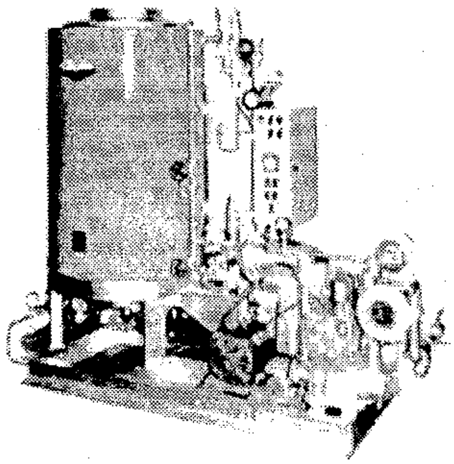
(Equipment used)

(1) Steam boiler

Actual amount of evaporation: 1,516 kg/h, Fuel: Fuel oil A, Maximum operating pressure: 10 kg/cm^2G, Heating surface area: 9.9 m^2

Figure 10.17 shows this boiler.

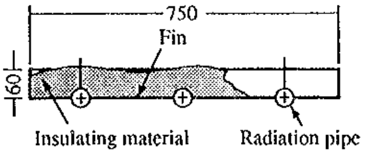
Figure 10.17 Clayton Boiler



(2) Radiation panel

The heater proper of the fin-tube type has a 20 to 30 % higher heat output compared with the conventional bare pipe shape. Figure 10.18 shows the fin-tube radiation panel.

Figure 10.18 Fin-Tube Radiation Panel



Fin is provided to a steel radiation pipe of 1-1/2 as shown in Figure 10.18. The surface of the fin is coated with a paint of large radiation. The back surface of the fin is provided with insulating material of 50 mm. The condensate from the heater is recovered in the boiler as hot water of about 80 °C.

(3) Gas-fired far infrared heating equipment: NC machine factory

Factory overview : Precision machine factory equipped with NC lathe and machining center

Overhead crane height: 5 m

Floor area : 800 m^2

Equipment overview : Ceiling-mounted far infrared heating equipment (Gas-fired): 18 units

Input per unit : 10,000 kcal/h
The equipment is of the vacuum type, and the combustion gas is discharged to the outside from the vacuum pump.

Figure 10.19 shows this heating equipment.

Figure 10.19 Vacuum Combustion System CO-Ray-VAC (Gas-fired)

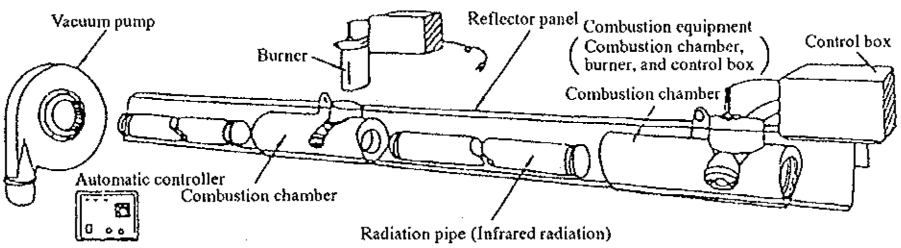
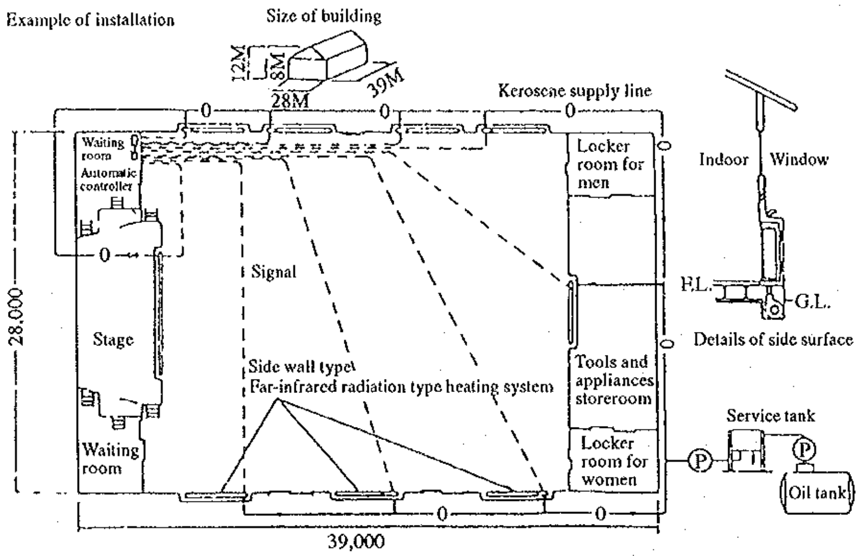


Figure 10.20 shows the system configuration of the equipment.

Figure 10.20 Side-wall Type OVSW-301 (Single unit) (Kerosene-fired)



A warm air convection heating system which uses a hot water boiler was initially installed. However, the heating effect was poor, thus posing problems such as absence of skilled employees due to illness. As the countermeasure for this problem, radiation heating was employed. According to the president's comment on this heater, "Ignition has only to be started 1 hour before the starting of work even in the coldest morning. This heating system first heats the floor and then the machines. Therefore, the heating effect starts at the foot. Additionally, this heating system, which is draftless, eliminates workers' discomfort and it is therefore recommended in terms of health and quality control."

10.3 Actual Cases of Improvements in Factory Heating

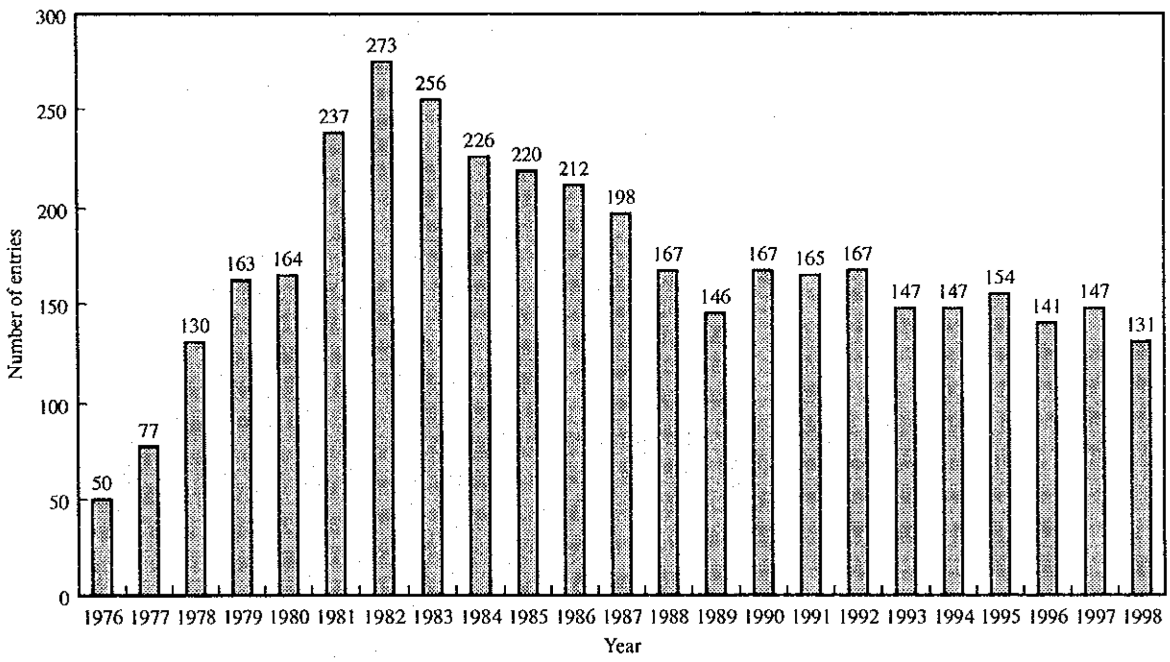
This section exemplifies the improvements in energy conservation related to the factory existing heating system.

These improvement cases have been picked up from those applied for the presentation convention for factory energy conservation cases which The Energy Conservation Center, Japan has called for every year. The presentation convention has been held since 1954, with the total number of entries so far amounting to 3,885 cases. Most of these presented cases show mainly the improvement results which have been achieved by currently working operator groups at their own worksite. The details of the improvements range widely from factory heating systems to various kinds of improvements in combustion, heat insulation, service water, compressed air at one's own workplace.

Improvement activities are voluntarily carried out (actually, however, there are many cases of request/guidance/support by their managers). It takes several months or a year to pick up or identify problems, study their solution, try, implement them and take measures for their more thorough implementation.

The presentation meeting organized annually by the Center is open to the public, and therefore anyone can participate in the meeting, through which hints for next improvements may be obtained. The details of these presented cases are distributed to the participants as a collection of data. Figure 10.21 presents changes in the number of entries.

Figure 10.21 Number of Applicants for Improvement Case Presentation Convention



10.3.1 Improvement of Heating Equipment in a High Ceiling Factory

Category of industry : Manufacture of metal dies for automobile plastic and rubber parts

No. of employees : 150

Fuel consumption (Annual): Fuel oil 70 kL

(1) Equipment to be improved

Six warm-air furnaces directly fired with fuel oil in the building of 3,000 m² × 2 stories, which are shown in Figure 10.22 and Table 10.4.

Figure 10.22 Layout of Heating Equipment

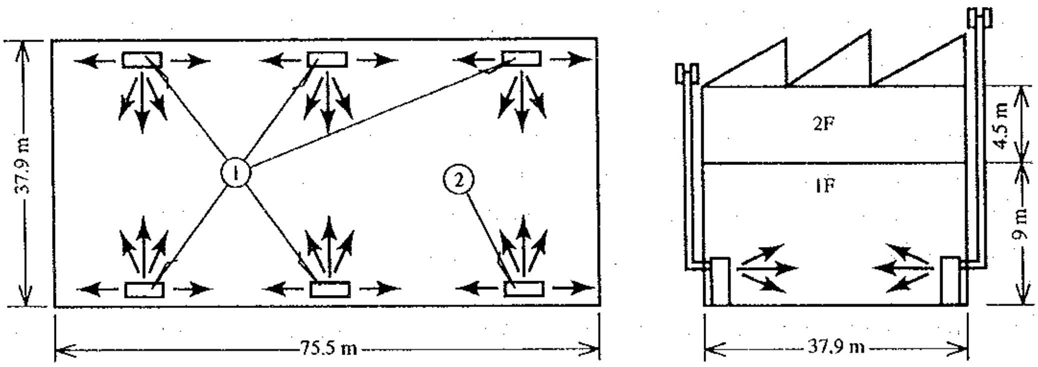


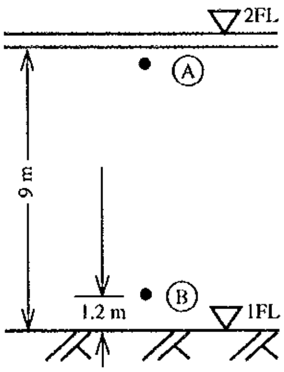
Table 10.4 Overview of Heating Equipment

NO	Type	Heating capacity	No. of units
1	Warm-air heating unit	100,000 kcal/H	5
2	Warm-air heating unit	75,000 kcal/H	1
	Total	575,000 kcal/H	6

(2) Problems

The result of measuring the temperature on the first floor ceiling and the temperature on the floor discloses that there is a temperature fluctuation of 5 °C, as shown in Figure 10.23.

Figure 10.23 Temperature Differences between Ceiling and Floor



Measuring point	Measuring place	Temperature
(A)	Ceiling	28 °C
(B)	Floor	23 °C
Temperature difference		5 °C

(3) Countermeasures

It was determined that 6 ceiling fans would be installed on the portions of high temperatures. In this case, 0.5 m/s of velocity was selected based on Yaglou's 'Necktie' Chart for reference so that operators would not feel cold at the velocity of air blowing down. Based on this, the velocity of the ceiling fans was calculated and as a result, approximately 1 m/s was obtained. Ceiling fans were installed at six places of high temperatures and thereby reduced the temperature difference to 2 °C.

Table 10.5 Specifications of Ceiling Fan

	Item	Specifications
Rating and type	Motor type	Open type single-phase capacitor motor
	Rated voltage	100 V
	Vane type	Plastic axial-flow 3-vane
Characteristics	Velocity	71 m/min, MAX 178 m/min
	Air flow	58 m^3/min, MAX 244 m^3/min

(4) Effect of energy conservation

Calculation shows that annual reduction in fuel oil is 7 kL, saving 10 % of fuel oil consumption for heating this factory.

10.3.2 Power Saving by Changing the Temperature of Warm Water for Heating

Category of industry: Manufacture of exclusive equipment and dies for manufacturing automobiles

No. of employees : 1,860

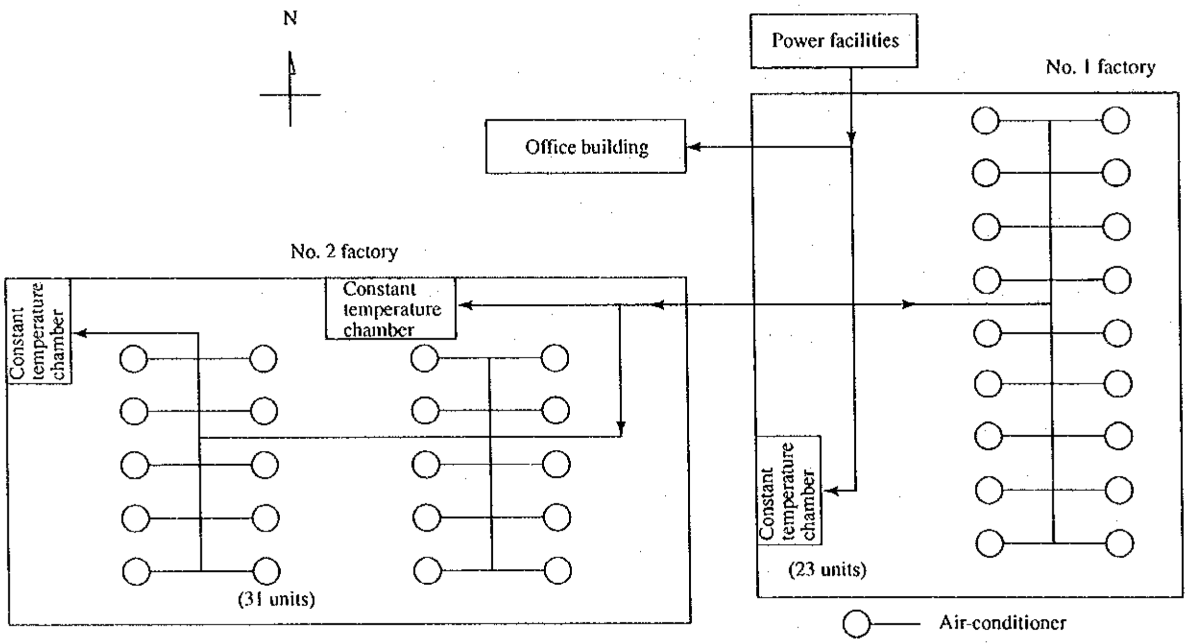
Energy consumption (annual):

Electricity : 2,300 MW
Fuel oil : 1,500 kL
Service water: 81,000 m^3

(1) Equipment to be improved

Two factory buildings (Total: 76,000 m^2) are heated by the hot water supplied from the power facilities. Figure 10.24 shows the general conceptual diagram.

Figure 10.24 General Plan View

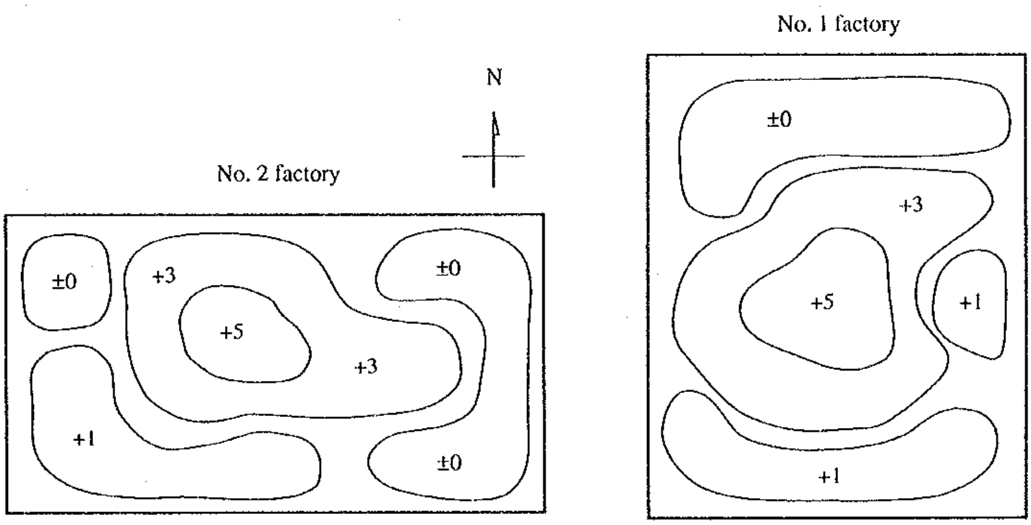


(2) Problems

a. The amount of internal circulating air in the air conditioner is actually used at the rate of 100 % instead of 50 % which was the initially planned rate. Therefore, the hot water from the air-conditioner is returned as it remains hot with only a small difference in the temperatures. Thus, it is necessary to make the temperature difference larger, reduce the amount of supply water, and thereby save the power for the pump.

b. The temperature distribution in the factory is uneven. The temperature at the center of the factory becomes higher than the setting temperature. Figure 10.25 shows the results of measuring the temperature differences from the setting temperature.

Figure 10.25 Distribution of Temperature Difference from the Setting Temperature



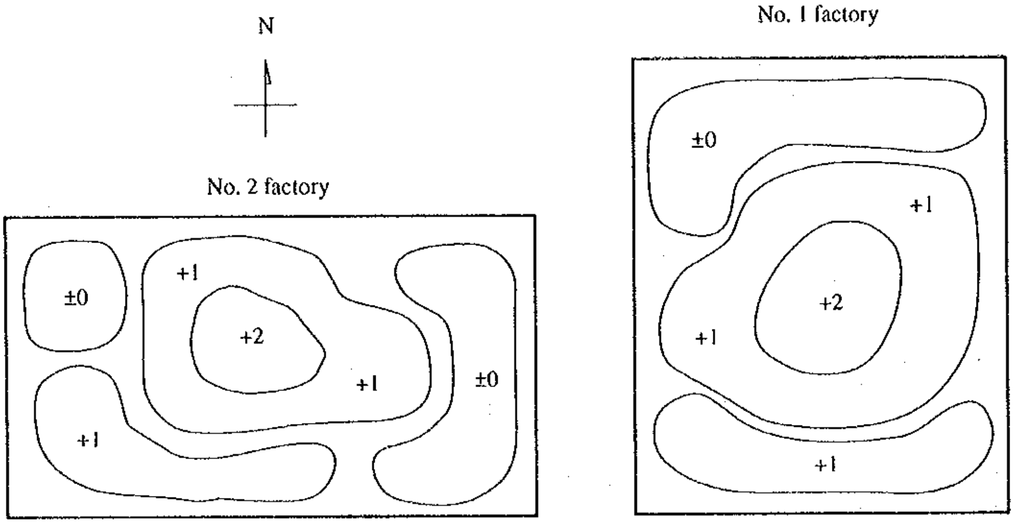
(3) Countermeasures

a. When the pressure setting value of the water feed main pipe was lowered in order to reduce the water feed amount, it became impossible to have good control of temperature/humidity in the constant-temperature chamber at the end of the factory. Therefore, the manual inlet valve of the air-conditioner there was adjusted by using the temperature distribution as reference. This could increase the temperature difference of the hot water from 5 °C to 10 °C, while the amount of water fed was reduced from 1,700 m^3/h to 600 m^3/h. The number of operating pumps also reduced from 3 units to 1 unit, thus leading to power saving.

b. The operating fans for the air-conditioner were categorized into groups according to the temperature distribution. Thus, the modification of the fans was such that the fan groups which fall into the zone of temperature higher than the setting temperature were to be stopped by means of the general monitoring system. This contributed to the reduction of power for the fans.

Also this improved the temperature distribution, which finally was as shown in Figure 10.26.

Figure 10.26 Final Temperature Distribution in the Factory



(4) Energy conservation effect

The foregoing countermeasures a. and b. reduced power consumption by 219 MW and fuel oil by 45 kL.

10.3.3 Improvement of Temperature Distribution by High-Velocity Nozzles

Category of industry : Manufacture of fiber machines and attachments to machine tools

Number of employees: 1,350

Energy consumption : Fuel : Fuel oil A 1,000 kL
Electricity: 7,800 MW

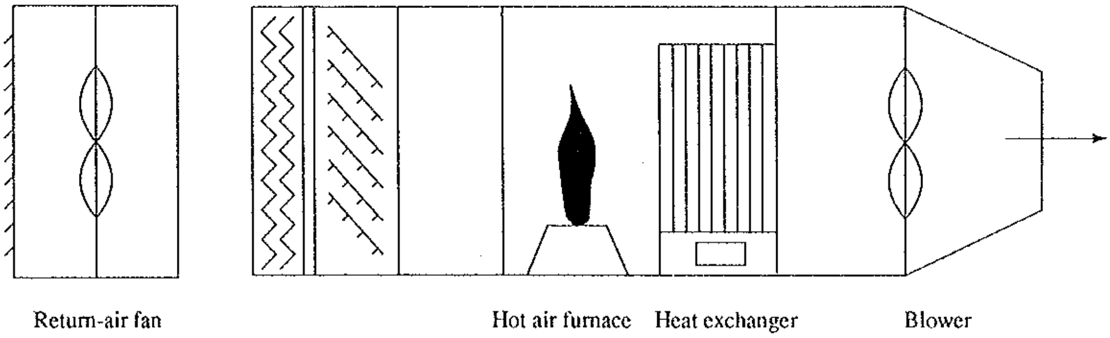
(1) Equipment to be improved

Building structure : Steel-framed concrete 3,374 m²

Heating equipment: Fuel oil direct-combusted heater 7 units

Figure 10.27 shows the heaters.

Figure 10.27 Air-conditioning System



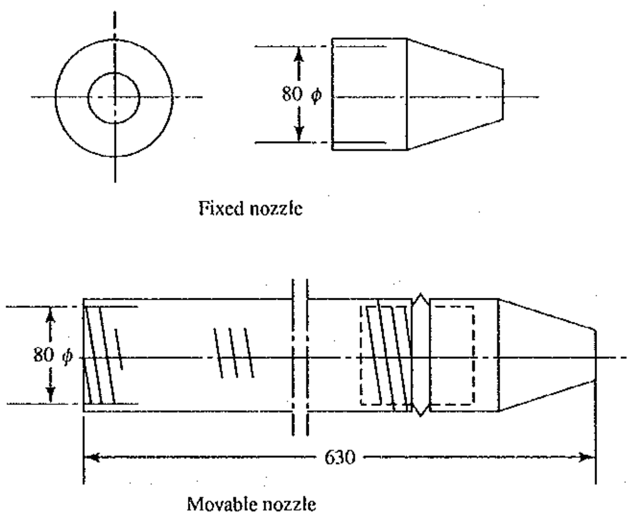
(2) Problems

95 % of fuel oil for the factory is used for heating. Only the three large entrance/exit doors can be opened/closed in the factory, while the other windows, which are of double glass, cannot be opened/closed. The ceiling height is 11.7 m at maximum and the warm air therefore remains at high portions, thus causing a large temperature difference.

(3) Countermeasures

A "high-velocity nozzle" was installed downward at a position higher than the warm-air outlet of the duct. By blowing down the warm air from the duct outlet, the temperature fluctuations in the upper and lower parts of the room can be reduced. Figure 10.28 shows the high-speed nozzle.

Figure 10.28 Dimensional Diagram of High-velocity Nozzle



No. of nozzles installed

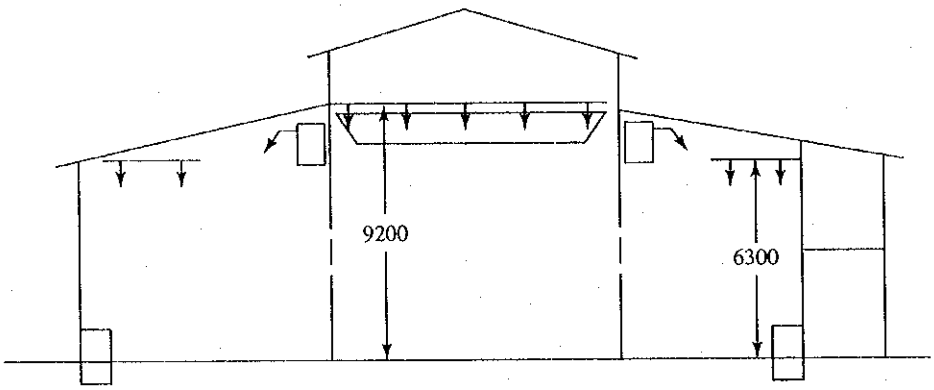
For the height of 6.3 m from the floor: 32 pieces

For the height of 9.2 m from the floor: 97 pieces

Blower for the nozzles: 1.5 kW × 2 units, 2.2 kW × 2 units, 3.7 kW × 3 units

Figure 10.29 shows the installation of the nozzles.

Figure 10.29 High-Velocity Nozzles Installed at the Upper Locations



(4) Energy conservation effect

The temperature difference in the upper and lower portions in the room was, as a whole, reduced from 3 °C to 1.3 °C.

10.3.4 Efficiency Improved by Modifying the Fuel Oil-fired Hot-Air Heating into the Steam-based Warm-Air Heating

Category of industry: Manufacture of automobiles

No. of employees : 21,000

Energy consumption (annual):

Fuel oil : 22,642 kL

Electricity: 692,755 MWh

LPG : 13,055 t

(1) Equipment to be improved

The overview of the existing fuel oil-fired hot-air heating for the car body, painting and assembly shops is as shown below.

Burner

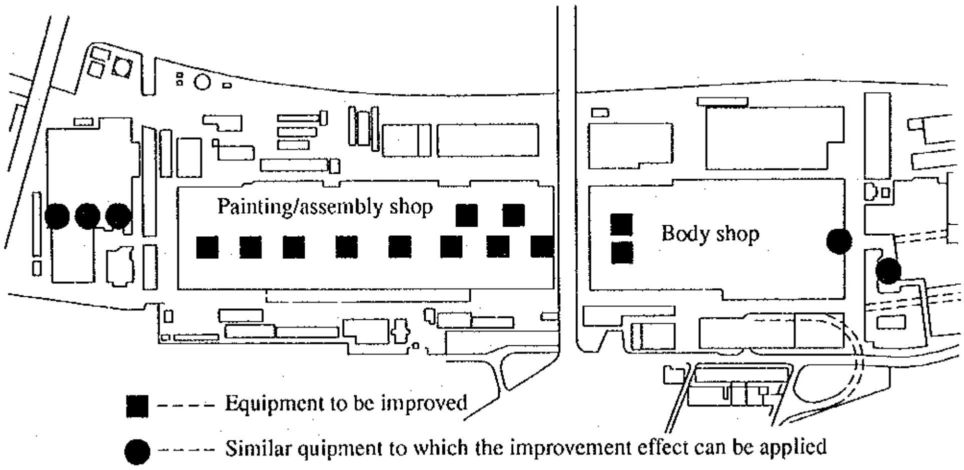
Type	: Fully automatic rotary
Maximum fuel oil consumption	: 170 L/h
Capacity of heat exchanger	: 800,000 kcal/h

Blower

Type	: Limit load fan
Volume of air supplied	: 90,000 m^3/h
Motor	: 37 kW

Figure 10.30 shows this system.

Figure 10.30 Layout of Heating Equipment



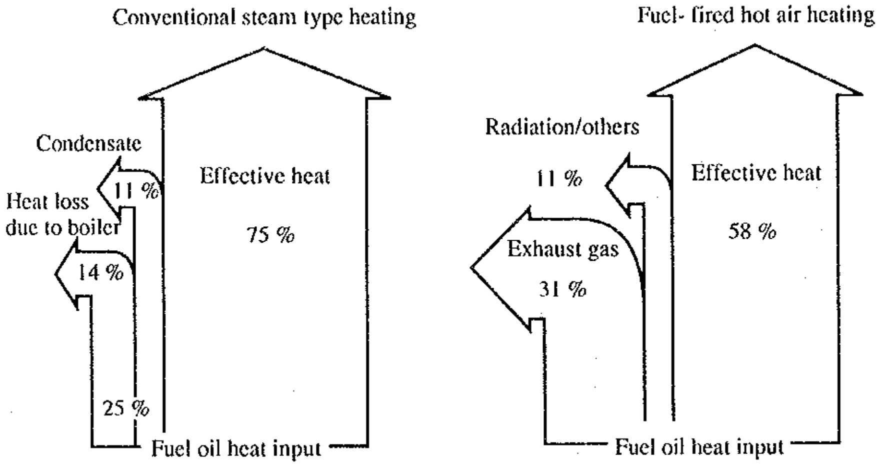
(2) Problems

Since this system is poor in energy efficiency, the required capacity changes along with the change in the operating condition in the factory. Thus, the optimization needs to be performed in accordance with the current operating situation.

(3) Countermeasure

Figure 10.31 shows the comparisons of energy performances between the existing fuel oil-fired heating equipment and the steam-type heating equipment under consideration.

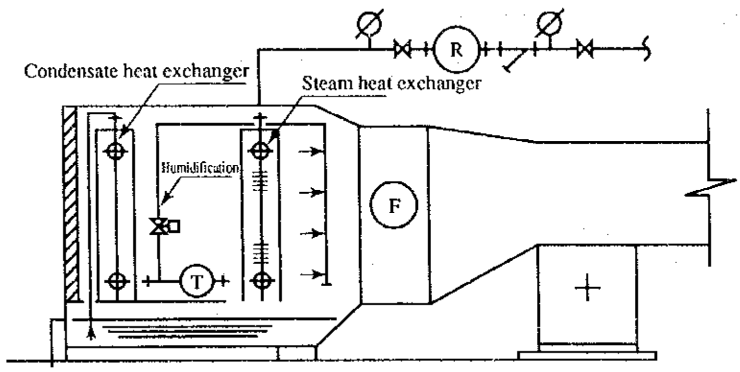
Figure 10.31 Comparison of Energy Balances



As shown in the figure, the hot-air heating system has a large heat loss due to exhaust gas and thus poor heat efficiency compared with the ordinary steam type heating.

The newly installed steam type heating system was so designed that the heat of the steam condensate would also be utilized for the condensate heat exchanger.

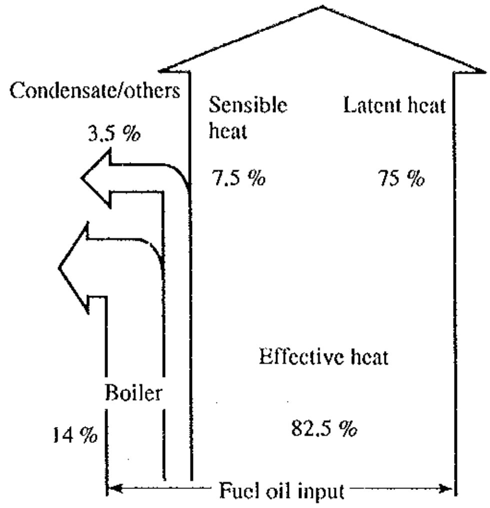
Figure 10.32 Improved System



(A humidifier using condensate was newly installed)

As a result of utilizing the sensible heat from the condensate, the heat balance was as shown in Figure 10.33 and the heat efficiency was 82.5 %, representing an improvement by as much as 42 %.

Figure 10.33 Energy Balance after Improvement



(4) Energy conservation effect

In addition to the renewal of heating equipment, warm-air ducts were consolidated or abolished according to the operation in the factory. The improved efficiency reduced the fuel oil consumption to half and power consumption to one-third. Also the number of the operators reduced to half.

10.3.5 Monitoring the Room Temperature

Category of industry : Manufacture of automobiles

Number of employees: 8,700

Energy consumption (annual):

Electricity	: 448,324 MWh
Butane gas	: 12,957 t
Fuel oil	: 35,537 kL
Coke	: 37,553 t

(1) Problems

While the unit heaters are automatically controlled at each worksite by the bellows type thermostat for each zone, they have a large disparity in the operating accuracy, resulting in the excessive heating. Figure 10.34 shows an example of measurement, and Figure 10.35 shows the temperature setter.

Figure 10.34 Overview of the Equipment to be Improved

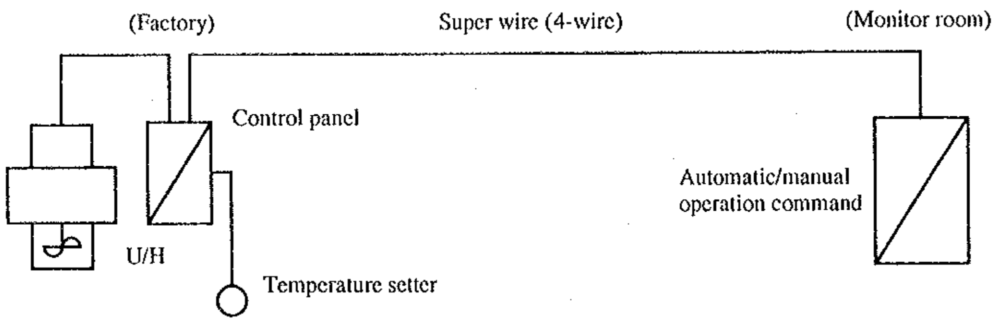
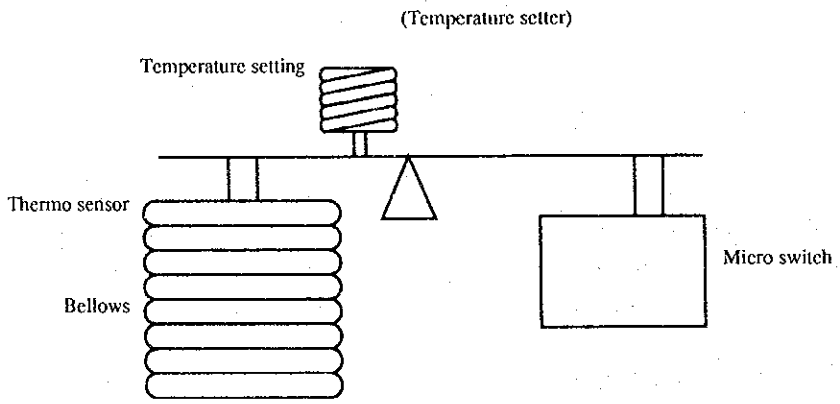


Figure 10. 35 Temperature Setter



(2) Countermeasures

a. Improving the accuracy of the thermostat

The bellows type thermostat was changed to the platinum resistance sensing element.

b. Controlling the setting temperature in the monitor room

A temperature signal was transmitted to the monitor room by the temperature transmitter, to set the temperature by means of the sequencer and personal computer.

c. Displaying the factory room temperature

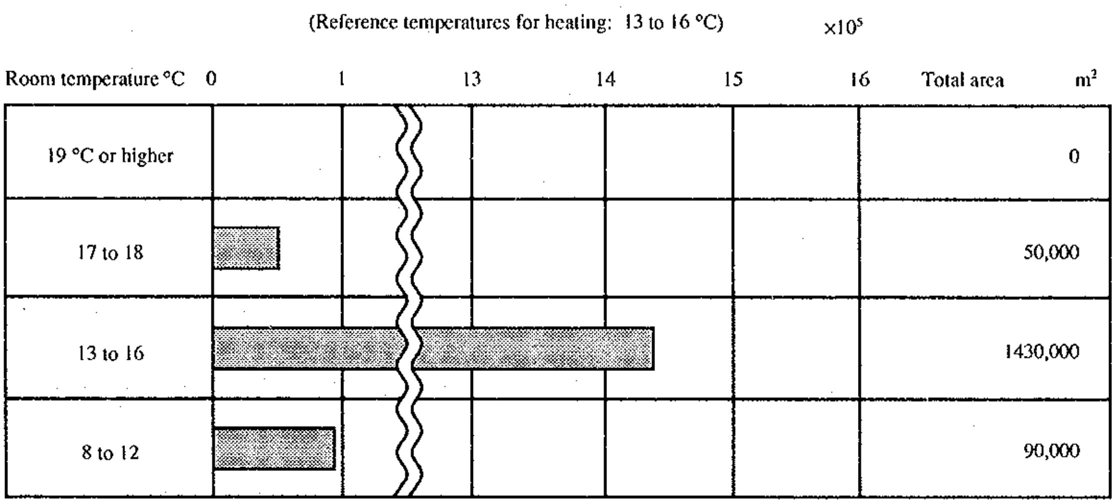
The factory room temperatures were represented in graph on the personal computer to open/close the heating valves at good timing.

(3) Energy conservation effect

The room temperature survey after improvement disclosed that the excessive heating decreased as shown in Figure 10.36. This reduced the steam consumption for heating: annual savings of 1,522 kL in terms of fuel oil.

Figure 10.36 Room Temperature Surveyed after Improvement

Measured on February 16, 1992



10.3.6 Heating/Hot Water Supply System Utilizing Factory Waste Heat

Category of industry : Training facilities in the company which manufactures and supplies the city gas

Number of employees: 15

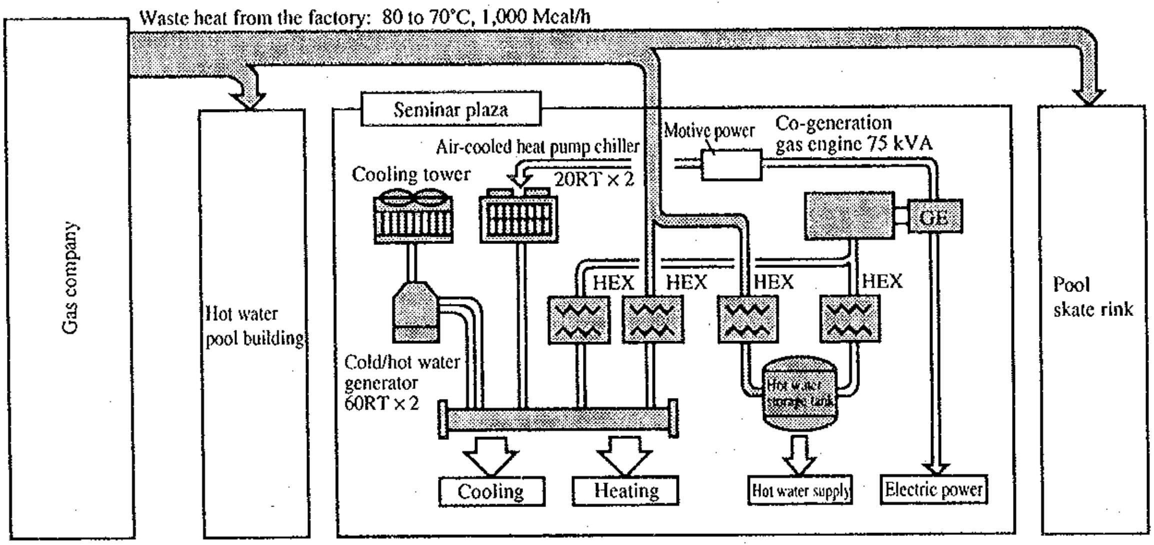
Energy consumption (annual):

City gas : 66,371 m^3_N
Electricity: 671,362 kWh

(1) Equipment to be improved and countermeasures

At installation, training facilities were so designed as to utilize the hot water from the company's own adjacent factory, which manufactures the coal gas and also to install co-generation system utilizing gas engine in order to reduce the peak power demand. Figure 10.37 shows the overview of the equipment.

Figure 10.37 Overview of the Equipment to be Improved



(2) Energy conservation effect

Table 10.6 shows the comparison of annual energy costs between this system and the existing system (assumed).

Table 10.6 Reduction Amount of Running Cost (for the year 1990)

	Conventional system (Unit: thousand yen)	Current system (Unit: thousand yen)	Running cost	
			Reduction amount	Reduction rate
Air-conditioning				
Electricity	585	621		
Gas	5,626	3,514	1,001,000 yen	84 %
Waste heat	–	1,075		
Hot-water supply				
Gas	939	–	556,000 yen	41 %
Waste heat	–	383		
Power consumption	975	–	975,000 yen	0 %
Total	8,125	5,593	2,532,000 yen	69 %

This table shows that the annual running cost was reduced by 69 %.

10.3.7 Induced Draft System by the Duct Installed on a High Ceiling

Category of industry : Manufacture of electrical appliances (Controls for industrial use, controls for power generation, devices for vehicles, etc.)

Number of employees: 6,758

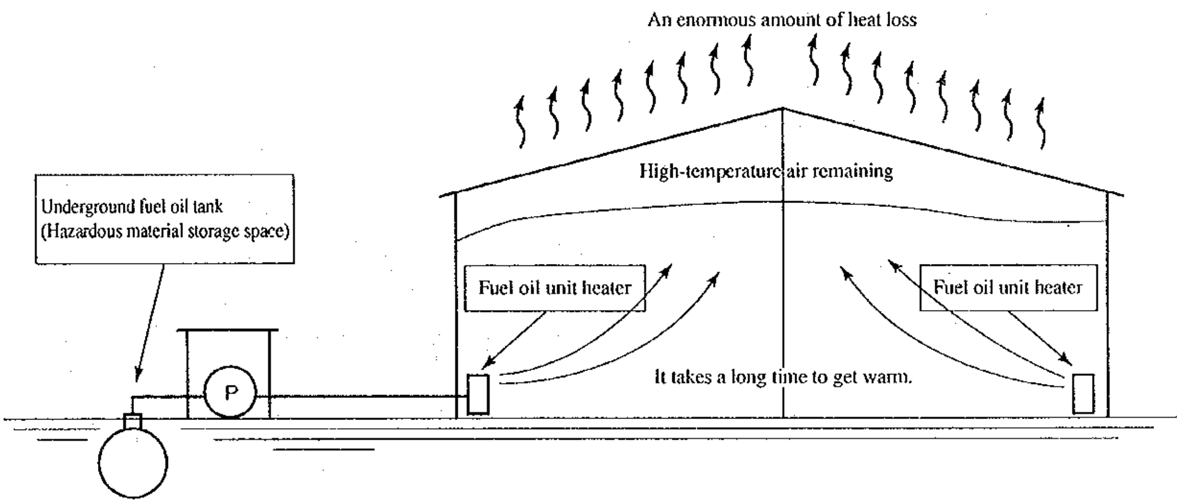
Energy consumption (Annual):

Fuel oil : 3,694 kL, City gas: 3,223,000 m^3
Electricity: 86,381 MWh

(1) Equipment to be improved

The factory, built in 1950's, has a high ceiling and fuel oil-fired unit and uses the heaters installed on the floor for heating. Figure 10.38 shows the conceptual diagram.

Figure 10.38 Overview of Equipment to be Improved



(2) Problems

a. It takes a long time to heat the floor working area because the warm air blown out from the heater goes up and remains there.

b. The warm air that thus rises up and stays there heats the roof, window outer wall, etc. more than necessary, and as a result, most of input energy is consumed as the heat loss due to radiation.

Along with the shift to the use of gas this time due to the need for the compliance to the fire laws, which has been requested since a few years ago, resolving of the above long-standing problems was also attempted.

The measurement of the present temperature distribution and the changes on a time basis disclosed the following problems.

- The temperature at high ceiling portion (15 m from the floor surface) reaches 20 °C in 1 hour after the start of heating, and then goes as high as 40 °C.

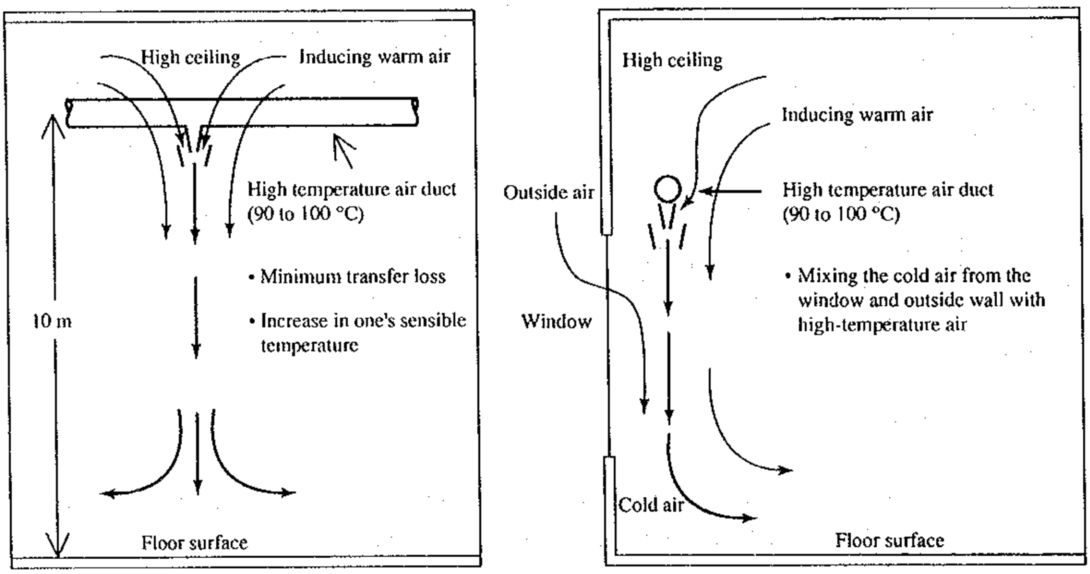
- In contrast, it takes 4 to 6 hours for the working area floor surface to rise up to 20 °C.

(3) Countermeasures

The heat radiation calculation shows that 42 % of the present heating capacity would be enough if 25 °C for the ceiling portion and 20 °C for the working floor portion could be accomplished. Additionally, the relevant fire laws requires the heating equipment to be installed outdoors.

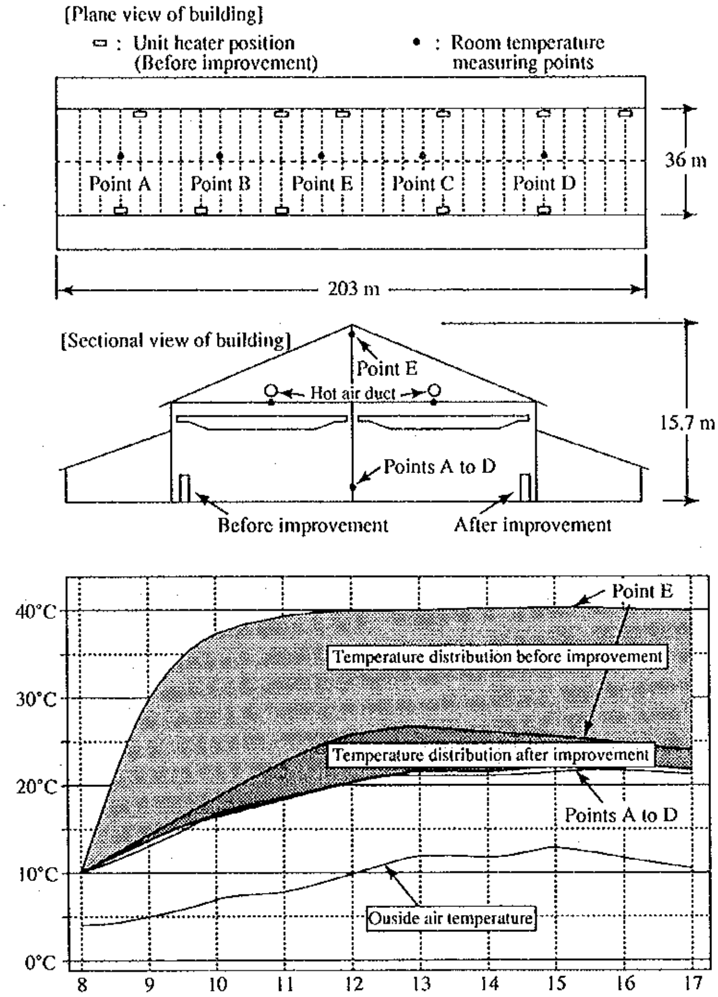
As a countermeasure, a "High ceiling/high-temperature air duct induced draft system" (IHI's product) was to be employed in order to reduce the temperature distribution by circulating high-temperature air. Figure 10.39 shows the conceptual diagram of this system.

Figure 10.39 Features of Reviera Heating System



The implementation of this countermeasure improved the temperature distribution as shown in Figure 10.40.

Figure 10.40 Effects after Improvement (Temperature distribution)



(4) Energy conservation effect

This measure reduced the fuel and power costs by 32.5 % in comparison with those in the past. Also, the heat radiation calculation shows that the reduction in the heat loss from the roof/wall surface and the heat loss due to the exhaust from the stack in turn reduced the radiation heat loss to the half.

References

Norio Matsuda: Daidan Technical Current News, "Air-conditioning Plan and Design for Large-space Production Facilities", No. 63 (May 1991), Daidan Co.Ltd.

Hiroshi Kurita, Katsutoshi Wakabayashi, and Junzou Mabuchi: "Cooling/Heating by Heat Pumps: Case study of air-conditioning systems by heat storage type heat pumps", Yokohama All Printing Company (The Yomiuri Shinbun Group), No. 41, Electric Air-conditioning Study Group.

Masaaki Kato: The Journal of The Japan Institute of Energy, "Far Infrared Space Heating Unit, Sauna Bath and Dryer Unit", Vol. 69; No. 6, The Japan Institute of Energy.

Nissei Oval Co. Ltd: Heating "Factory heating/system cases; Heating for NC machine factory by CO-RAY-VAC and heating for gymnasiums by oil VAC OVSC-301", Vol. 20; No. 233, Japan Heating Industrial Association

Takuma Co. Ltd.: Heating "Factory heating/system cases Machine factory using strip heaters", Vol. 21; No. 235, Japan Heating Industrial Association.

Kiyoharu Sakauchi: Air-conditioning and freezing "Selection and design of factory heating system", 2-1975, Japan Air-conditioning Technology Press

11. ENERGY CONSERVATION IN BOILERS

11. BOILER

11.1 Classification

Now, boilers used universally can be classified by structure as shown in Table 11.1.

Table 11.1 Classification of Boiler

Type	Model
Cylindrical boiler	Vertical boiler Flue boiler Smoke tube boiler Flue smoke tube boiler
Water tube boiler	Natural circulation water tube boiler Forced circulation water tube boiler
Once-through boiler	

11.1.1 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 1.0 MPa (10 kgf/cm^2 (G)) and 8 t/h in evaporation.

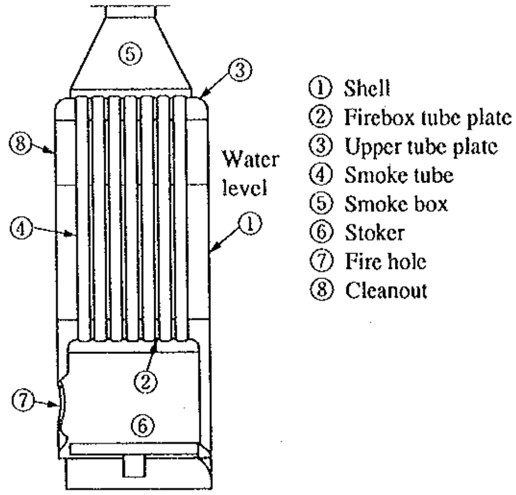
Since the cylindrical boiler has a larger water retaining volume per capacity compared with water-tube boiler, it demands much time to start up but a pressure fluctuation due to loading change is small.

(1) Vertical boiler

As shown in Figure 11.1, vertical boiler has a vertical cylinder and a combustion chamber in the bottom section. There are two systems of horizontal tubular type and multi-tubular 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 simply set 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 large.

Figure 11.1 Vertical Boiler (Multitubular type)



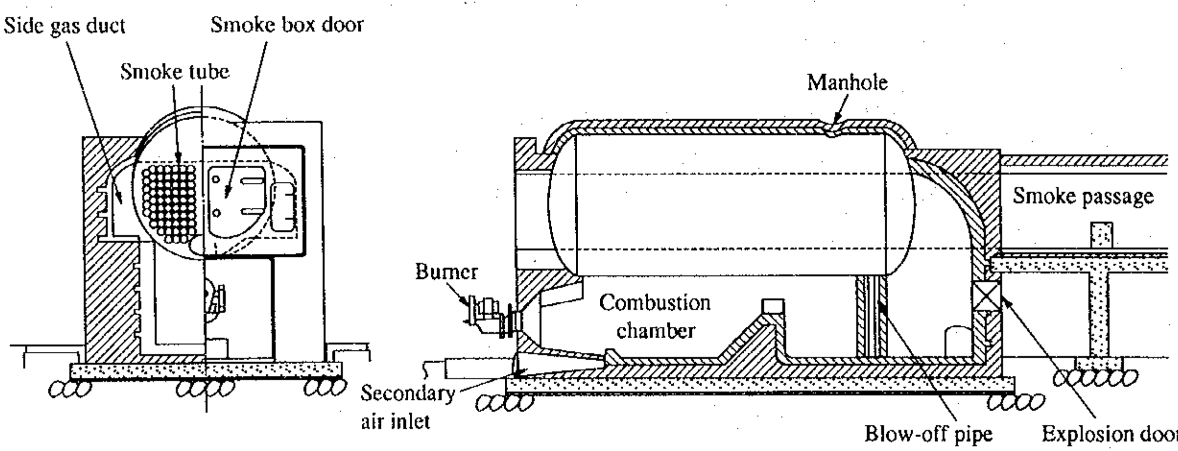
(2) Flue boiler

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-flue 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.

(3) Smoke tube boiler

As shown in Figure 11.2, 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.

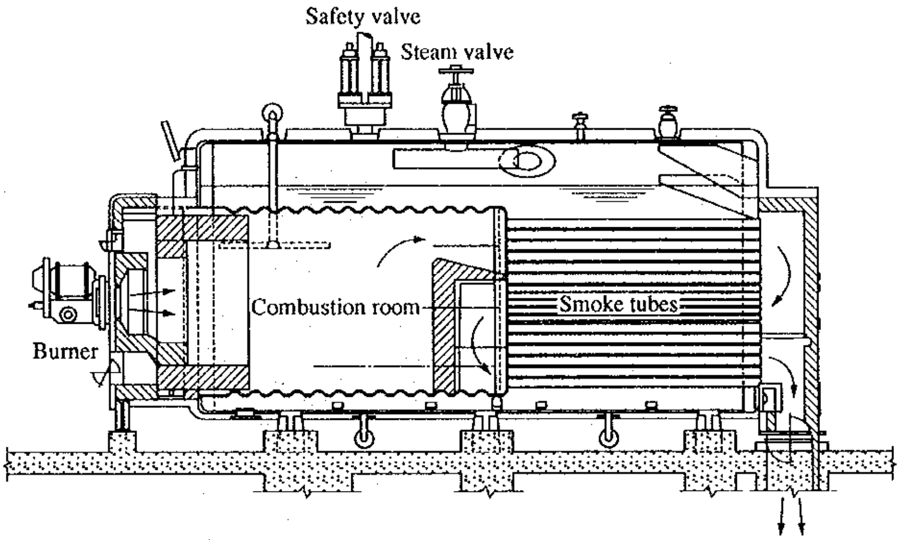
Figure 11.2 Externally Fired Horizontal Smoke Tube Boiler



(4) Flue smoke tube boiler

As shown in Figure 11.3, 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 generally limited to 1.5 MPa (15 kg/cm^2 (G)) in pressure and 25 t/h in capacity. An efficiency of 85 of 92 % is obtainable. On the other hand, the structure is complex, check and cleaning of the inside are difficult and feed water is required to be high quality.

Figure 11.3 Flue Smoke Tube Boiler



11.1.2 Water-Tube Boiler

As shown in Figure 11.4, 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 feed water evaporate 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 capable of obtaining a high pressure easily. The features of water-tube boilers are as follows:

(1) Because the combustion chamber can be made in any size, the combustion is in good condition and various fuels can be adapted easily.

(2) The thermal efficiency is higher because of a larger heating surface area.

(3) 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.

(4) 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 11.5). A high pressure boiler is required to adopt a forced circulation system because of the density difference between steam and water is small.

Figure 11.4 Water Tube Boiler

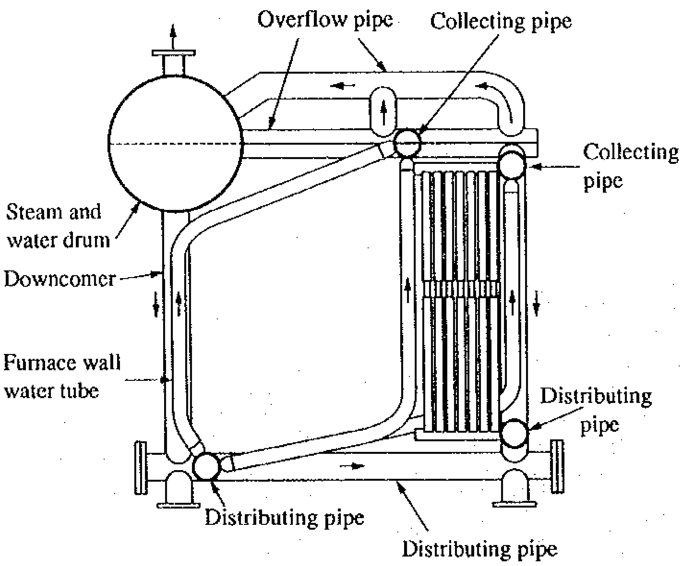
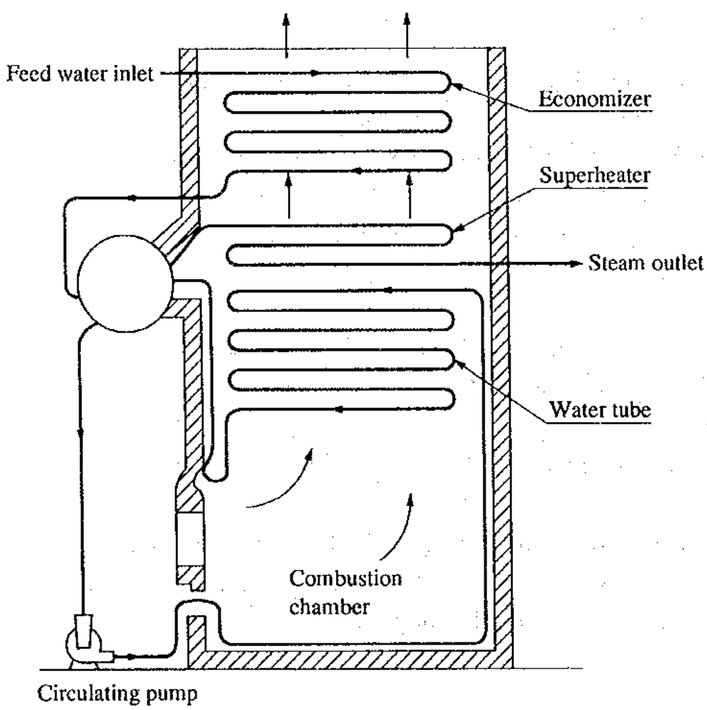


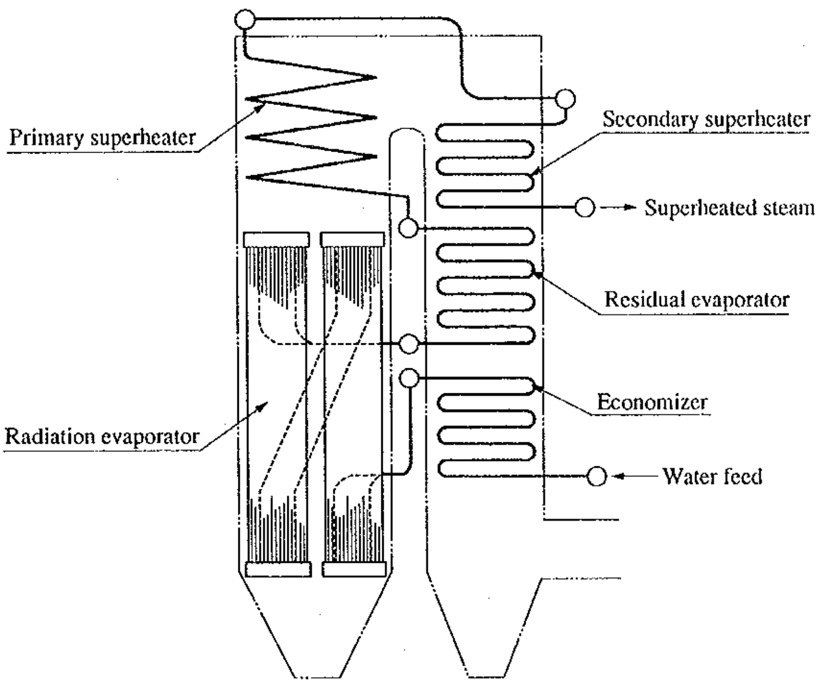
Figure 11.5 Forced Circulation Boiler



11.1.3 Once-through Boiler

A once-through boiler only composed of a series of long water tubes is so designed 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 11.6).

Figure 11.6 Schematic Flow Diagram of Benson Boiler (Once-through Boiler)



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

- Suit a high pressure boiler because there is no steam separator.
- Allow a compact design.
- Start-up time is short because of an extremely small amount the retaining water 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 once-through boiler has been applied in a wide variety from a supercritical pressure boiler to a small scale boiler.

Especially in recent years, also available is an increasingly popular method in which 3 to 10 small-size once-through boilers with the capacity of 1 t/h to 2 t/h are installed in order to change the number of operating units and the combustion rate according to the load.

11.1.4 Other Boilers

Other boilers include 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.

11.2 Boiler Trouble Prevention

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

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

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

The points remarked to prevent trouble are as follows:

11.2.1 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.

11.2.2 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 11.2 shows the routine check items for boilers.

Table 11.2 Daily Inspection of Boiler (1/18)

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
Routine inspection	1. Pressure of boiler	O				1. Reading. Check of the pointer movement.	1. Smooth moving without catching
					O	2. Surface temperature. Leakage	2. Check heat by hand touch.
				O		3. Initial and stop pressure of pressure controller.	3. No disorder. See item 9. Adjust the control range if necessary.
					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.

Table 11.2 Daily Inspection of Boiler (2/18)

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
Routine inspection	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 of the gage is clogged, the movement becomes dull. Compare the water levels of two water gages which are equipped in different levels. Attention should be paid for the water leakage of conncection pipe.
			O			2. Normality of water level at start and stop of the feed water pump.	2. Float type (mercury switch), Electrode type, etc. Attention shall be paid for scattering of mercury, disorder of link mechanism and dirt etc.
					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.)
	3. Combustion state	O				1. Change of burning sound.	1. Take care to abnormal sound at the start of combustion and during the rating up from low to high operation.
			O			2. Shape and color of flame.	2. Proper flame without touch to furnace wall 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 taken to a long time operation under a low load.

Table 11.2 Daily Inspection of Boiler (3/18)

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	4. Gage glass	○				1. Check of gage glass.	1. Open a drain cock, close a steam cock and blow out boiler water sufficiently. And then close the water cock, open the steam cock, check the steam side, then close the drain cock, open the water cock and watch forcible rising of water level.
					○	2. Check the open and closing condition and any leakage of each cock. Clean the inside.	2. Repair any leakage from the upper and lower glasses. Check whether or not the glass is mounted properly and it length is adequate.
			○				3. Clean the glass. Use a predetermined length of glass if exchanged. Take 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)	○				1. Check the open and close condition of the inter-connecting line and clean the inside.	1. Drain water in the column and remove sludge and scale.
					○	2. Built-in water level detector. Inspect the electric wiring terminal, any dirt and deterioration of the insulation of the electrode holder, dirt and crack of the electrode.	2. Check the electric wiring (heat resistance wiring). Measuring of insulation resistance—remove the wiring for the electrode holder to measure the resistance between the electrode and the earth. Confirm that its value is more than 100 MΩ. Clean the electrode. Check dirtiness and deterioration of the electrode holder including crack. Exchange it if necessary.

Table 11.2 Daily Inspection of Boiler (4/18)

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 (ancillary equipment of the Boiler)	6. Automatic feed water flow control device. Low level breaker. High and low water level alarm.		○			1. Check the open and close condition of the inter-connecting line. Check dirtiness inside.	1. Purge scale and sludge in the interconnecting pipe. Clean the inside (blow enough) in a condition of lower pressure if possible.
			○			2. Check the operational conditions by lowering the water level by blowing.	2. Make sure the operational conditions with blowing. If impossiblé to blow, remove the electric wire to check the operational conditions (stopping combustion).
					○	3. Check the internal mercury switch and bellows.	3. Check a scattering of mercury and balance. Check water leakage from the bellows.
					○	4. Check the electric wiring.	4. Check damage due to heat. Rewire with a heat resistance wire.
					○	5. Check a wrong operation due to vibration.	5. Mount a reinforcement stay Relocate of the device.
					○	6. Check dirtiness, crack and leakage of the electrode holder.	6. Replace the cracked and leaking insulator with a new one and clean the electrode. Insulation resistance shall be more than 100 MΩ.
	7. Automatic feed water flow control device (single element type)			○		1. Check the open and close condition of the valve in the connecting pipe and clean the inside.	1. Discharge scale and sludge in the interconnecting pipe of the thermostat.
				○		2. Check and adjust each inter-connection.	2. Make sure the specified position of the slide sprocket weight.
			○			3. Adjustment of the water level.	3. Adjust the water level control range according to the operational conditions.

Table 11.2 Daily Inspection of Boiler (5/18)

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 (ancillary equipment of the boiler)	8. Flame detector			○		1. Fire going-out, no ignition.	1. Both main burner and pilot burner shall be checked respectively.
					○	2. Check the degree of deterioration of a detector.	2. Measure the current by a microammeter, test by a false (test) flame.
					○	3. Defect of electric wiring. Influence of induced current of power.	3. Change to the independent shield wire.
					○	4. Detection of false (test) flame. Self-discharge. Check by a protect relay, no ignition.	4. Check mistake to detect red heated refractory as a flame and in this case, change the position of installation. A deteriorated tube shall be replaced.
				○		5. Check the dirtiness of lens and glass tube. Mounting position.	5. Cleaning of dirt. Mount them in correct position.
					○	6. Check (+ or –) phase of the electric wiring and loosening of connection.	6. Change the wiring and tighten it if necessary.
					○	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 11.2 Daily Inspection of Boiler (6/18)

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 (ancillary equipment of the boiler))	9. Pressure restriction device				O	1. Check the operation stop pressure and the setting of control range.	1. Clean and check the siphon pipe, meter cock and the detective part of the bellows. Change the setting of control range.
					O	2. Check leakage and deformation in the bellows of the detector. Check whether it is mounted in correct position.	2. Removal and installation shall be carried out from the base part in principle. Device is easy to get damaged if temperature goes up. In this case, the longer siphon tube shall be adopted.
					O	3. Check the two step setting values for control of high- and low-off.	3. Setting value shall be adjusted according to operation load.
					O	4. Check damage of the electric wire.	4. Check and replace it if necessary.
	10. Pressure controller				O	1. Check the width of proportional band.	1. Change the width of proportional band according to the operation load.
					O	2. Check inferior contact, dirtiness and disconnection or break of resistance wire of the potentiometer.	2. Check, clean and replace it.
					O	3. Check clogging of the detecting part.	3. Refer to item 9-2.
	11. Air 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.

Table 11.2 Daily Inspection of Boiler (7/18)

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 (ancillary equipment of the boiler)	12. Oil temperature switch				O	1. Check the setting value.	1. Set to a proper oil temperature for burner.
					O	2. Check dirtiness and installing condition of the heat sensitive cylinder and the detecting part.	2. Clean dirt. Investigate the length and replace it if it is not adequate. Investigate the installing location.
					O	3. Check the configuration of detecting part.	3. Check the defects and repair. Not exposed to the atmosphere directly.
	13. Latch switch. Low and high interlock, damper lock and burner lock				O	1. Check the setting of each latch switch.	1. Check that it is set in a proper position.
					O	2. Check loosening of the setting of installed position.	2. Check and adjust.
					O	3. Check the operational conditions of the interlock.	3. Check the operational conditions, inspect and repair if necessary.
	14. Control motor			O		1. Check the movement.	1. Smooth movement is required.
					O	2. Check the contact conditions of the balancing relay.	2. Check arc generation and clean the contact part. Investigate the installing position not to be influenced by vibration. Countermeasures shall be taken if necessary.
					O	3. Check dirtiness and contact defect of the potentiometer.	3. Inspection and cleaning.

Table 11.2 Daily Inspection of Boiler (8/18)

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	15. Pilot burner			O		1. Check the gas pressure.	1. Adjust the gas pressure.
					O	2. Check a deterioration of the ignition transformer.	2. Check a spark between the electrode and the earth to be 7 to 8 mm in atmosphere.
					O	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
					O	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper range.
					O	5. Check the clearance between the nozzle and the electrode.	5. Adjust a clearance to make it proper.
	16. Electric pilot firing device				O	1. Check an electric spark state.	1. Blue color is normal. If reddish, cleaning is necessary. Short spark is caused by a narrow clearance.
					O	2. Check of dirtiness and position of the pilot firing device.	2. When a frequent cleaning is required, electrode setting is not proper. If the electrode is set within the fuel jetting angle, the electrode is wetted with oil and doesn't spark. The electrode should be set to the specified position.
					O	3. Transformer insulation defect. Deteriorated lead wire.	3. Check the transformer and clean the insulator. Check the lead wire for any damage of the lead wire.

Table 11.2 Daily Inspection of Boiler (9/18)

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. Check and repair the burner tile.	1. Remove carbon and sludge.
				O		2. Check the atomizing cap and the shape of tip.	2. Cleaning and repair of tip. Check the size and shape of nozzle and replace it if necessary.
					O	3. Check of the fan and lubrication conditions.	3. Remove sludge and oil. Clean the shaft and the lubricating pipe. (Rotary burner)
					O	4. Check the bearing and sealing. (Rotary burner)	4. Apply grease and check the bearing, sealing and repair if required.
				O		5. Check the diffuser for any damage and carbon deposit.	5. Cleaning and adjustment of the pitch of the diffuser.
					O	6. Gun type burner. Check dirtiness of tip and strainer.	6. Disassembly and cleaning. Check the tip hole size.
					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 take countermeasures. Replace the bearing. Desassembly, repair and reassembling.
					O	9. Oil leakage	9. Repair leaking place.
					O	10. Burner fan belt	10. Replace cracked belt.
	18. Fuel shut off valve (main valve)			O		1. Check the shut off valve for any leakage.	1. A fire is extinguished entirely when the valve closed.
				O	O	2. Make sure the shut off valve operates exactly at a low water level or no ignition signal due to a low level or no ignition.	2. Check the operational conditions. Confirmation of water level. Repair or replace it if required.
						3. Check the electric wiring.	3. Check damage due to heat. Replace if required.

Table 11.2 Daily Inspection of Boiler (10/18)

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	19. Oil pump			O		1. Check the oil pressure.	1. Set to a proper oil pressure.
					O	2. Check dirtiness of strainer.	2. Remove drain and sludge.
					O	3. Check oil leakage.	3. Repair the leaking place. Replace the oil seal, if necessary.
					O	4. Check overheat and overcurrent.	4. Investigate the cause and replace the bearing.
	20. Oil preheater			O		1. Check the oil temperature.	1. Adjustment of the thermostat.
					O	2. Check dirtiness.	2. Remove drain and sludge.
					O	3. Check oil leakage.	3. Repair the leaking place.
					O	4. Check the sheath heater.	4. Scale and sludge removing.
	21. Service tank. Storage tank.			O		1. Make sure the oil level control system.	1. Make sure the operational conditions of the float switch and other controller.
					O	2. Temperature control. Operational conditions of the control valve and the steam solenoid valve.	2. Check leakage and operational conditions.
					O	3. Clean the oil strainer.	3. Cleaning of the element.
				O		4. Check the receiving quantity and the residual quantity.	4. Check and record.
					O	5. Check a leakage from the tank and the piping line.	5. Repair the leaking place.
					O	6. Remove drain and sludge.	6. To be carried out periodically.

Table 11.2 Daily Inspection of Boiler (11/18)

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	22. Oil flow meter		O			1. Check the oil flow meter indication record.	1. Disassemble and clean the meter and replace the parts if necessary.
					O	2. Grasp the oil temperature passing through the meter.	2. Since the efficiency calculation is based on the oil amount at passing through the meter and the amount is affected by the temperature (specific gravity), the oil temperature should be measured for correct calculation.
	23. Oil quantity controller			O		1. Check the link mechanism to the controller.	1. Adjust the link mechanism compared with the air volume. Check disorder and adjust it.
					O	2. Check the oil quantity by a flow meter measurement. Check dirtiness.	2. Check by operational condition and oil quantity. Disassemble and clean it if necessary.
	24. Oil strainer			O		1. Check the strainer operational conditions.	1. In autocleaner, turn the handle. In a change type strainer, a spare one should be always cleaned.
					O	2. Check the inlet and outlet pressure.	2. Remove drain and sludge. Grasp a good rating of cleaning by pressure difference between the inlet and the outlet. 3. Periodical cleaning. 4. Standardization of the cleaning work.

Table 11.2 Daily Inspection of Boiler (12/18)

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	25. Forced draft fan			○		1. Check abnormal sound and overcurrent.	1. If abnormal, disassemble and service it, and replace the bearing.
					○	2. Check foreign matter in the suction port.	2. Mount a wire gauze not to suck foreign matter.
					○	3. Check vibration. Check the belt.	3. Loosening of installed bolts. Loosening of the runner. Remove any deposit to the runner. Replace the bearing and belt if necessary.
	26. Damper			○		1. Check the link mechanisms of the primary and main dampers.	1. The damper should be adjusted to be opened slowly.
				○		2. Check the opening of damper.	2. Check distortion or loosening.
					○	3. Check of the pressue.	3. Adjust the draft in the outlet of boiler by the dumper. 0 ± 2 mm Aq in a pressurized combustion of rated operation.
				○		4. Check leakage of dampers and deterioration in operation.	4. Check and repair.
	27. Internal pressure gage of boiler			○		1. Check the indication of internal pressure gage of boiler.	1. Check a clogging in lead pipe. Check the opening and closing conditions of cock valve for the pressure gage. Check and repair a leaking point due to corrosion.
	28. Soot indicator of smoke					1. Check a difference between the indication and the actual soot concentration in smoke.	1. Cleaning of glass. Adjust a light source and a light receiving device. Blow air from a compressor for purging.
						2. Adjust the zero point.	2. Set the zero point.

Table 11.2 Daily Inspection of Boiler (13/18)

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	29. Exhaust gas analyzer			O		1. Check the operational condition of pointer.	1. Check a clogging and leakage in the lead pipe. Cleaning or replacement of the filter and tightness test of the lead pipe.
					O	2. Adjustment of the analyzer.	2. Adjustment of the water quantity in aspirator. Comparison of a normal operation through passing air to the sensor or analyzed gas by Orsat.
	30. Flue and stack				O	1. Check leakage and corrosion.	1. Inspection and repairing.
					O	2. Check dirtiness in the flue and the stack.	2. Remove soot, etc. in the flue and the stack. Periodical cleaning.
					O	3. Invasion of rainwater.	3. Discharge of rainwater.
	31. Water softening equipment			O		1. Check of the water pressure.	1. Adjust the pressure. Check leakage through the shut off valve.
					O	2. Check of hardness. Check in the secondary side.	2. Check periodically and at the time required.
					O	3. Leakage from the perforated valve.	3. Check for any leak from the seat part or packing of the valve.
					O	4. Care must be taken to leak during a stop of the pump operation.	4. Close valves to prevent leakage.

Table 11.2 Daily Inspection of Boiler (14/18)

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.	1. Confirmation of water level. Check clogging and leakage.
			O			2. Operational condition of low level alarm lamp.	2. Test in an actual level drop or test by an electric false signal.
			O			3. Make sure the level control performance.	3. Make sure the operational conditions by controlling manually.
			O			4. Check of temperature.	4. Check of abnormality. Check of trap.
					O	5. Check the painting on the tank inside and corrosion.	5. Check, repair and cleaning.
	33. Chemicals dosing device			O		1. Check the chemicals dosing condition.	1. Check contamination in the tank and the flow rate.
				O		2. Check a linkage to the feed water pump.	2. Check the operational condition and adjust it if required.
					O	3. Check leakage or clogging.	3. Inspection and repair.
	34. Feed water pump			O		1. Check overcurrent.	1. Adjust the valve opening degree.
					O	2. Check leakage from the gland.	2. Replace and tighten a packing.
					O	3. Check the lubrication condition.	3. Provide oil and grease if necessary.
					O	4. Check disorder of coupling.	4. Repair or replacement.

Table 11.2 Daily Inspection of Boiler (15/18)

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
	35. Injector				O	1. Check the operational condition.	1. Impossible to feed when the steam pressure lowers, the feed water temperature rises, air is sucked, and the feed water pressure is too much higher.
					O	2. Inspect the check valve. Adherence of scale, etc.	2. Check, disassemble and clean if required.
	36. Water flow meter strainer		O			1. Check the operational condition.	1. Check the actual situation and operational condition, and record them.
					O	2. Check clogging in the strainer.	2. Disassemble and clean.
	37. Check valve in feed water line				O	1. Check back flow.	1. Water hammer. Feed water pipe feels hot to the touch. Overhaul or replacement.
	38. Feed water inlet pipe				O	1. Check clogging in the inlet pipe.	1. Insufficient feed water quantity. Overhauling if required.
					O	2. Deterioration of the gasket packing for installation of the inlet pipe.	2. Water hammer. Replace the gasket packing.
	39. Relief valve		O			1. Check leakage of steam.	1. Repair the leaked place and overhauling if required.
					O	2. Check the working pressure.	2. Adjust the working pressure range according to the specification.
					O	3. Check the popping steam volume.	3. When the pressure rising in a rated combustion is 6 % or more even in the relief valve working, it is not acceptable.

Table 11.2 Daily Inspection of Boiler (16/18)

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
	40. Blow off valve			O		1. Check any leakage. Check heat by hand touch.	1. Overhaul or replacement if the leakage is found.
				O		2. Check the operational condition of valve.	2. Blow off with the boiler proper side as a quick opening valve and the secondary side as a slow opening valve. For 10 kg/cm^2 (G) or more, installation of two valves is required.
					O	3. Check the discharge port.	3. Check the pit size and the operational condition of silencer.
	41. Manhole			O		1. Check leakage from the manhole.	1. Tightening, replacement of gasket if required.
					O	2. Check the flange surface where gasket packing is mounted.	2. Apply graphite to prevent leakage. Keep the flange surface clean where the gasket packing is mounted.
	42. Insulation with casing				O	1. Check gas leakage.	1. Gas leakage should be checked and repaired as soon as possible.
					O	2. Check discolored place.	2. Find out the cause of overheat, check and repair.
	43. Refractory material				O	1. Check damage, falling and abnormality.	1. Repair the refractory materials as soon as possible.
					O	2. Check gas leakage.	2. Repairing.
	44. Inspection port. Cleaning port. Mounting part of ancillary equipment.				O	1. Check leakage of steam and water.	1. Repair the leaked place. Tightening, replacement of gasket packing.

Table 11.2 Daily Inspection of Boiler (17/18)

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
	45. Explosion door			O		1. Check gas leakage.	1. Repair a leaking portion.
					O	2. Check the spring.	2. Deteriorated 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 contactor of relay.	1. Replace the contactor and relay.
					O	2. Check loosening of the terminal.	2. Tighten the terminal.
	47. Timer. 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 disorder of the cam mechanism setting.	2. Check based on sequence.
	48. Actuation lamp Indicator lamp			O		1. Check a disconnection and luminosity.	1. Replace the lamp.
					O	2. Inferior contact.	2. Tightening.
	49. Spare fuse lamp				O	1. Check the spare parts.	1. Supplement of fuse and lamp spare.
	50. Protect relay (Timer motor)			O		1. Check the operational condition.	1. Check the sequence. Replace if inferior.
					O	2. Check the fixing and tightening of relay and the contactor.	2. Check the operational condition.
					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. Check of dirtiness.	2. Cleaning. Suck dust by a vacuum cleaner.

Table 11.2 Daily Inspection of Boiler (18/18)

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				○	1. Measurement of insulation resistance.	1. Measuring by 500 V megger. Measure in a removing condition of a low voltage equipment. If panel and secondary side has resistance less than 5 MΩ, inspection or repair is required.
	53. Electric wiring				○	1. Check overheat, damage and discoloration.	1. Check the wiring Repair or replace it if necessary.
					○	2. Check damage of coating.	2. Use care to a discolorization of the wiring around the terminal.
					○	3. Check of phase.	3. Pay attention to safety

11.2.3 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 could cause an accident to occur. 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 within 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 that 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 11.3 to Table 11.6.

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 2.0 MPa (20 kgf/cm^2 (G)) 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 contribute to energy conservation by reduction of makeup water and recovery of heat from condensate. But, on the way of recovery, O_2, CO_2 or iron rust 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.

Table 11.3 Quality of Feed Water and Boiler Water for Cylindrical Bolier

Classification					
Classification	Max. Servicing Pressure MPa		Below 1		From 1 to 2
	Max. Servicing Pressure kg/cm^2 (G)		Below 10		From 10 to 20
	Rate of Evaporation of heating surface ($kg/m^2 \cdot h$)	Below 30[1]	From 30 to 60	Over 60	–
	Type of make-up water	raw water[2]		softened water	
Feed water	pH (at 25 °C)	7-9	7-9	7-9	7-9
	Hardness ($mgCaCO_3/L$)	Below 60	Below 1	Below 1	Below 1
	Fat and Oil (mg/L)[3]	[4]	[4]	[4]	[4]
	Dissolved Oxygen (mgO/L)	[4]	[4]	[4]	[4]
Boiler water	Treatment Method		Alkali treatment		
	pH (at 25 °C)	11.0-11.8	11.0-11.8	11.0-11.8	11.0-11.8
	Alkalinity (pH 4.8) [5] ($mgCaCO_3/L$)	100-800	100-800	100-800	Below 600
	Alkalinity (pH 8.3) [6] ($mgCaCO_3/L$)	80-600	80-600	80-600	Below 500
	Total solids (mg/L)	Below 4000	Below 3000	Below 2500	Below 2300
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 6000	Below 4500	Below 4000	Below 3500
	Chloride ion ($mgCl^-/L$)	Below 600	Below 500	Below 400	Below 350
	Phosphate ion[7] ($mgPO_4^{3-}/L$)	20-40	20-40	20-40	20-40
	Sulfite ion[8] ($mgSO_3^{2-}/L$)	10-50	10-50	10-50	10-50
	Hydrazine[9] (mgN_2H_4/L)	0.1-1.0	0.1-1.0	0.1-1.0	0.1-1.0

Notes

(1) It is applied to a cast boiler which steam is used directly and water is made up constantly.

(2) These include tap water, industrial water, ground water, river water, lake and marsh water, etc. Soft water means water obtained by treating raw water by means of softener (filled with cation exchange resin), or by treating raw water by a reverse osmosis device.

(3) It means hexane extract or carbon tetrachloride extract. (See JIS B8224)

(4) It is desirable to keep it low.

(5) It is commonly called M-alkalinity.

(6) It is commonly called P-alkalinity.

(7) It is applied when phosphate is added in water.

(8) It is applied when sulfite is added in water as a deoxidizer.
When a deaerator is to be used, it is preferably adjusted to 10 - 20 mg SO_3^{2-}/L.

(9) It is applied when hydrazine is added as a deoxidizer in feedwater to a cylindrical boiler or a water-tube boiler with the maximum servicing pressure of 2 MPa (20 kgf/cm^2) or less.
When a deaerater is to be used, it should preferably be adjusted to 0.1 - 0.5 mg N_2H_4/L.

* Sulfite or Hydrazine is used separately in principle. (when they are utilized as a deoxidizer)

Table 11.4 Quality of Feed Water and Boiler Water for Water Tube Boiler (1/2)

Classification	Item									
Classification	Max. Servicing Pressure MPa	Below 1			From 1 to 2		From 2 to 3		From 3 to 5	
	Max. Servicing Pressure kg/cm² (G)	Below 10			From 10 to 20		From 20 to 30		From 30 to 50	
	Rate of Evaporation of heating surface (kg/m²·h)	Below 50	Over 50	–	–		–		–	
	Type of make-up water	Softened water			Ion-exchange water (1)		Ion-exchange water (1)		Ion-exchange water (1)	
Feed Water	pH (at 25 °C)	7-9	7-9	7-9	8.0-9.5		8.0-9.5		8.0-9.5	
	Hardness ($mgCaCO_3/L$)	Below 1	Below 1	Below 1	0		0		0	
	Fat and Oil (mg/L) (2)	(3)	(3)	(3)	(3)		(3)		(3)	
	Dissolved Oxygen (mgO/L)	(3)	(3)	Below 0.5	Below 0.5		Below 0.1		Below 0.03	
	Total iron (mg Fe/L)	–	Below 0.3	Below 0.3	Below 0.1		Below 0.1		Below 0.1	
	Total copper (mg Cu/L)	–	–	–	–		–		Below 0.05	
	Hydrazine (mgN_2H_4/L) (4)	–	–	–	–		Over 0.2		Over 0.06	
	Electrical conductivity (25 °C) (μS/cm) (at 25 °C)	–	–	–	–		–		–	
Boiler water	Treatment Method	Alkali treatment				Phosphate	Alkari	Phosphate	Alkari	Phosphate
	pH (at 25 °C)	11.0-11.8	11.0-11.8	11.0-11.8	10.5-11.5	9.8-10.8	10.0-11.0	9.4-10.5	9.6-10.8	9.4-10.5
	Alkalinity (pH 4.8) ($mgCaCO_3/L$) (5)	100-800	100-800	Below 600	Below 250	Below 130	Below 150	Below 100	–	–
	Alkalinity (pH 8.3) ($mgCaCO_3/L$) (6)	80-600	80-600	Below 500	Below 200	Below 100	Below 120	Below 80	–	–
	Total solids (mg/L)	Below 3000	Below 2500	Below 2000	–	–	–	–	–	–
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 4500	Below 4000	Below 3000	Below 1500	Below 1200	Below 1000	Below 800	Below 800	Below 600
	Chloride ion ($mgCl^-/L$)	Below 500	Below 400	Below 300	Below 150	Below 150	Below 100	Below 100	Below 80	Below 80
	Phosphate ion ($mgPO_4^{3-}/L$) (7)	20-40	20-40	20-40	10-30	10-30	5-15	5-15	5-15	5-15
	Sulfite ion ($mgSO_3^{2-}/L$)	10-50 (8)	10-50 (8)	10-20	10-20	10-20	5-10	5-10	5-10	5-10
	Hydrazine (mgN_2H_4/L) (9)	0.1-1.0	0.1-1.0	0.1-0.5	0.1-0.5	0.1-0.5	–	–	–	–
	Silica ($mgSiO_2/L$)	–	–	–	Below 50	Below 50	Below 50	Below 50	Below 20	Below 20

Table 11.4 Quality of Feed Water and Boiler Water for Water Tube Boiler (2/2)

Classification	Item									
	Max. Servicing Pressure MPa	From 5 to 7.5			From 7.5 to 10		From 10 to 15		From 15 to 20	
	Max. Servicing Pressure kg/cm^2 (G)	From 50 to 75			From 75 to 100		From 100 to 150		From 150 to 200	
	Rate of Evaporation of heating surface (kg/m^2·h)	-			-		-		-	
	Type of make-up water	Ion-exchange water (1)			Ion-exchange water (1)		Ion-exchange water (1)		Ion-exchange water (1)	
Feed Water	pH (at 25 °C)	8.5-9.5 (10)			8.5-9.5 (10)		8.5-9.6 (10)		8.5-9.6 (10)	
	Hardness (mg$CaCO_3$/L)	0			0		0		0	
	Fat and Oil (mg/L) (2)	(3)			(3)		(3)		(3)	
	Dissolved Oxygen (mgO/L)	Below 0.007			Below 0.007		Below 0.007		Below 0.007	
	Total iron (mgFe/L)	Below 0.05			Below 0.03 (11)		Below 0.03 (11)		Below 0.02 (12)	
	Total copper (mgCu/L)	Below 0.03			Below 0.02		Below 0.01		Below 0.005	
	Hydrazine (mgN_2H_4/L) (4)	Over 0.01			Over 0.01		Over 0.01		Over 0.01	
	Electrical conductivity (25 °C) (µS/cm) (at 25 °C)	-			-		Below 0.5 (13)		Below 0.5 (13)	
Boiler water	Treatment Method	Alkali treatment	Phosphate treatment	Volatile matter treatment	Phosphate treatment	Volatile matter treatment	Phosphate treatment	Volatile matter treatment	Phosphate treatment	Volatile matter treatment
	pH (25 °C)	9.6-10.5	9.2-10.2 (14)	8.5-9.5	9.0-10.0 (14)	8.5-9.5	8.5-9.8	8.5-9.6	8.5-9.8	8.5-9.6
	Alkalinity (pH 4.8) (mg$CaCO_3$/L) (5)	-	-	-	-	-	-	-	-	-
	Alkalinity (mg$CaCO_3$/L) (6)	-	-	-	-	-	-	-	-	-
	Total solids (mg/L)	-	-	-	-	-	-	-	-	-
	Electrical Conductivity (µS/cm) (at 25 °C)	Below 500	Below 400	Below 60 (13)	Below 150	Below 60 (13)	Below 60	Below 20 (13)	Below 60	Below 20 (13)
	Chloride ion (mgCl-/L)	Below 50	Below 50	Below 2	Below 10	Below 2	Below 2	Below 1	Below 2	Below 1
	Phosphate ion (mgPO_4^{3-}/L) (7)	3-10	3-10 (14)	(15)	2-6 (14)	(15)	0.1-3	(15)	0.1-3	(15)
	Sulfite ion (mgSO_3^{2-}/L) (8)	-	-	-	-	-	-	-	-	-
	Hydrazine (mgN_2H_4/L) (9)	-	-	-	-	-	-	-	-	-
	Silica (mgSiO_2/L)	Below 5 (16)	Below 5 (16)	Below 5 (16)	Below 2 (16)	Below 2 (16)	Below 0.3 (16)		Below 0.2 (16)	

Notes

(1) Water refined by an ion exchange equipment using strong acid cation exchange resin and strong basic anion exchange resin. This water is commonly called desalted water. It also includes the refined condensed water treated by evaporator.

(2) It means hexane extract or carbon tetrachloride extract. (See JIS B8224)

(3) It is desirable to keep it low.

(4) It is applied when hydrazine is added into feedwater as a deoxidizer.

(5) It is commonly called M-alkalinity.

(6) It is commonly called P-alkalinity.

(7) It is applied when phosphate is added in water.

(8) It is applied when sulfite is added in water as a deoxidizer. When a deaerator is to be used, it is preferably adjusted to 10 - 20 mg SO_3^{2-}/L.

(9) It is applied when hydrazine is added as a deoxidizer in feedwater to a cylindrical boiler or a water-tube boiler with the maximum servicing pressure of 2 MPa or less. When a deaerater is to be used, it should preferably be adjusted to 0.1 - 0.5 mg N2H4/L.

(10) When the pipe material in the feedwater heater is steel, pH is preferably adjusted to a higher value.

(11) It is preferably maintained at 0.02 mg Fe/L or below.

(12) It is preferably maintained at 0.01 mg Fe/L or below.

(13) For measurement, pass the sample through the column filled with hydrogen ion type strong acid cation exchange resin.

(14) In the case of waste-heat recovery boiler, pH is preferably adjusted within the range from 9 to 10.5, and phosphate ion within the range from 2 to 20 mg PO_4^{2-}/L.

(15) If a substance which will decrease calcium, magnesium and pH should be mixed because of the leakage of seawater from the condenser, add a required amount of phosphate as the temporary measure in accordance with the mixed amount of the substance.

(16) The concentration of the silica in the boiler water should be so kept that the concentration of silica in the steam will be 0.02 mg SiO_2/L or below based on the relationship between the silica concentration in the boiler water and that in the steam.

Table 11.5 Quality of Feed Water and Boiler Water for Low Circulation Ratio Water Tube Boiler

Classification	Type of boiler	Single tube type		Multitubular type	
	Max. Servicing Pressure MPa	Below 1	From 1 to 3	Below 1	From 1 to 3
	Max. Servicing Pressure kg/cm^2 (G)	Below 10	From 10 to 30	Below 10	From 10 to 30
	Type of make-up water	Softened water(1)		Softened water(1)	
Feed water	pH (25 °C)	11.0-11.8	10.5-11.0	7-9	7-9
	Hardness ($mgCaCO_3/L$)	Below 1(2)	Below 1(2)	Below 1	Below 1
	Fat and Oil (mg/L)(3)	(4)	(4)	(4)	(4)
	Dissolved Oxygen (mgO/L)	(4)	(4)	(4)	Below 0.5
	Total iron (mgFe/L)	–	–	Below 0.3	Below 0.3
	Total solids (mg/L)	Below 3000	Below 2500	–	–
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 4500	Below 4000	–	–
	Alkalinity (pH 4.8) ($mgCaCO_3/L$)(5)	300-800	Below 600	–	–
	Alkalinity (pH 8.3) ($mgCaCO_3/L$)(6)	200-600	Below 500	–	–
	Hydrazine (mgN_2H_4/L)(7)	Over 0.05	Over 0.05	–	–
	Chloride ion ($mgCl^-/L$)	Below 600	Below 400	–	–
	Phosphate ion ($mgPO_4^{3-}/L$)(8)	20-60	20-60	–	–
Boiler water	Treatment Method	–		Alkali treatment	
	pH (25 °C)	–		11.0-11.8	11.0-11.8
	Alkalinity (pH 4.8) ($mgCaCO_3/L$)(5)	–		100-800	Below 600
	Alkalinity (pH 8.3) ($mgCaCO_3/L$)(6)	–		80-600	Below 500
	Total solids (mg/L)	–		Below 2500	Below 2000
	Electrical Conductivity (μS/cm) (at 25 °C)	–		Below 4000	Below 3000
	Chloride ion ($mgCl^-/L$)	–		Below 400	Below 300
	Phosphate ion ($mgPO_4^{3-}/L$)(8)	–		20-40	20-40
	Sulfite ion ($mgSO_3^{2-}/L$)(9)	–		10-50	10-20
	Hydrazine (mgN_2H_4/L)(10)	–		0.1-1.0	0.1-0.5

Notes

(1) These include tap water, industrial water, ground water, river water, lake and marsh water, etc. Soft water means water obtained by treating raw water by means of softener (filled with cation exchange resin), or by treating raw water by a reverse osmosis device.
(2) It is applied to the feed water excluding return water.
(3) It means hexane extract or carbon tetrachloride extract. (See JIS B8224)
(4) It is desirable to keep it low.
(5) It is commonly called M-alkalinity.
(6) It is commonly called P-alkalinity.
(7) It is applied when hydrazine is added into feedwater as a deoxidizer.
(8) It is applied when phosphate is added in water.
(9) It is applied when sulfite is added in water as a deoxidizer.
When a deaerator is to be used, it is preferably adjusted to 10 - 20 mg SO_3^{2-}/L.
(10) It is applied when hydrazine is added as a deoxidizer in feedwater to a cylindrical boiler or a water tube boiler with the maximum servicing pressure of 2 MPa or less.
When a deaerater is to be used, it should preferably be adjusted to 0.1 - 0.5 mg N_2H_4/L.

Table 11.6 Quality of Feed Water for Once-through Boiler

Classification	Max. Servicing Pressure	From 7.5 to 10 MPa (From 75 to 100 kg/cm² (G))		From 10 to 15 MPa (From 100 to 150 kg/cm² (G))		From 15 to 20 MPa (From 150 to 200 kg/cm² (G))		Over 20 MPa (Over 200 kg/cm² (G))	
	Treatment Method	Volatile matter treatment	Oxygen treatment	Volatile matter treatment	Oxygen treatment	Volatile matter treatment	Oxygen treatment	Volatile matter treatment	Oxygen treatment
Feed water	pH (at 25 °C)[1]	8.5-9.6[2]	6.5-9.0[3]	8.5-9.6[2]	6.5-9.0[3]	8.5-9.6[2]	6.5-9.0[3]	9.0-9.6[2]	6.5-9.0[3]
	Electrical conductivity (at 25 °C) (μS/cm)	Below 0.3	Below 0.2	Below 0.3	Below 0.2	Below 0.3	Below 0.2	Below 0.25	Below 0.2
	Dissolved Oxygen (mgO/L)	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]
	Total iron (mgFe/L)	Below 0.03[5]	Below 0.02	Below 0.02	Below 0.01	Below 0.02[6]	Below 0.01	Below 0.01	Below 0.01
	Total copper (mgCu/L)	Below 0.01	Below 0.01	Below 0.005	Below 0.01	Below 0.003	Below 0.005[7]	Below 0.002	Below 0.002
	Hydrazine (mgN_2H_4/L)[8]	Over 0.01	–	Over 0.01	–	Over 0.01	–	Over 0.01	–
	Silica ($mgSiO_2/L$)	Below 0.04[9] Below 0.02[10]	Below 0.02	Below 0.03[9] Below 0.02[10]	Below 0.02	Below 0.02	Below 0.02	Below 0.02	Below 0.02

Notes
(1) Add ammonia or volatile amine for pH adjustment.
(2) Where the pipe material in the heater for feedwater is steel, pH is preferably adjusted to a higher value.
(3) When copper alloy is used in this system, pH is preferably maintained within the range of from 8.0 to 8.5.
(4) Use a minimum value within this range which will be appropriate for minimizing the corrosion product.
(5) It is preferably maintained at 0.02 mg Fe/L or below.
(6) It is preferably maintained at 0.01 mg Fe/L or below.
(7) It is preferably maintained at 0.003 mg Cu/L or below.
(8) The concentration of hydrazine should be within the range where pH value will not exceed its upper limit.
(9) It is applied to a boiler with separator.
(10) It is applied to a bolier without separator.

The boiler internal treatment is a method which treats water by addition of a conditioner (PH), 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, 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 11.3 to 11.6.

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

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

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

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

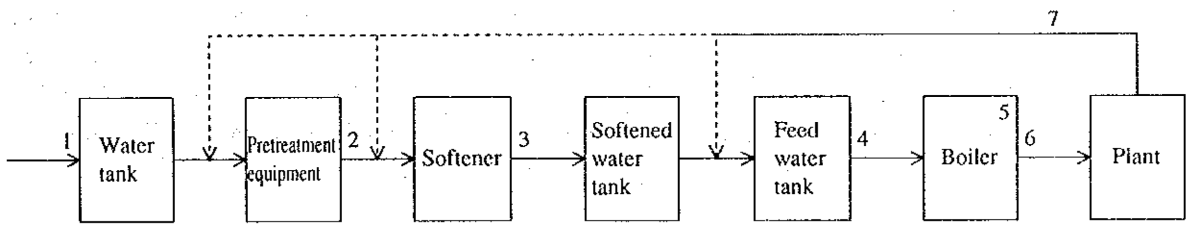
Although an M-alkalinity, total solids, silica and chloride ion are taken as the control subject, the analyses of those are not easy in practice and the electrical conductivity is sometimes taken as a good measure, especially by low pressure boilers. It is desirable to control through premeasurement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

Table 11.7 is a standard of the water quality measuring frequency shown as reference in JIS.

Table 11.7 Standard for Water Quality Measuring Frequency (Cylindrical Boiler)

Sampling location	1	2	3	4	5	6	7
Item	Raw water	Pretreatment equipment outlet water	Softener outlet water	Feed water	Boiler water	Steam	Condensate
Appearance	d	d		d	d		d
Turbidity	n	n	n				
pH	n	n	n	d	d	n	W
Total solids					n		
Electrical conductivity	d	n	n	d	d	n	W
P-Alkalinity (pH8.3)					W		
M-Alkalinity (pH4.8)	n			M	W		
Hardness	n(1)	n	d	d			n
Chloride ion	n	n		W	W		n
Residual chlorine	n	n					
Silica	n			M	M		n
Total iron	n	n	n	M	n		M
Phosphate ion					d		
Hydrazine					d		
Sulfite ion					d		
COD_{Mn}	n						

Remarks: d: Once per day, W: Once per week, M: Once per month, n: Accoding to demand.



Note

(1) When raw water is used as feed water, measure the hardness once per month.

11.3 Expression of Boiler Capacity

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

11.3.1 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.

11.3.2 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 (539 kcal/kg) at temperature of 100 °C.

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

$$G_e = \frac{G(h_2 - h_1)}{2,257} \text{ (kg/h)}$$

In addition, the boiler capacity may sometimes be expressed by a heating surface area (m^2) 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/in^2 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.

11.4 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 11.7. 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 11.8 and the operation record should be described on the items of Table 11.9. The results of the heat balance should be entered into the formula of Table 11.10. The important items and referred items for calculation are picked up and indicated hereinafter.

Figure 11.7 Standard Range of Boiler Heat Balance

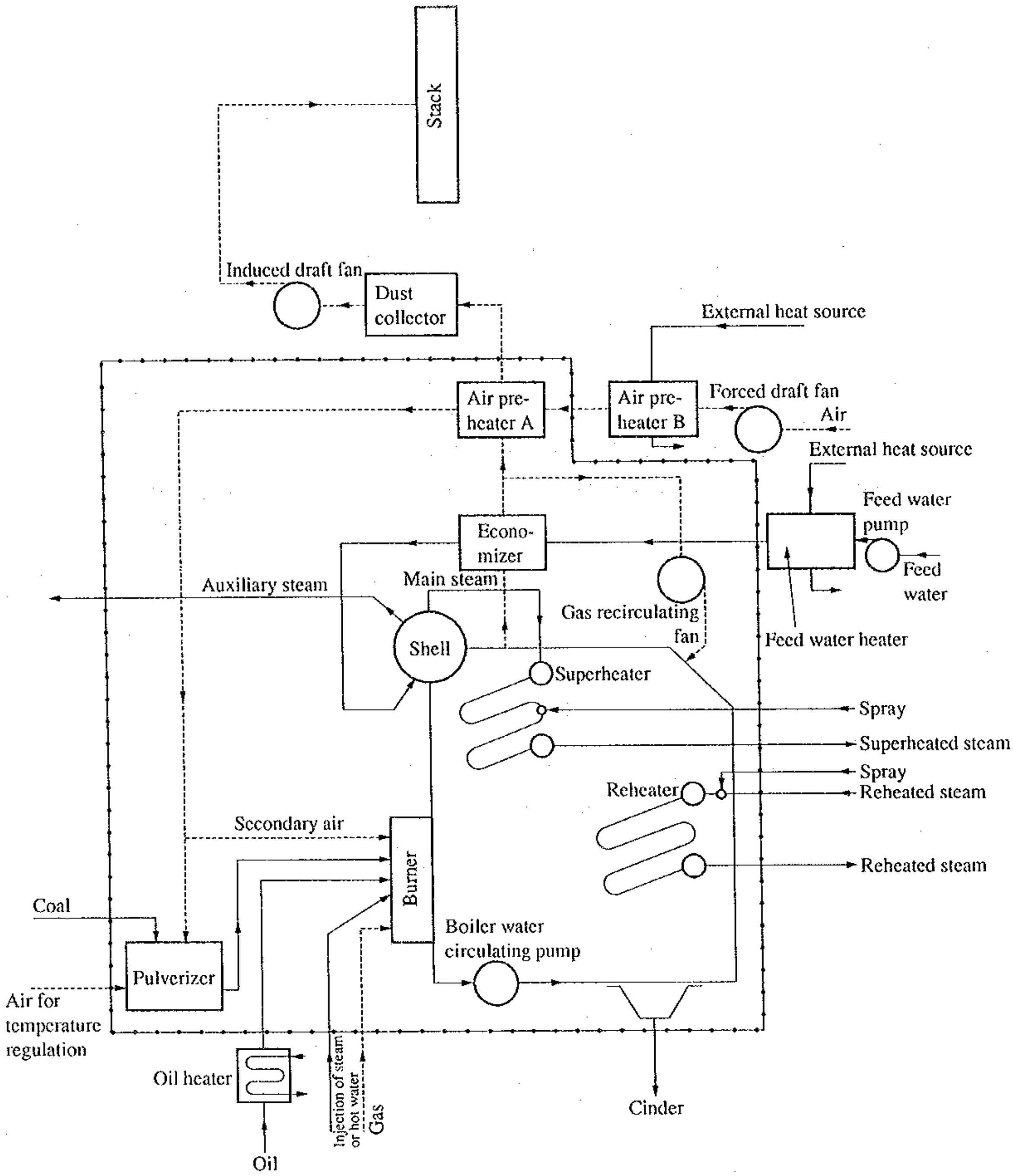


Table 11.8 Outline of Equipment

Outlines of the installation shall be indicated as follows.

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

Note(1) The pressure is a gage pressure.

Table 11.9 Results of Measurement (1/2)

The test results shall be indicated as follows.

			Unit	Remarks
Date and time of test				
Personnel in charge				
Weather, atmospheric pressure, wind velocity				
Ambient temperature, dry bulb and wet bulb temperatures			°C	
Duration of test			h	
Load factor			%	
Fuel	Type of fuel			
	Mixing ratio			
	Temperature as used		°C	
	Total moisture		%	
	Proximate analysis	Analysed value	%	
		As used	%	Correct by moisture. (Industrial analysis)
	Ultimate analysis	Analysed value	%	
		As used	%	Correct by moisture. (Chemical composition analysis)
	Lower calorific value of fuel used	Analysed value	kJ/kg (m^3_N)	Measure a high calorific value by a calorimeter and obtain a low calorific value by calculation. Correct by moisture.
		As used	kJ/kg (m^3_N)	
	Fuel consumption Total		kg (m^3_N)	
	Fuel consumption per hour		kg (m^3_N)/h	
	Firing quantity per burner		kg (m^3_N)/h	
	Combustion chamber heat generation		kJ/m^3h	
Condition of firing equipment				
Condition of control device				
Condition of drafting equipment				
Condition of water feeding equipment				
Condition of dust catcher				
Feed water	Quantity of feed water	Total (corrected value)	kg	
		Per hour	kg/h	
		Per unit volume of fuel	kg/kg (m^3_N)	
	Temper-rature	Economizer inlet	°C	
		Boiler proper inlet	°C	
	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum	MPa	
		Superheater outlet	MPa	
		Reheater inlet	MPa	
		Reheater outlet	MPa	
	Tempe-rature	Superheated outlet	°C	
		Reheater inlet	°C	
		Reheater outlet	°C	
	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (Ex. 98%)
	Evaporation	Total (corrected value)	kg	
		Per hour	kg/h	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
		Equivalent evaporation per hour	kg/h	
		Reheated steam	kg/h	
Steam injection into furnace	Source of steam or hot water			If impossible to measure, use an approximate figures.
	Quantity of steam or hot water		kg/h	
	Pressure and temperature		MPa, °C	

Table 11.9 Results of Measurement (2/2)

Air for combustion	Air quantity per unit volume of fuel		m^3_N/kg (m^3_N)	
	Temperature and pressure	Air preheater inlet	°C, Pa	
		Air preheater outlet	°C, Pa	
		Outlet of forced draft fan	°C, Pa	
		Inlet of combustion chamber	°C, Pa	
	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^3_N/kg (m^3_N)	
	Temperature and pressure	Furnace inside	°C, Pa	
		Outlet of boiler proper	°C, Pa	
		Economizer inlet	°C, Pa	
		Economizer outlet	°C, Pa	
		Air preheater inlet	°C, Pa	
		Air preheater outlet	°C, Pa	
		Induced fan suction	°C, Pa	
		Induced fan delivery	°C, Pa	
	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	
Condition of smoke				
Auxiliary	Steam consumption		kg	
	Electric power consumption		kWh	
Remark				

Remarks 1. The values entered to this sheet, such as analysis data of the fuel 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.
   - Pulverized 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.

6. Condition of control device means automatic or manual, controlling items and setting value etc.

7. Condition of dust catcher means using period, pressure loss, temperature of gas and leakage etc.

Table 11.10 Heat Balance Table

	Heat input	kJ/kg (m^3_N)	%
(1)	Calorific value of fuel	H_l(2)	
(2) (1)	Sensible heat of fuel	Q_1	
(3) (1)	Sensible heat of air	Q_2	
(4) (1)	Carrying heat of furnace injection steam	Q_3	
(5) (1)	Heat corresponding to the work of auxiliary devices	Q_4	
	Total	H_l(2) + Q	100

		Heat input	kJ/kg (m^3_N)	%
Effective heat input	(1)	Heat of generated steam	Qs	
	(2)	Heat of blow water	(Qd)	
	(3)	Others		
		Subtotal	Qs	
Heat loss	(1)	Heat loss in exhaust gas	L_{1l}(3)	
	(2)	Heat loss due to furnace injection steam	L_2	
	(3)	Heat loss due to incomplete burning exhaust gas	L_3	
	(4)	Heat loss due to combustible in refuse	L_4	
	(5)	Heat loss due to dissipation	L_5	
	(6)	Heat loss due to others	L_6	
		Subtotal	L_l (3)	
		Total		100

	Boiler efficiency	%
(1)	Input-and-output heat method $\eta_1 = \dfrac{Qs}{H_l+Q} \times 100,$	
(2)	Heat loss method $\eta_2 = \left(1 - \dfrac{L_l}{H_l+Q}\right) \times 100$	

Note (1) (2), (3) and (4) are due to the external heat source.

(2) In case of a high heating value basis, it shall be taken as H_h.

(3) In case of a high heating value basis L_l shall be taken as L_{lh} and L_l be taken as shall be taken as L_h.

11.4.1 Method to Obtain Lower Combustion Heat from Higher Combustion Heat

Solid fuel and liquid fuel: $H_\ell = H_h - 24.7\,(9h + w)$ kJ/kg-fuel

($H_\ell = H_h - 5.9\,(9h + w)$ kcal/kg-fuel)

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

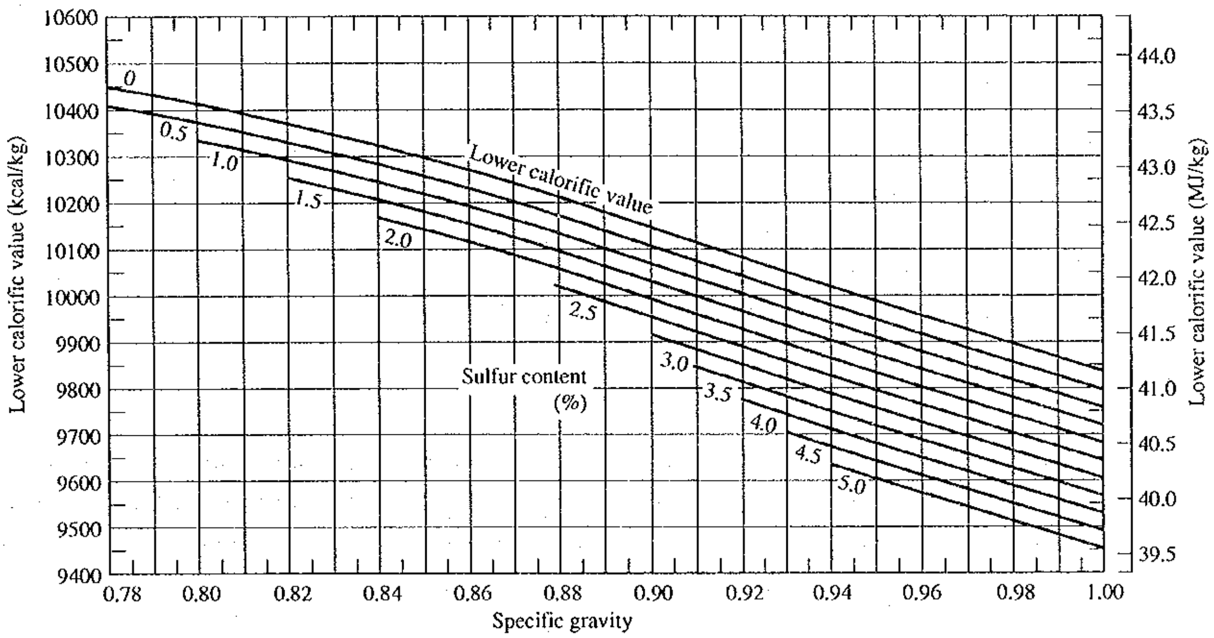
w: Moisture content in service condition (wt%)

When omitting elementary analysis, h shall take the following value.

Kerosene, light oil, crude oil and heavy oil A; h = 13 %
Heavy oil B: h = 12 %
Heavy 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 11.8).

Figure 11.8 Relation between Calorific Value (Low) and Specific Gravity of Petroleum Fuel



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.

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

Even if the following equation is applied, error is not so much. (See Table 11.11)

Gaseous fuel: $H_\ell = 108\,(H_2) + 126\,(CO) + 360\,(CH_4)$
$+ 595\,(C_2H_4) + 645\,(C_2H_6) + 879\,(C_3H_6)$
$+ 934\,(C_3H_8) + 1{,}181\,(C_4H_8)$
$+ 1{,}235\,(C_4H_{10})$ kcal/m^3_N Fuel

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

Table 11.11 Specific Gravity, Sulfur Content and Mean Calorific Value of Petroleum Fuel

	Specific gravity d_{15}	Sulfur content (%)	Mean calorific value (low)
Kerosene	0.79 ~ 0.85	0.5 or Below	43,500 kJ/kg
Light oil	0.82 ~ 0.86	0.5 or Below	43,100
Whole heavy oil			41,200
A heavy oil	0.84 ~ 0.86	0.5 ~ 2.0	42,700
B heavy oil	0.88 ~ 0.92	0.5 ~ 3.0	41,400
C heavy oil	0.90 ~ 0.95	1.5 ~ 3.5 (Over)	40,800

11.4.2 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/kg·°C
LPG : 2.93 ~ 4.19 kJ/kg·°C
Air : 1.30 kJ/m^3_N °C (Influence of humidity in air can be neglected.)

11.4.3 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.

$$A_0 = \frac{1}{100}[37.2c + 112(h - \frac{o}{8}) + 14s] \ m^3{}_N/\text{kg-fuel}$$

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

Case of coal

$$A_0 = 0.241 \times \frac{H_\ell}{1{,}000} + 0.56 \ m^3{}_N/\text{kg-fuel}$$

Case of fuel oil

$$A_0 = 2.96 \times \frac{H_\ell}{10{,}000} + 1.36 \ m^3{}_N/\text{kg-fuel}$$

Case of gaseous fuel

$$A_0 = 2.68 \times \frac{H_\ell}{10,000} \quad m^3{}_N/m^3{}_N\text{-fuel}$$

The actual air input (A) can be obtained by the following equation.

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

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

The value of z can be obtained from Figure 11.9.

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 and hydrogen contents in the fuel are 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 simplified equation.

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

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

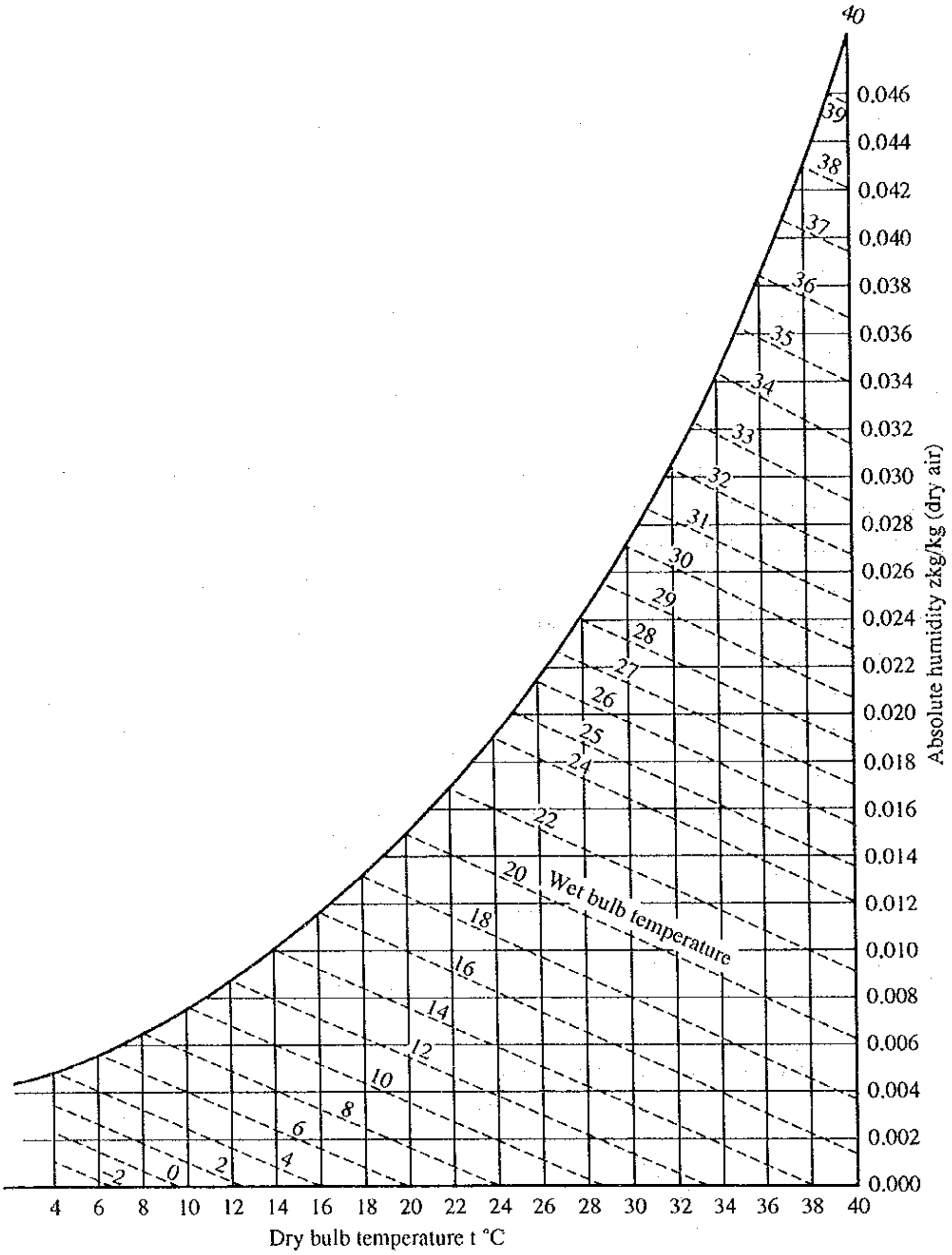
or

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

(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 11.9 Absolute Humidity of Air



11.4.4 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 11.12 and 11.13.

Table 11.12 Thermodynamic Properties of Saturated Water and Saturated Steam (Temperature reference)

Temperature	Saturation pressure	Specific volume (m^3/kg)		Specific enthalpy (kJ/kg)		
t (°C)	Ps (MPa)	v'	v''	h'	h''	r = h'' − h'
0.00	0.0006108	0.0010002	206.3	−0.04	2501.6	2501.6
0.01	0.0006112	0.0010002	206.2	0.00	2501.6	2501.6
2	0.0007055	0.0010001	179.9	8.39	2505.2	2496.8
4	0.0008129	0.0010000	157.3	16.80	2508.9	2492.1
6	0.0009345	0.0010000	137.8	25.21	2512.6	2487.4
8	0.0010720	0.0010001	121.0	33.60	2516.2	2482.6
10	0.0012270	0.0010003	106.4	41.99	2519.9	2477.9
12	0.0014014	0.0010004	93.84	50.38	2523.6	2473.2
14	0.0015973	0.0010007	82.90	58.75	2527.2	2468.5
16	0.0018168	0.0010010	73.38	67.13	2530.9	2463.8
18	0.002062	0.0010013	65.09	75.50	2534.5	2459.0
20	0.002337	0.0010017	57.84	83.86	2538.2	2454.3
22	0.002642	0.0010022	51.49	92.23	2541.8	2449.6
24	0.002982	0.0010026	45.93	100.59	2545.5	2444.9
26	0.003360	0.0010032	41.03	108.95	2549.1	2440.2
28	0.003778	0.0010037	36.73	117.31	2552.7	2435.4
30	0.004241	0.0010043	32.93	125.66	2556.4	2430.7
32	0.004753	0.0010049	29.57	134.02	2560.0	2425.9
34	0.005318	0.0010056	26.60	142.38	2563.6	2421.2
36	0.005940	0.0010063	23.97	150.74	2567.2	2416.4
38	0.006624	0.0010070	21.63	159.09	2570.8	2411.7
40	0.007375	0.0010078	19.55	167.45	2574.4	2406.9
42	0.008198	0.0010086	17.69	175.81	2577.9	2402.1
44	0.009100	0.0010094	16.04	184.17	2581.5	2397.3
46	0.010086	0.0010103	14.56	192.53	2585.1	2392.5
48	0.011162	0.0010112	13.23	200.89	2588.6	2387.7
50	0.012335	0.0010121	12.05	209.26	2592.2	2382.9
55	0.015741	0.0010145	9.579	230.17	2601.0	2370.8
60	0.019920	0.0010171	7.679	251.09	2609.7	2358.6
65	0.02501	0.0010199	6.202	272.02	2618.4	2346.3
70	0.03116	0.0010228	5.046	292.97	2626.9	2334.0
75	0.03855	0.0010259	4.134	313.94	2635.4	2321.5
80	0.04736	0.0010292	3.409	334.92	2643.8	2308.8
85	0.05780	0.0010326	2.829	355.92	2652.0	2296.5
90	0.07011	0.0010361	2.361	376.94	2660.1	2283.2
95	0.08453	0.0010399	1.982	397.99	2668.1	2270.2
100	0.10133	0.0010437	1.673	419.06	2676.0	2256.9
110	0.14327	0.0010519	1.210	461.32	2691.3	2230.0
120	0.19854	0.0010606	0.8915	503.72	2706.0	2202.2
130	0.27013	0.0010700	0.6681	546.31	2719.9	2173.6
140	0.3614	0.0010801	0.5085	589.10	2733.1	2144.0
150	0.4760	0.0010908	0.3924	632.15	2745.4	2113.2
160	0.6181	0.0011022	0.3068	675.47	2756.7	2081.3
170	0.7920	0.0011145	0.2426	719.12	2767.1	2047.9
180	1.0027	0.0011275	0.1938	763.12	2776.3	2013.1
190	1.2551	0.0011415	0.1563	807.52	2784.3	1976.7
200	1.5549	0.0011565	0.1272	852.37	2790.9	1938.6
210	1.9077	0.0011726	0.1042	897.74	2796.2	1898.5
220	2.3198	0.0011900	0.08604	943.67	2799.9	1856.2
230	2.7976	0.0012087	0.07145	990.26	2802.0	1811.7
240	3.3478	0.0012291	0.05965	1037.6	2802.2	1764.6
250	3.9776	0.0012513	0.05004	1085.8	2800.4	1714.6
260	4.6943	0.0012756	0.04213	1134.9	2796.4	1661.5
270	5.5058	0.0013025	0.03559	1185.2	2789.9	1604.6
280	6.4202	0.0013324	0.03013	1236.8	2780.4	1543.6
290	7.4461	0.0013659	0.02554	1290.0	2767.6	1477.6
300	8.5927	0.0014041	0.02165	1345.0	2751.0	1406.0
310	9.8700	0.0014480	0.01833	1402.4	2730.0	1327.6
320	11.289	0.0014995	0.01548	1462.6	2703.7	1241.1
330	12.863	0.0015615	0.01299	1526.5	2670.2	1143.6
340	14.605	0.0016387	0.01078	1595.5	2626.2	1030.7
350	16.535	0.0017411	0.008799	1671.9	2567.7	895.7
360	18.675	0.0018959	0.006940	1764.2	2485.4	721.3
370	21.054	0.0022136	0.004973	1890.2	2342.8	452.6
374.15	22.120	0.00317		2107.4		0.0

Table 11.13 Thermodynamic Properties of Saturated Water and Saturated Steam (Pressure reference)

Pressure	Saturation temparature	Specific volume (m³/kg)		Specific enthalpy (kJ/kg)			Specific entropy (kJ/kg·K)	
P(MPa)	(°C)	v'	v''	h'	h''	r = h'' − h'	s'	s''
0.001	6.0828	0.0010001	129.20	29.34	2514.4	2485.0	0.1060	8.9767
0.002	17.513	0.0010012	67.01	73.46	2533.6	2460.2	0.2607	8.7246
0.003	24.100	0.0010027	45.67	101.00	2545.6	2444.6	0.3544	8.5785
0.004	28.983	0.0010040	34.80	121.41	2554.5	2433.1	0.4225	8.4755
0.005	32.898	0.0010052	28.19	137.77	2561.6	2423.8	0.4763	8.3960
0.006	36.183	0.0010064	23.74	151.50	2567.5	2416.0	0.5209	8.3312
0.007	39.025	0.0010074	20.53	163.38	2572.6	2409.2	0.5591	8.2767
0.008	41.534	0.0010084	18.10	173.86	2577.1	2403.2	0.5925	8.2296
0.009	43.787	0.0010094	16.20	183.28	2581.1	2397.9	0.6224	8.1881
0.010	45.833	0.0010102	14.67	191.83	2584.8	2392.9	0.6493	8.1511
0.02	60.086	0.0010172	7.650	251.45	2609.9	2358.4	0.8321	7.9994
0.03	69.124	0.0010223	5.229	289.30	2625.4	2336.1	0.9441	7.7695
0.04	75.886	0.0010265	3.993	317.65	2636.9	2319.2	1.0261	7.6709
0.05	81.345	0.0010301	3.240	340.56	2646.0	2305.4	1.0912	7.5947
0.06	85.954	0.0010333	2.732	359.93	2653.6	2293.6	1.1454	7.5327
0.08	93.512	0.0010387	2.087	391.72	2665.8	2274.0	1.2330	7.4352
0.10	99.632	0.0010434	1.694	417.51	2675.4	2257.9	1.3027	7.3598
0.101325	100.00	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
0.12	104.81	0.0010476	1.428	439.36	2683.4	2244.1	1.3609	7.2984
0.14	109.32	0.0010513	1.236	458.42	2690.3	2231.9	1.4109	7.2465
0.16	113.32	0.0010547	1.091	475.38	2696.2	2220.9	1.4550	7.2017
0.18	116.93	0.0010579	0.9772	490.70	2701.5	2210.8	1.4944	7.1622
0.2	120.23	0.0010608	0.8854	504.70	2706.3	2201.6	1.5301	7.1268
0.3	133.54	0.0010735	0.6056	561.43	2724.7	2163.2	1.6716	6.9909
0.4	143.62	0.0010839	0.4622	604.67	2737.6	2133.0	1.7764	6.8943
0.5	151.84	0.0010928	0.3747	640.12	2747.5	2107.4	1.8604	6.8192
0.6	158.84	0.0011009	0.3155	670.42	2755.5	2085.0	1.9308	6.7575
0.7	164.96	0.0011082	0.2727	697.06	2762.0	2064.9	1.9918	6.7052
0.8	170.41	0.0011150	0.2403	720.94	2767.5	2046.5	2.0457	6.6596
0.9	175.36	0.0011213	0.2148	724.64	2772.1	2029.5	2.0941	6.6192
1.0	179.88	0.0011274	0.1943	762.61	2776.2	2013.6	2.1382	6.5828
1.2	187.96	0.0011386	0.1632	798.43	2782.7	1984.3	2.2161	6.5194
1.4	195.04	0.0011489	0.1407	830.08	2787.8	1957.7	2.2837	6.4651
1.5	198.29	0.0011539	0.1317	844.67	2789.9	1945.2	2.3145	6.4406
1.6	201.37	0.0011586	0.1237	858.56	2791.7	1933.2	2.3436	6.4175
1.8	207.11	0.0011678	0.1103	884.58	2794.8	1910.3	2.3976	6.3751
2.0	212.37	0.0011766	0.09954	908.59	2797.2	1888.6	2.4469	6.3367
2.2	217.24	0.0011850	0.09065	930.95	2799.1	1868.1	2.4922	6.3015
2.4	221.78	0.0011932	0.08320	951.93	2800.4	1848.5	2.5343	6.2690
2.5	223.94	0.0011972	0.07991	961.96	2800.9	1839.0	2.5543	6.2536
2.6	226.04	0.0012011	0.07686	971.72	2801.6	1825.0	2.5831	6.2315
2.8	230.05	0.0012088	0.07139	990.48	2802.0	1811.5	2.6106	6.2104
3.0	233.84	0.0012163	0.06663	1008.4	2802.3	1793.9	2.6455	6.1837
3.5	242.54	0.0012345	0.05703	1049.8	2802.0	1752.2	2.7253	6.1228
4.0	250.33	0.0012521	0.04975	1087.4	2800.3	1712.9	2.7965	6.0685
4.5	257.41	0.0012691	0.04409	1122.1	2797.7	1675.6	2.8612	6.0191
5.0	263.91	0.0012858	0.03943	1154.5	2794.2	1639.7	2.9206	5.9735
5.5	269.93	0.0013023	0.03563	1184.9	2789.9	1605.0	2.9757	5.9309
6.0	275.55	0.0013187	0.03244	1213.7	2785.0	1571.3	3.0273	5.8908
6.5	280.82	0.0013350	0.02972	1241.1	2779.5	1538.4	3.0759	5.8527
7.0	285.79	0.0013513	0.02737	1267.4	2773.5	1506.0	3.1219	5.8162
7.5	290.50	0.0013677	0.02533	1292.7	2766.9	1474.2	3.1657	5.7811
8.0	294.97	0.0013842	0.02353	1317.1	2759.9	1442.8	3.2076	5.7471
9	303.31	0.0014179	0.02050	1363.7	2744.6	1380.9	3.2867	5.6820
10	310.96	0.0014526	0.01804	1408.0	2727.7	1319.7	3.3605	5.6198
11	318.05	0.0014887	0.01601	1450.6	2709.3	1258.7	3.4304	5.5595
12	324.65	0.0015268	0.01428	1491.8	2689.2	1197.4	3.4972	5.5002
13	330.83	0.0015672	0.01280	1532.0	2667.0	1135.0	3.5616	5.4408
14	336.64	0.0016106	0.01150	1571.6	2642.4	1070.7	3.6242	5.3803
15	342.13	0.0016579	0.01034	1611.0	2615.0	1004.0	3.6859	5.3178
16	347.33	0.0017103	0.009308	1650.5	2584.9	934.3	3.7471	5.2531
17	352.26	0.0017696	0.008371	1691.7	2551.6	859.9	3.8107	5.1855
18	356.96	0.0018399	0.007498	1734.8	2513.9	779.1	3.8765	5.1128
19	361.43	0.0019260	0.006678	1778.7	2470.6	692.0	3.9426	5.0332
20	365.70	0.0020370	0.005877	1826.5	2418.4	591.9	4.0149	4.9412
21	369.78	0.0022015	0.005023	1886.3	2347.6	461.3	4.1048	4.8223
22	373.69	0.0026714	0.003728	2011.1	2195.6	184.5	4.2947	4.5799
22.12	374.15	0.00317		2107.4		0.0	4.4429	

11.4.5 Exhaust Gas Loss

The average specific heat of combustion exhaust gas is 1.38 kJ/(m^3_N °C) (0.33 kcal/m^3_N °C)from the result obtained in the range of 0 to 300 °C in a temperature and 1.0 to 1.3 in an air ratio (1.5 for a solid fuel).

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

Case of coal

$$G_l = \frac{0.216\ H_\ell}{1,000} + 1.67\ m^3{}_N/\text{kg-fuel}$$

Case of fuel oil

$$G_l = \frac{3.762\ H_\ell}{10,000} - 3.91\ m^3{}_N/\text{kg-fuel}$$

Case of gaseous fuel

$$G_l = \frac{2.926\ H_\ell}{10,000}\ m^3{}_N/\text{kg-fuel}$$

(Case of hydrocarbon-mixed gas)

Actual exhaust gas quantity is as the following equation.

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

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

11.4.6 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 injection steam = Injection 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.

11.4.7 Heat Loss Due to Incompletely Burning Gas

It is calculated according to the following equation.

$$\text{Heat loss} = 126.0\,[G_0 + (m - 1)\,A_0]\,(CO)\quad \text{kJ/kg}\ (m^3_N)\text{-fuel}$$

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

11.4.8 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 339c kJ/kg-fuel.

11.4.9 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 %.

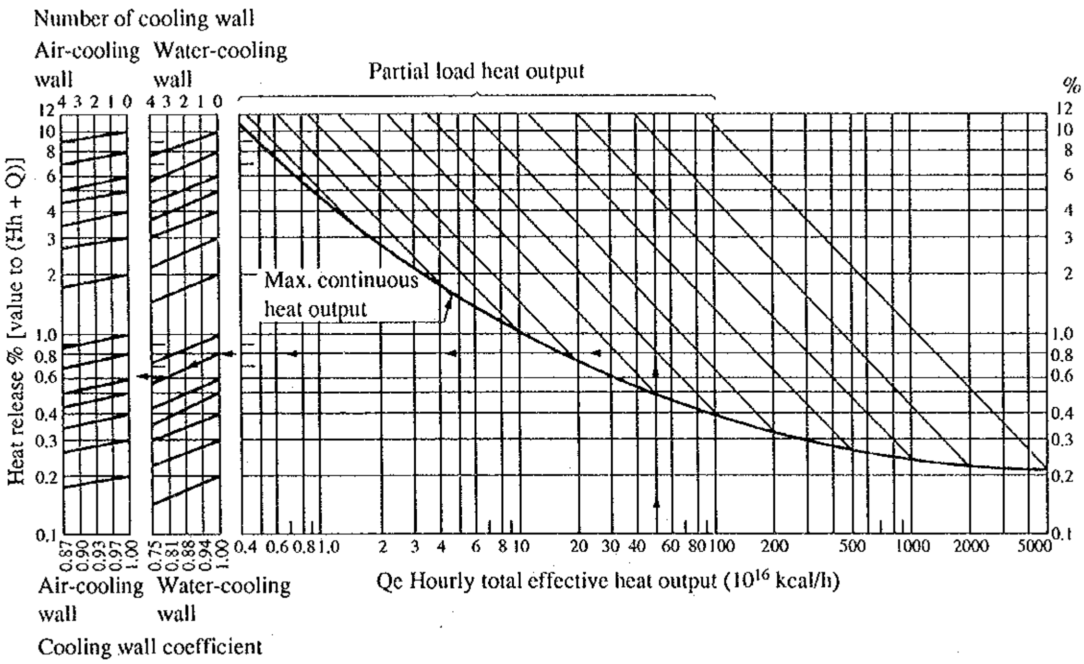
The following values are shown as round figures for heat loss. (Table 11.14)

For reference, the diagram shown in the Power Test Code of the ASME (American Society of Mechanical Engineering) is shown in Figure 11.10. 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 11.11. This diagram is for a high calorific value. For a low calorific value it should be multiplied by H_h/H_l.

Table 11.14 Radiant Heat Loss

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

Figure 11.10 Heat Loss Chart (From ABMA chart in power test code of ASME)



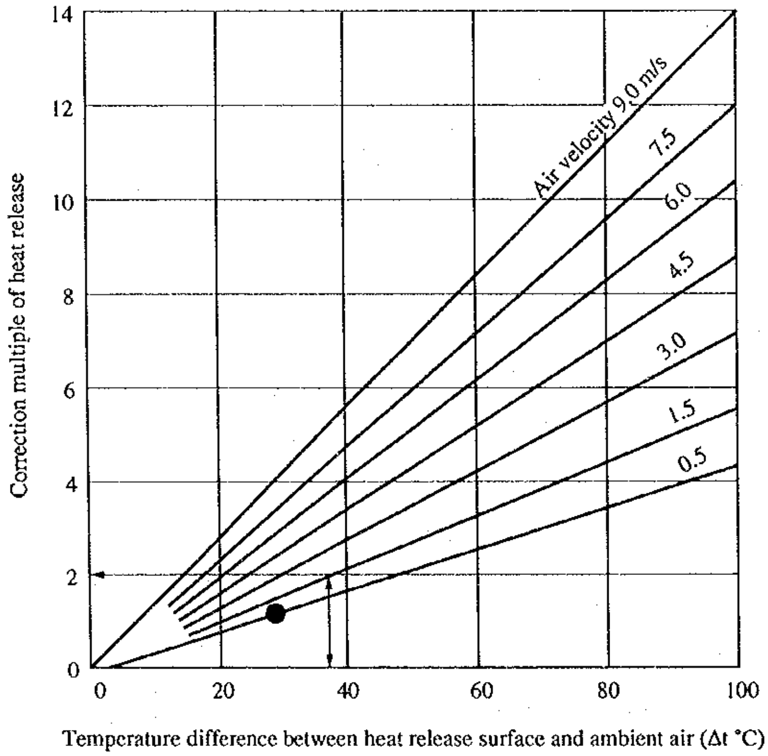
(The figure shows the case that the temperature difference between the heat release surface and the ambient air is 28 °C and the wind velocity on the heat release surface is 0.5 m/s. Correction multiples in other condition are based on that of Figure 11.11.)

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.

1 MJ = 4.1868 kcal

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 11.11 Correction Multiple of Temperature Difference and Air Velocity to Figure 11.10



11.4.10 Other Heat Losses

They are sum of heat loss other than calculated heat loss.