SOCIALIST REPUBLIC OF VIETNAM
Ministry of Industry and Trade (MOIT)

Guideline for Technical Regulation Volume 2

Design of Thermal Power Facilities

Book 1/12

« Boiler »

Final Draft

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List of Acronyms/Abbreviations

AFNOR	Agence Fracaise de Normalisation
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BFB	Bubbling Fluidized Bed
BS	British Standard
B&W	Babcock and Wilcox
CFB	Circulation Fluidized Bed
COM	Coal Oil Mixture
CWM	Coal Water Mixture
DCC	Drag Chain Conveyor
EN	European Standard
FDF	Forced Draft Fan
FW	Foster Wheeler
GRF	Gas Recirculation Fan
GTCC	Gas Turbine Combined Cycle
HRSG	Heat Recovery Steam Generator
ISO	International Organization for Standardization
JIS	Japanese Industrial Standard
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MWe	Megawatt electric
NGL	Natural Gas Liquid
NOx	Nitrogen Oxide
MLR	Multi Lead Robbed Tube
OMLR	Optimized Multi Lead Ribbed Tube
OTU	Once Through Utility
RDF	Refuse Derived Fuel
RPF	Refuse Paper and Plastic Fuel
PAF	Primary Air Fan
PFBC	Pressurized Fluidized Bed Combustion
SAH	Steam Air Heater
SOx	Sulfur Oxide
TDR	Technische Regeln für Dampfkessel
UP	Universal Pressure
VR	Vacuum Residual Oil

Chapter-1. Comparison between Technical Regulation and Technical Guideline of boiler

The article number of this guideline is shown in the Table-1 contrasted technical regulation with technical guideline for easy understanding.

Table- 1: Comparison between Technical Regulation and Technical Guideline of boiler

Technical Regulation		Technical Guideline	
Article 21.	General provision	Article 21.	General provision
-1.	Definition of boiler	-1.	Definition of boiler
-2.	Function of boiler	-2.	Function of boiler
-3.	Function of independent super-heater	-3.	Function of independent super-heater
-4.	Function of steam accumulator	-4.	Function of steam accumulator
		-5.	Classification of types for boiler
		-6.	Typical construction of boiler
		-7.	Steam condition for boiler
		-8.	Materials for main part of boiler
Article 22.	Material for boiler, etc.	Article 22.	Material for boiler, etc.
-1.	Pressure parts	-1.	Pressure parts
-2.	Stable chemical composition and mechanical strength	-2.	Stable chemical composition and mechanical strength
Article 23.	Structure for boiler, etc.	Article 23.	Structure for boiler, etc.
-1.	Safety structure	-1.	Structure for boiler, etc.
-2.	Allowable stress	-2.	Allowable stress of material
		-3.	Hydrostatic test
		-4.	Body of vessel
		-5.	Rectangle header
		-6.	Head for vessel
		-7.	Flat head plate of vessel
		-8.	Dished cover plate with flange for vessel
		-9.	Tube sheet for vessel
		-10.	Pipe and stub
		-11.	Flange
		-12.	Cylindrical boiler
Article 24.	Safety valve for boiler, etc.	Article 24.	Safety valve for boiler, etc.
-1.	Over-pressure	-1.	Over-pressure
-2.	Appropriate safety valve	-2.	Appropriate safety valve
Article 25.	Feed-water equipment for boiler, etc.	Article 25.	Feed-water equipment for boiler, etc.
-1.	Requirement for feed-water equipment	-1.	Quantity of feed-water equipment
-2.	Harmful heat	-2.	Type of feed-water equipment
		-3.	Two or more feed-water equipment of boiler
		-4.	Harmful heat
Article 26.	Isolation of steam and feed-water of boiler, etc.	Article 26.	Isolation of steam and feed-water of boiler, etc.
-1.	Isolation of steam	-1.	Main steam stop valve
-2.	Isolation of feed-water	-2.	Feed-water valve and non-return valve
Article 27.	Blow-down equipment for boiler, etc.	Article 27.	Blow-down equipment for boiler, etc.
-1.	Blow-down equipment for circulation boiler	-1.	Blow-down equipment for circulation boiler
Article 28.	Instrument equipment for boiler, etc.	Article 28.	Instrument equipment for boiler, etc.
-1.	Instrument to monitor operation status	-1.	Instrument to monitor operation status
		-2.	Boiler trip item and application

Article 21. General provision

Article 21-1. Definition of boiler

1. The boiler for power generation must be called the facility which generates steam by flame, combustion gas and other high temperature gas (hereinafter so called "combustion gas, etc.) and must be pursuant to follows.

1.1 The boiler for power generation does not include followings.

1) Boilers for steam locomotive, marine boilers
2) Steam boiler with maximum operation pressure 0.1 MPa and more, and the inside diameter of body is not more than 200mm and length is not more than 400mm, or the heat transfer area is not more than $0.5m^2$
3) Once-through boiler with operation pressure 1MPa or less and the heat transfer area is not more than $0.5m^2$

1.2 JIS B8201-2005 "Stationary steel boilers-Construction" is applied to following boiler in the permissible range of construction.

1) The boiler which generates high pressure or high temperature steam and which is applied main material that is not stipulated in JIS B8201-2005 "Stationary steel boilers-Construction".
2) Those which has special construction.

1.3 The boiler contains the steam stop valve and related valve, the feed-water valve (those if it exist between BFP and economizer, the economizer inlet valve if it does not exist) and related non-return valve and blow valve (the farthest one if there are two or more), and contains boiler body, super-heater, economizer and piping, etc.

Article 21-2. Function of boiler

The modern thermal power plant is required high temperature, high pressure and large capacity one to improve thermal efficiency. When the combustion temperature in the furnace raise up, the radiation heat which increases in proportion to the 4^{th} power of temperature comes win more than the contact heat transfer. Therefore, it comes easy to burn out the furnace wall. In order to prevent burning and facilitate evaporation and super-heating of water, the water wall boiler which 20~100mm diameter water tubes are arranged vertically around the furnace wall is mainly adopted. It is called water cooled furnace wall. The recent boiler furnace has been devised forms of combustion burners to increase radiant heat transfer surface in stead of contact heat transfer surface.

Article 21-3. Function of independent super-heater

1. The independent super-heater may be used to heat up to saturated steam of existing boiler to high temperature and expand the steam use (private power, process steam, etc). The typical configuration and construction are shown in Fig-1 and Fig-2.

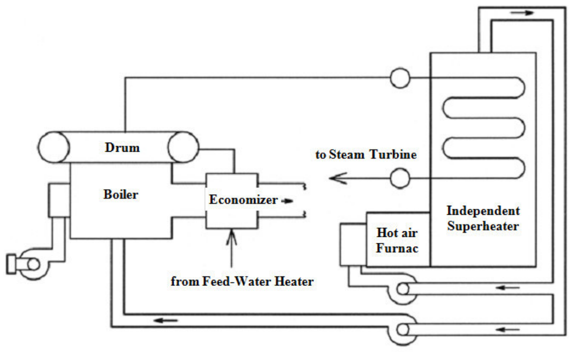


Fig- 1: Independent super-heater cycle

http://www.bhic.co.jp/products/plant/industrial_system/industrial_system_01/index.html

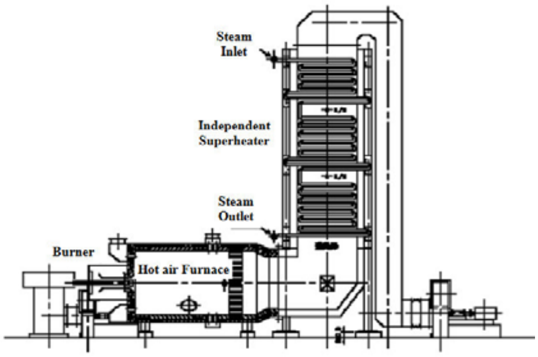


Fig- 2: Independent super-heater

http://www.bhic.co.jp/products/plant/industrial_system/industrial_system_01/index.html

Article 21-4. Function of steam accumulator

1. The steam accumulator is the facility to storage excess steam generated by boiler in the saturated water status. It is capable to operate boiler at efficient and economical certain conditions even when the boiler load change, and to obtain steam in the nighttime without operating boiler by storing excess steam during daytime, and to supply steam at constant pressure in case of the industry that heat load changes. The typical configuration is shown in Fig-3 and Fig-4.

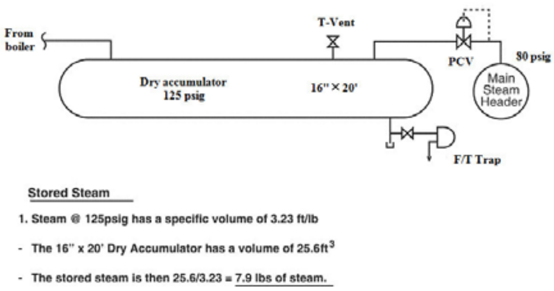


Fig- 3: Dry accumulator

http://www.esmagazine.com/ext/resources/ES/Home/Files/PDF/0909Fultonwhitepaper.pdf

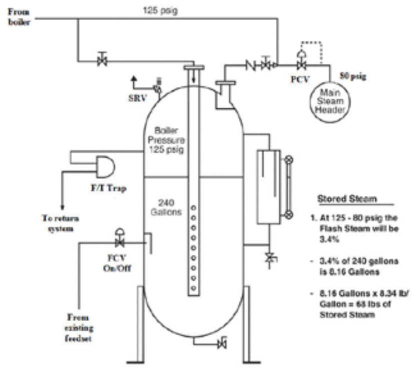


Fig- 4: Wet accumulator

http://www.esmagazine.com/ext/resources/ES/Home/Files/PDF/0909Fultonwhitepaper.pdf

Article 21-5. Classification of types for boiler

1. The steam power generation facility has classic but universal characteristic that is capable to obtain electric power by steam turbine if the combustion heat or waste heat by boiler is recovered. The boiler which is for electric sale, for private power or for energy recycle are applied widely and they are classified by evaporation method as shown in Table-2.

Table- 2: Classification of types for boiler

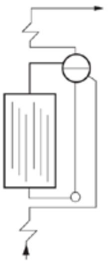
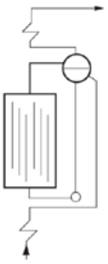
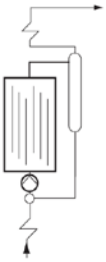
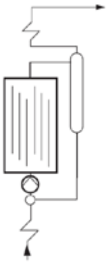
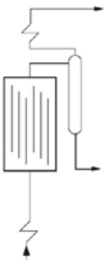
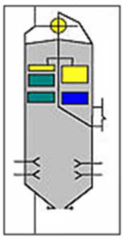
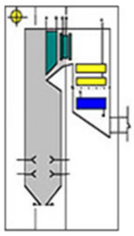
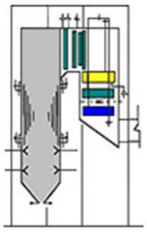
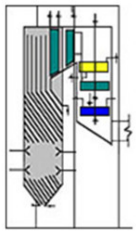
No.	classification	subsection		remarks
1	Smoke tube boiler	Furnace tube boiler	—	Biomass & incineration generation
2		Smoke tube boiler	—	Biomass & incineration generation
3		Vertical boiler	—	—
4	Water tube boiler	Cast iron boiler	—	—
5		Water tube boiler	(natural circulation type)	For commercial power generation
6		Water tube boiler	(strait tube type)	Biomass & incineration generation
7		Water tube boiler	(bend tube type for small & medium capacity)	Biomass & incineration generation
8		Water tube boiler	(bend tube type for large capacity)	For commercial power generation
9		Water tube boiler	(forced circulation type)	For commercial power generation
10	Once-through boiler			For high efficiency commercial power generation

2. The water flow large fossil fuel fired utility boilers which are used for the efficient and environmentally safe power generation is classified either “drum” or “once-through” types. The selection of the circulation method dictates the configuration of the boiler and its auxiliary systems as well as the modes and method for operation and control. In drum type units (see Fig-15: El Paso and Fig-17: Carolina), the steam flow rate is controlled by the fuel firing rate. The super-heat steam temperature that is determined by the proper sizing of the super-heater heat transfer area is controlled by spray water attemperation. In a once-through type boiler (see Fig-21: UP and Fig-27: Benson), the steam flow rate is established by the boiler feed-water pump, and the super-heat steam temperature is controlled by the fuel firing rate. Since the once-through boiler does not rely on the density difference between steam and water to provide proper circulation and cooling of the furnace enclosure tubes, it can be operated at supercritical pressures. The operation above the supercritical pressure significantly improves plant heat rate and therefore efficiency which not only results in reduced fuel costs, but also has the environmental benefit of less carbon dioxide production (green house effect) and less emission of SOx and NOx that are characteristic of the fuels fired. In the United States, OTU (hereinafter referred to Once Through Utility) supercritical boilers, especially for large scale (>500MWe) units, were very popular in the 1960s and accounted for close to 50% of the capacity ordered at that time. However, this trend dwindled through the1970s due to

various real and perceived problems with the high pressure, first generation of OTU boilers and the general drop in the USA market for large scale steam generators due to rising interest rates, reduced rate of growth of electrical demand, and regulatory actions. The development and advances in OTU technology continued through the 1980s in Europe and Japan where there was a need for efficient, large scale units with the ability to cycle to meet load demands. The design of the Spiral OTU, which was first introduced in the 1960s in a configuration close to its current form, continued to incorporate design enhancements to make it the preferred configuration for current large OTU supercritical units.

The continuing development of the technology that is the Benson Vertical OTU boiler which utilizes an evaporator circuit with a “natural circulation” characteristic and optimized rifled tubing have been led to the introduction in the early 1990s. The features of this design provide for a simple, cost effective configuration which also provides increased operational flexibility. With a renewed interest in the United States for efficient and environmentally safe power production from coal combustion, there is much interest in the advantages that supercritical OTU power production can provide. The features of all types of large scale power boiler are summarized in the Table-3.

Table- 3: Type of power boiler

<table>
<tr><td rowspan="2">Evaporation system</td><td colspan="2" rowspan="2">Natural circulation</td><td colspan="2" rowspan="2">Forced circulation</td><td colspan="2">Once-through</td></tr>
<tr><td>Constant pressure</td><td>Sliding pressure</td></tr>
<tr><td rowspan="3">Type of boiler</td><td>El Paso</td><td>Carolina</td><td>La Mont
(B&W)</td><td>Superposed</td><td>UP
(B&W)</td><td>Benson
(Siemens)</td></tr>
<tr><td>—</td><td>—</td><td>—</td><td>—</td><td>Sulzer</td><td>Foster Wheeler</td></tr>
<tr><td>—</td><td>—</td><td>—</td><td>—</td><td>Ramsin</td><td>CE or Alstom</td></tr>
<tr><td>Model of Water circulation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Outline</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Evaporation pressure</td><td><190bar
<19MPa</td><td><190bar
<19MPa</td><td><200bar
<20MPa</td><td><190bar
<19MPa</td><td><200bar
<20MPa</td><td>No limit</td></tr>
<tr><td rowspan="2">MS steam condition</td><td colspan="2">538~566°C</td><td colspan="2">~566°C</td><td colspan="2">~630°C</td></tr>
<tr><td colspan="2">12.4~16.8MPa</td><td colspan="2">~16.57MPa</td><td colspan="2">~25MPa</td></tr>
<tr><td>Circulation ratio</td><td colspan="2">14~6</td><td colspan="2">~4</td><td colspan="2">1</td></tr>
<tr><td>End point of evaporation</td><td colspan="3">Fixed location within drum</td><td colspan="2">Fixed location within super-heater</td><td>Variable within the heating surface</td></tr>
</table>

Remarks: *Sub-critical* *: MS pressure is less than 22.1MPa and temperature is 566°C or less*

Super Critical *: MS pressure is 22.1MPa and more and temperature is 566°C or less*

Ultra Super Critical *: MS pressure is 22.1MPa and more and temperature is 566°C and more*

Circulation ratio *: = influent quantity for vaporizer / amount of evaporation*

Reference: http://www.docstoc.com/docs/75102789/33-Steam-generators-3-Fossil-f

Combustion Engineer was consolidated to ALSTOM in 1912.

3. Classification by steam condition

3.1 Steam condition for boiler

The combination of steam condition, for instance, main steam pressure, and main steam temperature and reheat steam temperature are depending on the type, kind and use, and are not stipulated. The general condition is organized in following Table-4 for reference.

Table- 4: Steam condition for boiler

Steam condition	Type / Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MS press.	MPa (g)	5.9	8.6	10.0	10.0	12.5	16.6	16.6	18.6	24.1	24.1	24.1	31.0	24.1	24.1	24.0	25.0
MS temp.	^{o}C	485	510	538	538	538	566	566	538	538	538	538	566	538	566	593	600
RS temp.	^{o}C	–	–	–	538	538	538	566	538	538	566	552	566	593	593	593	610
		–	–	–	–	–	–	–	–	–	–	566	566	–	–	–	–

Reference: Thermal and nuclear generation handbook Ver.7 P257: TENPES (Thermal and Nuclear Engineering Society of Japan)

Note-1: It may be dealt with as being conformed to this table, if the main steam pressure is within ±5% of listed above and main steam temperature is within ±5% ^{o}C.

Note-2: Type 11 and 12 show the example of the two-stage reheat type.

3.2 At the moment, the main steam conditions which are applied to large scale power facility are organized as shown in Table-5 and Table-6.

Table- 5: Classification of steam power plant by use conditions (C1)

Class	C1					
MSP (MPag) (psig)	Sub-Critical					
	5.9	8.6	10.0	12.5	16.6	18.6
	850	1,250	1,450	1,800	2,400	2,700
Main Steam/Reheat Steam Temperature (Fahrenheit: ^{o}F /Celsius: ^{o}C)						
～1,000(^{o}F)	485/-	510/-				
1,000(^{o}F)			538/-	538/538		538
			538/538	538/566		
1,050^{o} (F)					566/538	
					566/566	

Table- 6: Classification of steam power plant by use conditions (C2, C3, C4)

Class	C2		C3				C4
MSP	Super Critical		Ultra Super Critical				A-USC
(MPag)	24.1		25.0	31.0			34.5
(psig)	3,500		3,625	4,500			5,000
Main Steam/Reheat Steam Temperature (Fahrenheit: °F /Celsius: °C)							
1,000(°F)	538/538						
	538/566						
	538/552/566						
	538/593						
1,050(°F)		566/593		566/566/566			
1,100(°F)			600/600				
			600/610				
1,150(°F)					(621/621)		
1,200(°F)						(649/649)	
1,300(°F)							(700/720/720)

Note-1: MSP : Main Steam Pressure

Note-2: (   ) means the plant which is not commercial at this moment but may be in the future

Note-3: A-USC : Advanced Ultra Super Critical

4. Classification by fuel

The boiler, which is applied to a variety of liquid, gas and solid fuel, the features when applying typical gas, petroleum and coal fuel are organized as follows.

4.1 Gas-fired

Natural gas, LNG (Liquefied Natural Gas), blast furnace gas, coke oven gas and oil refining gas are applied as gaseous fuel for thermal power generation. Here, natural gas or LNG is introduced as typical “gas-fired”. The gas-fired boiler has following features as compared to other fuels.

1) less constraint for dimensions of furnace
2) fuel system and air/flue system are relatively simple
3) special consideration for dirt and clogging are not required

The typical construction of gas-fired boiler is shown in Fig-5. The combustion of gas is close to non-luminous flame intensity when compared with pulverized coal and oil, so heat flux reaching the furnace is low. Therefore, the design of the furnace conditions is most loosely and fewer restrictions on the dimensions of boiler furnace compared with other fuels. As consideration for the heat transfer department, the appropriate gas velocity which overall economic efficiency is excellent must be selected considering the cost of facility and draft power, while a gas velocity is as faster as, a smaller selection of facility, auxiliary power increases due to the increasing draft loss (draft fan power).

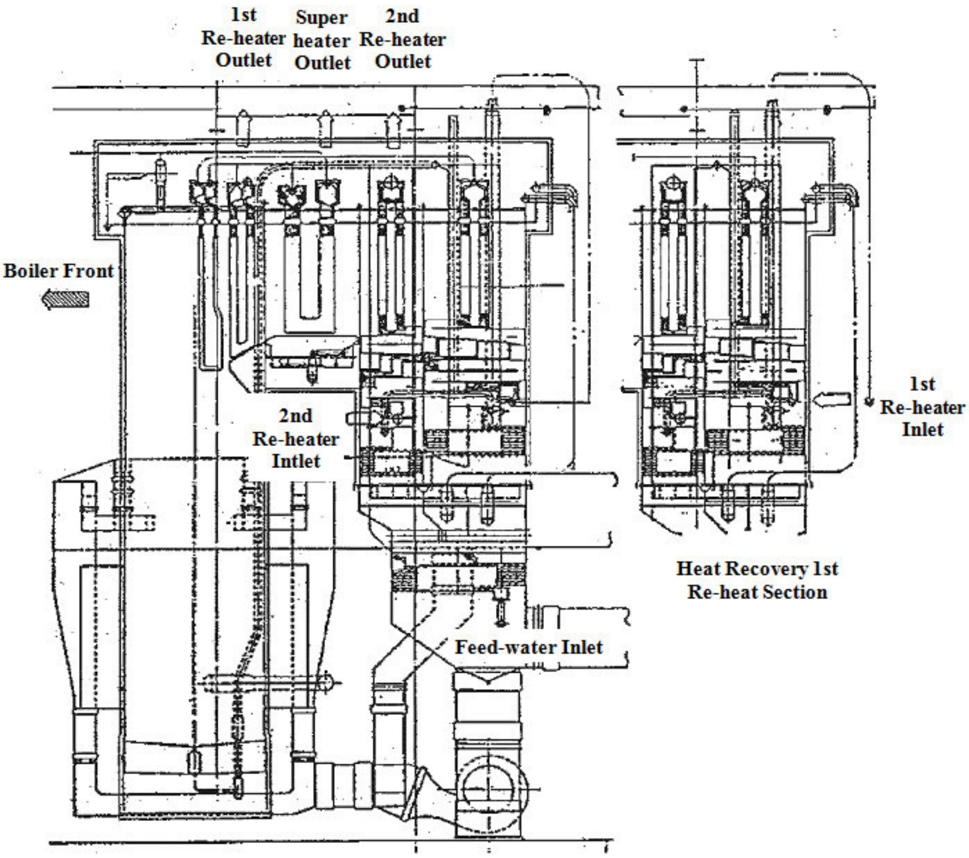


Fig- 5: Gas-fired once-through boiler (700MW)

Reference: P-58 of No.583 (April/2006) Journal of TENPES

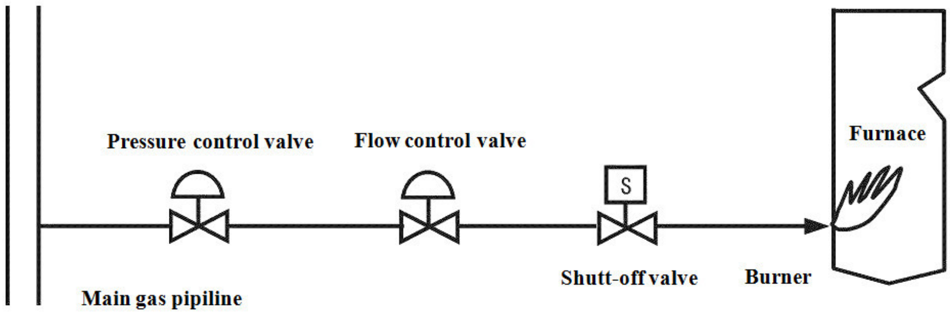


Fig- 6: Typical fuel System of gas-fired boiler

Reference: P-73 of No.587 (Aug. /2005) Journal of TENPES

It is easy to ignite gas, and is capable to use main fuel gas as the ignition gas or the tart up fuel. The light oil burner for ignition and start-up is not required, the ignition burner for main burner is provided for fuel system. The fuel system for gas-fired type boiler is shown in Fig-6. The fuel gas system is the very simple system which the fuel gas is branched from main supply line, reduced gas pressure, controlled the fuel flow to the boiler by the flow control valve and supplied to each burner. Generally, the forced draft type is adopted for draft system. The forced draft system maintains furnace pressure positive status and inducing draft fan (IDF) is not provided. In addition, the gas recirculation fan (GRF) other than forced draft fan (FDF) is adopted for the measures of NOx reduction and reheat steam temperature control. The bi-sector type air heater which the gas side and combustion air side are separated is applied. Generally, the desulfurization equipment or the electric dust precipitator is not provided for environmental measures, because the generation of NOx, SOx or dust is very low compared with other fuels containing a trace amount of nitrogen and sulfur in the gas. The NOx removal equipment may be provided depending on the environmental limit required for plant.

4.2 Oil-fired

The liquid fuel is the petroleum products mainly refined from the crude oil of which the typical product is the heavy oil. The C-class heavy oil is general as the fuel for boiler of power generation. Incidentally, the VR (Vacuum Residual Oil) is the residual oil in the process of purification to extract the light components as much as possible by applying distillation equipment for deep drawing. The by-products converted by coking process which decompose by heat to VR and convert to light hydrocarbons (such as gasoline base material) and coke are the petroleum coke. The comparison of general properties of fuel is shown in Table-7 and Table-8. In this guideline, the C-class heavy oil and the crude oil is introduced as the fuel for typical oil-fired boiler. The specific attention to the combustion of petroleum coke, Orimulsion and VR is appended to the end. The oil-fired boiler has the following characteristics compared with the gas-fired.

Table- 7: Comparative example for general properties of C-heavy oil, VR, Orimulsion

item	unit	C-heavy oil	VR	Orimulsion
Higher heating value	MJ/kg (kcal/kg)	43.1 (10,300)	41.9 (10,000)	29.3 (7,000)
Specific gravity 15/4^{o}C	—	0.95	1.03~1.05	—
Kinetic viscosity 100^{o}C	mm2/s	20	>3000	—
Sulfur content	Wt%	2.3	5.0~6.0	2.87
Nitrogen content	Wt%	0.2	0.4~0.5	0.48
Ash content	Wt%	0.01	0.05	0.13
Moisture content	Wt%	<0.1	—	28~30
Residual carbon content	Wt%	11	25~30	12
Vanadium content	ppm	<50	150~250	280~550
Nickel content	ppm	—	—	40~70

Reference: P-74 of No.587 (Aug. /2005) Journal of TENPES

Table- 8: Analysis value of petroleum coke and bituminous coal

item			unit	Petroleum coke	Bituminous coal (Australian coal)
Dry coal higher heating value			MJ/kg (kcal/kg)	34.8 (8,320)	30.1 (7,200)
Proximate analysis	Surface moisture		%	5.40	4.5
	Dry base	Inherent moisture	%	1.10	3.5
		Volatile matter	%	9.90	34.0
		Fixed carbon	%	88.00	51.3
		Ash content	%	1.00	11.2
		Total	%	100	100
Ultimate analysis (moisture free basis)	C		%	84.9	72.3
	H		%	3.8	4.5
	O		%	2.60	9.3
	N		%	1.40	1.6
	S		%	6.30	0.6
	Ash		%	1.00	11.7
HGI (Hardgrove Grindability Index)			—	(40~90)	50
Fuel ratio (Fixed carbon/ Volatile matter)			—	8.9	1.5

Reference: P-74 of No.587 (Aug. /2005) Journal of TENPES

1) scale up of furnace slightly
2) increase of fuel system
3) contamination, clogging and hot/cold corrosion must be considered

The example of oil-fired boiler must be referred to Fig-7. The furnace of oil-fired boiler is larger than the gas-fired boiler from the perspective of tube metal temperature for the furnace wall because the oil combustion has higher brightness than the gas combustion and the strong thermal radiation. It is necessary to account for changes in the heat absorption because of contaminants in the oil-fired furnace and heat exchanger tubes due to minute remaining carbon, sulfur and heavy minerals in the fuel, although no effect on the heat absorption because of no contamination of the furnace walls tubes on gas-fired type. Generally, the furnace wall deslugger is not necessary, but the sootblower is provided to remove dirt on the heat surface of tubes. The light oil and gas burner for ignition and starting up is provided in consideration of the stable combustion at starting up as well as heavy oil burner equipment. The C-class heavy oil must be heated and burn so that the kinematic viscosity suitable for spray combustion by heavy oil heater, because C-class heavy oil is high kinematic viscosity at room temperature.

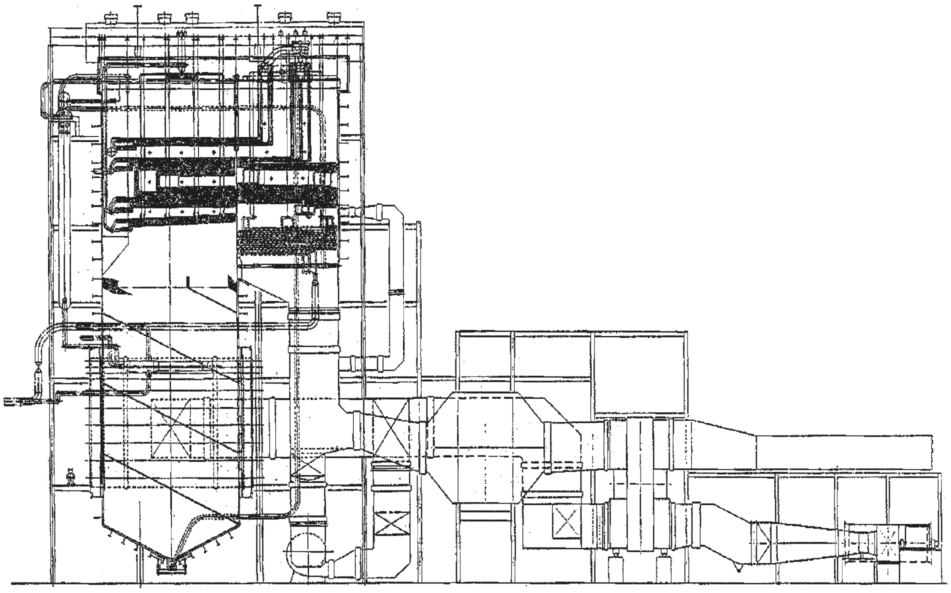


Fig- 7: Oil-fired once-through boiler (700MW)

Reference: P-58 of No.583 (April/2006) Journal of TENPES

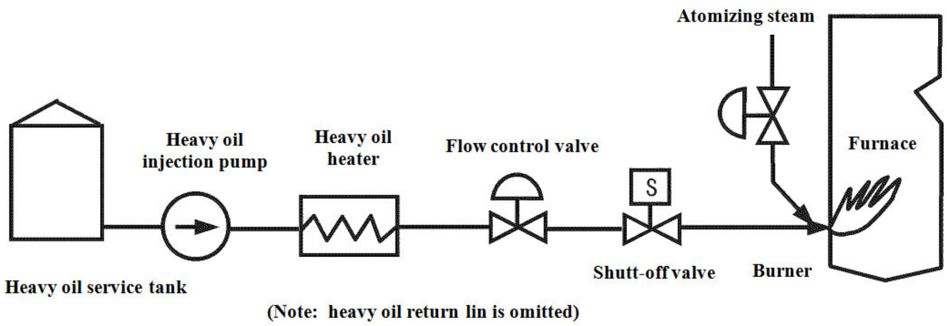


Fig- 8: Typical fuel system of heavy oil-fired boiler

Reference: P-75 of No.587 (Aug. /2005) Journal of TENPES

The example of the fuel system for heavy oil-fired boiler is shown in Fig-8. The heavy oil is sucked from the heavy oil service tank and pressurized by heavy oil burning pump. The heavy oil is supplied to each burners controlling fuel flow to boiler by the flow control valve after heating heavy oil through the heavy oil heater applied steam as heating medium. The steam spray type is often employed as the method which has excellent spray property in order to improve spray property of burner, although there is the pressure spray type, medium spray type (steam spray, air spray). It is necessary to prevent cavitations of the oil burning pump, to prevent vaporization in the tank, to prevent leakage from piping or others and to take measurement for static electricity in consideration with the volatile components contained in clued oil, although it is possible to burn without warming particularly because the crude oil contains large amount of volatile light components in general and the kinematic viscosity is low and flash point is low compared with the heavy oil.

Forced type is adopted for the draft system as well as gas-fired boiler, and the gas recirculation fan (GRF) is adopted for the measures of NOx reduction and reheat steam temperature control. The bi-sector type air pre-heater is applied. However, the steam air heater (SAH) is provided in the upstream of the air pre-heater to prevent the low temperature (sulfuric acid) corrosion due to contain sulfur in the heavy/crude oil. The purpose of this is to maintain the average cold end temperature of air pre-heater higher than the acid dew point temperature by heating the combustion air that has been boosted by the FDF. The cold end average temperature shows the average temperature at the cold end of air pre-heater (air inlet side and gas outlet side).

In case of heavy oil-fired boiler, generally the electric precipitator is provided for dust collection, the desulfurizer is provided depending on the concentration of sulfur in the fuel as the environmental measures. In addition, the denitrizer is provided depending on the NOx limit required to plant. It is necessary to take measure against high temperature corrosion of super-heater and re-heater, corrosion of furnace wall tubes, clogging and dirt of heat exchange tubes, ash removal under economizer and air heater and incarnation of environmental equipment in case of boiler applying VR, Orimulsion and petroleum coke which contain a large amount of sulfur, residual carbon and heavy metals in the fuel compared with heavy oil. In case of high sulfur fuel, the measure for corrosion such as the high temperature corrosion of super-heater and re-heater by injection of fuel additive and the high Cr metal spray is often taken. It is necessary to pay attention to pitch of heat transfer tubes and arrangement of sootblower depending on the nature of the fuel as the measure of the clogging and dirt of heat transfer tubes. In addition, it is necessary to pay attention to the control of the exhaust gas maintaining the low end average metal temperature higher than that of heavy oil-fired boiler, strengthen of sootblower and adoption of such material which has excellent corrosion resistance at low temperature end element as the measure against the low temperature corrosion and ash clogging. The denitrizer, desulfurizer or electric precipitator must be reinforced according to the increase in NOx, SOx and dust due to increased nitrogen, sulfur and residual carbon in the fuel as the environmental equipment.

In addition, it is necessary the fuel system on a par with coal fired boiler such as bunker, feeder and pulvelizer (mills) because the petroleum coke is supplied as solid fuel. Since the petroleum coke has flame retardant and fire proof comparable among the anthracite coal, the storage combustion system (bottle system) and circulating fluidized bed boiler is mainly adopted traditionally. Although the storage combustion system is capable to control primary air flow and hot air for drying mill separately, the fuel system becomes complicated compared with direct combustion fuel system by the cyclone (or bag-filter) or the fuel storage facility (bottle), etc. In addition, the fluidized bed combustion boiler discharges a lot of ash including bed material compared with the conventional pulverized coal combustion. It is necessary a large cost burden for the petroleum coke, since vanadium and other heavy metals are contained. In recent years, it became to adopt direct combustion without auxiliary fuel and contributes to the simplification of facility and the improvement of reliability and maintenance.

4.3 Coal-fired

Coal has most reserve among the energy resources and has become a major fuel for boiler of thermal power generation. The degree of carbonization of coal are classified in peat, lignite, sub-bituminous coal, bituminous coal and anthracite, the bituminous or sub-bituminous coal is used from overall economy in reality. When the coal used as fuel for power generation boilers is not produced at all or not produced enough domestically, it is necessary to import from abroad. In this guideline, the bituminous coal-fired is introduced as a typical representative of “pulverized coal-fired”.

The pulverized coal-fired type is mainly adopted for the large scale boiler for power generation, although there are the pulverized coal-fired which burns fine coal powder pulverized by coal pulverizer or below mentioned the fluidized bed boiler. The pulverized coal-fired boiler has the following characteristics compared with oil-fired or gas-fired.

1) scale up of furnace and steel structure
2) increase in coal-related facility and draft equipment
3) contamination and clogging by ash, discharge, etc. must be considered

Examples of pulverized coal-fired boilers are shown in the Fig-9, Fig-10 and Fig-11. The slugging of the furnace and the upper furnace heat exchanger tube occurs due to coal ash (adhesion of melt ash). The heat load is reduced lower than oil-fired considering reducing slugging of furnace without interference with the actual operation. Also, the combustion speed of pulvelized coal is slow compared with oil-fired. In addition, the selection of dimensions of furnace must be considered the characteristics such as NOx. For these reasons, the pulverized coal-fired boiler may become relatively larger. Incidentally, the furnace which is applied higher slugging coal may become large, because a high quality bituminous coal is candidate as same pulvelized fuel for coal-fired defer from the case the furnace which is applying candidates including with a high slugging.

The tube pitch is set based on experience considering the prevention of ash erosion as well as ash deposition according to the appropriate gas velocity depending on the amount of ash and properties for tubes at the convection heat transfer part. Therefore, the gas velocity is lower than oil-fired or gas-fired boiler and may have a large tube pitch. The pulverized coal burner, the starting or auxiliary burner which is applied light oil, heavy oil and gas for start-up and boosting is provided for fuel system.

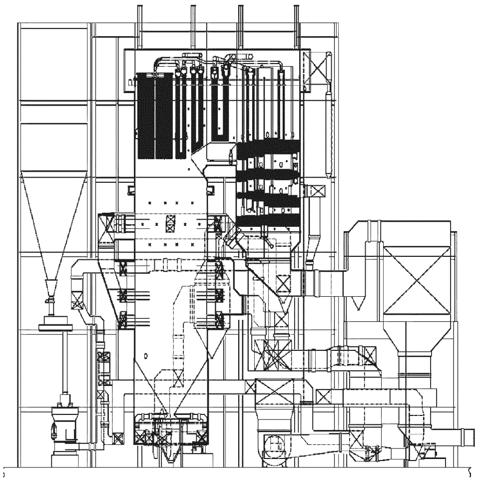


Fig- 9: Coal-fired Once-through boiler (1000MW)

Reference: P-6 1 of No.583 (April/2006) Journal of TENPES

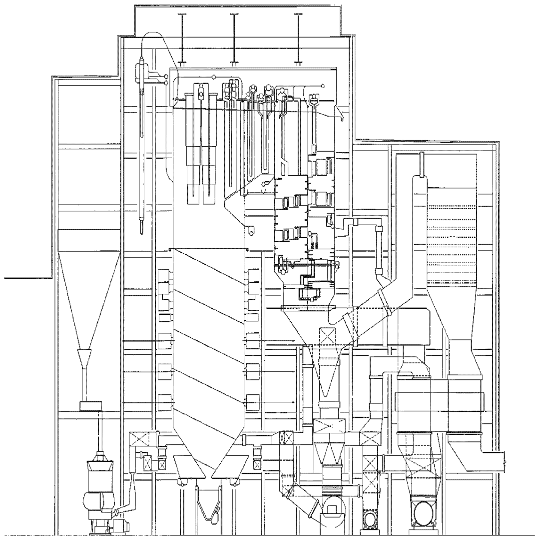


Fig- 10: Coal-fired Once-through boiler (1050MW)

Reference: P-6 1 of No.583 (April/2006) Journal of TENPES

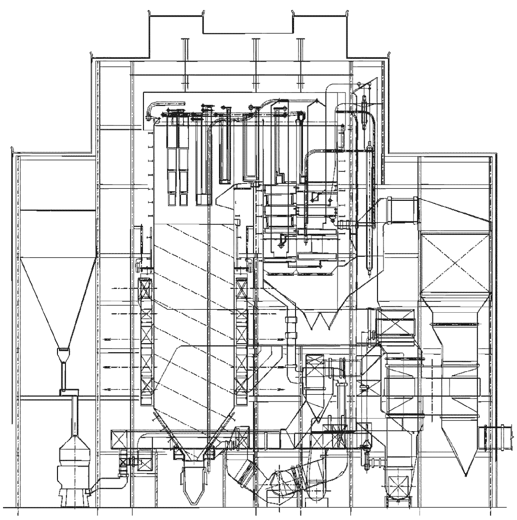


Fig- 11: Coal-fired Once-through boiler (1050MW)

Reference: P-62 of No.583 (April/2006) Journal of TENPES

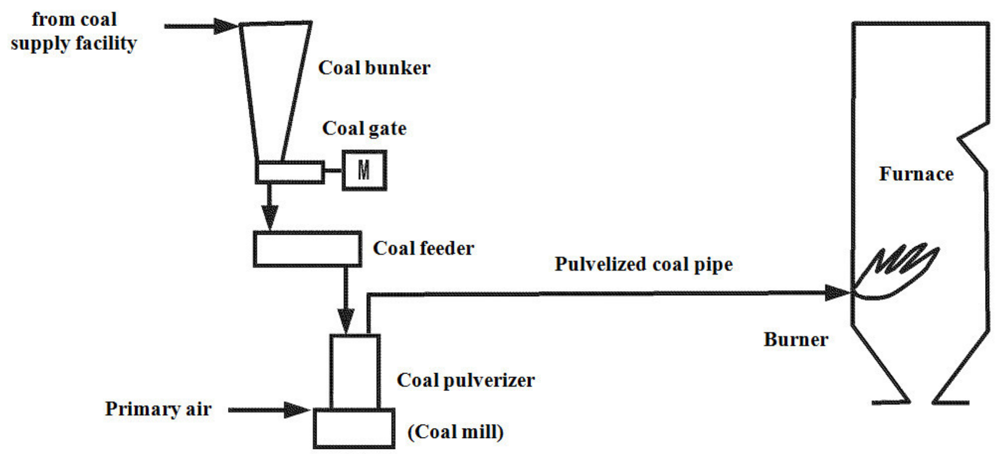


Fig- 12: Typical fuel system of coal for pulverized coal-fired boiler

Reference: P-76 of No.587 (Aug. /2005) Journal of TENPES

The fuel system for the pulverized coal-fired boiler is shown in Fig-12. The first, the raw coal is supplied to each boiler bunker by the coal supply facility. The coal feeder is installed at the bottom of the bunker and controls the amount of coal needed to operate the boiler. The raw coal is pulverized and dried by the coal pulverizer which is installed under the coal feeder; and supplied to each burner by transportation air. In addition to being the furnace larger compared with oil-fired and gas-fired boiler, it is necessary to increase the capacity of the boiler steel structure because it is necessary to provide space to install the coal bunker, coal feeder and pulverizer.

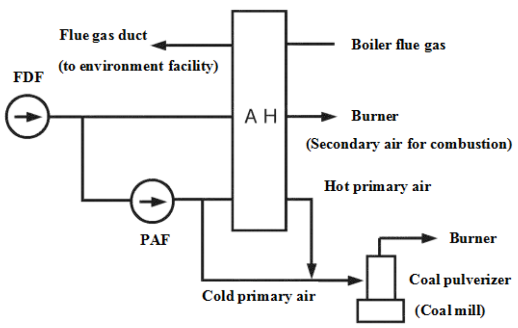


Fig- 13: Boost arrangement of primary fan

Reference: P-77 of No.587 (Aug. /2005) Journal of TENPES

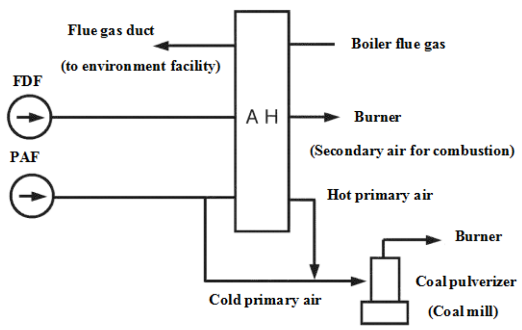


Fig- 14: Parallel arrangement of primary fan

Reference: P-77 of No.587 (Aug. /2005) Journal of TENPES

Generally, the balanced draft system is adopted to the draft system. In case of the balancing draft, the furnace pressure is controlled in negative pressure (about -0.1kPa). The PAF (Primary Air Fan) is provided in addition to the FDF (Forced Draft Fan) and IDF (Induced Draft Fan). The typical arrangement of PAF is shown in Fig-13 and Fig-14. There are two methods to capture the air to FDF, the one is to suck in the atmosphere directly and the other is to suck in upper hot air from indoor intake in the boiler room to improve efficiency by recovering heat that is dissipated in the boiler room. Generally, the indoor type is applied to the coal-fired boiler. In addition to these, there was once also employed the GIF for a re-heat steam temperature control.

The facility for recirculation draft system will be complicated because it is necessary to remove ash in the recirculation gas by means of the dust collector (multi-cyclone) which is installed in upstream as a measure of wear of gas recirculation fan. Recently, the gas recirculation system is not provided in order to simplify the facility, and the unit which employing only a re-heat steam temperature control method such as controlling by the flue gas distribution rear damper has been increased . The three sectors type air pre-heater which is divided into three fluid flow sectors, gas path, primary air path, secondary air path, is mainly used to large boilers. In addition, the unit that uses heavy oil in addition to coal, a SAH (steam air pre-heater) is installed as the measures to prevent low temperature corrosion, the SAH is not often provided if the auxiliary fuel is only light oil.

The adhered ash on the furnace wall tube and the AH (air pre-heater) is removed periodically during the boiler operation by the deslugger and the sootblower. The dropped and removed ash is discharged from the bottom discharge throat for the natural discharge by the clinker hopper, the water sealed drag chain conveyor (DCC) or the furnace bottom dry ash handling equipment. The fly-ash which dropped into the hopper below economizer, the hopper below AH is often transported by vacuum. The pyrite which is discharged from coal mill after once saving in coal pyrite hopper is collected manually and periodically, transported by conveyor and transported to the furnace bottom handling equipment. In the view point of environment, it is necessary to enhance the environmental equipments such as the denitrizer, desulfurizer and electric precipitator compared with the heavy oil-fired, gas-fired plant in order to remove NOx, SOx and dust generated depending on the nature of coal.

4.4 Other Fuels

Oil, coal and natural gas are applied to commercial generation facility as the main fuel, on the other hand the following various fuels are capable to apply for the private power or municipal generation activity. The fuels for power generation is classified and organized in the Table-9.

Table- 9: Type of fuel for thermal power boiler

Classification	Type of Fuel
Pulverized Coal	pulverized coal, CWM
Coal except pulverized coal	grain coal, lump coal, coke, COM
Crude Oil	crude oil, naphtha, mixed crude oil, NGL
Petroleum except crude oil	ABC heavy oil, kerosene, light oil, by-product oil, residual oil, paraffin, asphalt, orimulsion
Liquefied Gas	LNG, LPG
Gas	gasification gas, coke oven gas, blast furnace gas, converter gas, refinery gas, naphtha cracking gas, residual gas, natural gas , bio-gas

Classification	Type of Fuel
Others	Burke, coal tar, black liquor, bagasse, refuse, pitch, mineral sulfide, methanol, scrap tire, rice husk, wood scrap, poultry litter

Note-1: CWM: Coal Water Mixture, COM: Coal Oil Mixture

Note-2: NGL: Natural Gas Liquid, LNG: Liquefied Natural Gas, LPG: Liquefied Petroleum Gas

5. Classification by system

5.1 Conventional boiler

5.1.1 Natural circulation boiler

5.1.1.1 Bent water tube boiler

This type of boiler is a medium size industrial boiler that is standardized as for the captive power plant and the steam plant. As for the power generation boilers, this is used in the wide range of the evaporation capacity 80~400t/h, the steam pressure 4.4~13MPag and the steam temperature 420~520^{o}C and is commonly employed as captive power generation boiler for industry. The furnace water wall is assembled at the factory, the panels and each block having a completely air-tightness of welded fin diameter tube which has the outside diameter of about 76.2mm, so that the insulation work of furnace or the installation work of ducts has been simplified in the short time, and has been designed with the thermal efficiency can be increased and equipments such as the economizer or pre-air heater. The typical construction is shown in Fig-15.

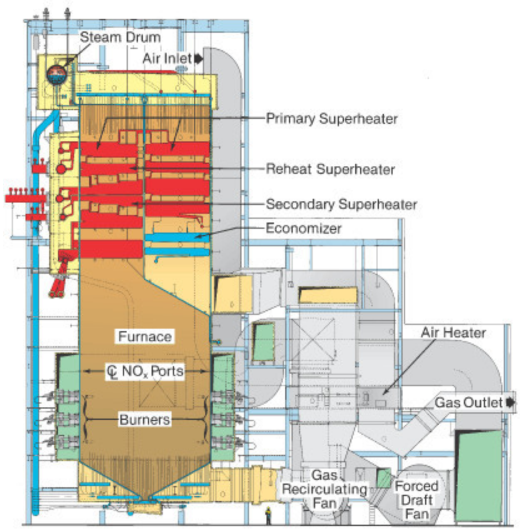


Fig- 15: EL Paso type boiler (B&W)

http://www.babcock.com/products/boilers/el_paso.html

5.1.1.2 Large scale radiation boiler

The natural circulation boiler or the forced circulation boiler are often employed for the recent large scale boiler with high pressure (12~18.5MPag), although the supercritical plant is adopted and the forced circulation one is rarely employed. The almost large scale boiler with evaporation capacity more than 1,000t/h is outdoors type and has the drum height to the center height more than 40m. Entire boiler has been suspended from the top beams of boiler steel structure.

The few large downcomers are installed outside the furnace and connected from the drum mounted on the top of the boiler to the furnace inlet header. Heat of combustion gas is absorbed by the contact heat surface of super-heater, re-heater and economizer in the exit of the furnace after cooling down gas temperature to about 1,000^{o}C, the combustion gas is guided to air pre-heater and led to chimney to be discharged after heat exchange with combustion air.

The Fig-16 and Fig-17 shows the coal-fire natural circulation boiler which was adopted to the thermal power for business use with the evaporation capacity 520t/h, main steam temperature/reheat steam temperature 566^{o}C/538^{o}C. In addition, the high pressure natural circulation boiler has a feature to use the relatively large inner diameter of about 60mm for furnace water wall.

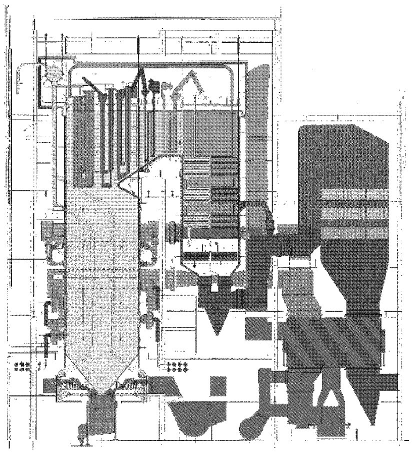


Fig- 16: Natural circulation type boiler (156MW)

Reference: P-67 of No.583 (April/2006) Journal of TENPES

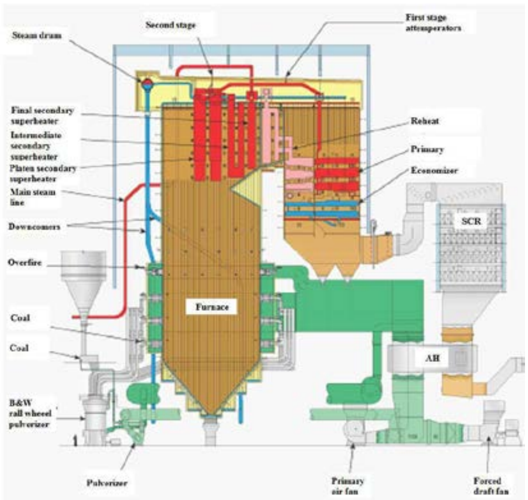


Fig- 17: Carolina type boiler (B&W)

http://www.babcock.com/products/boilers/carolina.html

5.1.1.3 Forced circulation boiler

It may require special consideration in the design of circulation system including furnace, because the density difference between saturated water and saturated steam as shown in Fig-18 reduce the natural circulation power in increasing pressure under the sub-critical. The forced circulation boiler is to provide the boiler water recirculation pump in the middle of the downcomer, and it is capable to always ensure a sufficient amount of circulation.

In addition, the forced circulation boiler is installed orifice at inlet of evaporator to control flow, and it is capable to maintain stable nucleate boiling by means of distributing boiler water depending on the absorbed heat and the heat load of evaporator. Moreover, the small diameter tubes are used for the forced circulation boiler compared with the natural circulation boilers. An example of the coal-fired forced circulation boiler with evaporation capacity 660t/h, turbine inlet steam pressure 16.6MPa is shown in Fig-19 and other is shown in Fig-20.

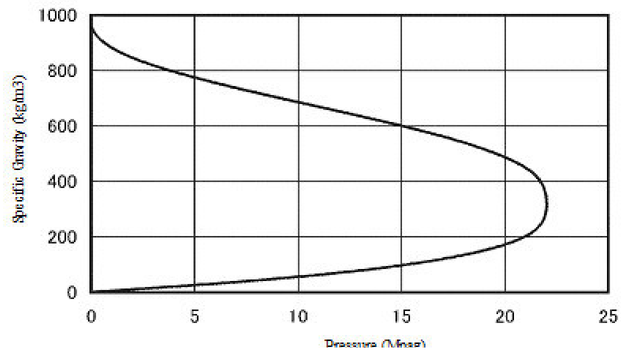


Fig- 18: Relation specific gravity of water with steam

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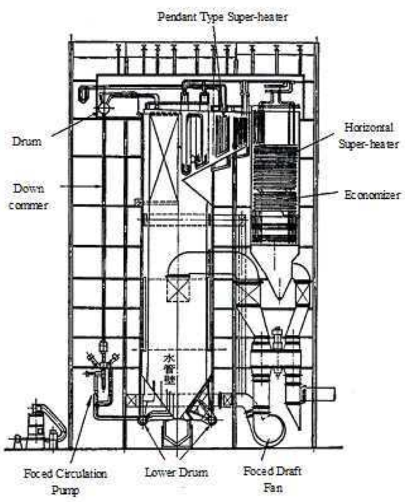


Fig- 19: Lamont boiler

http://fnorio.com/0103heat_engine(steam_cycle)1/Steam_Boiler1.html

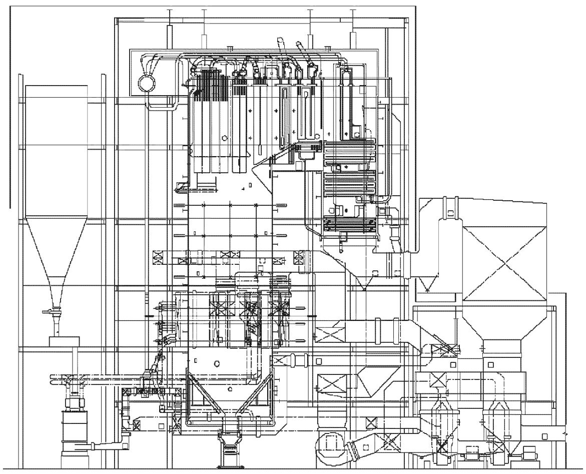


Fig- 20: Forced circulation type boiler (220MW)

Reference: P-68 of No.583 (April/2006) Journal of TENPES

5.1.1.4 Combined circulation boiler

This is the supercritical boiler which is combined both features of the forced circulation boiler and the once-through boiler, and has been developed in the USA to improve Sulzer boiler. In general, the once-through boiler is designated to cool the furnace water wall at the minimum allowable amount of water, and the minimum allowable amount of water is the 30% of maximum continuous load operation of boiler.

The combined circulation boiler always ensure sufficient flow rate to protect furnace water by means of passing through water such as start-up, even if the flow rate of furnace water wall is less than or equal to the minimum allowable amount of water. When the protection of furnace water wall is achieved only by the amount of feed-water, the no-return valve in the circulation system closes automatically stop circulation and may be switched based on the principle of once-through operation. By adopting the principles as described above, it can be simplify the turbine bypass system, reducing starting losses and shortening start-up time is achieved because the flow is secured by the circulation pump regardless of the feed-water flow rate. Moreover, it is possible to reduce the temperature difference between inlet and outlet of furnace water wall by boiler water circulation.

5.1.2 Once-through boiler

The once-through boiler, as the name implies, the water circulation is not conducted in the furnace water wall. Feed-water that is pushed in by feed-water pump will be heated, evaporated (in case of sub-critical pressure), super-heated, heated to a specified temperature and supplied to turbine from the outlet of super-heater in the course through the economizer, furnace water wall and super-heater. This type boiler can be applied to both of sub-critical and supercritical, however, the supercritical boiler must be the once-through boiler inevitably. It is possible to maintain the concentration of impurities within the standard and ensure the steam purity supplying to turbine by means of separating dissolved impurities which is concentrated in the boiler water in the steam drum and blowing from drum in case of drum type boiler.

On the other hand, since there is no drum which can separate dissolved impurities between the evaporator and the super-heater, and is not capable to blow from system, the impurities in water will be supplied to turbine with steam contained in all. Thus, when a once-through boiler is used, it is essential to obtain high-purity water which has the concentration of impurity below the standard. Recently, a number of plants with efficiency characteristics utilizing supercritical plant have been designated, produced and operated commercially.

5.1.2.1 Universal Pressure (UP) Boiler

Whereas the Benson boiler has been developed in Europe, this UP boiler is the once-through boiler which is developed in United States and is capable to apply both sub-critical and supercritical.

The small tube with diameter 22~31.8mm is applied to boiler water tube. In case of the sub-critical boiler, it is considered and designated to avoid film boiling phenomena and problems of dissolved impurities the by means that the furnace wall tubes are arranged to occur only upward flow, because a mixture of water and steam during heating process i.e., two-phase basin cause. In case of the supercritical boiler, the fluid is always single-phase of water or steam, the furnace wall tubes are employed both upward type and downward type.

The ribbed-tube which is cut grooves inside of tube are applied to the area in the vicinity of the burner Which has the high heat absorption in the furnace so as not to cause overheating by keeping the nuclear boiling phenomena, even if a high content of steam flow to prevent the so-called film boiling phenomena which occur on the inner surface stagnant air bubbles. The typical construction of UP boiler is shown in Fig-21.

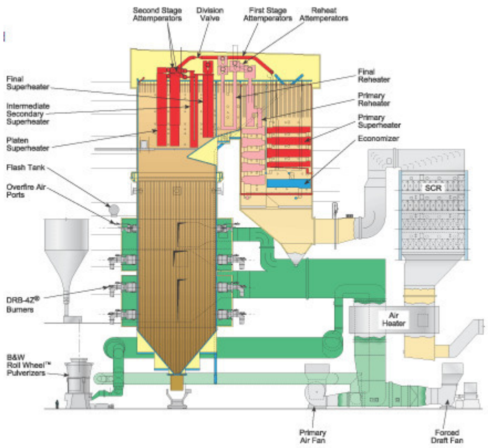


Fig- 21: Universal pressure (UP) boiler (B&W)

http://www.babcock.com/products/boilers/up_specs.html

5.1.2.2 Sulzer boiler

This is the once-through boiler which Swiss company Sulzer has started to production in 1931, and it is characterized providing the header in the middle arranging tubes in parallel. It is said to be an alias "mono-tube boiler". The prototype was developed for sub-critical, keeping wet steam containing 5~10% concentration at outlet of evaporator in high load, the small separator which is provided at the outlet of evaporator separates water and the separated water is collected to deaerator and the part of them are blow out to system. And this way, it is one of the features to have elimination effect removing dissolved solid in the moisture at outlet of evaporator. In addition, the Sulzer type subcritical mono-tube boiler is provided the starting water separator in the outlet of super-heater, and the feed-water is fed to super-heater in the early starting stage to protect simultaneously and cooling re-heater with steam generated in the super-heater during startup. Sulzer boiler was adopted to both supercritical and sub-critical pressure region and the furnace water wall has been adopted for the spiral type tube, the configuration of feed-water and steam system is not different with the Benson boiler. The typical flow and construction of Sulzer boiler is shown in Fig-22 and Fig-23.

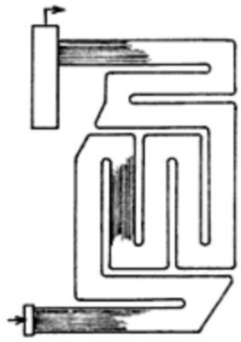


Fig- 22: Mono tube Sulzer boiler

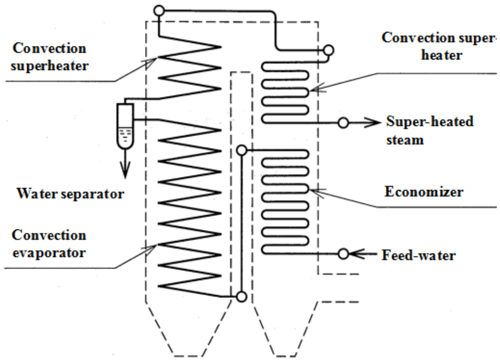


Fig- 23: Mono tube Sulzer boiler

5.1.2.3 Benson boiler

This is the once-through boiler which was invented in 1922 by Mark Benson of England, and was then developed by Siemens Company of Germany; it has been adopted by both the sub-critical and supercritical pressure field. The Benson boiler has been adopted the rise and fall tube method which placed header in the middle of the array of evaporator tubes (especially the furnace wall tubes) making water to merge and divide several times in long time since its inception more than 30 years. However, the meander type have been developed in around 1960, the spiral method has been developed to further improve this and have been adopted in many European type Benson boilers. The spiral method can be adjusted the number of the tubes by the inclination angle of tube in order to achieve the proper flow rate through tube. In addition, it has the feature such that the endotherm per tube is homogeneous. The sliding pressure operation unit is considered to maintain the flow rate by such a circulation pump for dissolved impurities in order to ensure the minimum flow through the low load operation range. This has been possible to good start features and good capability to load as the intermediate load plant. The typical flow and construction of Benson boiler is shown in Fig-24, Fig-25, Fig-26 and Fig-27.

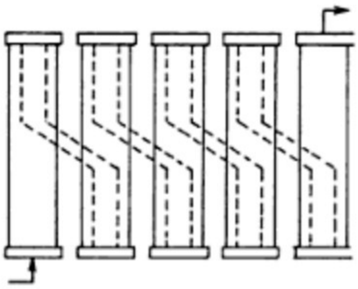


Fig- 24: Benson boiler (Rise and fall type)

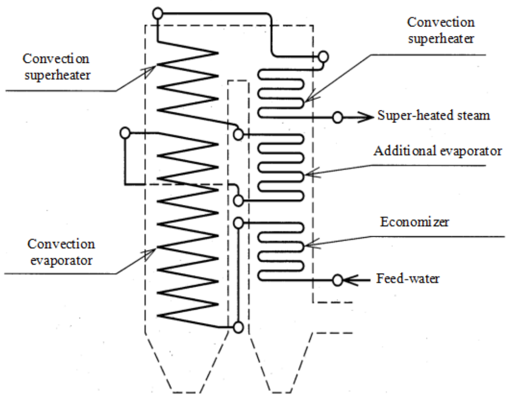


Fig- 25: Benson boiler (Meander type)

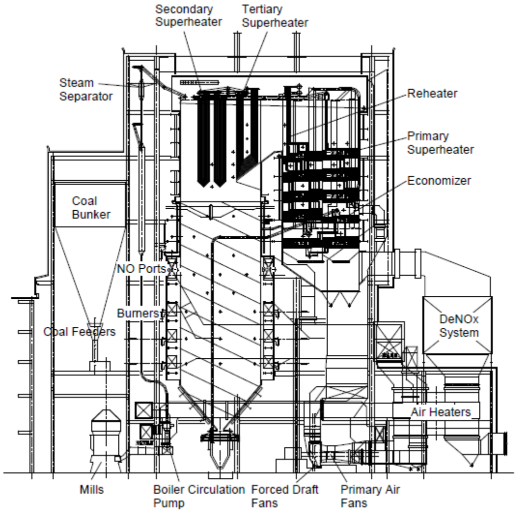


Fig- 26: Benson boiler (BKH)

http://www.hitachipowersystems.us/siteimages/forbus/hpsa/products/steam_generators/index-29.jpg

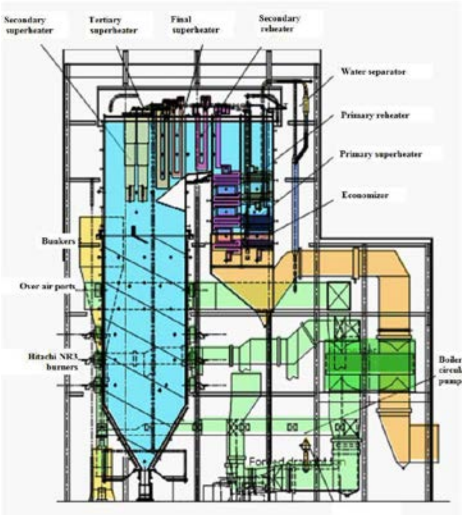


Fig- 27: Benson boiler (BKH)

http://www.hitachipowersystems.us/siteimages/forbus/hpsa/products/steam_generators/index-29.jpg

5.1.2.4 Foster wheeler boiler

This boiler is also the supercritical boiler which was developed in United States, the tube with outside diameter 32~38.1mm is applied to the furnace water wall, the furnace water wall is configured with multiple paths and placed so that always water flow only upward and the safety measures that will be thoroughly mixed fluid flow between each pass has been taken.

5.1.2.5 Ramsin Boiler

This is the high pressure boiler which was invented in the Soviet Union and has different arrangement of tubes, although it is same way as steam generation of Sulzer boiler and Benson boiler. That is, the Ramsin boiler is unlike as Benson boiler at the point in a long coiled steam tube, unlike as Sulzer boiler at the point in arrangement of a number of small-diameter tubes. Its features are to arrange a number of evaporator tubes, providing header between the economizer and the evaporator, providing header between the radiation heat transfer part and contact heat transfer part of evaporator tube and super-heater, stabilizing the flow by providing orifices with 6~14mm hole and placing coiled tubes in almost horizontal position. The separator to separate dissolved impurities is provided; the evaporation termination unit is placed at the low-temperature gas part, if not provided. The typical construction is shown in Fig-28.

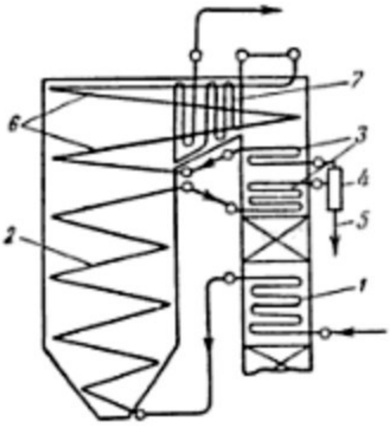


Fig- 28: Ramsin boiler

5.2 Circulation fluidized bed boiler

The fluidized bed boiler have been promoted development and practical application of various methods, since it was focused on the feature to burn extensive coal more efficiently and in-furnace desulfurization performance compared with pulverized coal-fired boiler. Nowadays, not only coal but also such as RDF (Refuse Derived Fuel), RPF (Refused Plastic Fuel), waste wood chips, paper sludge and waste tire has been burn commercial operation by fluidized bed boiler. In the fluidized bed boiler, the fluidized material (inactive granules such as sand, combustion ash products limestone) is filled in the combustion chamber, supplied fluidized gas (such as air) to form a fluidized bed to supply and the combustion reaction of fuel and desulfurization by limestone is carried out in the layers that relatively low temperature (800~900^{o}C). The flow status of particles in the combustion chamber is determined by particle size and flow rate of gas, it takes the form of a bubbling fluidized bed, circulating fluidized bed and air transport. The change of flow condition is shown in Fig-29. Generally, type of fluidized bed boilers can be classified into following three by the fluidized flow conditions of particle, operation pressure.

1) Bubbling fluidized bed boiler (BFB)
2) Circulation fluidized bed boiler (CFB)
3) Pressurized fluidized bed combustion boiler (PFBC)

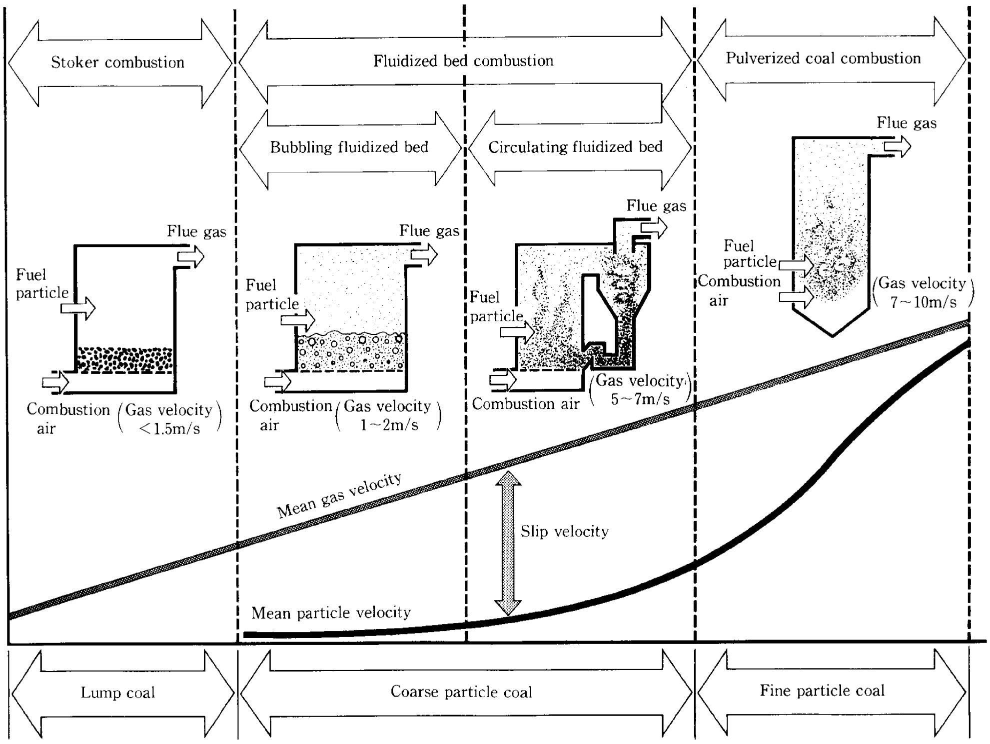


Fig- 29: Relation furnace gas velocity with solid combustion method

Reference: NKK technical report (No.174: Aug/2001)

5.2.1 Bubbling fluidized bed boiler

The fuel is burn in the fluidized bed with low flow rate fluidization of bed material. In the fluidized bed, the particles move randomly around violently suspended by the gas, the gas form a large number of bubbles riddle between particles. In this type, the amount of airborne particles from the fluidized bed is small; the particles may be recycling to the combustion chamber by after separation or collected by such as the bag filters or cyclone to improve combustion efficiency.

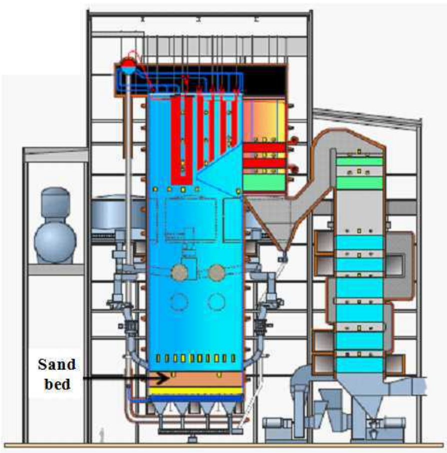


Fig- 30: Bubbling FBB

http://www.stanford.edu/group/uq/events/optimization/2011/11-Saario_Ylitalo_Oksanen_Stanford_2011x02x01.pdf

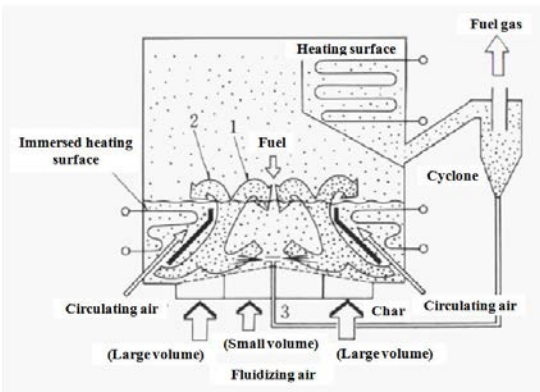


Fig- 31: Internally CFB boiler (Ebara)

Reference: P-336 of (T.Hirota and others of Ebara corporatiom)

5.2.2 Circulation fluidized bed boiler

Increasing gas flow rate further, the fluidized bed expanded and motion becomes more intense and more agitated, it becomes the fast fluidized bed of dense particles are dispersed throughout the combustion chamber. It is necessary to collect the particles by the cyclone and to circulate into the combustion chamber in order to maintain the amount of particles in the fluidized bed boiler increasing the residence time of particle because the amount of airborne particles from the fluidized bed increase. Especially, in the circulating fluidized bed the slip speed (=average gas velocity-average particle velocity) become maximum compared with other flow conditions, the heat transfer and mass transfer characteristics will be good. Furthermore, since the amount of circulation will be 40~100times of input fuel, the combustion chamber is formed in a uniform temperature across the field and the high combustion efficiency can be achieved by long residence time. The system of the coal-fired circulation fluidized bed boiler is shown in Fig-32, Fig-33, Fig-34, Fig-35 and Fig-36.

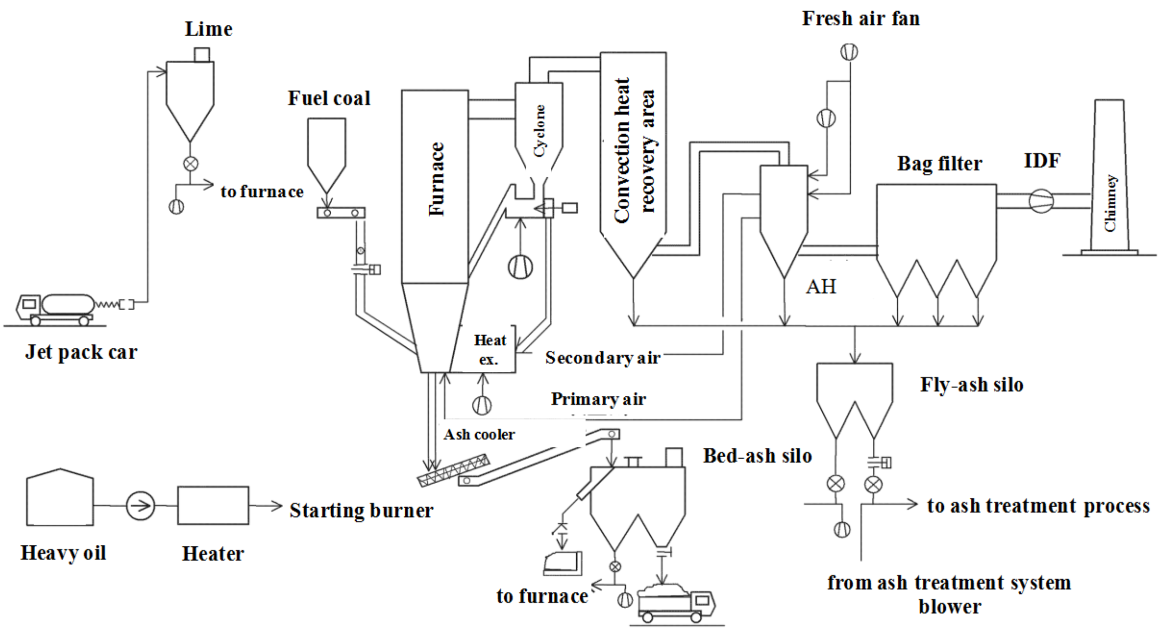


Fig- 32: Typical system of coal-fired circulation fluidized bed boiler

Reference: P-78 of No.587 (Aug. /2005) Journal of TENPES

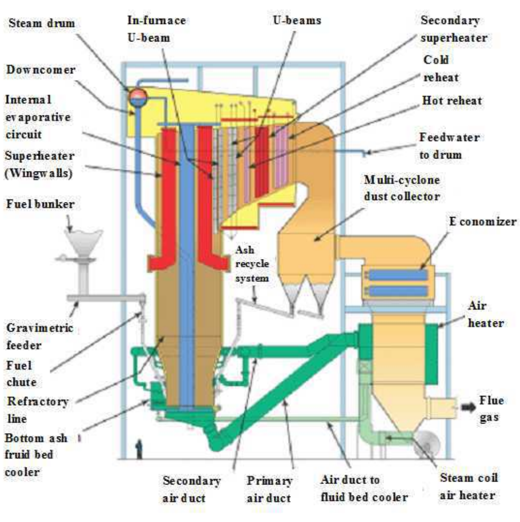


Fig- 33: CFB reheat boiler (B&W)

http://www.babcock.com/products/boilers/circulating_fluidized_bed_specs.html

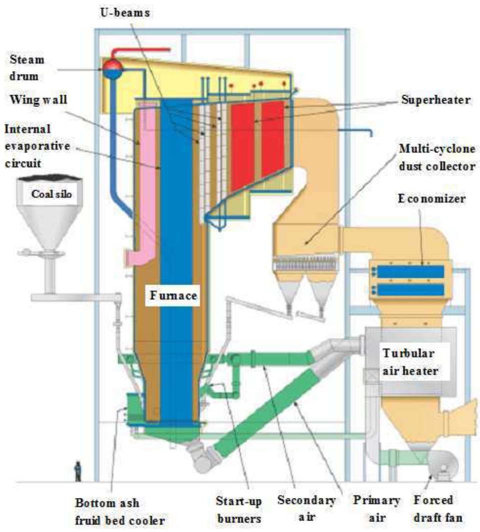


Fig- 34: CFB non-reheat boiler (B&W)

http://www.babcock.com/products/boilers/circulating_fluidized_bed_specs.html

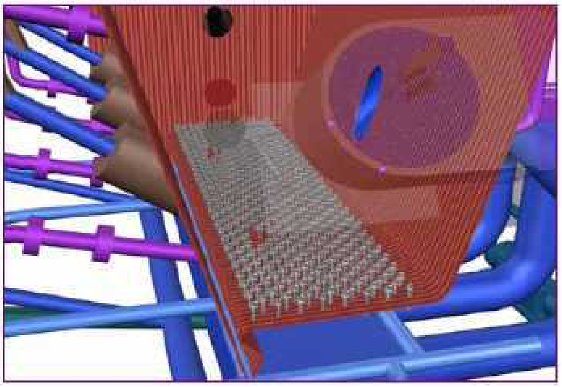


Fig- 35: CFB FA nozzle in furnace

Reference: P-11 of (PPT material of Formosa Heavy Industries Co-Gen Department)

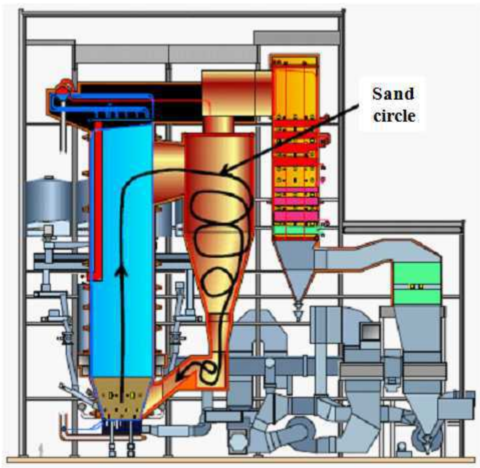


Fig- 36: Circulation FBB

http://www.stanford.edu/group/uq/events/optimization/2011/11-Saario_Ylitalo_Oksanen_Stanford_2011x02x01.pdf

5.2.3 Pressurized fluidized bed combustion boiler

There are another classifications of fluidized bed boiler, one is atmospheric type which burns fuel under atmosphere and the other is the pressurize type which burns fuel under pressure 0.6~2MPag. The principle of the pressurized fluidized bed boiler and the atmospheric fluidized bed boiler are same, however, that is the different characteristics with the atmospheric fluidized bed boiler that it is possible to improve efficiency by the combined-cycle gas turbine, reducing the space required to be applied by pressurizing. The typical flow is shown in Fig-37.

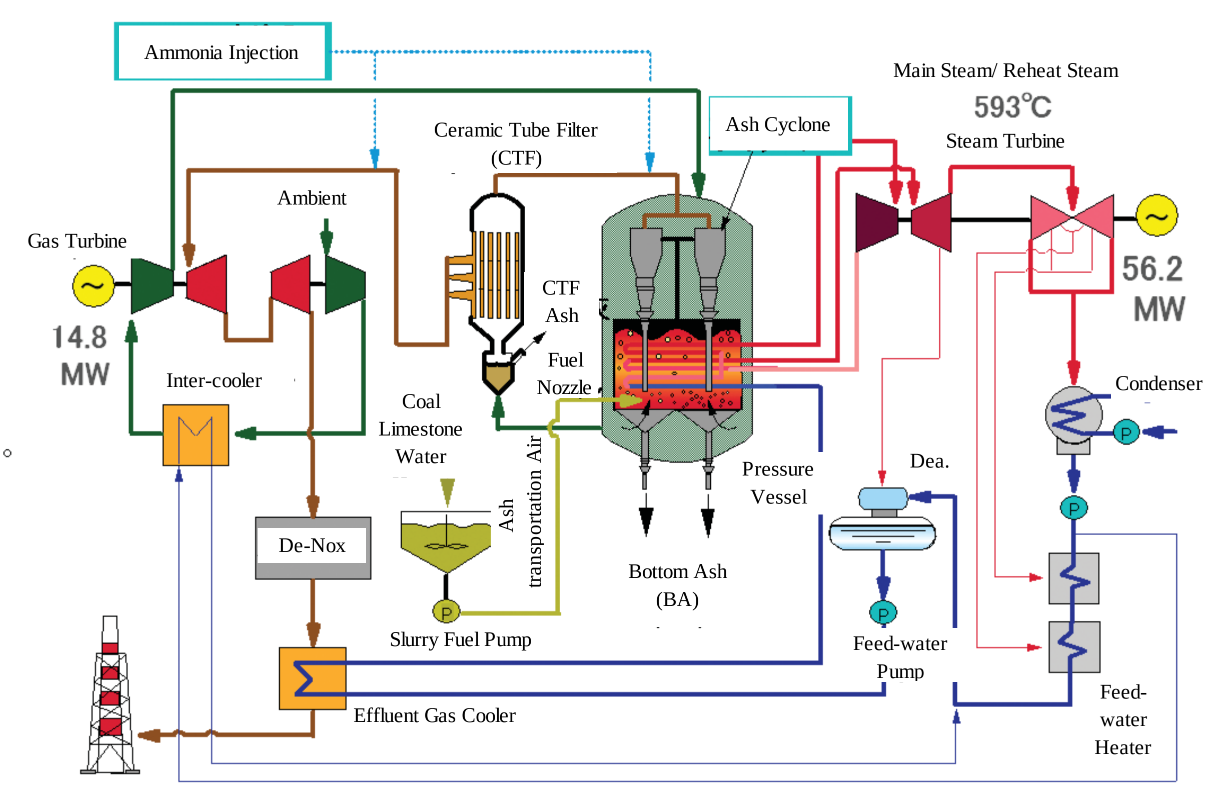


Fig- 37: Pressurized fluidized bed combustion boiler

Reference: P-31 of clean technology journal Japan

5.3 Heat recovery steam generator

5.3.1 Classification of HRSG

There is such a classification of HRSG (Heat Recovery Steam Generator) as shown in the Table-10. The system which has the best combination of them is employed from conditions such as the applied the steam condition or the required space. In addition, it is classified in the horizontal type and vertical type shown in Photo-1, Photo-2, Photo-3 and Photo-4 by gas direction.

Table- 10: Type of HRSG

Steam generation	Boiler water circulation	Gas flow direction	Auxiliary combustion
Single-pressure	Natural circulation	Horizontal	Yes
Non re-heat, Multi-pressure	—	—	—
Re-heat, Multi-pressure	Forced circulation	Vertical	No

Reference: P-60 of No.647 (Aug. /2010) Journal of TENPES

Photo- 1: HRSG for GTCC (Horizontal type)

http://www.power-technology.com/projects/West-County-Energy/images/8-west-county-energy.gif

Photo- 2: HRSG for GTCC (Horizontal type)

http://upload.wikimedia.org/wikipedia/en/b/bf/ModularHRSG-Picture.JPG

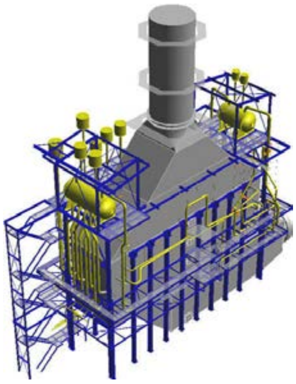


Photo- 3: HRSG for GTCC (Vertical type)

http://www.power-technology.com/contractor_images/cmi-energy/3-image.jpg

Photo- 4: HRSG for GTCC (Vertical type)

http://gaungsinergitama.files.wordpress.com/2010/01/cat-hrsg3.jpg

There are types of HRSG, one is the single-pressure type which has single pressure bevel and the other is the multi-pressure type which has more than two kind of pressure, moreover the reheat multi-pressure type. In the single-pressure type boilers, steam and water system is most simple because the steam from boiler is limited one type. In the contrast, the multi-pressure type has become somewhat more complicated compared with the single-pressure type, the heat recovery from exhaust gas of gas turbine is improved and thereby the plant efficiency is improving.

In the recent years, the many reheat and triple-pressure types have been adopted which improved plant efficiency because it becomes possible to multi-pressure, high temperature, high pressure and reheat due to the high efficiency and large scale of gas turbine. For boiler water circulation model, there are the natural circulation type which utilizes the circulation force by the density difference between fluids circulating within the boiler water circulation system and forced circulation type which circulates boiler water by circulation pump. Also, it is classified by the exhaust flow direction in vertical and horizontal. In addition to increase the output of steam turbine and to drive alone HRSG, the appropriate type is selected to account for the characteristics of each type in some cases to establish an auxiliary burner.

5.3.2 Boiler efficiency of HRSG

The boiler efficiency of HRSG is determined by the ratio of heat output to heat input. The heat output is the amount of heat absorbed by the working fluid in HRSG and the heat input is the heat which is supplied by exhaust of gas turbine, the heat from the combustion of auxiliary fuel and the sum of other heat added to boiler.

$$Boiler\ efficiency = \frac{heat\ output}{heat\ input} \times 100\%\ (heat\ input\ and\ output\ method)$$

$$Boiler\ efficiency = \left(1 - \frac{heat\ loss}{heat\ imput}\right) \times 100\%\ (heat\ loss\ method)$$

It runs up the cost of equipment due to the large heat transfer area, although the efficiency of HRSG will increase when decreasing the gas temperature at the outlet of HRSG. In addition, the exhaust gas temperature at the outlet of HRSG is regulated by the corrosion problem of sulfuric acid if the sulfur is contained in the exhaust gas, the carbonate corrosion even if the sulfur is not contained. Typically, the exhaust gas temperature at the outlet of HRSG is about 100^{o}C in case of gas fuel which does not contain sulfur in the fuel, whereas, in case of gas fuel which includes sulfur or oil fuel is roughly about 150~200^{o}C. There are two cases of the definition of boiler efficiency, the one is to calculate the heat input including the latent heat of vapor in the exhaust gas (higher heating value basis) and the other is to calculate the heat input excluding the latent heat of vapor in the exhaust gas (lower heating value basis). It is often defined the plant efficiency for thermal power plant by the higher heating value basis.

5.3.3 Design matters to be considered for HRSG

The example of a temperature gradient diagram representing the performance of reheat and triple-pressure HRSG is shown in Fig-38. The design considerations and factors affecting the performance of this boiler are described as below.

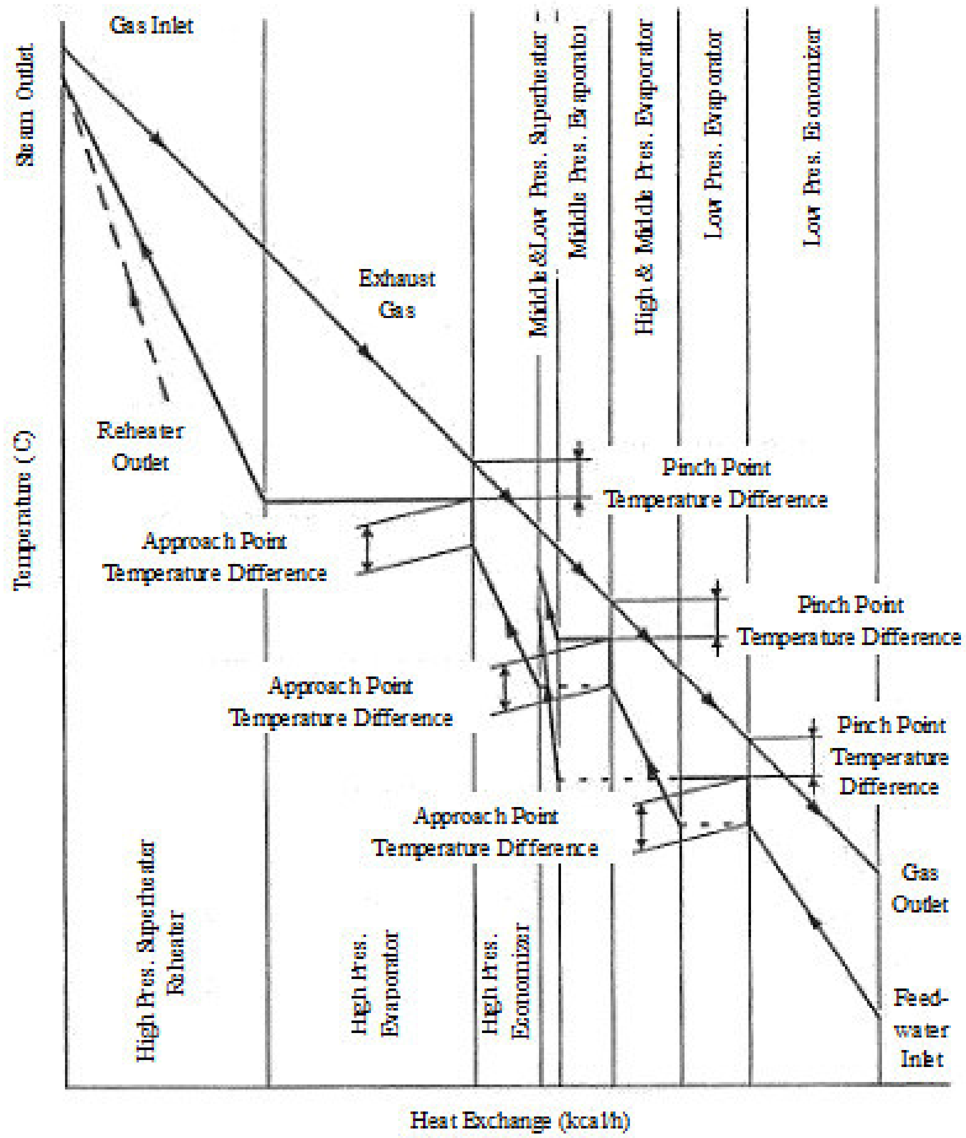


Fig- 38: Temperature gradient diagram for HRSG

Reference: P-60 of No.647 (Aug. /2010) Journal of TENPES

5.3.4 Component of flue gas from gas turbine

The gas turbine exhaust gas is a mixture of exhaust which fuel is almost entirely burn with combustion air and a lot of combustion turbine cooling air. The component of exhaust gas changes depending on the component of fuel and the amount of injected steam or water in the gas turbine. An example of the component of exhaust gas from gas turbine fired LNG is shown in Table-11. In addition, the relationship between temperature and enthalpy at each component of fuel gas is shown in Fig-39. The enthalpy of each component is different and H_2O shows a great value compared with other components. Therefore, the enthalpy changes according to the component of exhaust gas.

Table- 11: Sample of effluent composition

Sample of effluent composition	
Component	Ratio by weight (%)
CO_2	5.5
H_2O	4.7
N_2	73.5
O_2	15
Ar	1.3

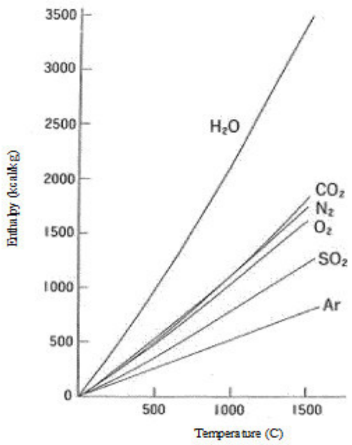


Fig- 39: Temp. VS Enthalpy diagram of exhaust gas components

Reference: P-61 of No.647 (Aug. /2010) Journal of TENPES

The low temperature corrosion problem of heat exchanger tube arise due to the SOx or CO_2 in the exhaust gas, although the heat inlet increases and the heat output increases in the HRSG by lowering the gas temperature at outlet of HRSG. The sulfuric acid and carbonic acid corrosion occurs in the HRSG as low temperature corrosion. The sulfuric acid corrosion is caused by sulfuric acid H_2SO_4 which a part of SO_2 generated from component in the fuel becomes SO_3 combined with oxygen in the air and condensed below the acid dew point. Moreover, the carbonate corrosion is a phenomenon which the carbonic acid combined CO_2 in the exhaust gas and water corrodes such as heat transfer surface of low temperature part below water due point temperature. Generally, it must be kept the outside temperature of heat transfer tubes below the acid dew point or water dew point and the boiler inlet feed-water temperature above these temperatures in order to prevent the low temperature corrosion.

5.3.5 Temperature and mass flow of flue gas

In recent years, the temperature in the combustor increases, the latest gas turbine which has the gas turbine inlet gas temperature of 1,500°C class is realized and the advance gas turbine which has the gas turbine inlet gas temperature of 1,700°C class has also been developing. An increase in exhaust gas temperature and flow means an increase of the heat input to HRSG and an increase of the heat output as the result.

5.3.6 Steam temperature of HRSG

Generally, if deigning the temperature of generated steam high, the amount of steam decreases, however, the output of steam turbine increases and the output and efficiency of entire plant tends to improve.

However, the smaller difference between the steam temperatures up to the exhaust gas temperature, the heat transfer area of HRSG is needed more. In addition, the gas turbine exhaust temperature changes depending on the load of gas turbine, ambient temperature, atmospheric pressure, and the temperature of steam generated in HRSG will vary following these. Therefore, it is necessary to determine the design steam temperature to accommodate the steam temperature within acceptable limits such as the thermal stress of steam turbine considering the operation of the plant and external conditions.

5.3.7 Steam pressure of HRSG

If the steam pressure increases, the efficiency of HRSG drops, because the amount of steam reduces due to the reduced heat exchange being equal other conditions. However, the steam conditions for a steam turbine are improved and the efficiency increases because the steam which has high heat is supplied. There is a pressure to minimize the thermal efficiency and this varies depending on various conditions when considering the efficiency as the combined cycle power plant. The steam pressure is determined in considering the heat input from gas turbine (gas flow rate and exhaust gas temperature), the combination of steam turbine and gas turbine and wetness of the last stage of steam turbine. The typical combination of gas turbine gas temperature and steam temperature is shown in Table-12.

Table- 12: Outlet steam pressure of HRSG

Type of GTCC	Single shaft		Multi shaft	
1,100 ^{o}C class	about 7~8MPa	Dual pressure	about 7~8MPa	Dual pressure
↓	about 9~11MPa	Triple pressure	about 14MPa	Triple pressure
1,500 ^{o}C class	about 14MPa	Triple pressure	about 14MPa	Triple pressure

Reference: P-61 of No.647 (Aug. /2010) Journal of TENPES

5.3.8 Temperature difference pinch point with approach point

The pinch point temperature difference and the approach point are the important factors in designing HRSG. The pinch point temperature difference is the point which the difference between exhaust gas and water or steam is smallest, and it is the outlet of evaporator in a typical HRSG. Also, the approach point temperature difference is the deference between the saturation temperature in the drum and the feed-water temperature at economizer outlet. If taking both approach point temperature difference and pinch point temperature difference small, the amount of steam increases and the efficiency of HRSG raise up. Also, it is necessary to determine the economic value considering the measures to prevent steaming because both approach point temperature difference and pinch point temperature difference drop when the gas turbine load decreases. The detail relation between the pinch points and approach points must be referred in Fig-38.

Pressure loss of flue gas

If reducing the size of HRSG and increasing the draft loss, the back pressure of gas turbine increases and gas turbine output is reduced and the entire heat efficiency of combined cycle will drop. Conversely, if decreasing the draft loss, the output of gas turbine increases and the entire heat efficiency of combined cycle will increase, however, the size of HRSG will be larger. Thus, the exhaust gas draft loss must be determined in terms of economy of entire plant.

5.4 Stoker boiler

5.4.1 Outline

The stoker boiler is widely applied as the measure to incinerate the low grade fuels such as household garbage, RDF in municipal, bagasse, chaff, wood chip from agriculture and forestry, construction debris, waste tires, waste paper sludge, lump coal, lignite and other medical waste. Generally, the combustion heat is recovered and utilized for the power generation, worming or drying at same time.

5.4.2 Features of facility

There are two types of grates, one is the stationary grate stoker shown in Fig-40 and the other is the traveling stoker Fig-41. The stoker method has traditionally been used because it is most easy to use. However, there is disadvantage that becomes low efficient combustion, if the size of fuel is too small and uneven in size, when using the fuel which has a low melting point, it must be careful. When the combustion in the furnace sustained more than expected during the design, melted ash cause the damage of the chain. In case of the traveling stoker, it has advantage that has few fly-ashes because the left ash on the chain falls behind. If this type of boiler is selected, it is necessary to select an appropriate fuel first. RPF which is compressed waste plastic can be burned on the stoker; however, the melting of ash must be very aware. The stoker boiler is still used today, because it is cheaper process than the fluidized bed boiler.

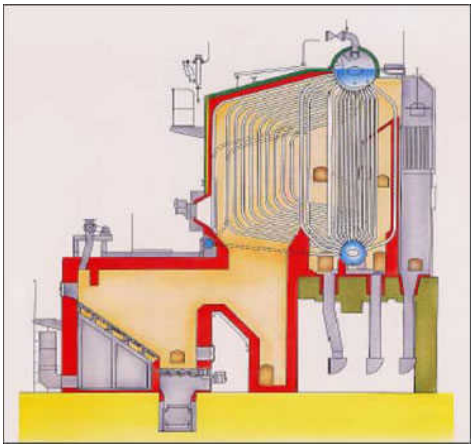


Fig- 40: Stationary stoker boiler

http://www.yoshimine.co.jp/products/product_h.html

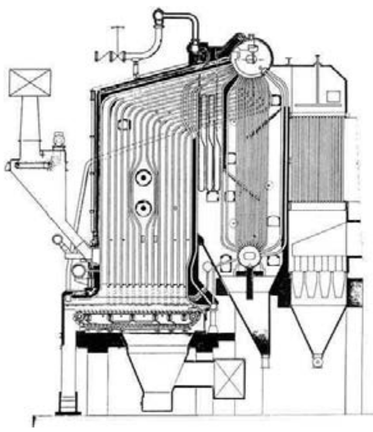


Fig- 41: Travelling stoker boiler

http://www.fao.org/docrep/P2396E/p2396e03.jpg

5.5 Kiln boiler

5.5.1 Outline

The rotary kiln furnace is a horizontal cylindrical furnace lined with refractory material and the axis has been inclined slightly like a Photo-5 and forms a slope down towards the discharge. The combustion burner and the waste feed port are provided at one end of furnace and the discharge port for ash and melt at the other end. It can be incinerated relatively large because the burning material roles by rotation of the furnace. Nowadays, it is often used in conjunction with the stoker furnace or the melting furnace. The kiln stoker furnace is a combination of the rotary furnace and stoker furnace shown in Fig-42, it can be properly incinerated wastes such as liquid mud, powder and plastic and especially suitable for burning oil mud or waste plastic which has fast gasification speed.

5.5.2 Features of facility

The kiln stoker furnace is the one to accommodate the widest range of waste combining the best of both the rotary furnace and kiln furnace. It is suitable the plastic waste and oil sludge that has high liquidity and viscosity, refuse such as wood chips, paper sludge, and household waste that is required high combustion efficiency; it is also suitable for the waste such as waste plastic, oil sludge and paint sludge which has high liquidity and viscosity. The stoker is arranged in series in order to improve the post-combustion, also it can be prevented a problem occurring in the rotary kiln clinker in general. Combustion gases discharged from kiln after complete combustion in the secondary combustion chamber and heat is recovered by HRSG and power generation by steam is performed.

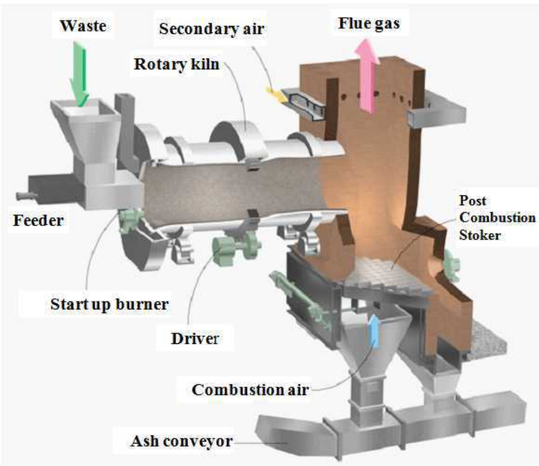


Fig- 42: Kiln stoker boiler

http://www.gec.jp/waste/data/waste_G-5.html

Photo- 5: Kiln boiler

http://www.remediationequipment.com/rotarykilnincinerator.htm

Article 21-6. Typical construction of boiler

1. Conventional Boiler

1.1 Consideration for the boiler construction

The boiler for power generation must be pursuant following requirements for the public interest.

1) Be efficient
2) Long-term operation is possible

3) Be safe

It is necessary to consider following points in addition to the strength and corrosion resistance when designing and installing boiler based on above.

1) Relief of thermal expansion of boiler parts
2) Gas sealing of boiler furnace
3) Economical use of materials

In addition, the heat stress must be considered to be particularly resistant to frequent starts and stops in case of the load adjustment boiler. The boiler must be unconstrained due to the thermal expansion since the hot water or steam flows in the boiler tubes and outer surface is exposed to hot combustion gases. The gas sealing is necessary in order to use hot combustion gas for heat transfer effectively and increase the thermal efficiency of boiler. The structure of furnace is described in the section 1-7 “construction of boiler furnace” and the economic use of materials is described in the section 1-8 “materials for furnace wall tube”.

1.2 Construction of drum

In case of water tube boiler such as the natural circulation type or the forced circulation type, the steam-water mixture which is heated up during passing the furnace and evaporator tubes is led to the sealed horizontal cylindrical body (typically, about 1,200~1,500mm inner diameter) which is called drum, steam and water is separated in here, and the separated steam is supplied to steam turbine via the super-heater. The separated water is fed to the evaporator tubes again through the downcomer header mixed with economizer outlet feed-water. The typical drum for the large boiler 1,200t/h x 19MPa x 570^{o}C/540^{o}C class is 25m long and 170mm thickness will also be over beyond 200tons in weight. SB450 or SB480 of JIS standard is often applied to drum material, the hemispherical or dished head is butt with two or three body plates (five plates in case of large size), and are assembled in a sealed vessel by usually submerged arc welding (submerge welding, melt union welding).

The drum internal equipment which is described in the following section is equipped, the manhole and manhole cover is provided on the head plates and the nozzle for safety valve, level gauge and contact piping are attached on the outer surface of drum, it has been suspended from boiler top beam. Although the above drum is large, some small boilers which operates at low pressure the steam drum is installed on the top of the group of tubes (the same as those described above for the water separator) and lower water drum is installed smaller than the steam drum (usually smaller than the diameter 1,100mm) for water collection and separation. In addition, in case of the sliding pressure once-through boiler, the vertical steam-water separator is installed at the boundary point of evaporator outlet which will be super-heater zone from there. The over-view of the steam-water separator is descried in section-1.4.

As a covert for the structure of the drum, it is important to prevent the occurrence of thermal stressing the boiler at the point where the boiler water passes through the drum wall. The heat stress is caused if connecting directly, because the water temperature is low at the feeding point to the drum. To overcome this, the example to reduce the thermal stress which is appropriate for the penetration point of the feed-water pipe through the end plate or the body plate by dual structure is shown in Fig-43.

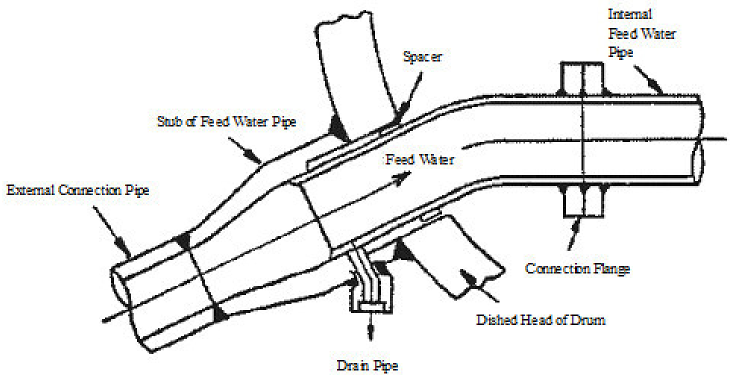


Fig- 43: Typical construction of dual system to prevent thermal stress

Reference: P-76 of No.584 (April/2005) Journal of TENPES

1.3 Drum internal equipment

It is very important to prevent steam from entering into the downcomer by means of separation water and steam perfectly in the drum in order to ensure head difference as large as possible due to the density difference of fluid between riser and downcomer for the circulation boiler.

The internal feed-water distribution pipe to distribute feed-water longitudinally equally, the water separator to separate steam-water mixture to steam and water, the steam dryer to get the dry steam, the continuous blow internal pipe to prevent the deterioration of water quality such as concentration of impurities in the drum have been deployed in the drum. In this section, the steam separator and dryer (also referred to as scrubber) which have an important role are described. These are called as steam cleaning equipment and the demand for purity and dryness of the high-pressure steam will be sever. It is capable to achieve the purpose well by the simple guide plate, baffle plate and stem collection inner pipe because it is easy to separate steam and water in case of low pressure boiler, however, a variety of complicated equipments are applied because it is difficult enough to high pressure. The steam separator is applied the changing flow direction by the guide plates and baffle plates, the centrifugal action, the collision action to baffle plates, and is effective in a relatively large grain separation of water drops. The corrugated baffle plate dryer mesh (also referred to scrubber) is provided at outlet of steam for drying, and collects the residual moisture during passing between them in a low speed.

Fig-46 shows the example for medium and small boiler which is combined the inversion separation and drying mechanism which changes direction of water/steam mixture rapidly guided by the baffle plate and separate water, dry up it through the scrubber arranged to close a number of thin corrugated steel sheets and discharge from the drum. Fig-44, 45 shows the example for large high pressure drum with the cyclone separator and Fig-47 shows the example for large high pressure drum with the expression swirler separator, they are attached primary scrubber on the top of centrifugal separator and attached secondary scrubber to outlet of the steam drum. Fig-48 also shows the example for large high pressure drum which has horizontal centrifugal separator and chevron type dryer. The vortex eliminator (anti-vortex device) has been installed at the inlet of the main downcomer pipe for this drum in order to prevent the contamination of air bubbles in the tube. The photo-6 shows the situation of drum internal without internal equipments.

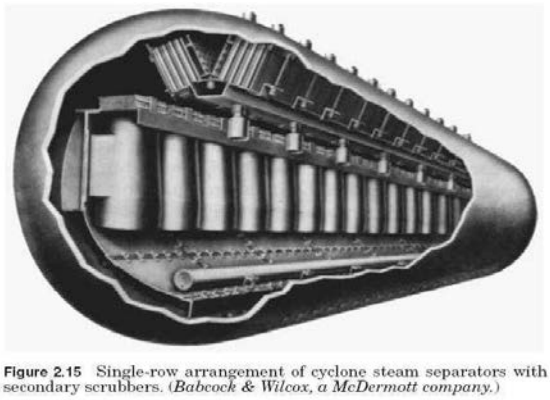


Fig- 44: Drum internal (B&W)

http://science-hamza.blogspot.jp/2011/07/boiler-drum-roles.html

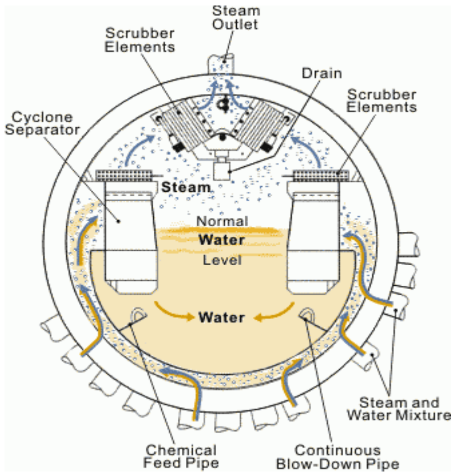


Fig- 45: Centrifugal steam separator (for large boiler)

http://www.thermopedia.com/content/1236/

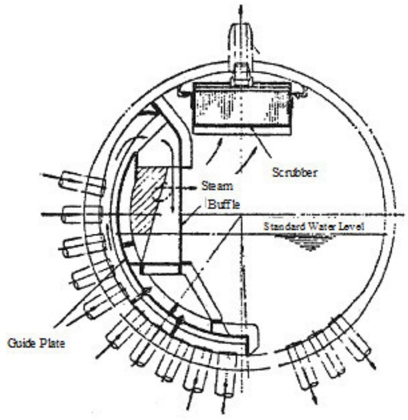


Fig- 46: Inversion steam separator (for middle boiler)

Reference: P-77 of No.584 (April/2005) Journal of TENPES

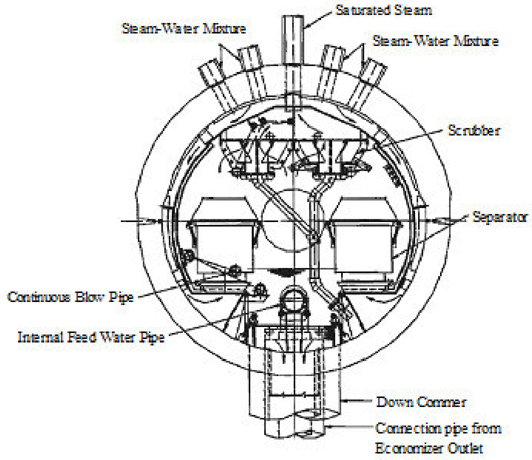


Fig- 47: Centrifugal steam separator (for large boiler)

Reference: P-77 of No.584 (April/2005) Journal of TENPES

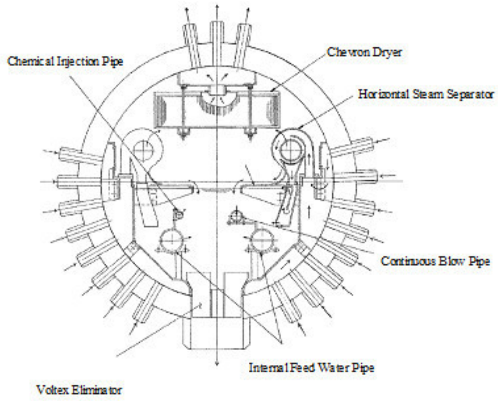


Fig- 48: Horizontal centrifugal steam separator (for large)

Reference: P-77 of No.584 (April/2005) Journal of TENPES

Photo- 6: Drum internal without parts

http://picasaweb.google.com/lh/photo/Ipsb-U7RNPJQN_Vn2jj6Pg

1.4 Steam/water separator

The vertical steam separator and separator drain tank which is installed for the sliding once-through boiler is shown in Fig-49. Wet steam comes out from the evaporator flow into from the plural separator nozzles tangentially to the swirl motion in the separator. As the result, the drain in the wet steam is separated by the centrifugal force, and the steam is introduced to the super-heater from the center top of separator via the outlet nozzle of separator. On the other hand, the separated water is guided to the separator drain tank and flows into the drain recirculation system. Furthermore, the separator is provided plural depending on the amount of evaporation unlike the drum. Also, there is example to apply separator which was integrated separator and drain tank (usually one on a unit).

The drip ring which is placed on the top preventing drops flow into the super-heater, the vortex eliminator for the purpose of preventing inflow of drops are applied to the internal equipment for the separator, however, there is one without them. Furthermore, the separator is provided for the convenience of start-up in same case of the constant pressure once-through boiler.

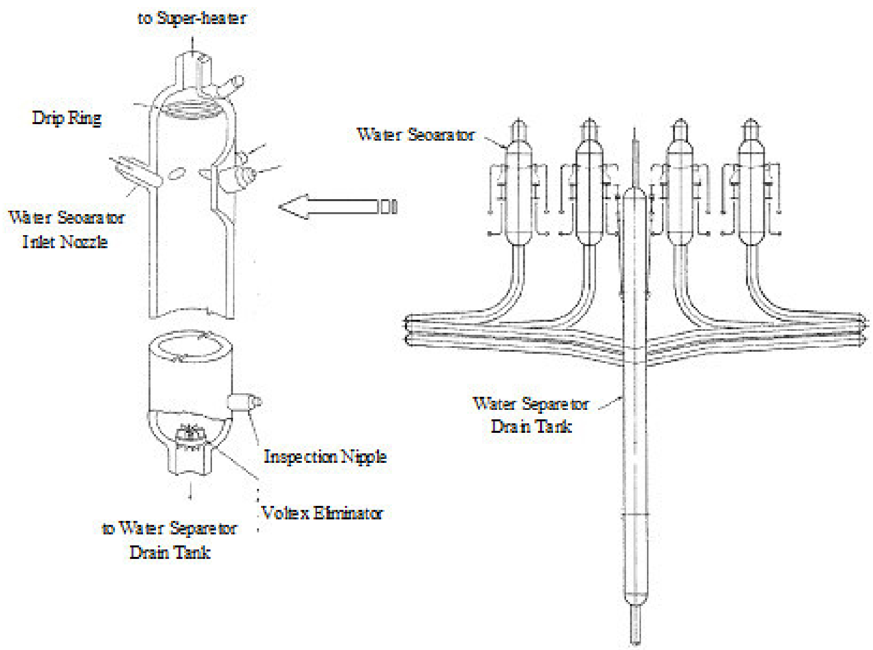


Fig- 49: Water separator and drain tank

Reference: P-77 of No.584 (April/2005) Journal of TENPES

1.5 Size of boiler furnace

The boiler furnace (combustion chamber) is a space where the combustion air and fuel fed by the fuel burning equipment is mixed well and exchange chemical energy of fuel to heat energy. The furnace wall must aim to complete combustion of fuel, sufficient size to lower the exit gas temperature moderately and have the appropriate construction to avoid leakage of internal heat especially in case of coal-fired boiler in order to prevent adhesion of melted ash on the convection heat transfer area (heat recovery heat transfer surface). Its size depends on the type of boiler, type of fuel, combustion method, draft system and construction of furnace wall and is designated so that the wall metal temperature is always stable and acceptable avoiding localized high heat load. The furnace heat liberation ration as the guide to determine the size of the furnace is shown in Table-13. The route leading from burner to the outlet of furnace is suitably determined by considering the required complete combustion time or adhesion of ash in case of pulverized coal, oil and gas. Moreover, in recent years, the furnace is tend to be planned relatively large aimed the low-NOx combustion.

Table- 13: Furnace heat liberation ratio

<table>
<tr><th rowspan="2">boiler</th><th rowspan="2" colspan="2">Combustion method</th><th colspan="2">Furnace heat liberation ratio</th></tr>
<tr><th>Per furnace volume (1)</th><th>Per furnace radiant heat transfer area (2)</th></tr>
<tr><td rowspan="4">Water tube boiler</td><td colspan="2">Pulverized coal combustion</td><td>380~840
(90,000~200,000)</td><td>630~1260
(150,000~300,000)</td></tr>
<tr><td colspan="2">Gas combustion</td><td>630~1680
(150,000~400,000)</td><td>670~2100
(160,000~500,000)</td></tr>
<tr><td rowspan="2">Heavy oil combustion</td><td>Package boiler</td><td>2100~5440
(500,000~1,300,000)</td><td rowspan="2">840~2100
(200,000~500,000)</td></tr>
<tr><td>Ordinal on-shore boiler</td><td>840~2930
(200,000~700,000)</td></tr>
</table>

(1) Upper column: MJ/m^3h, Lower column: $kcal/m^3h$ (2) Upper column: MJ/m^2h, Lower column: $kcal/m^2h$

Reference: P-78 of No.584 (April/2005) Journal of TENPES

1.6 Type of evaporator

The following consideration for the distribution of fluid and the property of heat transfer must be given to the evaporator because the steam and water mixture flow in the evaporator tube as two-phase flow status.

1) To ensure a stable heat absorption, flow rate and to suppress the heat transfer inhibition caused by the two-phase flow
2) To plan the design condition of outlet and inlet, the arrangement and construction of contact pipe appropriately to avoid the un-uniform inflow and outflow of two-phase flow.

The furnace which is capable to ensure the heat transfer are obtaining sufficient heat load and endotherm from combustion gas at most upstream is the typical evaporator. The evaporation type economizer introduced in section1.19-(2) is a example because the are arranged at the most upstream, can be obtain stable feed-water condition and can be connected to drum immediate after evaporation. In addition, there are examples of placing the flue gas duct evaporator between the furnace and the separator. This may be placed downstream in the flue gas duct as well as the economizer. In addition, the some structure of furnace outlet nose is separated the path from the furnace as the evaporator.

1.7 Construction of boiler furnace

The construction of furnace wall which has been adopted in recent years is shown in Fig-50. The type-(a) was the conventional type which placed tubes with intervals and refractory and insulation behind tubes, and then the type-(b) which placed tubes in dense, the skin casing and isolate combustion gas by this has been adopted. The type-(c) which is all welded water wall (which is called a membrane wall or mono-wall) construction and be capable to isolate combustion gas completely has been mainly adopted with increasing oil-fired boiler and changes from the balance draft method to positive draft method. The reason why the welded wall is adopted to so many boilers, it is capable to gas-tight by air-tight structure. The example of a water wall corners construction of all welded boiler furnace which shows the situation of the evaporator tubes, insulation, backstay and outer casing is shown in Fig-51.

The all-welded water wall method is shown in Fig-54 such as to weld fins placed between tubes (a: fin-weld type), to fill a metal between tubes with fusion metal (b: fusion weld type), to weld together fin tubes (c: welded fin tube type). In addition, Fig-52 is the configuration example of vertical tube furnace wall, those of spiral wound furnace wall structure (helical structure or spiral structure) are often employed at the bottom which has high heat load in case of sliding pressure once through boiler. Fig-53 is an example of the construction for furnace wall corner constituted by the spiral (helical) tube.

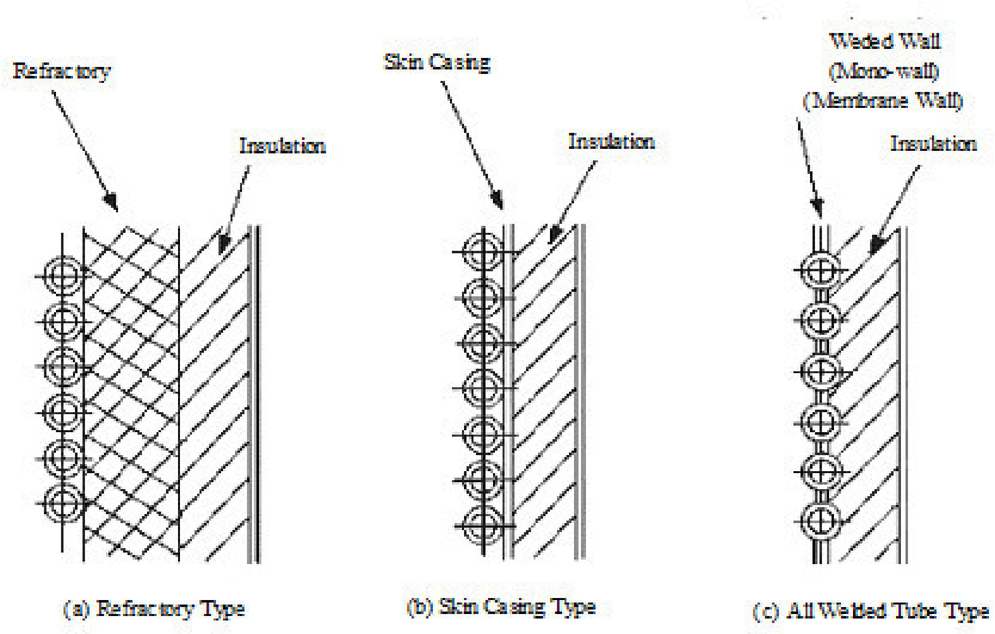


Fig- 50: Typical construction of furnace wall

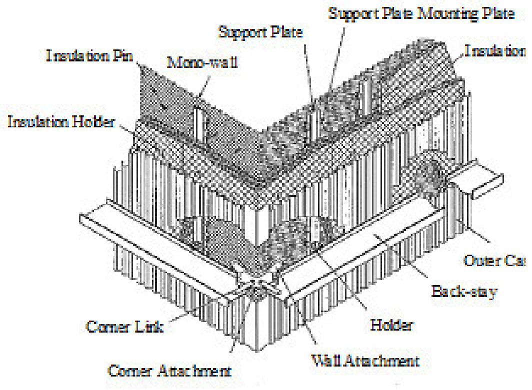


Fig- 51: Spiral tube wall

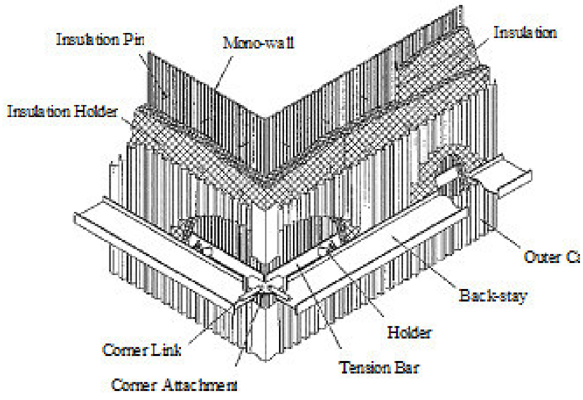


Fig- 52: Vertical tube wall

Fig- 53: Typical construction of furnace wall corner

Reference: P-53 of No.585 (Jun/2005) Journal of TENPES

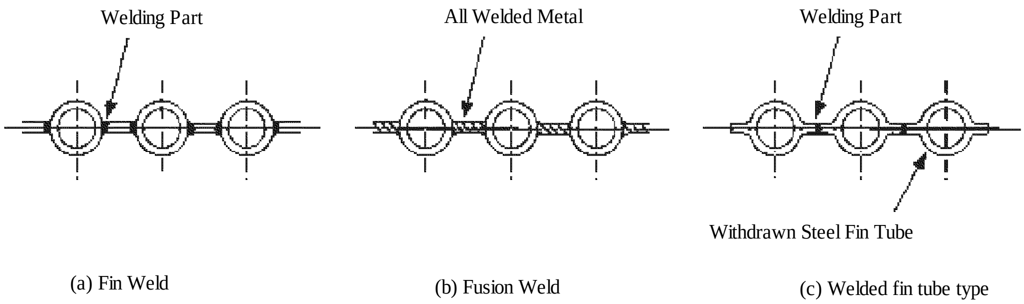


Fig- 54: Typical construction of welded water wall

Reference: P-79 of No.584 (April/2005) Journal of TENPES

1.8 Material for furnace wall tube (water wall tube)

JIS STB340 with outside diameter 63.5~76.2mm is applied to the furnace water wall tube of natural circulation boiler, STB410 with outside diameter 38.1~45mm is applied to the furnace water wall tube of the forced circulation boiler, STB410, STBA12, STBA20 or STBA23 with outside diameter 22.2~38.1mm is applied to the furnace water wall tube of the once-through boiler, and also the ®STBA21~®STBA23 is used for the part where is exposed high temperature flame.

Furthermore, the rifle tube (the tube which has groove on the inner surface enhancing heat transfer) may be applied to the part where the heat load is high. The typical construction of the spiral furnace water tube and the rifle tube for vertical water wall is shown in Photo-7.

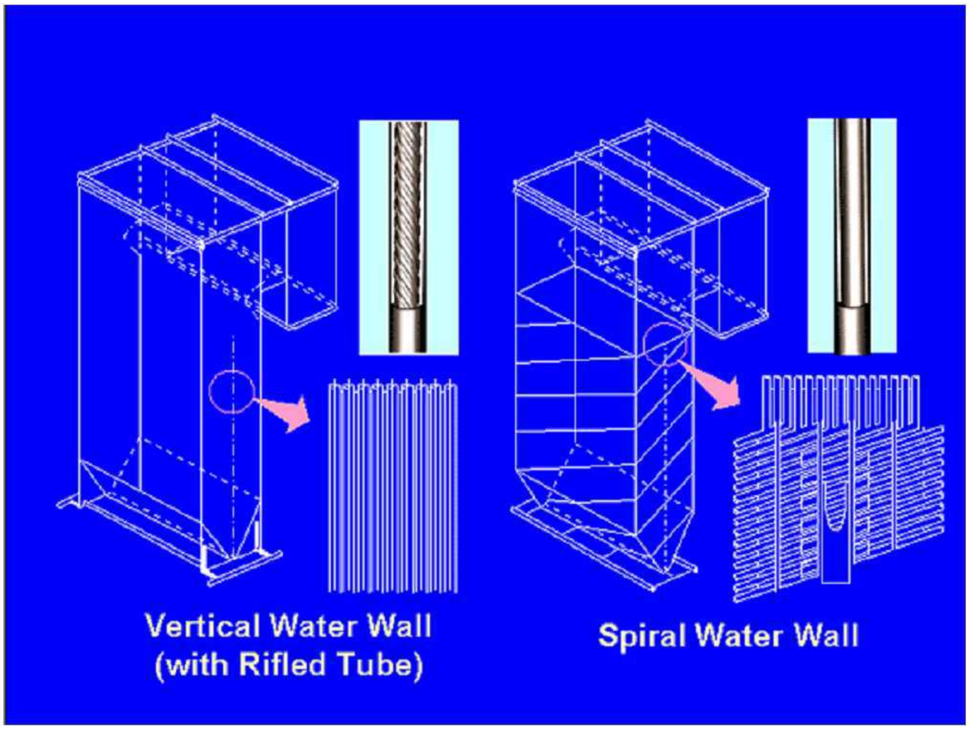
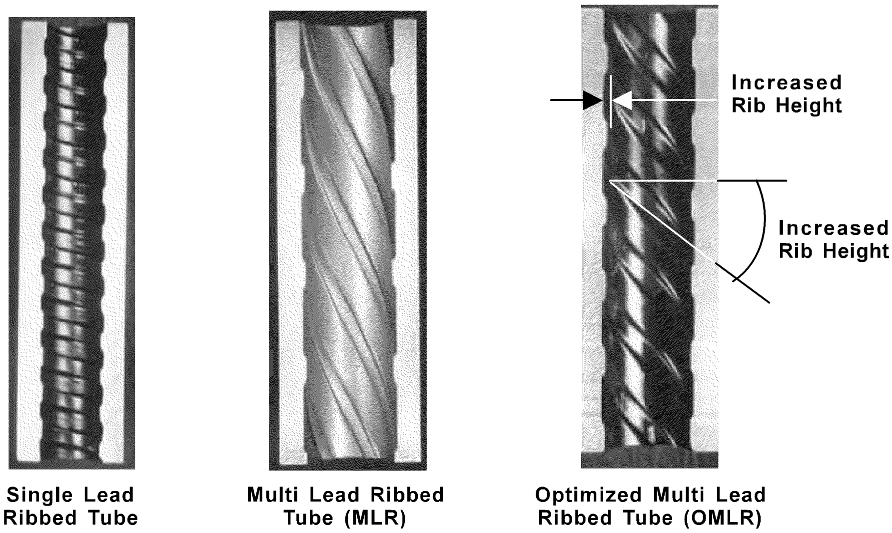


Photo- 7: Typical furnace wall tube

http://www.mhi.co.jp/en/products/expand/once-through_boiler_sample_05.html



http://www.babcock.com/library/pdf/br-1723.pdf

1.9 Material for furnace wall (caster and thermal insulation)

The high-quality alumina brick or JIS standard type-1 or type-2 clay brick is used in the part where exposed to high temperature flame, the JIS standard type-6 or type 7 clay brick is used in the part where exposed in the furnace, the JIS standard type -8 clay brick is used as the refractory bricks. The plastic refractory and castable refractory is used in the part where exposed to high temperature flame such as the burner flame touching tile as shown in photo-8,9, the plastic refractory is kneaded together with binder such as clay and bone material such as shiyamotto, high aluminum and high chrome, and beat in by hammer. The castable refractory is the refractory concrete blended with the aggregate material with the alumina cement, and smears them by trowel or spraying. Calcium silicate, glass wool, perlite and diatomite are used as thermal insulation material (insulation), and they are JIS standard products.

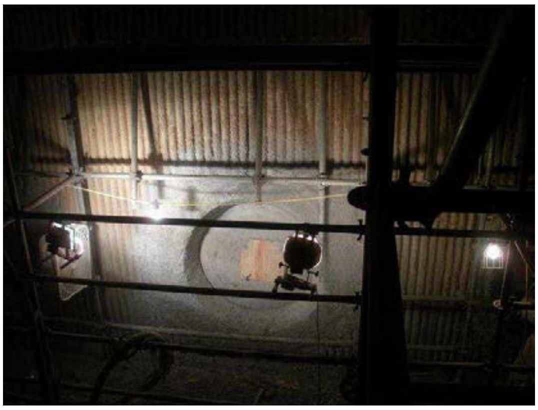


Photo- 8: Burner throat on furnace wall

http://www.thermbond.com/Full%20Application%20Reports/Coal%20Fired%20Power%20Boiler-slobber%20nozzled.aspx

Photo- 9: Ready for burner casting work

http://www.thermbond.com/power/Wiki/Burner%20Throats-1300%20MW%20Power%20Station-%20Rammed,%20Hand%20Packed.aspx

1.10 Type of super-heater

Steam generated in the boiler body is the saturated steam and contains some moisture. The super-heater is used to produce super-heated steam by heating hole and evaporating the moisture. There are following benefits by using super-heated steam.

1) Increase of thermal efficiency
2) Reduction of steam consumption by increasing the heat drop
3) Reduction of erosion by water droplets in the low-pressure steam turbine stage blade

The heating temperature is limited by the materials to be used, although these benefits are greater the higher the super-heating. Recently, the turbine inlet steam temperature for the main steam is adopted 600°C and for re-heat steam 610°C in maximum (generally, 538°C~593°C) is applied practically because the material development of plant with ultra high pressure and temperature in countries has been conducted to withstand the turbine inlet steam condition (30MPa, 630°C).

1.11 Classification of super-heater by heat transfer method

The super-heater is classified in the convection type (contact type), the convection type and the radiation type and the radiation-convection mixing type, if classifying by the heat transfer method. The convection type super-heater is placed inside the boiler body of relatively low temperature gas passage and heat up by contacting with hot gas as shown in S of Fig-55, the radiation type super-heater is placed on top of the furnace wall or split wall in furnace and is exposed to radiant heat at the same time heat up by contacting with hot gas as shown in R of Fig-55, the radiation-convection type super-heater is exposed to radiation heat at the same time, which is heated by contact with hot gases as shown in RS of Fig-55.

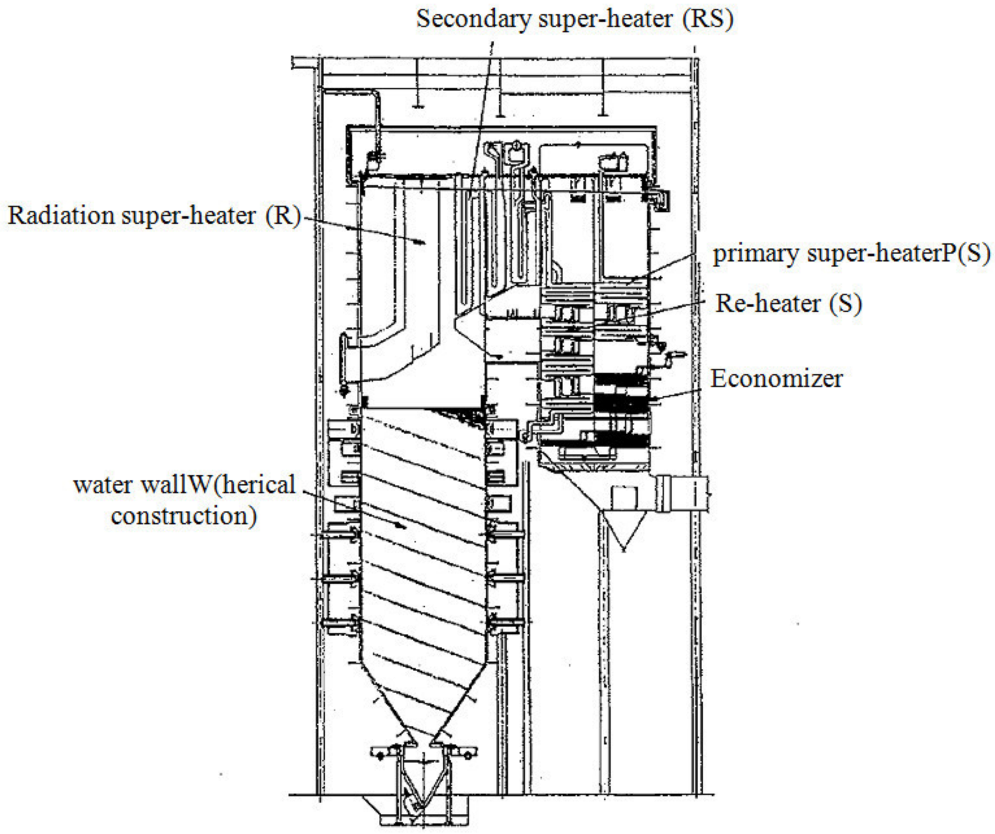


Fig- 55: Typical construction of super-heater, re-heater, economizer

Reference: P-54 of No.585 (Jun/2005) Journal of TENPES

1.12 Classification of super-heater by flow type

The super-heater is classified in the parallel flow type as shown in Fig-56-(a), the counter flow type as shown in Fig-56-(b) and the combined flow type as shown in Fig-56-(c) and (d) by the relationship between the flow direction of steam and hot gas, if classifying by the flow. The metal temperature of super-heater is rare to overheating and heat utilization is also low, because the parallel flow type is placed in contact with the lowest temperature steam and the highest temperature gas. The counter flow type may cause corrosion or oxidation of the tube if the temperature is high, although the heist temperature steam contact with the highest temperature gas and good utilization of the heat. The combined method incorporated the best of both worlds and supplemented with shortcomings, there are various piping methods for this.

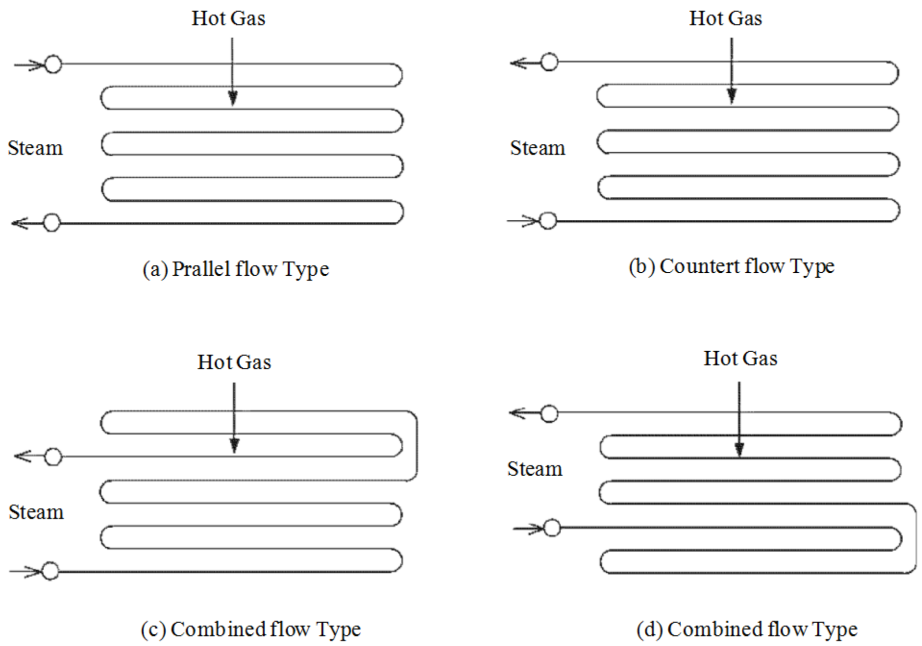


Fig- 56: Flow type of super-heater

Reference: P-54 of No.585 (Jun/2005) Journal of TENPES

1.13 Performance of super-heater

The steam temperature of the super-heater commonly used varies with changes in boiler load. The degree of super-heat of the radiation type super-heater decreases with increasing the amount of evaporation and the degree of super-heat of the convection type super-heater tends to rise conversely. The radiation type super-heater and the convection type super-heater may be connected in series to obtain relatively flat steam temperature characteristics for the boiler load combining the characteristics of these two, because it is desirable for the boiler to maintain a constant temperature over a wide range of loads. The boiler which is shown in Fig-55 is one example of the radiation type super-heater which is placed in the furnace.

1.14 Type of re-heater

The re-heater is provided in the boiler in order to improve the heat efficiency if turbine plant, to prevent the corrosion of turbine blades by means of extracting steam close to the saturation temperature after constant expansion in the HP turbine, heating up again up to a suitable temperature and return it IP /LP turbine in order to carry out the work. The hot gas type re-heater which is heated up by the combustion gas is generally used, although there is the steam type re-heater which is heated up by high temperature.

There are the radiation type and the convection type for these. The former is placed in the furnace and used radiation heat, the latter which is used mainly today is placed in the flue duct as convection (contact) re-heater. The construction and performance is same as the super-heater. However, the different point with the super-heater is that the handled steam pressure is low generally, high volume, need to be designed with low pressure loss of steam. The re-heat system is employed in thermal power plants with more than 75MW, mainly single stage is applied, in some cases two stages is adopted for large capacity plant. The temperature at turbine inlet is often employed 538°C~593°C same as the super-heater.

1.15 Material and construction of super-heater and re-heater

The super-heater and re-heater are made of tubes and headers. The seamless carbon steel tube is used in low temperature part in general, the seamless alloy steel tube containing such as Ni, Cr, Mo and V in the high temperature as the tube material.

The super-heater tube and re-heater tube must have high resistance to creep and oxidation because they are exposed to high temperature. The carbon steel tube (STB340 and 410) is used respectively up to the maximum core temperature of tube 450°C, the molybdenum steel tube (STBA12) 500°C, the Cr-molybdenum steel tube (STBA20) 525°C, the Cr-molybdenum steel tube (STBA22) 550°C, the Cr-molybdenum steel tube (STBA23) 575°C, the Cr-molybdenum steel tube (STBA24 and 25) 600°C, the Cr-molybdenum steel tube (STBA26 and 29) 625°C. The austenitic steel tube (SUS304HTB, SUS316HTB, SUS321HTB and SUS347HTB) are often used in temperature above 600°C. In addition to the JIS standard materials, the materials (the material name have ® mark) set force in the "interpretation of the technical regulation for thermal power generation facility" of Japan are often used because of benefits such as excellent high temperature strength compared to the equivalent standard material. ®STBA24J1 and ®STBA28 is used to the Cr-Mo alloy steel pipe, ®SUS304J1HTB, ®SUS321J1HTB, ®SUSTP347HTB and ®SUSTP310J1HTB are used to austenitic steel tube. In addition, the material name which "J" is marked was developed in Japan.

As the material of header, the seamless steel pipe or welded steel pipe is used, it has annealed and tube holes are provided away from the weld part. The tube is placed in vertically or horizontally with formed in such a U-shape type or meander type together some of the tubes. They are connected by welding when connecting it to the header. It has been considered for welding and preventing deterioration by using inconel which has the intermediate value of thermal expansion of both when welding austenitic steel tube and chromium-molybdenum steel pipe.

1.16 Temperature control method (de-super-heater method)

In general, if determining the heat transfer area of the super-heater to obtain specified temperature at the lowest load in the steam temperature control range, the steam temperature exceeds a specific value in the more load, therefore it is necessary to reduce the steam temperature by de-super-heater to a specified temperature. There are some cases to provide the de-super-heater after the super-heater, to provide in the intermediate between super-heater and re-heater heat transfer are (for example, between the primary super-heater and the secondary super-heater) and to provide in inlet of re-heater.

There are the spray (fountain) type and the surface cooling type for the de-super-heater. The construction of the spray type de-super-heater is shown in Fig-57, the spray nozzle is attached to a venturi provided in the steam pipe, a thermal sleeve to avoid thermal shock due to spray water have been provided. Also, it is placed between the primary re-heater and the secondary re-heater, consideration is made to inject worming steam always to reduce thermal shock when turning the spray water for the re-heater de-super-heater which is use in emergency case. In addition, if there is amount of solids, it causes the deposits on such as super-heater, re-heater and turbine blades.

It is necessary a high purity water as the spray water and is taken from the outlet of feed-water pump or economizer inlet. An example of a surface cooling type is shown in Fig-58. Fig-58-(a) and Fig-58-(b) are surface cooling method by boiler water, Fig-58-(c) is the surface cooling method by feed-water, they are to cool the steam by heat exchanger.

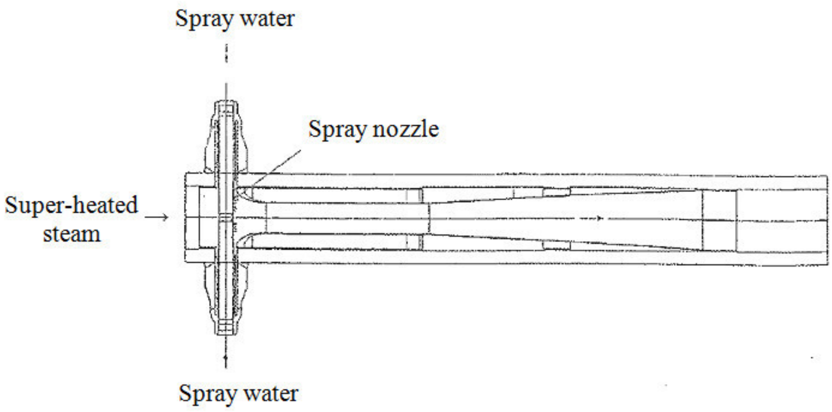


Fig- 57: Construction of de-super-heater

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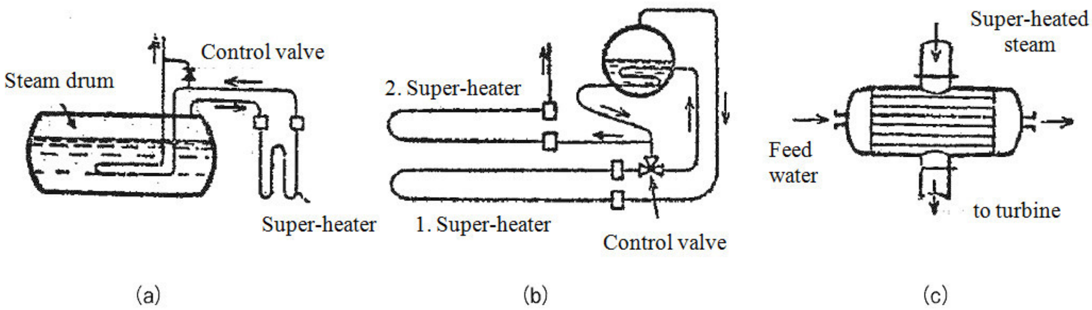

Fig- 58: Cooling method by surface-heat exchange

Reference: P-56 of No.585 (Jun/2005) Journal of TENPES

1.17 Supporting method of tubes

The vertical and horizontal type super-heater and re-heater tubes must be prevented the disturbance by appropriate bracket and metal spacers to each other and need to free from thermal expansion stress. Since these bracket and spacers are exposed to hot combustion gases, the selection of sizes and materials must be done carefully. Especially for the heavy oil-fired boiler, the consideration to using austenitic alloy spacer in the hot gas area or reduce height of spacer as much as possible in order to prevent corrosion due to vanadium, the steam cooled spacer is adopted as part of the secondary super-heater especially in the hot gas area and some structure have been taken to keep the tubes aligned with the welding portion of super-heater tubes. These various examples of the support apparatus are shown in Fig-59, Fig-60, Fig-61 and Fig-62. In case the relatively long span of postfix horizontal tube arrangement, since the deflection of the tube increase, it is necessary to support three or more points such as vertical support (such as super-heater tube or water tube).

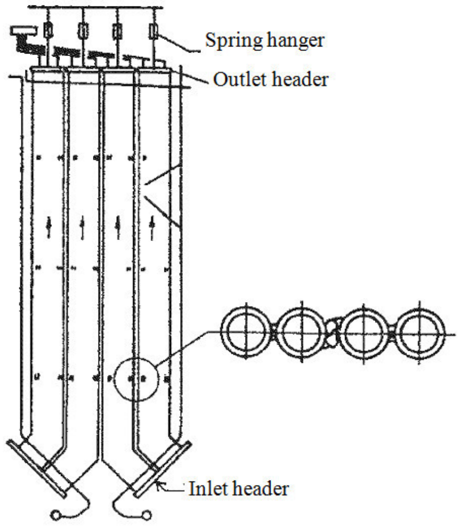

Fig- 59: Supporting bracket for separating wall

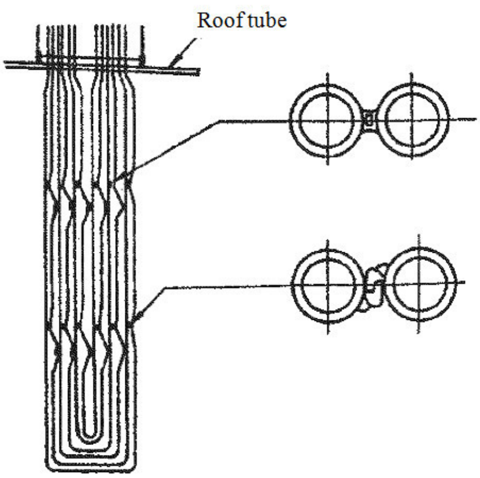

Fig- 60: Supporting bracket for hanging SH

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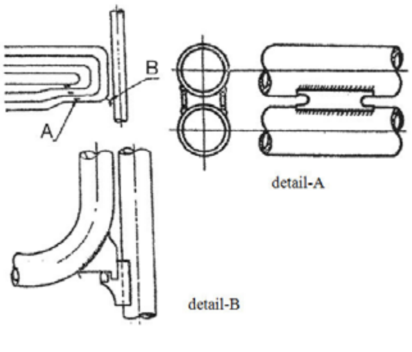

Fig- 62: Supporting bracket for RH hot part

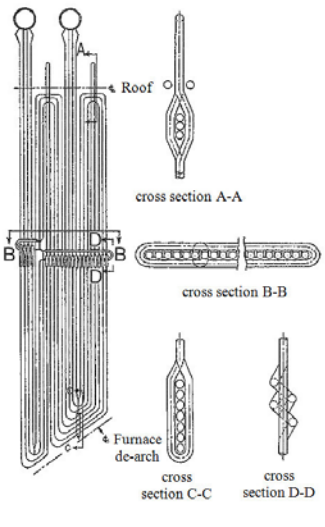

Fig- 61: Steam cooling type support

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1.18 Benefits by use of economizer

The economizer is an equipment to preheat the boiler feed-water using the waste heat of flue gas, which benefits are as follows.

(1) To increase boiler efficiency by reducing heat loss in the exhaust gas. The boiler efficiency increases about 1% every drop of exhaust gas temperature of about 20^{o}C.

(2) It is easy to separate dissolved gas in the water by preheating the feed-water, it helps to reduce the thermal stress caused to the drum of boiler by means of reducing the temperature difference by preheating of feed-water.

1.19 Type of economizer

(1) There are the co-current type which the direction of gas and water are same, the con-current type which the direction of gas and water is opposite, the mixed type which combined the co-current type and the con-current type. The con-current type is mainly used for the economizer because heat conductivity is best.

(2) There are the evaporation type and non-evaporation type, if classifying by the degree of heat. Generally, the former that the temperature of economizer outlet feed-water keeping below the saturation temperature (so-called sub-cooled state) and supply to boiler is used. The evaporation type is to heat up to evaporates some of the water in the economizer, send to boiler in the steam/water mixture. It is required consideration of the drum level control and how to connect them to boiler drum.

1.20 Construction of economizer

The economizer is consisting of tubes and headers, and there are U-shaped bend type, the meander type tube and finned type tube. The meander type shown in Photo-10 and Fig-63 which long steel tubes with 45~60mm outside diameter is bent suitably and reach from economizer inlet to outlet continuously is called the loop type. Also, the finned tube type economizer is the tube which is bent wound fin on the steel tube and bend it in U-shape shown in Photo-12,13 and is connected with the inlet and outlet header, and such as those attached plate fins to the strait tube shown in photo-12. When applying the finned tube, it is possible to reduce installation space of gas side because the heat transfer area of gas side became significant larger, although gas flow resistance are used to increase due to fins. In addition, the tube material of economizer is often used STB340 or 410 in general.

Photo- 10: Serial economizer

http://www.oppd.com/NC2/22_002461

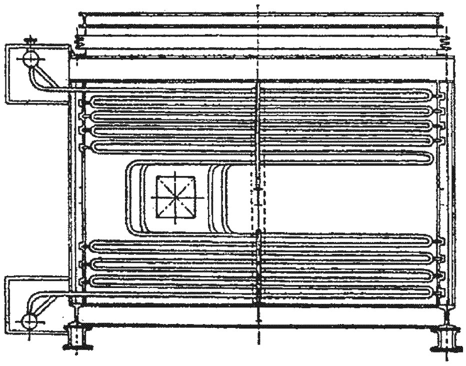


Fig- 63: Serial economizer

Reference: P-57 of No.585 (June/2005) Journal of TENPES

Photo- 11: Economizer tube with straight-fin

http://www.alibaba.com/product-gs/262494964/H_fin_tube_Economizer Coil Economizer.html

Photo- 12: Economizer tube with straight-fin

http://www.made-in-china.com/showroom/olieve/product-detailyeqJGKUYvnkQ/China-Square-Fin-Tube-002-.html

Photo- 13: Economizer tube with spiral-fin

http://www.rosink-raa.de/en/rippenrohre/spiralrippenrohre.html

1.21 Usage notes for economizer

It is necessary that the inlet water temperature of economizer not lower than acid dewpointof gas for the oil-fired boiler to prevent low temperature corrosion due to sulfuric acid, it is desirable 140°C and more for the carbon tube economizer. Also, it is desirable to de-gas especially for steel tube type to prevent inside corrosion because it is advantageous to increase the inlet water temperature. The inlet water temperature of economizer is about 140~300°C. It is necessary to provide the air and steam sootblower in the gas side to clean up the heat transfer surface clean and to perform the injection in a timely manner. The water washing is carried out, if the low-temperature corrosion is a problem on gas part.

1.22 Overview of the boiler steel structure

1.22.1 Concept for design

The boiler steel structure is usually hold functions of boiler by hanging entire weight of the boiler body and its accessories from the top beam. For this reason, the boiler steel structure is designed to ensure the necessary strength for the loads acting at all times. On the other hand, when conducting seismic design of thermal power equipment, a comprehensive consideration such as structural characteristics of the equipment, importance, type, size, location, similar facility, record of earthquake must be made to comply with these designs. In particular, because the boiler steel structure serves as an essential part of seismic design in a boiler, it must be no collapse and falls against large earthquakes.

1.22.2 Applicable regulations and standards

Laws and regulations for boiler such as the Electric Utility Law, the Architectural Law, the Fire Fighting Law and the Gas Related Law are applied in each country. When designing the boiler, they must be fully considered with other related laws, regulations and standards. The specific steps for the design of steel structure are described as follows.

1.23 Loads and forces for the design of boiler steel structure

As mentioned above, the boiler steel structure is designated to perform with the necessary strength for the load applied. The expected loads and forces in the design are as follows.

1.23.1 Fixed load

The fixed weight such as the weight of boiler steel structure itself and the boiler body, and is calculated under the conditions that they have been installed in place with auxiliary equipments.

1.23.2 Movable load

The movable load is determined according to such as the boiler operation and maintenance plan.

1.23.3 Snow load

The snow load is different in the region according to the architectural standards, applicable laws and regulations.

1.23.4 Wind load

The wind load is in the region according to the building standards, applicable laws and regulations.

1.23.5 Seismic force

The seismic force must be considered according to the formula. The details of seismic force are given in the next section.

The long-term and short-term stress caused on each cross section of key parts of the boiler steel structure is calculated according to the load combination based on the weight and force of above. Moreover, it is confirmed that each stress value of part is less than the allowable stress of material by the primary design. In addition, the secondary design to confirm that the layers shear force is lower than the horizontal retention strength is conducted, if necessary. Furthermore, when evaluating the dynamic the seismic design based on the dynamic design method, the evaluation method is different. The primary design, secondary design and dynamic design is shown as follows.

1.24 Seismic design procedure for boiler steel structure

The flow of the seismic design procedure for boiler steel structure is shown in Fig-64. When conducting the seismic design, the comparison and evaluation with tolerance depending on the conditions will be done in accordance with the concept of primary design and secondary design.

The primary design is a design phase objective without causing damage at all to such buildings from relatively frequent to small earthquakes. On the other hand, the secondary design is a design phase objective without causing serious damage to the building and collapse by the very large earth quakes which occur infrequently.

The earthquake "occurs vey rarely" which is assume as a secondary design is the earthquake that has frequency to occur once or not within the useful life limit of building (about 50~60 years). If designing for this level of intensity of the earthquake without any damage at all, it is very uneconomical considering the frequency of earthquakes. Therefore, for this kind of earthquake, the idea that the building enter from the elastic zone to plastic zone is allowed as basic. Therefore, the secondary design is the design method to control for the purpose of destruction of the structure. In addition, the difference in specific techniques of the primary design and secondary design is as follows;

1.24.1 Primary design

The primary design is a design method to ensure that the degree of stress on the structural components caused by the aforementioned the seismic forces does not exceed the allowable stress.

1.24.2 Secondary design

The secondary design is a design method to ensure that the shear force acting on each floor in the earthquake does not exceed the floor holding strength which is calculated from the cross-section of building members selected by the primary design.

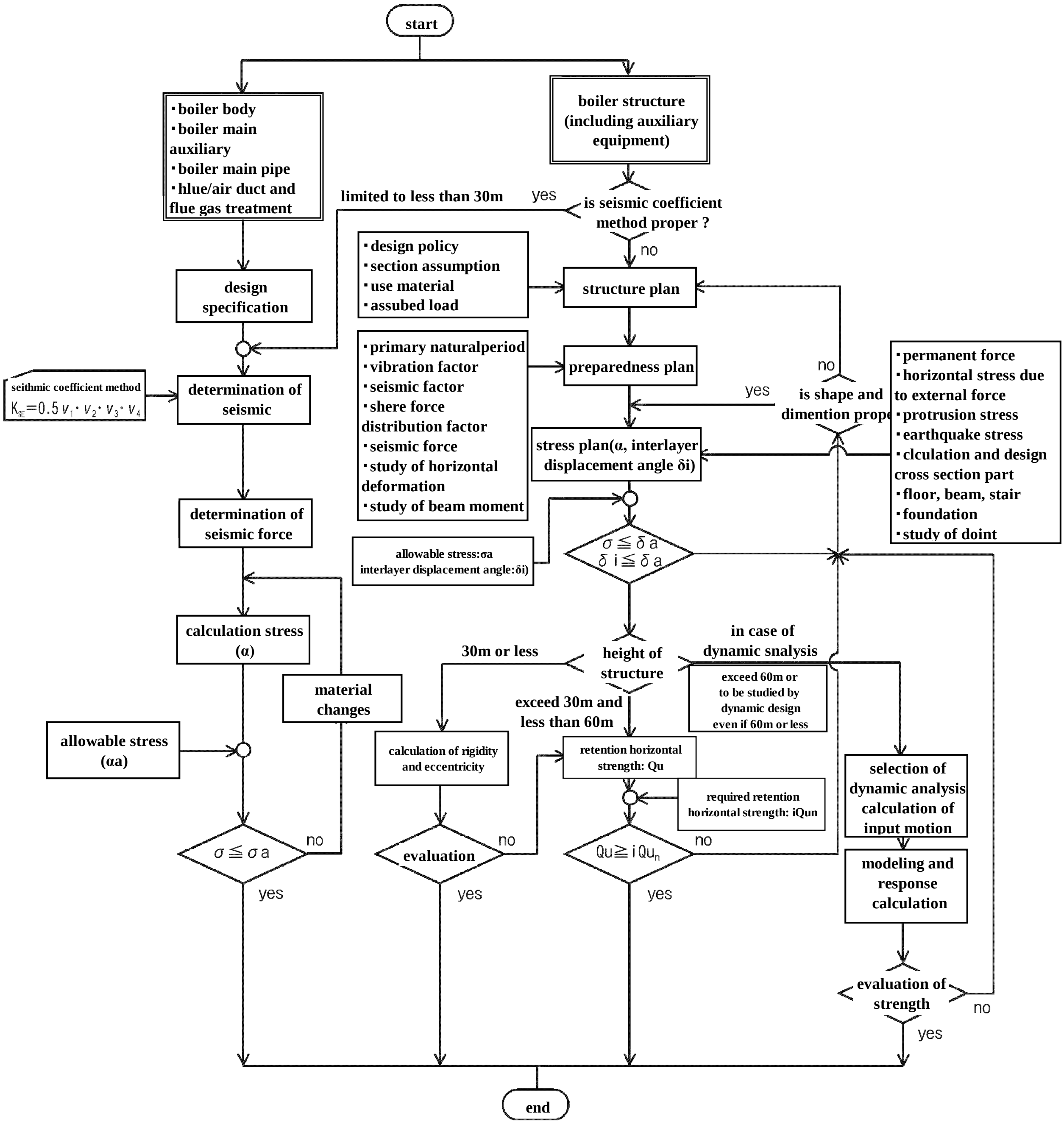


Fig- 64: Seismic Design procedure for boiler steel structure

Reference: P-60 of No.585 (June/2005) Journal of TENPES

1.25 Calculation method of seismic force

The seismic design of boiler and auxiliary facility is targeted no occur and little damage to relatively frequent small earthquakes and aims to not cause sever damage even for very large earthquakes occur infrequently. For these targets, the seismic design has been conducted on the basis of seismic design methodology shown in Table-14 basically.

Table- 14: Seismic design methodology

Items	Seismic coefficient method	Modified seismic coefficient method	Dynamic analysis
Boiler body	**O**	—	—
Boiler steel structure	**O**	**O**	**O**
Boiler main auxiliary equipment	**O**	—	—
Boiler main piping	**O**	—	—
Air and flue duct	**O**	—	—

Reference: P-60 of No.585 (June/2005) Journal of TENPES

To apply appropriate method which the circle is marked.

1.25.1 Seismic coefficient method

This is the method to evaluate the structural displacement and stress by means of the acceleration subjected in earthquake of structures are generally considered equivalent to a horizontal ground surface acceleration, as the static seismic force acting on its mass multiplied by the maximum acceleration, in case of the rigid structure. This method has been widely used in the conventional because it can be obtained reasonable results to evaluate the elastic damage of structure. When evaluating, the horizontal seismic coefficient is calculated by the factors depending on the area, ground and importance of structure required seismic design. The typical seismic design method of buildings in the past is the static design method which is represented by this method. The only static methods can not deal with the difficult elements, although this method can be designated for seismic lateral force of building easily and very reasonable and is evaluated in terms of achievements are considerable since the seismic design treat the earthquake (dynamic issues).

1.25.2 Modified seismic coefficient method

This method does not focus solely on the effects of internal forces during earthquake and is taken into consideration of the natural period and vibration damping of structure. It is reasonable to be base on this method when designing of structures with relatively long natural period the cycle. In this method, the inertial force of the earthquake is determined multiplying the horizontal seismic load considering the natural period of structure with the weight and movable load. In addition, this is the approximate approach considering only the primary natural period of structures most important on the seismic design; it is considered to perform design considering the dynamic characteristics and the characteristics of ground by means of calculating the natural period simply in the same amount of work as the seismic coefficient method.

1.25.3 Dynamic analysis

As mentioned above, the only static methods can not deal with the elements because the seismic design treats the earthquake (dynamic issue). This problem has been recognized since ancient times and it has been desired to establish a system for the dynamic design. The Japanese architectural standard which is revised in 1980 is reviewed from the conventional static method to the dynamic method and the shear force method is added in addition to the seismic coefficient method. In addition, when comparing the result which is obtained by dynamic analysis, it can be roughly divided into two methods, the former is the analysis focusing only on the maximum value of seismic response (such as the displacement, velocity and section force) of structural parts (response spectrum method) and the latter is the analysis focused on how to change over time in response to the earthquake (time history analysis).

The response spectrum method is a method to obtain the maximum structural response parameters using a response spectrum with damping constant by means of changing a period of mass system, damping constant variously and by a variable period of response to specific maximum design earthquake. On the other hand, the time history analysis is the method to obtain the continuous response of each parts of structure to the specific earthquake by means of applying to structure the design waveform which has become a function of time. There is a difference on accuracy and computation time between the two methods; the selection has been entrusted to the designer because the practical assessment is good enough. The cases to build the damping mechanism into the structure have also come out as a rational measure to improve seismic safety. There are oil damper, damping stud and damping brace as practical damping system.

1.26 Supporting equipment and stabilizer

The supporting equipment and the stabilizer are two important equipments as the seismic equipment for boiler. However, the supporting equipment normally has been supporting prudence (1G) and is designated to 1/1.5 or less of yield stress due to stress. The earthquake seismic stress becomes below the yield stress (elastic range), even if force is equivalent to 0.5G. Thus, the analysis has been omitted in the seismic design determined that has sufficient strength.

On the other hand, the special function is required for the stabilizer different from the anti-seismic device. The utility boiler is often large ones, usually supported from the top of the boiler structure; it is same as a bell if the stabilizer is not installed. In this case, it is basically said that high seismic structure because it does not respond to earth earthquake with a few seconds or less by the reason of the size of boiler. However, the stabilizer is provided to prevent resonance against long-period ground motion because it is necessary to limit the relative movement of boiler body, structure, ducts and various piping component that are connected to a boiler body. The force is applied to the boiler through this stabilizer, the boiler steel structure will be subject to the inertial force of the boiler body conversely.

Therefore, the stabilizer is required to work protecting the boiler steel structure which is the fundamentals of the seismic equipment by preventing excessive inertial force applied to the boiler steel structure by means of the stabilizer restricting the relative movement between boiler steel structure and boiler body and protecting piping, equipment and duct which are connected with boiler body

Thus, it can be maintained operation in the case of small or medium earthquake, it makes possible to revert to operation in the short term repair in the case of a major earthquake. In addition, the stabilizer is shown in the schematic diagram Fig-65.

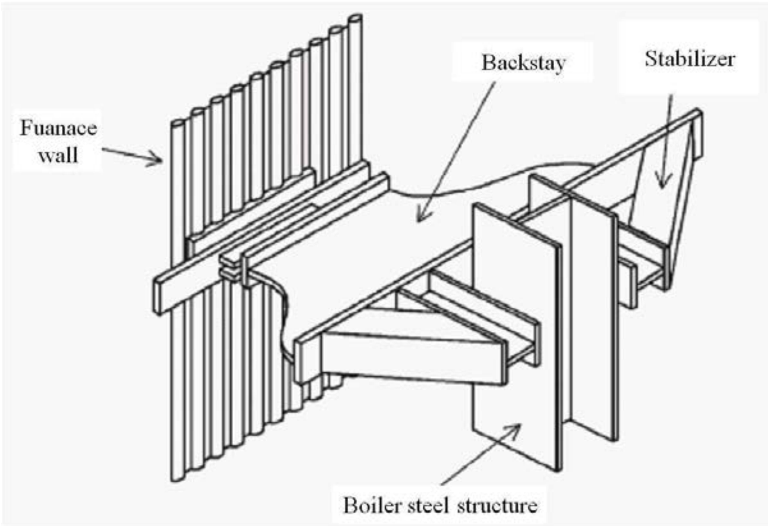


Fig- 65: Schematic diagram of stabilizer

Reference: P-62 of No.585 (June/2005) Journal of TENPES

1.27 Backstay

The schematic diagram Fig-51 shows an example status of the boiler furnace corner with insulation, backstay and casing. The deformation caused by the gas pressure in the furnace pressure is prevented by the backstay through a special bracket attached to the tube wall in case of welded wall structure. The backstay is designated to provided around the four furnace walls in the vertical spacing of about 1.5~3m as shown in Fig-67, the seismic force of boiler will be supported by stabilizer and steel structure through this backstay. Also, the tension bar is the fulcrum end portion of the backstay member that is subject to the horizontal force such as furnace pressure and seismic force. The tension bar is placed on four laps of backstay of the peripheral wall, is placed in contact with wall tube considering the thermal expansion and shrinkage caused by temperature changes of furnace wall tube and is kept same temperature as furnace wall as shown in Fig-66. Therefore, the furnace wall (welded wall) itself does not take as a tension structure. In addition, when configuring the furnace wall by the spiral (helical) tubes, the furnace wall itself is playing the role of the tension bar.

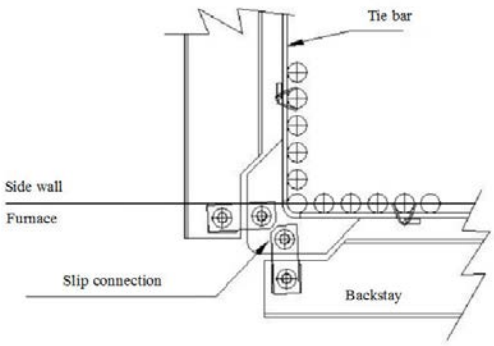
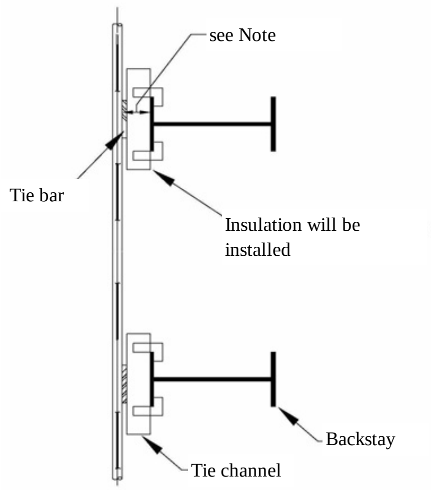


Fig- 66: Furnace corner backstay



Note:
The distance behind the backstays is established by the boiler manufacturer and is equal to the insulation thickness it requires on the boiler walls.

Fig- 67: Furnace side-wall backstay

http://steamofboiler.blogspot.jp/2011/03/design-buckstay-in-steam-boiler.html

2. Circulation fluidized bed boiler

2.1 Summary

The Circulating fluidized bed (CFB) combustion, with its well-known benefits of fuel flexibility and low emissions, has established itself as a boiler technology suitable for utility-scale power generation. Plant sizes up to 330MWe are in operation today, and the designs for larger boilers are being developed. Along with the desire for increased size, there is a desire for increased power plant efficiencies. Almost all of the CFB boilers in operation today, and the bulk of US power stations, operate with natural circulation (drum type boilers). Since increases in size and boiler pressures and temperatures will result in increased power plant efficiency, there is a desire to operate CFB boilers in both larger sizes and at ultra supercritical pressures conditions (steam temperatures typically 1,100ºF or higher).

Since the CFB combustion temperature is relatively low and uniform, the heat flux to its furnace enclosure walls are considerably lower than those of a PC furnace as shown in Fig-68. In addition, up to 25 feet of the lower furnace height is covered by a relatively thin layer of refractory; this covering protects the tubes from corrosion and erosion caused by localized substoichiometric conditions and circulating bed material and contributes to reduced heat fluxes. Because CFB furnace heat fluxes are relatively low and uniform, its tubes do not require internal rifling and they can operate with water mass flow rates that are lower than those of a PC furnace and still be protected from dry-out. Because a supercritical CFB boiler will be designed with lower mass flow rates, it will operate with a “natural circulation” rather than a “once through” characteristic. With the flow rate reduced, the tube friction loss is much smaller than the hydrostatic pressure effect. Although an increase in heat input still increases the friction loss, the increase is less than the reduction in hydrostatic pressure. With the tube total pressure loss now less than that of the average tube, the water flow rate to the tube will increase; this flow increase provides additional cooling that will help limit increases in tube metal temperatures. This is the desirable self-compensating, “natural circulation” characteristic wherein an excessively heated tube will experience an increase in flow that tends to limit over heating. Even though the furnace walls of a CFB will not require rifled tubing, evaporative tube surfaces that protrude into the furnace will be provided with normal rifling as, being heated from both sides, their heat fluxes are significantly higher than the one-side heated enclosure wall values. Compared with a supercritical pressure PC boiler, a supercritical pressure CFB boiler will operate with lower water mass flow rates that result in reduced pressure loss/pumping power.

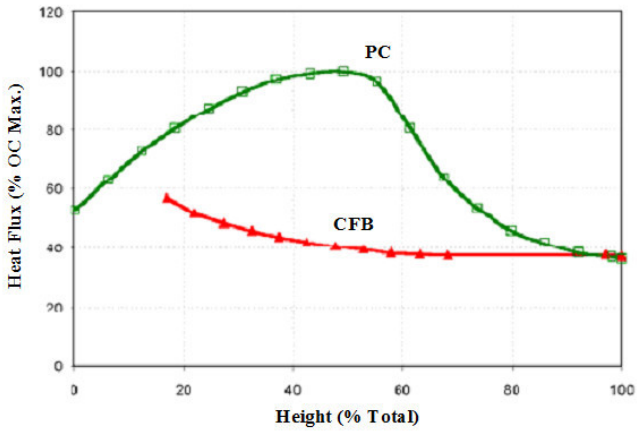


Fig- 68: CFB vs. PC heat flux distribution

Reference: P-3 of “800MWe Circulating Fluidized Bed Boiler with 1300oF Supercritical Steam”

(June/ 2008: Z.Fan and others of Foster Wheeler)

2.2 Features of equipment

The circulating fluidized bed combustion boiler has the following features;

1) Better fuel-air agitation and high combustion efficiency due to high superficial velocity and severe fluid in the furnace
2) More efficient combustion because unburned fuel are collected by cyclone at the outlet of the furnace and returned to the furnace. It can accommodate wide fuel properties such as waste fuel containing high-ash and moisture, anthracite and petroleum coke containing small amount of volatile coupled with the characteristics of 1).
3) The generation of NOx is small because the temperature in the furnace is relatively low in the furnace 850°C~900°C. It is capable to desulfurize efficiently in case of using limestone as bed material for desulfurization because the unreacted limestone go back to the furnace through the cyclone.

2.3 Consideration for the super-heater

It is difficult to increase the temperature of generated steam further in traditional municipal incinerator boiler since the problem becomes significant due to high temperature corrosion of super-heater chlorine contained in municipal solid waste, if the steam temperature rise up to 400^{o}C~450^{o}C. When increasing the steam temperature, it is necessary to consider preventing contact super-heater with corrosive gases.

2.4 Consideration for the foreign object in the waste

While the big size of fuel is available in the fluidized bed boiler, there may be a barrier to operation due to stuck in the bottom of furnace without metal wires or metallic particle scattering when using coal which is containing waste such as waste tire or detonator and other foreign matter as fuel. In the general fluidized bed boiler applied coal as main fuel, the construction to discharge a large diameter ash retained in the furnace bottom through plural drain holes on the bottom is corresponding as this measures.

There were no previous problems with this method on discharge of ash because ash is fluidized and move to next hole with light specific gravity. It is necessary to consider to reuse bed material only by means of discharging the residual foreign materials from furnace bottom of the hopper because it is difficult to flow without lateral movement a foreign object such as a heavy metal wire.

3. HRSG

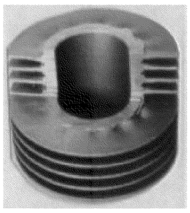
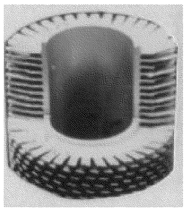
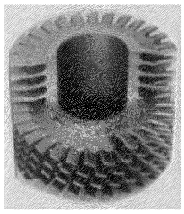
3.1 Summary

The specification of HRSG for GTCC is highly dependent on the conditions of gas turbine exhaust gas. The dimensions of HRSG have been larger due to large capacity, high-efficiency of gas turbine in recent years, and the accompanying multi-pressure of boiler. In addition, since the frequent and rapid start and stop utilizing the characteristics of gas turbine for GTCC is required, the consideration in particular to thermal stress must be given to be capable to track the operation condition.

3.2 Features of construction

The HRSG in the system of GTCC utilizes the low temperature gas compared to the conventional boiler, therefore the heat recovery is forced to expect in the contact heat transfer. Also, if a gas fuel such as LNG is applied, the finned tube is used in order to compact because the exhaust gas is relatively clean. The finned tube are mainly made by high-frequency welding of the spiral fin sheet material on the tube, there are types of finned tubes, solid-fin, serrated-fin which has notches, Table-15 shows its appearance.

Table- 15: Shape of fin-tube

Solid fin-tube	Serrated fin-tube	
	flat	twist
		

Reference: P-62 of No.647 (Aug. /2010) Journal of TENPES

The type of HRSG body is divided into horizontal and vertical by the direction of gas flow, and it is selected depending on the space of site, arrangement of chimney or flue gas duct. The typical construction of vertical and horizontal HRSG with re-heat, and triple pressure is shown in Fig-69 and Fig-70. The HRSG is applied the natural circulation boiler with drum because the steam pressure is relatively low. The natural circulation type is adopted to the horizontal type which is easily obtained circulating power by the density difference of fluids that is placed in vertical heat exchanger tubes, the advance type which addition to the forced circulation type which circulate boiler water by pump and keeping drum in proper height in the view point of saving auxiliary power in horizontal heat exchanger tubes is adopted to vertical type.

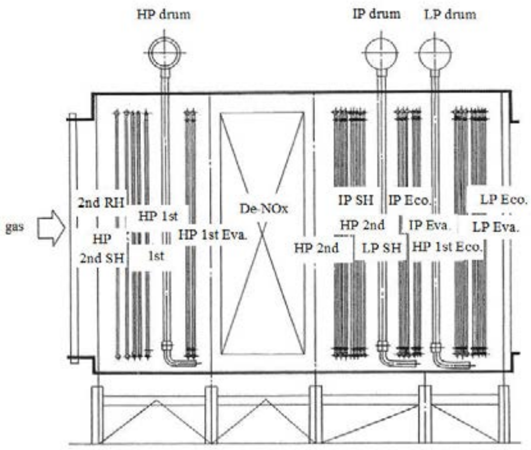


Fig- 69: Typical construction of Re-heat triple pressure HRSG (horizontal type)

Reference: P-62 of No.647 (Aug. /2010) Journal of TENPES

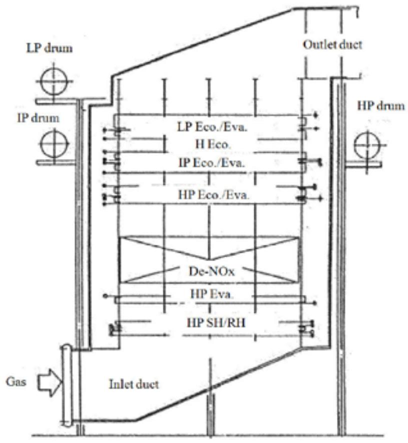


Fig- 70: Typical construction of Re-heat triple pressure HRSG (vertical type)

Reference: P-62 of No.647 (Aug. /2010) Journal of TENPES

Since the boiler body forms hot gas flow path having heat transfer tube group inside, it is reduced the radiation loss of by means of inner or outer insulation. There is advantage that it ca be kept body temperature low in case of attaching insulation inside and can be used carbon steel materials in the gas side where the gas temperature is high, can be simplified supporting structure because the thermal expansion of the body is suppressed. Meanwhile, when installing insulation outside of body, though it is necessary to consider the thermal expansion measures, there is advantage that the construction is easy. The denitrizer is installed in the boiler body to reduce nitrogeNOxides in the exhaust gas from gas turbine. This must be installed in the optimum temperature range of gas which a high NOx removal efficiency can be achieved of each load. The various design considerations are required for a gas duct from the outlet of gas turbine to the inlet of boiler and from the outlet of boiler to the chimney.

At first, a careful consideration must be taken so that the draft loss is within the planned value in order to achieve high efficiency which is characteristic of the combined cycle power plant. Also, it is important to obtain uniform gas flow distribution in the duct across section at the boiler inlet as to adversely affect the heat transfer performance. Generally, the duct is the round or rectangular one with steel structure; it is required to have a seismic, pressure and wind intensity as the gas seal function and the structure. In addition, the heat transfer surface is clean because the clean fuel such as LNG is used for GTCC plant in general. However, when using a fuel containing the sulfur, it becomes an important consideration in the establishment of effective removal equipment because SO^3 in the gas reacts with NH3 which is injected to remove NOx in the exhaust gas and produces the ammonium sulfate and acid precipitation to adhere.

3.3 Construction of drum

The HRSG for GTCC has the sealed horizontal cylindrical vessel which is called the drum because it became the circulation boiler due to the relatively low steam pressure. Feed-water heated by evaporator flows into the drum in the two-phase mixing status and is separated into steam and water. The steam is distributed to turbine either directly or through the super-heater. The feed-water separated in the drum is sent back to the evaporator through the downcomer.

Generally, SB450 or SB480 is used as the material of the drum body. In case of the vertical HRSG, the drum is installed on the steel structure or is suspended from boiler body. On the other hand, in case of horizontal HRSG, the drum is often placed above the evaporator. The separator which separates two phase mixture to steam and water, the blow pipe which prevent concentration of boiler water and the chemical injection pipe which adjust the water quality of drum water are deployed in the drum.

The typical construction of drum internal is shown in Fig-71. It is easy to reach the goal by a guide plate or baffle plate against the requirement for purity and dryness of drum outlet steam, because it is easy to separate steam and water in the low pressure boiler. The steam separator is applied the changing flow direction by the guide plates and baffle plates, the centrifugal action, the collision action to baffle plates, and is effective in a relatively large grain separation of water drops. The corrugated baffle plate dryer mesh (also referred t as scrubber) is provided at outlet of steam for drying, and collects the residual moisture during passing between them in a low speed.

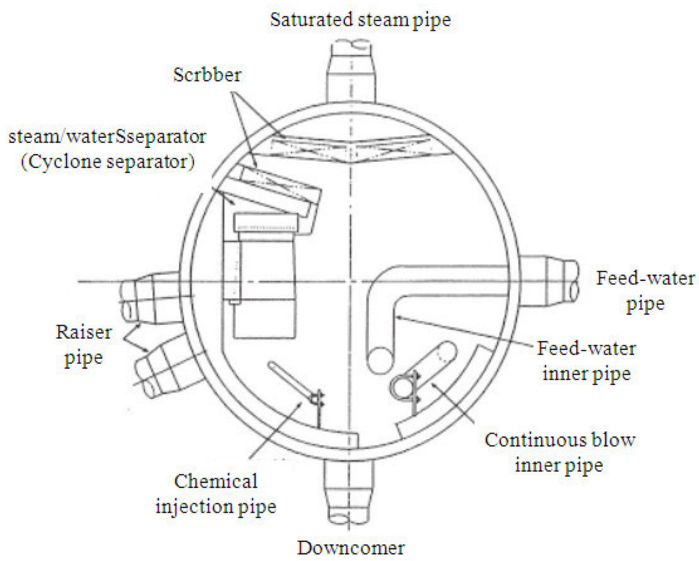


Fig- 71: Typical construction of drum internal

Reference: P-63 of No.647 (Aug. /2010) Journal of TENPES

There is another notable problem that the heat stress occurs near the feed-water inlet. It is typical measures to mitigate this problem by double pipe (sleeve) construction, because water temperature is lower than the temperature of body itself and the large thermal stress occurs when connecting directly with nozzle.

In addition, the drum water level fluctuates greatly according to a lot of and rapid heat input from gas turbine at start up because the operating pressure of drum is relatively low. So-called swelling phenomenon occurs. It is required to provide the drum level reduction blow system and to select proper drum size, because it is necessary to control the drum level in a regulated value even if in this case. The measuring device for measuring the water level in the drum has been defined by “technical regulation for thermal power generation facility” for the circulation boiler in order to prevent heating empty boiler and carry over, adjusting feed-water depending on the change of output.

3.4 Boiler body and supporting construction of heat transfer tubes

The supporting method of the boiler body is broadly classified into the autonomous and structure-supporting type depending on the type and capacity of boiler. HRSG for GTCC is generally applied the autonomous type foe the horizontal type, the structure-supporting type for the vertical type.

The example for the structure-supporting type which supports vertical boiler from the top beam of boiler structure is shown in Fig-72 and Fig-73. In this case, the hanging beam becomes a huge with increase in boiler capacity, although it will be easy to absorb the thermal expansion. On the other hand, some system supports in the middle of the vertical height of boiler, the flexible structure absorb thermal expansion of the boiler body to secure all supporting points welded considering the seismic strength and easy maintenance. It is necessary to pay special attention to the contrast in the combination with boiler, though the boiler structure has the complicated structure consisting of column, beam, vertical brace, horizontal brace, etc.

That is, it is necessary to consider limitation of distortion of supporting beam, ensuring the proper spacing and installation of the anti-vibration equipment to prevent working excessive stress on the boiler body, heat transfer tube, header, etc. The comprehensive study related to the member joining method, maintaining rigidity of column, equalization of column base load including design, manufacturing, transportation and installation is also required with that the steel structure for boiler is becoming increasingly large.

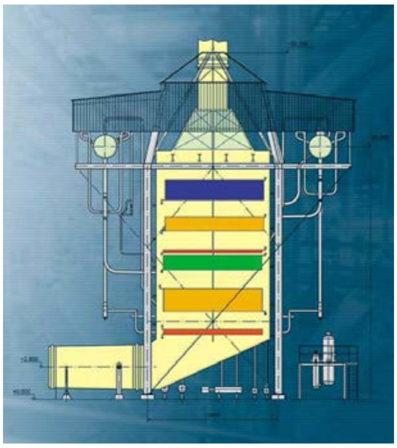


Fig- 72: Vertical type HRSG

http://aozio.ru/eng/production/ob-teplo/2/3/

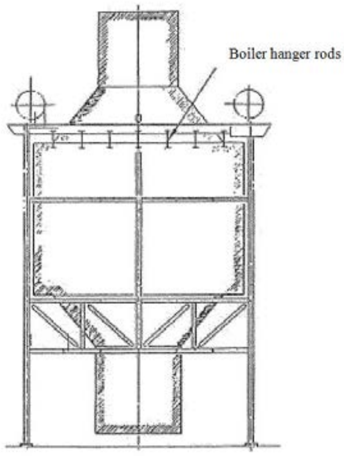


Fig- 73: Vertical type HRSG

Reference : P-64 of No.647 (Aug. /2010) Journal of TENPES

The steel structure for HRSG must have a sufficient strength against the earthquake to ensure safety of boiler in the earthquake country. There are various types of supporting the heat transfer tube panel as with the boiler body. In case of the horizontal type, there are the bottom support type which the panel stands on the bottom beam and the top beam type which the panel is suspended from the upper support beam. Also in vertical type, the heat transfer tube panel is generally hung from beams because the heat transfer tube panel is horizontal. The typical construction of the bottom support type and the top support type in the horizontal boiler is shown in Fig-74 and Fig-75. It is necessary to select consider the buckling limit and economy which scheme is to be selected, varies with the specification of heat transfer tube, the construction of panel and the local conditions.

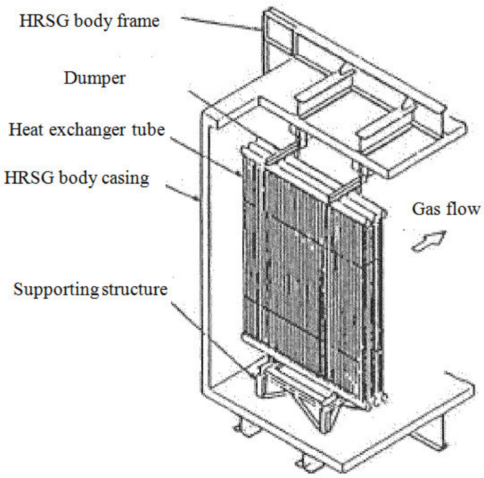


Fig- 74: Bottom support type panel

Reference: P-64 of No.647 (Aug. /2010) Journal of TENPES

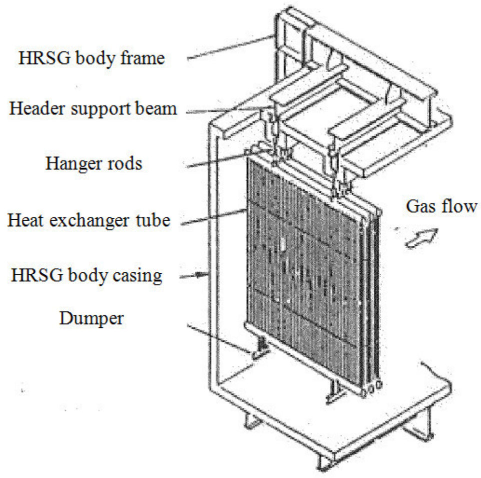


Fig- 75: Top support type panel

Reference: P-64 of No.647 (Aug. /2010) Journal of TENPES

4. Stoker boiler

4.1 Over-all system

Waste incineration plants shown in Fig-76 is composed of several units that have specific tasks, and together they recover the energetic content of the municipal solid waste.

(1) Waste Bunker : holds the waste and is the part where the plant operator can pick up, sort the waste and feed the incinerator using a crank.

(2) Feeding Unit : pre-dries the waste and feeds the incinerator.

(3) Furnace : incinerates the waste and destroys the organic component at temperatures above 800°C; ash and metals are recovered.

(4) Boiler : utilizes the heat from the burning waste to superheat the waterpipes.

(5) Energy Generation : the super-heated steam is supplied to a turbine generator to generate electricity.

(6) Flue Gas Cleaning : remove solid and gaseous pollutants from the gas before releasing through the stack.

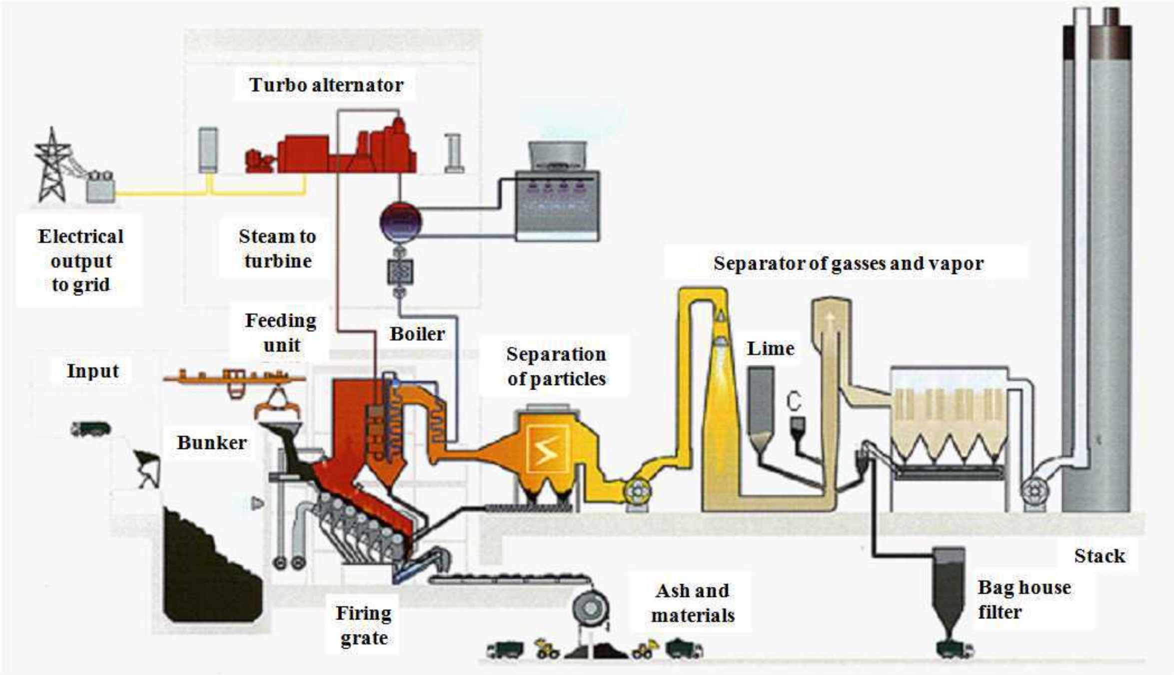


Fig- 76: System of incineration plant based on stoker boiler technology

http://www.wtert.eu/default.asp?ShowDok=13

4.2 Firing grate and boiler

1) Combustion air from a forced draft fan enters the furnace from underneath the grate floor, passes through holes in the grates to supply combustion air to the fuel on the moving bed.
2) Above the traveling grate, all fuels not heavy enough (fines) to land on the traveling bed burns in suspension. The Over Fire Air system supplies combustion air from the front and back of the boiler above the traveling grate for suspension of burning.

4.1 Feeding unit

To approach even energy release, it is necessary to have fuel feeder/distributors which will evenly feed the fuel over the entire grate surface. These feeder/distributors can be mechanical, pneumatic or a combination of both. They must be placed across the width of the front of the stoker in sufficient quantity to achieve even lateral distribution of the fuel and have the means to longitudinally adjust fuel distribution for various types of fuels and sizing. They should be able to bias the feed rate one feeder to another, and to adjust for segregation of fuel sizing from one feeder to another. How well the fuel feeder/distributors can adopt to the different characteristics of solid fuels plays a major part in the ability to operate at lowest possible emissions and highest combustion efficiency.

There are many types of feeders that have been installed through the years. Feeders have been furnished which are reciprocating, vibrating, drum or chain conveyor. There are distributors which have overthrowing, overrunning rotors or under-throw rotors. For the distribution of refuse both mechanical and pneumatic types have been utilized. The chain type feeder both over-throw and under-throw types will be discussed for fuel burning. Air swept distributor spouts are used almost universally for refuse burning. Regardless of the type of feeder, the results and goals must be the same, which is to distribute the fuel evenly over the entire grate surface. This then relates to the feeders having the ability to adjust the longitudinal distribution for differences in coal sizing characteristics. Lateral distribution is a function of the feeding width in relation to the grate width, as well as the ability of the rotor blades of mechanical feeders to splay the fuel in a lateral direction as well as longitudinally. The absolute minimum feeder width to grate width is 40%. The goal should be to have a feeder width of at least 50%.

Fuel feeders should have a non-segregating distributor interfacing between the fuel bunker and the stoker feeder. A fuel scale is recommended between the non-segregating spout and the fuel bunker. A fuel scale provides a method for tracking daily, weekly, or monthly fuel usage. All modern fuel scale electronics provide for real time usage in terms of fuel rate per hour which is useful for tracking efficiency.

Each fuel feeder has the mechanism to regulate fuel feed rate within the feeder. Older methods of control were to connect the feeders mechanically to a pneumatic control system. Present day distributed computer control systems can send a 4-20 mA signal to the feeder. With computers there is better control of fuel feed to maximize boiler efficiency and emission control.

It is not practical to meter refuse at the fuel distributer except for special refuse fuels that will pass through a mechanical feeder without problems. The nature of most refuse fuels requires large metering devices of special design to prevent bridging of the fuel and blockages within the feeding device. These feeders do not adapt to the boiler front where the distributor is located. Therefore, the refuse metering device is located above the distributor with a connecting chute in between. For maximum efficiency, best load following characteristics and lowest emissions, it is recommended that there be a separate metering device for each fuel distributor, and that the metering devices be kept full of fuel at all times. It is also important that the metering device be kept in a vertical plane from the front to prevent lateral mal-distribution of the refuse in the furnace.

4.2 Ash collection facility

As the fuel on the traveling bed completes its burning it turns to an ash called bottom ash. The bottom ash drops off the traveling grates at the boiler front as they cycle there way back to the rear of the boiler. The ash falls down into a bottom ash collection hopper at the base of the boiler front.

4.3 Environmental facility

The emissions of sulfur dioxide cannot be controlled in the combustion process since at least 95% of the sulfur in the fuel is converted to SOx. Newer existing plants regulated under the Clean Air Act have had to install SO^2 scrubbers. Older units have had to change to low sulfur fuel. The emissions of nitrogeNOxide, carbon moNOxide, and hydrocarbons are affected by the combustion process. Some of the results from the combustion process are predictable. ExcesSOxygen and heat release affect nitrogeNOxide emissions from spreader stokers.

Combustion air temperature affects furnace temperature and thus, nitrogeNOxide emissions. Units with preheated will emit higher emissions than those utilizing ambient combustion air. If steam conditions permit, it would be well to design a unit with just an economizer rather than a combination of economizer and air heater. The emissions of carbon moNOxide and Hydrocarbons from a spreader stoker are affected primarily by excesSOxygen, heat release rate, and the proper application of over-fire air turbulence. ExcesSOxygen, if it becomes too high, will result in a slight increase in carbon moNOxide emissions. At some minimum excesSOxygen, this could be different from one unit to another, the carbon moNOxide increases rapidly.

The control of emissions from spreader stokers has been limited to the combustion techniques for minimizing the emissions of nitrogeNOxide and carbon moNOxide. There are additional in furnace techniques that have been developed. These include: Natural Gas Re-burn Technology Flue Gas Recirculation to Reduce ExcesSOxygen Combination of Gas Re-burn and Flue Gas Recirculation Post combustion systems in use today are Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR). A combination of best combustion technology, in furnace systems, and post combustion systems is possible.

5. Kiln boiler

5.1 Over-all system

The kiln furnace can be operated in the state for variations in the amount of waste, properties, heat value such as the variety of industrial waste without using additional fuel such as A-class heavy oil for the stable combustion. The effective use of energy is measured by means of utilizing steam recovered by the heat recovery boiler to power generation, heat source of drying and re-heating of flue gas. The typical system of incineration plant based on kiln boiler technology is shown in fig-77. It will be the power generation facility when the generated steam is used for power generation.

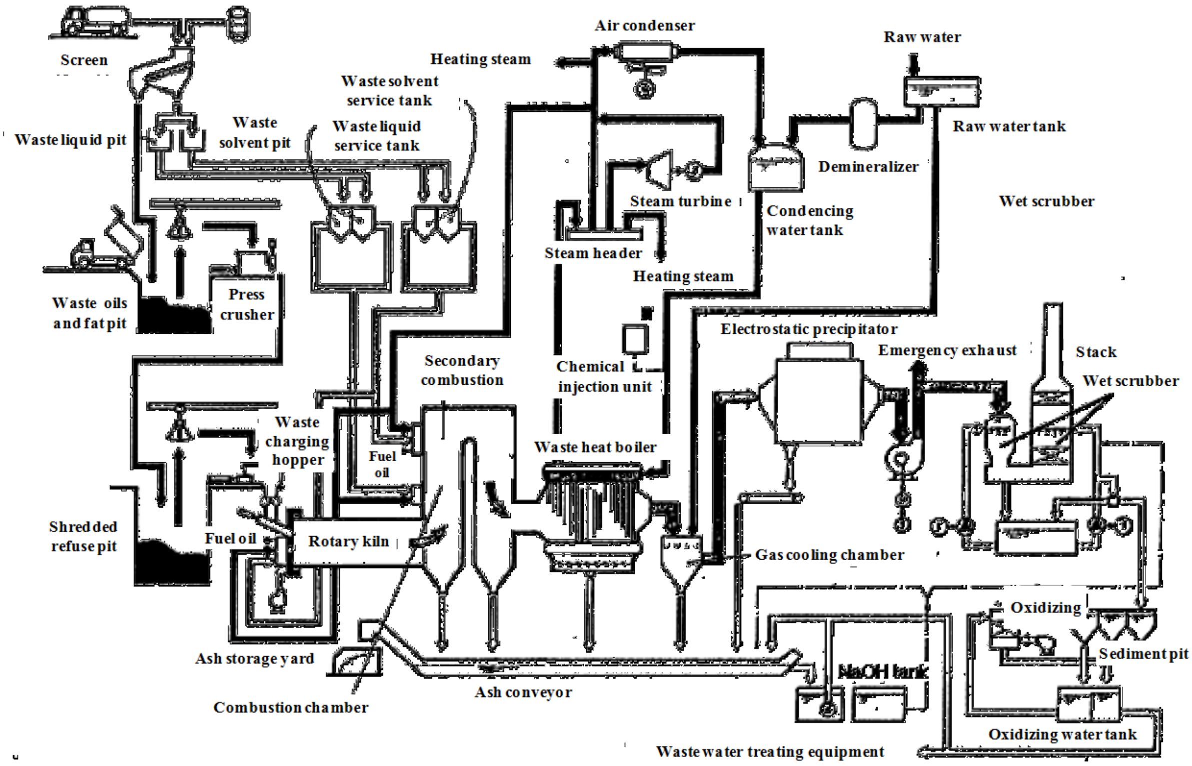


Fig- 77: System of incineration plant based on kiln boiler technology

http://infohouse.p2ric.org/ref/26/japan/Waste-069.html

5.2 Furnace and waste heat recovery boiler

In this section, the kiln stoker is introduced as most advanced rotary kiln furnace. The kiln stoker is composed the rotary kiln furnace which is applied in the wide range of waste-fired or co-combustion of waste and the stoker furnace which has high performance as coal-fired and municipal waste incinerators has been characterized by a complete combustion of a stable and efficient combustion characteristics of different kinds of waste.

The waste is response to the radiation heat from rear part of rotary kiln and stalker, and then the mainly unburned carbon is fixed complete combustion on the stalker after drying, burning, carbonizing and gasification. It can be incinerated the hazardous wastes such as infectious waste because it have secured a sufficient residence time in the kiln. In addition, the unburned gas which is generated in the kiln can be completely burned in the secondary combustion chamber. The nitrogeNOxide is decomposed, reacted and removed by the catalyst-free denitrification method for spraying the urea water at secondary combustion chamber.

5.3 Fuel feed facility

Waste plastics, wood chip, paper waste, waste rubber, textile waste and animal/plant residues are received to the trash pit, is supplied by crane to crusher and is crushed by two-axis shearing crusher. The crushed waste is put into the hopper after stirring the mixture evenly and supplied to the rotary kiln by conveyor. Sludge is received to sludge pit and put into the hopper after stirring the evenly and supplied to the rotary kiln by conveyor. The infectious waste is transported and stored by roller conveyor automatically and fed into the rotary kiln by pusher. The waste oil and waste water is stored in the tank after removing foreign object, is sprayed into the rotary kiln and the secondary combustion chamber by pump.

5.4 Ash removal facility

The ash from kiln stoker is extinguished, humidified and conveyed by the water sealed conveyor, and is stored in the ash container. In addition, the fly-ash which is collected in the heat recovery boiler, gas cooling tower and bag filter is stored in silo; they will be stored in the dust container after adjusting the humidity by dampening mixer and adding the chelating agents to prevent the leaching of heavy metals and other hazardous substances.

5.5 Environmental facility

The exhaust gas from the heat recovery boiler will be cooled down rapidly to about 170^{o}C by the gas cooling tower. The harmful acid gas is removed together with dust by a bag filter having a high trapping efficiency that is provided on the gas duct before bag filter and blowing into the slaked lime. Dioxins is resolved and removed by injection of the activated charcoal at duct before bag filter and catalysis reaction by catalyst pack column installed subsequent stage of bag filter.

<u>Article 21-7. Steam condition for boiler</u>

1. The steam cycle of the conventional steam power generation plant is described in Fig-78. The thermal efficiency of steam cycle can be derived by dividing the sum of the square surrounded by blue lines and red triangle by the line surrounded by a red line. The higher steam pressure and temperature above critical point as shown in Fig-79, it is possible to obtain high thermal efficiency because of the large proportion of the triangle enclosed in a rectangle surrounded by blue line to red. Therefore, the effort to obtain steam conditions as high as Fig-80 is continued.

   The saturation field (mixed situation water and steam) is present under the sub-critical pressure when the water becomes steam, and the density difference occurs in the saturation field. The drum boiler has a drum and circulation system that circulates water using power of this natural circulation caused by differences in specific gravity, and can ensure adequate water flow in the pipe thereby.

   The circulation pump is provided for the high pressure sub-critical boiler as it becomes high pressure, because it is difficult to obtain the sufficient amount circulation in the saturation field. On the other hand, there is no saturation field in the supercritical boiler and it is impossible to maintain the sufficient water flow in the tube because the natural circulation force is nearly zero. Therefore, the once-through boiler is adopted to the ultra supercritical coal-fired boiler which pushes out the feed-water from boiler inlet to outlet by feed-water pump forcibly and ensure adequate water flow in the pipe (therefore, without drums and the circulation system).

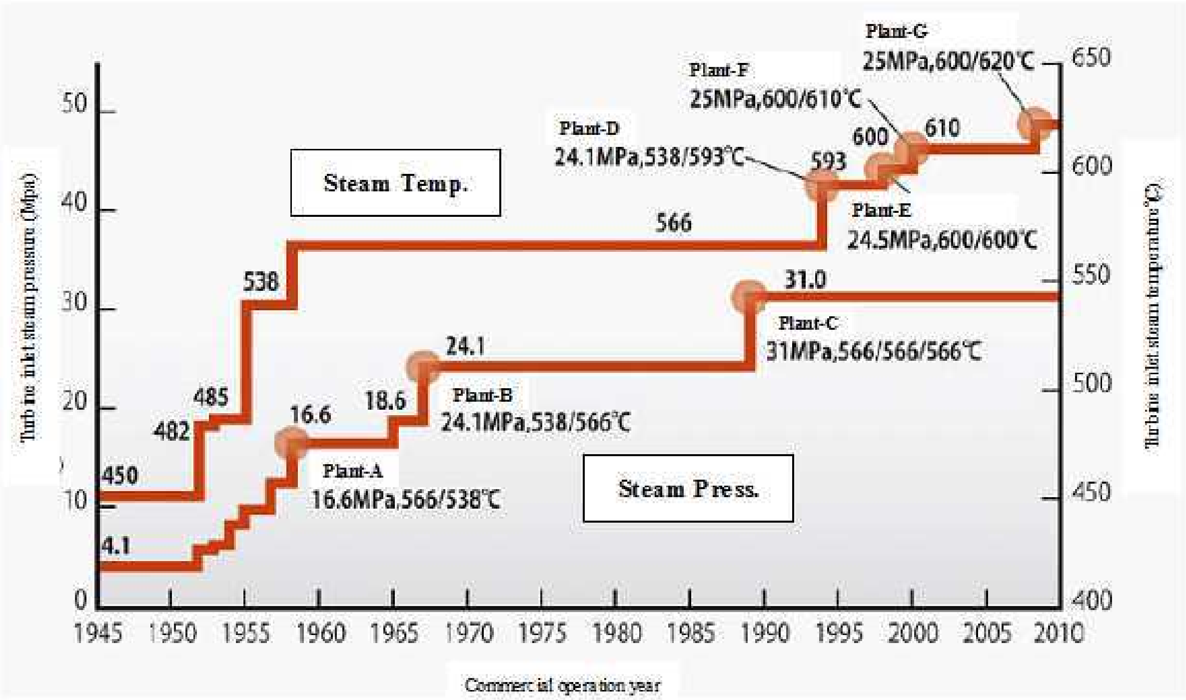


Fig- 78: Steam condition and unit output of power boiler

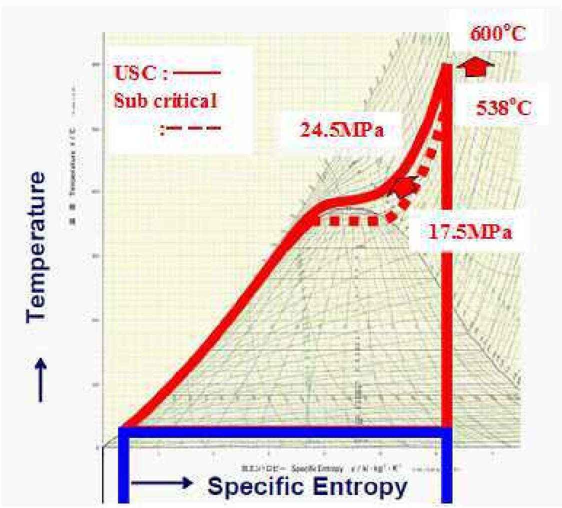


Fig- 79: USC thermal power plant

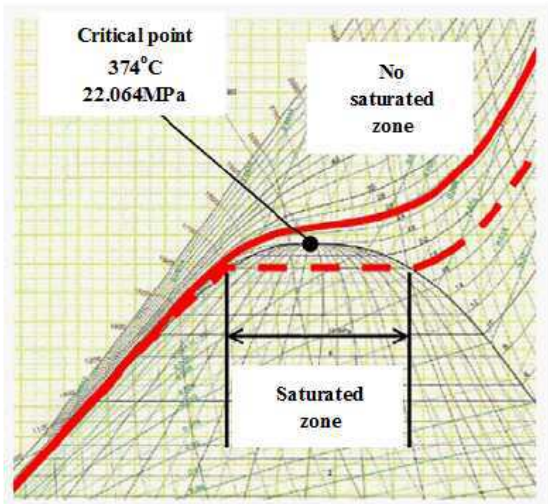


Fig- 80: Critical point

Article 21-8. Materials for main part of boiler

1. The strengthening of the material has been required depending on the development of high temperature and high pressure boiler. The ultra supercritical boiler was built in the late 1950s and they were

designated as the base load operation, however, there are significant differences with a current intermediate load operation technically which is designated subjected to the frequent start-stop operation.

Recently, the ferritic steel which has a small linear expansion coefficient have been used for thick-wall pressure part, therefore the limit of steam condition is determined depending on the heat resistance of the ferritic steel. Recently, the 9~12Cr ferritic steel has been developed and now the high strength ferritic steel has been developed having a strength comparable to 18Cr-8Ni stainless steel. Meanwhile, the austenic stainless steel is used for the tube of super-heater and re-heater because it is required high strength and corrosion resistance than the ferritic steel. The adoption of the ultra supercritical condition and 600°C class steam condition was made possible by the development of 20~25Cr stainless steel which has the high temperature strength and corrosion resistance, although the conventional 18Cr-8Ni stainless steel come to the limit. There are the ones made in the course of pursuit of efficiency and conservation based on the strong demand for energy saving in recent years, the achievement of such conditions and design consideration as well as the development of these materials has contributed significantly. The recommended material which is applied to the hot part of boiler and hot piping is organized in Table-16.

Table- 16: Recommended materials for main part of boiler

Main steam temperature		538°C	566°C	593°C	625°C
Boiler	Furnace wall tube		STBA20(0.75Cr Alloy),	STBA22(1Cr Alloy),	STBA24(2.25Cr Alloy)
Boiler	Super-heater tube	SUS321HTB(18Cr Alloy) SUS347HTB(18Cr Alloy)		® SUS304J1HTB(18Cr Alloy) ® SUS321J1HTB(18Cr Alloy), TEMPELOY AA-1	® SUS310J1TB(25Cr Alloy) ® SUS310J2TB(21Cr Alloy)
Boiler	Main steam piping	STPA24(2.25Cr Alloy)	® STPA24J1(2.25Cr Alloy) ® STPA28(9Cr Alloy)	® STPA29(9Cr Alloy) ® SUS410J3TP(11Cr Alloy)	NF12 SAVE12
Boiler	Re-heater tube	SUS321HTB(18Cr Alloy), STBA24(2.25Cr Alloy) SUS347HTB(18Cr Alloy)		® SUS321J1HTB(18Cr Alloy) TEMPALOY AA-1	® SUS310J1TB(25Cr Alloy) ® SUS310J2TB(21Cr Alloy)
Boiler	Hot re-heat piping	SCMV4(2.25Cr Alloy)		® SCMV28(9Cr Alloy)	® SUS410J3TB(11Cr Alloy) TEMPALOY F-12M

2. Many kinds of materials for steel pipe, steel plate, casting and forging products are use for the pressure part of boiler, and the notes about the required property for the most important material for the super-heater and re-heater tube are organized as follows.

2.1 High temperature strength (such as creep strength, fatigue strength)

This property is the most basic things when exposed high temperature and high pressure in a long period. Not only single property of the creep and the fatigue but also superimposed effect of action can not be ignored in case of ultra high temperature and high pressure boiler.

2.2 High temperature corrosion resistance

The outer surface is exposed from 20^{o}C~tens of degrees higher than the design steam temperature, the inclusion in the heavy oil or coal fuel such as Na, K, V and S contents may become corrosive adhesion and promote corrosion and other failure such as thinning and are exposed to harsh conditions.

2.3 Steam oxidation resistance

The inner surface iSOxidized by steam and the scale is generated. If this scale detaches, fall into and deposit the bend part, there is possibility to cause bursting by over-heating due to the flow inhibition. Also, if the scale is scattered to the turbine, it causes the erosion of valve or turbine blades. In addition, this scale may cause bursting due to over-heating when it is generated a thick without peeling.

2.4 Textural stability

The metal structure changes in the meantime if it is heated under high temperature in a long time. For example, the change of carbide shape and precipitation circumstances of 2.25Cr-Mo alloy steel, etc. begin from 550^{o}C and thousands of hours, it affects the strength in high temperature due to the change of metal structure. Thus, material selection is desirable for understanding the properties of the material in long term service.

2.5 Mechanical properties

It is necessary to confirm the linear expansion coefficient and thermal conductivity as related to heat stress other than the general mechanical property such as tensile, hardness and toughness.

2.6 Workability

The boiler tubes are particularly important to the bendablity and the ductility. Also, the sufficient toughness in the cold working is required.

2.7 Weldability

It is required have the good weldability without occurring cracking, excess hardness. In addition, it is necessary that there is no significant decrease in weld strength.

2.8 Economy

Also recently, the life assessment technology corresponding to each material has been developed not only satisfy the above properties because of the needs to extend the life of boiler and from being frequently used as an intermediate thermal load operation with frequent start and stop.

Article 22. Material for boiler, etc.

1. The “**Pressure part**” stipulated in Article 22-1 of the design technical regulation means the part which is bear inner pressure more than 0MPa .

2. The material which has "**stable chemical composition and mechanical strength**" stipulated in Article 22-2 of the design technical regulation means the material which is excellent in welding performance, strain strength, ductility, toughness and hardness, etc. It is recommended using the materials listed in Appendix-1-1. "Ferrous material", 1-2-1 "ASME Sec. II Part-D Standard Material", 1-2-2 "ASME B31.1 Standard Material", and Appendix-2-1. "No-ferrous material", 2-2-1 "ASME Sec. II Part-D Material".

Article 23. Structure for boiler, etc.

Article 23-1. Structure for boiler, etc.

1. "**Shall be safe**" stipulated in Article 23-1 of the design technical regulation means the boiler which has structure stipulated in Article 23-4 to 23-12 and the performance stipulated in Article 23-3 in this design guideline. However, in case of the pressure part where it is impossible to apply due to the shape and location of holes, etc. and the maximum operation pressure does not exceed the performance test pressure which is obtained by means of the testing procedure stipulated in "Annex-2: Hydrostatic pressure test" of JIS B8280-2003 "Pressure vessel with non-circular body", this provision is not applied.

2. In the proviso in preceding paragraph, when the fittings are conform to JIS B2311-2001 "Steel butt-welding pipe fittings for ordinary use", JIS B2312-2001 "Steel butt-welding pipe fittings", JIS B2313-2001 "Steel plate butt-welding pipe fittings" or JIS B2316-1997 "Steel socket-welding pipe fittings" and the maximum operation pressure does not exceed the performance test pressure, the performance hydrostatic pressure test is capable to omit.

Article 23-2. Allowable stress of material

1. The tensile strength of "**allowable stress**" stipulated in Article 23-2 of the design technical regulation must be pursuant to followings items:

(1) The tensile strength of the materials which are listed in Appendix-1-1. "Ferrous material" and Appendix-2-1. "No-ferrous material" must be the value stipulated in that table.

(2) The tensile strength of the materials which are not listed in Appendix-1-1. "Ferrous material" and Appendix-2-1. "No-ferrous material" must be the minimum one which is listed as follows. However, it must be 2/3 of that value incase of the casting steel products of ferrous materials, must be 0.8 times of that value in case of static-castings, must be 0.85 times of that value in case of centrifugal castings.

1) Allowable tensile stress in the area under the creep temperature range

(a) 1/4 of the specified minimum tensile strength at room temperature

(b) 1/4 of the tensile strength at such temperature

(c) 2/3 of the specified minimum yield point or proof stress at room temperature

(d) 2/3 of the yield point or proof stress at such temperature

However, in case of the austenitic stainless steels, the allowable tensile stress of material for water tube, super-heater, re-heater, economizer, heat-exchanger and the like must be 0.9 times of yield point or proof stress, and the allowable tensile stress below room temperature must be (1) or (3) and smaller.

The tensile strength and yield point or proof stress at such temperature must be calculated by the following formula.

$$Tensile\ strength\ at\ such\ temperature = 1.1\sigma_t R_t$$

$$Tensile\ yield\ po\mathrm{int}\ and\ proof\ stress\ at\ such\ temperature = \sigma_y R_y$$

Where

σ_t : the specified minimum tensile strength at room temperature

σ_y : specified minimum yield point or proof stress at room temperature

R_t : average value of (actual value of tensile strength at such temperature/actual value of tensile strength at room temperature)

R_y :average value of (actual value of yield point or proof stress at such temperature/actual value of yield point or proof stress at room temperature)

2) Allowable tensile stress at the creep temperature range

(a) The average stress which cause creep of 0.01% at such temperature within 1,000 hours

(b) The 0.8 times of minimum stress which cause creep rupture at such temperature within 100,000hours

(c) The 0.67 times of average stress which cause creep rupture at such temperature within 100,000hours

2. The allowable compressive stress and allowable shear stress of the allowable stress stipulated in paragraph-1 of the technical regulation must be 1.0 times and 0.85 times of the allowable tensile stress prescribed in the preceding.

Article 23-3. Hydrostatic test

1. The performance of pressure resistance of the pressure part of boiler, etc. and its auxiliary equipment must be pursuant to the following items;

(1) They must withstand the hydrostatic test pressure after boosting pressure up to 1.5 times of maximum operation pressure and hold it in an appropriate time (1.25 times of maximum operation pressure by gas, if it is impossible to conduct hydrostatic test for the auxiliary equipment).

(2) They must not have leakage when inspecting under the hydrostatic test pressure above maximum operation pressure (the gas pressure above muximum operation pressure, if it is impossible to conduct hydraulic test for the auxiliary equipment) following the previous test.

2. Temperature limit during hydrostatic test

The toughness requirement is specified in ASME standard and EN standard as follows, although it has not been specified in the Japanese interpretation of technical regulation for thermal power facility. There are provisions regarding the temperature limit at impact test and hydraulic test and chemical composition considering the prevention of brittle fracture in ASME Sec.8-1 and EN 13445 for pressure vessel. EN 12952 stipulates the boiler water temperature limit as 0~50^{o}C at the hydraulic test and requires no brittle fracture occurred. In addition, the limitation to the chemical composition, tensile strength, toughness, impact ductility and hardness has been stipulated and in order to prevent and secure brittle fracture. ASME Sec.-1 specifies the water temperature during the hydrostatic test more than 20^{o}C and the limit of the amount of carbon less than 0.35% when further more welding.

Table- 17: Standards for tough fracture

Item and Code	Interpretation of Japanese technical regulation	ASME Sec.-1	EN 12952	ASME Sec.8-1	EN 13445
Chemical composition	carbon content: 0.3% or less	carbon content: 0.35% or less	carbon, phosphorus, sulfur component are specified in each kind of steel	carbon content: 0.35% or less	carbon, phosphorus, sulfur component are specified in each kind of steel
Hydrostatic pressure test	not specified	water temperature must be not lower than 20^{o}C	(the temperature without fair of brittle fracture) freezing point ~50 ^{o}C	(above the design temperature with no risk of brittle fracture) metal temperature: 17 ~48 ^{o}C	based on maximum allowable temperature
Impact test	For liquefied gas Lowest operation temperature (in case exceed -30 ^{o}C, no need) The minimum absorbed energy is with respect to 14J.	with reference to Sec.8-1 USC-66 (with reference to exemption curve of fracture toughness)	whichever is smaller 20^{o}C or lowest operation temperature 27J and more: lateral direction 35J and more: longitudinal direction	There must not be warmer than the minimum design metal temperature. The minimum absorbed energy is with respect to 20J.	The minimum absorbed energy is with respect to 27J against design temperature. at test temperature -196: 40J

Fracture toughness exemption curve: “shall have stable chemical composition and mechanical strength” prescribed in Article 22-1 of design technical regulation means the good weldability, tensile strength, toughness, ductility hardness and it is interpreted that the materials listed in Appendix-1 and 2 may conform to the m without toughness. The toughness of the material listed in Appendix-1 and 2 must be determined the necessity of the toughness according to fracture toughness exemption curve stipulated in ASME Sec.Div.1 USC-66 (relationship with a nominal thickness of minimum design metal temperature), and the absorbed energy at Charpy impact test must satisfy the provision ASME Sec.8 Div1. USC-84 if it is not exempt.

Minimum design metal temperature: the lowest metal temperature under the pressurized status during operation, pressure test or stand-by or suspension.

Reference: Application study of international standards for thermal power generation facilities—Part-4 regarding overall evaluation: (No.629: 16/Sept/2008): TENPES

Article 23-4. Body of vessel

1. The shape of body of vessel (excluding the body of rectangular header, hereinafter referred to as) must be pursuant following items:

(1) It must be the cylindrical or the conical one which are shown in Fig-80 to Fig-4 (in case of boiler, etc. and the independent economizer, limited to the one Fig-80 and Fig-83).

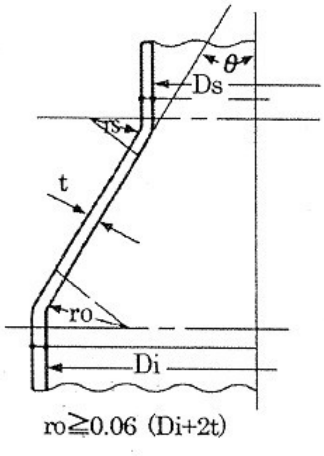


Fig- 81: Type1

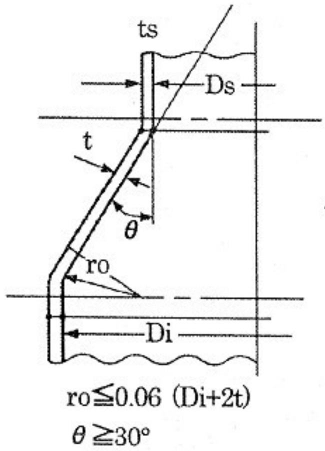


Fig- 82: Type2

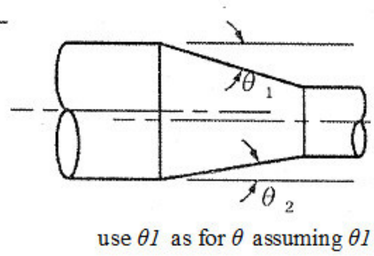


Fig- 83: Type3

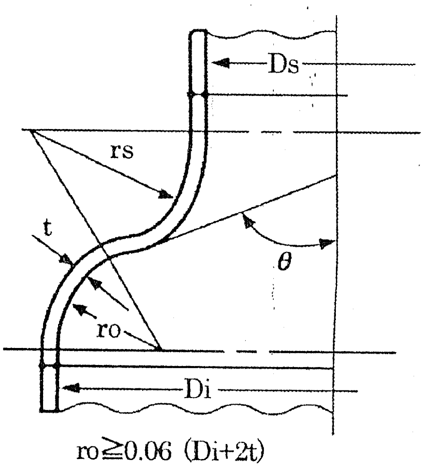


Fig- 84: Type4

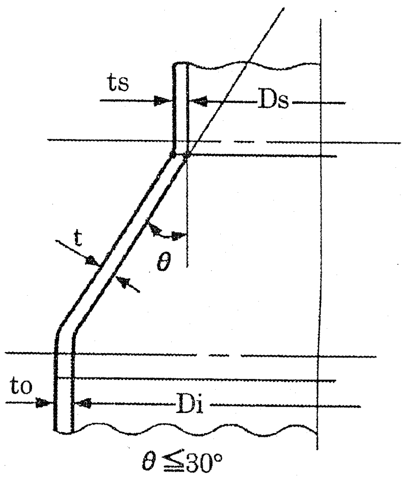


Fig- 85: Type5

Reference: Interpretation of technical regulation for thermal power facility: NISA

(2) In case of the body of cylindrical and conical one, the difference of the maximum inner diameter and minimum diameter in the same cross-section perpendicular to the axis must be 1% or less of the cross-sectional diameter of such standard inner diameter.

2. The thickness of body of vessel must be not less than the larger one of values specified in each of following items. However, the part of the tube hole on which the tube is installed with a tube expander must not be smaller than 10mm.

(1) The thickness of the body belonging to the boiler, independent super-heater, steam accumulator and the like must be the value shown in the right column of the following table according to the inside diameter of the body shown in the left column of the table which is stipulated in "6.1.1: Limitation of minimum thickness of body" of JIS B8201-2005 "Stationary steel boilers-construction" in case of boiler, etc. and independent economizer. The limit of cylindrical or conical body must be pursuant Table-18. The thickness of the body belonging to other than the boiler, etc. and having a weld joint must be 3mm in case they are made of carbon steel plate or low alloy steel plate and 1.5mm in case they are made of other material.

Table- 18: Limitation of thickness for cylindrical or conical body

No.	Inside diameter of body (*Di*)	Limit of minimum thickness of body
1	900mm ≥ *Di*	6mm (in case attaching stay: 8mm)
2	1350 ≥ *Di* >900mm	8mm
3	1850 ≥ *Di* >1350mm	10mm
4	*Di* >1850mm	12mm

Reference: No.240 of ministerial notification of MITI Japan

(2) It must be the value which is calculated by the formula stipulated in "6.1.2: Minimum thickness of inner pressure body" of JIS B8201-2005 "Stationary steel boilers-construction" in case of cylindrical, the value which is calculated by the formula stipulated in "6.1.11: Minimum thickness of inner conical body" of JIS B8201-2005 "Stationary steel boilers-construction" in case of conical (the value calculated as half angle from maximum angle of which eccentric corn and connected cylinder make in case of eccentric cone body). However, "corrosion allowance" must be "0" in case of the body of vessel which belong to other than boiler, etc. and independent economizer.

$$t = \frac{PD_o}{2\sigma_a\eta - 0.2\kappa P} + \alpha$$

Where

t	: required calculating thickness of body	(mm)
P	: maximum allowable working pressure	(MPa)
D_o	: outside diameter of body	(mm)
σ_a	: maximum allowable tensile stress of material	(N/mm^2)
η	: efficiency of longitudinal joint or efficiency of the part concerned in case it has continuous holes. However, in case of the distance between the holes and the deposited metal on the weld zone of the longitudinal joint is not more than 6mm or in case the holes pass through the longitudinal joint, the product of the efficiency of the welded joint and the efficiency of the part with the holes.	—
κ	: value shown in the right column of the following table according to the temperature of internal steam or water shown in the left column of the table-19	—
α	: corrosion allowance: at least 1mm	(mm)

Table- 19: “κ” value (according to ASME)

material	Temperature (^{o}C)					
	Below 480	510	535	565	590	Above 620
Ferritic steel	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steel	0.4	0.4	0.4	0.4	0.5	0.7

Remarks: The intermediate values of temperature must be obtained by proportional calculation.

Reference: P-10 of JIS B8201-2005 “Stationary steel boilers-construction”

3. The efficiency of longitude joint in the previous provision must be the efficiency of welding joint and be the value stipulated in “8.2.3: Efficiency of welding joint” of JIS B8201-2005 “Stationary steel boilers-construction”. In this case, “what the radiographic examination is to be done” must be pursuant following items.

(1) In case of the vessel and piping which belong to boiler, etc. and independent economizer, the radiographic examination must be conducted according to the provision of Article 127 “Non-destructive examination” of Interpretation of technical regulation for thermal power facility Japan and conform to the provision of it.

(2) In other case other than above mentioned item-(1), the radiographic examination must be conducted according to the provision of Annex-25 of Interpretation of technical regulation for thermal power facility Japan and conform to the provision of it.

4. The efficiency of such part where continuous holes which stipulated in parsgraph-2 are must be 1.0 when reinforcing according to the provision paragraph-5 in other case, it must be pursuant from “6.1.5: Strength of hole portion where arranged in longitude” to “6.1.9: Efficiency when holes are arranged randomly” of JIS B8201-2005 “Stationary steel boilers-construction”.

5. When providing hole on the body of vessel, it must be reinforced according to from “6.6.9: Hole that is not required reinforcement” to “6.6.14: Strength of reinforcement material” and “8.2.6: Welding of stub and reinforcements” of JIS B8201-2005 “Stationary steel boilers-construction”. However, “t_{nr}” in “6.6.12: Effective area for reinforcement” must be calculated applying the same formula to obtain “6.1.2: Minimum thickness of inner pressure body” and the “Corrosion allowance: α” must be “0”.

6. The connection with the cylindrical body and conical one must be pursuant to following items.

(1) The connection with the cylindrical body and conical one must be pursuant from Fig-81 to Fig-85 shown in paragraph-1 item-1.

(2) The end portion of the large and small end diameter must be pursuant to “b): Large end of conical section”, “c): Small end of conical section” of “2.4 conical body” of “Annex-1: body and head of pressure vessel” of JIS B8265-2003 “Construction of pressure vessel-general”.

Article 23-5. Rectangle header

1. The thickness of body of rectangle header must be not less than the value calculated according to “6.7.13: Rectangular header” of JIS B8201-2005 “Stationary steel boilers-construction” (the value calculated as η_2=1, in the case of reinforcing according to preceding Article 23-4 paragraph-5) However, the stub part where tube is attached by expanding must be at least 10mm.

2. The provision of Article 23-4 paragraph-5 must be applied mutatis mutandis to rectangle header. “Inner diameter of body” must be read “inside distance between walls which has tube holes of body of rectangular header”; “outside diameter of body” must be read “outside distance between side walls which has tube holes of body of rectangular header”, “cross-section appeared in vertical and voluntary

plane with body plate" must be read "cross-section appeared in vertical and longitudinal with body plate". The factor "F" must be 1.

Article 23-6. Head for vessel

1. The shape of head plate for vessel must be conformed to either stipulate in following items. The dimensions of each part must be pursuant to Fig-86 and Fig-87;

(1) Those which have dished head and conform to following items.

1) The outside diameter must be not less than the inner radius at central.

2) The radius of fillet must be at least 3 times of thickness and 0.06 times of outside diameter (in case less than 50mm, it is 50mm)

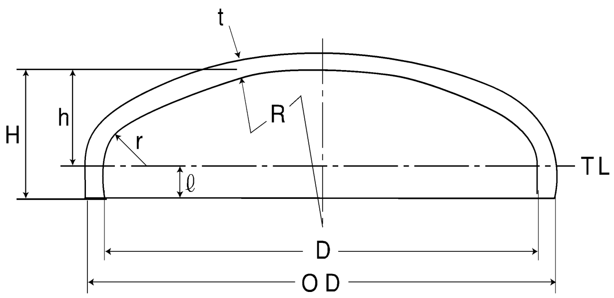
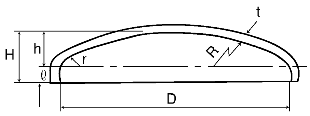
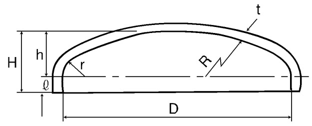
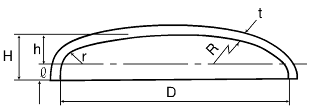
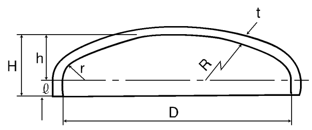
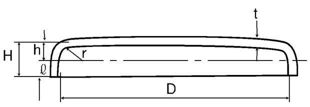
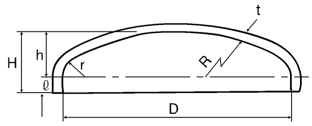


Fig- 86: Details of dished heads

t	: thickness	*l*	: length of flange portion
D	: inside diameter	*H*	: height
OD	: outside diameter	*TL*	: tangent-line
R	: inner radius at center	*h*	: height excluding length of flange portion
r	: inner radius at corner	—	—

(2) Those which are full hemispherical.

(3) Those which are ellipsoidal and have the ratio of long diameter with short diameter at inner surface 2 or less.

皿形鏡板 (Standard Flanged Dished Heads) 	SD R＝D r ＝0.1D h ＝0.194D	正半だ円体形鏡板 (Ellipsoidal Dished Heads) 	ED $\frac{R}{r}$＝2 : 1 Elliptical h＝1/4D
浅さら形鏡板 (Flanged and shallow Dished Head Plate) 	FD R＝1.5D r ＝0.06D h ＝0.1288D	近似半だ円体形鏡板 (Approximate Ellipsoidal Dished Heads) 	AD R＝0.9045D r ＝0.1727D h＝1/4D
平鏡板 (Flanged Only Heads) 	FH r ≧ 3t	深皿形鏡板 (Deep Dished Heads) 	DD R＝0.8D r ＝0.155D h ＝0.255D

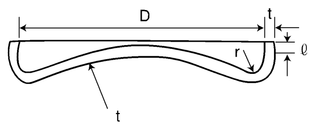
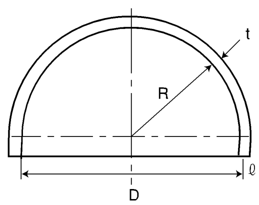
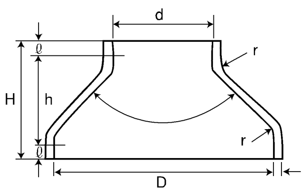
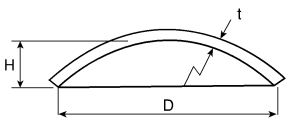
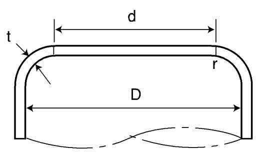
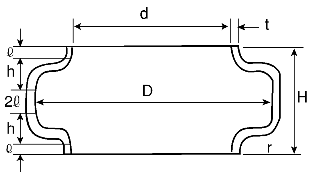
揚底鏡板 (Flanged & Reverse Dished Heads) 	WD R ≧ D　r≦250	半球形鏡板 (Hemisherical H.P.) 	HH R ＝0.5D
円すい体形鏡板 (Conical Heads / Shells) 	CD D_1≧400 H ≧2000	欠　球 (Dished Only Heads) 	DR R/D≧0.8 t ≦30 D ≦6500
ジャケット (Jacket) 	JA P ≦3000φ d ≧350 20≦ r ≦250 3 ≦ t ≦22	エキスパンション (Expansion Joint) 	EX D ≦3200φ D_1≧400 20≦ r ≦250 3 ≦ t ≦22

Fig- 87: Various dished heads

2. The thickness of head plate for vessel must be less than the calculated values according “(1): In case no hole” of “6.2.3: Minimum thickness of end plate with dish-shape which has not stay under the pressure in low and middle surface and full hemispherical” of “(1): in case no hole” of “6.2.4: Minimum thickness of end plate for semi-elliptical body under the pressure in low and middle surface” and “6.2.7: Minimum thickness of end plate with dish-shape which has not stay under the pressure in low and middle surface” of JIS B8201-2005 “Stationary steel boilers-construction”. However, the flange part where are superimposed on the body can be reduced to 0.9 times of that value, and the efficiency of joint “η” may applied the provision of Article 23-4 paragraph-3. Or, the corrosion allowance must be 1mm in case of the end plate of vessel belong to boiler, etc. and independent economizer, 0mm in case of others.

3. When providing hole on the head plate of vessel, those part must be reinforced. However, if the hole conform to “(2): Hole provided on end plate” of “6.6.9: Hole which is no requirement of reinforcement” of JIS B8201-2005 “Stationary steel boilers-construction”, this paragraph must not be applied. In this case, “hole for connection pipe to level gauge” of “(2)-(b): Hole provided on head plate” of “6.6.9: Hole which is no requirement of reinforcement ” must be replaced “the hole for monitoring instrument, chemical injection pipe, continuous blow-down pipe, etc. and with inner diameter not more than 20mm”.

4. In case of reinforcing according to the preceding paragrapg-3, it must be pursuant to following items. When reinforcing a hole by infolded flange, it must be pursuant following items.

(1) The shape of hole must be circle or oval.

(2) The height of flange must be not less than the value which is calculated according to following formula and Fig-87.

$$h = 0.96\sqrt{tr} + 0.5r$$

Where

h	: height of flange from flat plane along the exterior of hole	(mm)
t	: required calculated thickness of head plate	(mm)
r	: value calculated by following formula $r = \dfrac{a+b+t}{2}$	(mm)
a, b	: in case of oval: long radius and short radius, in case of circle: radius	(mm)

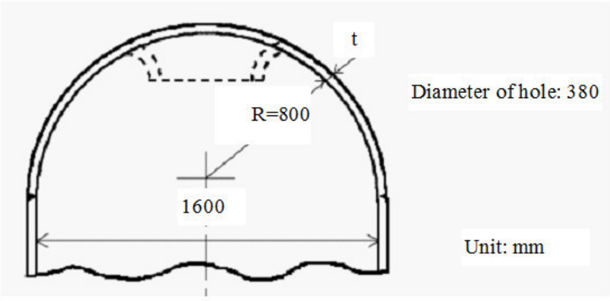


Fig- 88: Reinforcement of hole by infolded flange

(3) The thickness of head plate must be added at least 0.15 times (3mm in case less than 3mm) with following value.

1) The value which is calculated by the formula stipulated in paragraph-2 applying inner radius at center of end plate as 0.8 times of inner radius of flange in case of dished head plate, the value which is calculated by the formula stipulated in paragraph-2 in other case.
2) The value which is calculated by the formula stipulated in paragraph-2 applying inner radius at center of end plate as 0.8 times of inner radius of flange in case of all hemispherical end plat.
3) The value which is calculated by following formula in case of semi-elliptical body end plate.

$$t = \frac{1.77PR}{2\sigma_a \eta - 0.2P} + \alpha$$

Where

t	: required calculating thickness of head plate	(mm)
P	: maximum operating pressure: head plate which is bear in concave side of head, 1.67 times of maximum operating pressure: head plate which is bear in convex side of head	(MPa)
R	: 0.8 times the inside diameter at flange of head plate	(mm)
σ_a	: allowable tensile stress of material	(N/mm^2)
η	: joint efficiency when product by stitching, it is applied the provision Article 23-4 paragraph-3	—
α	: corrosion allowance: head plate in case of boiler, etc, and independent economizer: 1.0, others: 0	(mm)

1) When reinforcing around whole installing stiffener by welding, it must be pursuant to the provision stipulated in Article 23-4 paragraph-5. In this case, the area of stiffener must be greater than equal to the value calculated according to "(1)-(a): In case reinforce installing stiffener around hole" of

“11.2.1: In case of body plate, dish-shape end plate, hemispherical, semi-elliptical end plate or header” of “11.2: Calculation for reinforcement” of JIS B8201-1995 “Stationary steel boilers-construction”. In addition, the factor “F” must be 1.0.

Article 23-7. Flat head plate of vessel

1. The thickness of the flat head plate of vessel must be not less than the value stipulated in the respective items according to the categories listed plate in the following items. However, the corrosion allowance must be 1mm for flat head plate of boiler, etc. and independent economizer, for others 0mm.

(1) The value calculated according to “E.3.6.-b): Shape and calculated thickness of flat head plate” of “E.3.6: Flat head plate attached by welding” of “Annex-1: body and head plate for pressure vessel” of JIS B8265-2003 “Construction of pressure vessel-general” with welding joint efficiency as η=1.0.

(2) The value calculated according to “a): Thickness of flat cover plate” of “L.3.2: Calculated thickness of flat head plate with bolt tightening” of “Annex-L: cover plate of pressure vessel” of JIS B8265-2003 “Construction of pressure vessel-general”.

(3) The value which is calculated according to “L.4.2: calculated thickness of lid insert circular flat plate-shaped”, “Annex-L: cover plate for pressure vessel” of JIS B8265-2003 “Construction of pressure vessel-genera”.

2. When providing hole on the flat plate of vessel, it must be reinforced pursuant to following items. In case of this, the constant “C: Which is determined according to the installation method of flat plate” of “Fig-6.7: installation of flat plate” of JIS B8201-2005 “Stationary steel boilers-construction” must be applied the value stipulated in previous paragraph.

(1) When the diameter “*d*” of hole is o.5 times or less which is stipulated in “Annex-E Fig-E8: shape of flat end plate attached by welding” of JIS B8265-2003 “Construction of pressure vessel-general” and “Annex-L Fig-L1: construction of bolting cover flat plate” of JIS B8265-2003 “Construction of pressure vessel-general”.

1) It must be reinforced pursuant to the provision stipulated in Article 23-4 paragraph-5. The necessary area for reinforcement must be not less than the value calculated according to the formula “(1): In case of enforcement around hole by stiffener” of “6.6.10-b): In case of flat plate”, “6.6.10: Calculation of enforcement”, JIS B8201-2005 “Stationary steel boilers-construction”.

2) The thickness of flat plate must be not less than the value which is calculated according to "6.6.9-c): Hole providing on flat plate」(b)" of "6.6.9: Hole not required reinforcement" of JIS B8201-2005 "Stationary steel boilers-construction".

(2) When the diameter "*d*" of hole exceed o.5 times which is stipulated in "Annex-E: shape of flat end plate attached by welding" of JIS B8265-2003 "Construction of pressure vessel-general" and "Annex-L Fig-L1: Construction of bolting cover flat plate" of JIS B8265-2003 "Construction of pressure vessel-general", the thickness must be calculated according to "6.2.8: The minimum thickness of flat cover plate with hole and without stay" of JIS B8201-2005 "Stationary steel boilers-construction". In this case, it must not be calculated the flat plate as the bolting flange.

<u>Article 23-8. Dished cover plate with flange for vessel</u>

1. The cover plate of vessel which has bolting flange must be the one bear inner pressure and the shape of it must be pursuant to "a) to d) of Annex-L Fig-L.3: Dished cover plate with flange" of "L.5.1: Construction of dished cover plate with flange" of "Annex-L: cover plate of pressure vessel" of JIS B8265-2003 "Construction of pressure vessel-general".

2. The thickness of prescribed cover plate (excluding flange) must be not less than the value stipulated in following items.

(1) The value which is calculated according to the formula base on the inside diameter of "E.4.5-b): Dish shape end plate" of "Annex-E: body and end plate of pressure vessel" of JIS B8265-2003 "Construction of pressure vessel-general".
(2) The value which is calculated according to the formula "1): Bear inner pressure" of "end plate stipulated in b) Annex-L Fig-3b), c) and d)" of "L.5.2.1: Thickness of the part of head plate" of "L.5.2: Calculated thickness of dished cover plate with flange" of "Annex-L: cover plate of pressure plate" of JIS B8265-2003 "Construction of pressure vessel-general" in case the cover plate of prescribed in Annex-L Fig-L.3b) to d).
(3) In the prescribed item-(2), the efficiency "η" of joint must be pursuant to the provision of Article23-4 paragraph-3.

3. The part regarding dished end plate in the provision of Article 23-6 paragraph-3 and 4 must be pursuant to the provision of cover plate in paragraph-1.

Article 23-9. Tube sheet for vessel

1. The tube sheet of vessel (excluding those of round boiler) must be pursuant following items.

(1) The structure of tube sheet must conform to “K.3.1: Construction of tube sheet” of “Annex-K. Tube sheet of pressure vessel” of JIS B8265-2003 “Construction of vessel-general principle”.

(2) The thickness must be at least the calculated value (incase of less than 10mm, it is 10mm) by means of “K.4.2: calculated thickness of tube sheet” of “Annex-K: tube sheet for pressure vessel” of JIS B8265-2003 “Construction of vessel-general principle”.

Article 23-10. Pipe and stub

1. The thickness of cylindrical pipe (excluding the part of pipe flange and reducer) must not be less than either of the values shown in each of the following items whichever larger. In this case, the allowable tensile stress of material must be the value at the mean temperature of tube wall which the inner fluid absorb heat and the value at the temperature of fluid which the inner fluid emit the heat.

(1) For water tubes, super-heater tubes, re-heater tubes and economizer tubes (excluding cast pipe, same as next item and item-5), down-comers, risers, connection pipes of header and the pipe which has outside diameter not larger than 127mm, it must be the value which is calculated by the formula stipulated in “6.7.4: Minimum thickness of steel tube for water, super-heater, re-heater and economizer, etc.” of JIS B8201-2005 “Stationary steel boilers-construction”. In this case, the corrosion allowance must be “0” except expanding.

$$t = \frac{Pd}{2\sigma_a + P} + 0.005d + \alpha$$

Where

t	: required calculating thickness of pipe or tube	(mm)
P	: maximum allowable working pressure	(MPa)
d	: outside diameter of pipe or tube	(mm)
σ_a	: maximum allowable tensile stress of material	(N/mm^2)
α	: 1mm. In case the thickness of the opening on which the tube is expanded and the thickness of the part connected to it and not larger than 25mm are smaller than the values shown in the right column of the following table according to the outside diameters of the tubes shown on the left column of the table respectively, 1mm. In other case, 0mm.	(mm)

Table- 20: Factor “α” for minimum thickness of water type, super-heater tube, re-heater tube, economizer tube

Outside diameter of tube	Thickness of tube (α)
38.1mm and less	2.3mm
Larger than 38.1mm but not larger than 50.8mm	2.6mm
Larger than 50.8mm but not larger than 76.2mm	2.9mm
Larger than 76.2mm but not larger than 101.6mm	3.5mm
Larger than 101.6mm but not larger than 127mm	4.0mm

Reference: P-42 of JIS B8201-2005 “Stationary steel boilers-construction”

(2) For water tubes, super-heater tubes, re-heater tubes, economizer tubes, downcomers, risers and connection pipes of header for which are larger than 127mm in outside diameter and used for steam, it must be the value which is calculated by the formula stipulated in “6.7.7: Minimum thickness of steel pipe for steam ” of JIS B8201-2005 “Stationary steel boilers-construction”. In this case, the corrosion allowance must be “0” except expanding. However, the maximum operation pressure “*P*” may not be 0.75MPa in case of less than 0.7MPa.

$$t = \frac{Pd}{2\sigma_a \eta + 2\kappa P} + \alpha$$

Where

t	: required calculating thickness of pipe	(mm)
P	: maximum operating pressure of inside the pipe	(MPa)
d	: outside diameter of pipe	(mm)
σ_a	: allowable tensile stress of material	(N/mm^2)
η	: longitudinal joint efficiency Table-21	(—)
κ	: value shown in the right column of the following table according to the temperature of internal steam or water showing the left column of the table. Table-22	(—)
α	: Table-23 however in case of corrosion and erosion, the appropriate value must be appended.	(mm)

Table- 21: Longitudinal joint efficiency

Classification No.	Type of joint	Efficiency of welding joint (η: %)	
		Applying RT	Without RT
1	Both side butt weld joint or one side butt welding joint which are considered equivalent with it	100	70
2	One side butt welding joint attached back plate in case leaving it	90	65
3	One side butt welding joint other than 1 and 2	—	60
4	Full fillet both side lap welding joint	—	55
5	Full fillet one side lap welding joint	—	45

Reference: P-54 JIS B8201-2005 "Stationary steel boilers-construction"

Table- 22: "κ" value

material	Temperature (^{o}C)						
	Below 350	480	510	535	565	590	Above 620
Ferritic steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steel	0.4	0.4	0.4	0.4	0.4	0.5	0.7
Carbon steel pipe	0.4	—	—	—	—	—	—

Remarks: The intermediate values of temperature must be obtained by proportional calculation.

Reference: P-43 JIS B8201-2005 "Stationary steel boilers-construction"

Table- 23: Corrosion allowance

Type of tube	Outside diameter of tube (mm)	Minimum value of α (mm)
Screw type	Less than 34	1.65
	34 and more	The height of the thread
Without screw	Less than 114.3	1.65
	114.3 and more	0

Remarks: Thread height "h" is obtained from the following equation as the number of threads about 25.4mm in "n".

h=20/n (mm)

Reference: P-43 JIS B8201-2005 "Stationary steel boilers-construction"

(3) In case of the pipe for feed-water, it must be the value which is calculated by the formula stipulated in "6.7.4: Minimum thickness of steel pipe for feed-water" of JIS B8201-2005 "Stationary steel boilers-construction". In this case, the corrosion allowance must be "0" except expanding. However, the maximum operation pressure "*P*" may not be 0.75MPa in case of less than 0.7MPa.

Same calculation formula as (2) must be applied.

(4) In case of the pipe for blow-out from boiler to safety valve (if there are two or more safety valves, it must be farthest one), it must be the value which is calculated by the formula stipulated in “6.7.4: minimum thickness of steel piping for blow-out” of JIS B8201-2005 “Stationary steel boilers-construction”. In this case, the corrosion allowance must be “0” except expanding. However, the maximum operation pressure “*P*” may not be 0.75MPa in case of less than 0.7MPa.

Same calculation formula as (2) must be applied.

(5) In case of the pipe for evaporator, super-heater, re-heater, economizer, down-comer, riser, header connection pipe and the pipe which is applied carbon steel, it must be the value which is calculated by the formula stipulated in “6.7.3: Minimum thickness of steel pipe for smoke tube, evaporator, super-heater, re-heater and economizer, etc.” of JIS B8201-2005 “Stationary steel boilers-construction”.

Table- 24: Limit of minimum thickness

Outside diameter of tube	Thickness of tube (α)
38.1mm and less	2.0mm
Larger than 38.1mm but not larger than 50.8mm	2.3mm
Larger than 50.8mm but not larger than 76.2mm	2.6mm
Larger than 76.2mm but not larger than 101.6mm	3.2mm
Larger than 101.6mm but not larger than 127mm	3.5mm
Exceed 127mm	4.0mm

Reference: P-42 JIS B8201-2005 “Stationary steel boilers-construction”

(6) In case of the pipe for evaporator, super-heater, re-heater, economizer, down-comer, riser, header connection pipe and the pipe which is applied carbon steel, it must be the value which is calculated by the formula stipulated in “6.7.11: Minimum thickness of cast pipe for economizer” of JIS B8201-2005 “Stationary steel boilers-construction”.

$$t = \frac{Pd}{2\sigma_a - 1.2P} + \alpha$$

Where

t	: required calculating thickness of cast iron pipe	(mm)
P	: appropriate pressure to supply feed-water or set pressure for relief valves	(MPa)
d	: inside diameter of cast iron pipe	(mm)
σ_a	: allowable tensile stress of material	(N/mm^2)
α	: with fin: 4mm, without fin: 2mm	(mm)

(7) In case of other than item-(1) to (4) and item-(6), it must be the value which is calculated by the following formula.

$$t = \frac{Pd}{2\sigma_a \eta + 0.8P}$$

Where

t	: required calculating thickness of pipe	(mm)
P	: maximum operating pressure of inside the pipe	(MPa)
d	: outside diameter of pipe	(mm)
σ_a	: allowable tensile stress of material	(N/mm^2)
η	: efficiency of longitudinal joint	—

1. The reducer part of pipe must be applied the conical part pertaining provision of Article 23-4 paragraph-2. However, the corrosion allowance must be 0.005 times of outside diameter in case of the water tube, super-heater, re-heater, economizer (excluding cast iron pipe), down-comer, raiser, header connection pipe and the part of steam pipe and feed-water piping from the closest portion to feed-water stop valve to the closest portion to boiler steam stop valve.

2. The pipe must be welded at right angles to the centerline of pipe cross section, unless stipulated to the following items.

(1) In case that crossing angle is not greater than 30 degree, and the value is greater than the value multiplying required thickness stipulating in preceding paragraph with the value calculated according to following formula.

$$\frac{R - 0.5r}{R - r}$$

Where

R	: radius of curvature of the centerline of pipe	(mm)
r	: inside diameter of pipe	(mm)

(2) In case attaching pipe by welding.

4. The provision of paragraph-1 must be applied to the thickness of nozzle. However, the minimum thickness of the nozzle must be at least 8mm for cast steel, 11mm for cast iron, in any case.

5. The provisions of article-6 paragraph-5 must be applied to pipe and stub.

6. The thickness of the plate attached to the piping must be the value which calculated according to the formula stipulated in Article-9 in case of other than inserted blank plate, the value which calculated according to the following formula in case of insert blank plate.

$$t = d_B \sqrt{\frac{3P}{16\sigma_a}}$$

Where

t	: minimum thickness of insert blind plate	(mm)
P	: the value stipulated in item-7	
σ_a	: the value stipulated in item-7	—
d_B	: measured diameter of blind plate according to Fig-1 to 3	(mm)

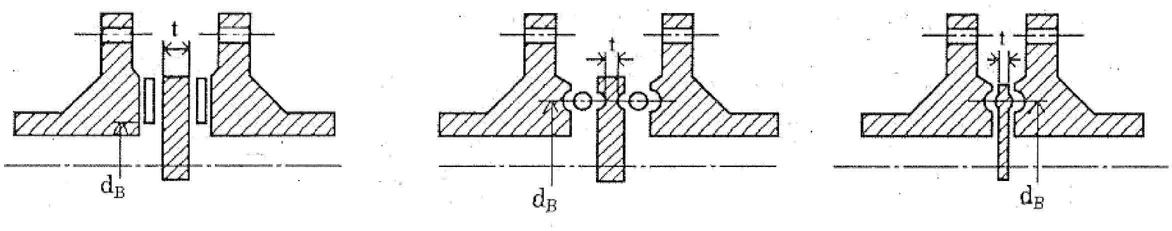


Fig- 89: Type1 Fig- 90: Type2 Fig- 91: Type3

Reference: Interpretation of technical regulation for thermal power facility: NISA

Article 23-11. Flange

1. The flange must conform to any of following items. However, if the calculation method stipulated in "Annex-3: bolting flange of pressure vessel" of JIC B8265-2003 "Construction of pressure vessel-general principles" is applied, this shall not be applied. In this case, the factor "σ_f" and "σ_n" must be the allowable stress which is stipulated in Article23-2 of this design guideline.

(1) JIS B2220-2004 "Steel welding pipe flanges (excluding the part of material) " and JIS B2239-2004 "Cast iron pipe flanges (excluding the part of material) "

(2) The American society of mechanical engineers ASME B16.5-2003 “Pipe flange and flanged fittings (excluding the part of fitting with flange and material) “ and ASME B16.47a-1998 “ Large diameter steel flanges (excluding the part of material)”

(3) JPI-7S-15-99 “Flange for oil industry (excluding the part of material)” and JPI-7S-43-2001 “Large diameter flange for oil industry (excluding the part of material)”

2. The thickness of flange stipulated in Article 23-8 paragraph-1 of this design guideline must be pursuant to following items.

(1) In case of the flange which has the shape shown in “Annex-L fig-1.3: Structure of flange with dish-shaped cover a)” of “L.5.1: Structure of flange with dish-shaped cover” of JIS B8265-2003 “Construction of pressure vessel-general principles” stipulated in article Article 23-8 paragraph-1 of this design guideline, it must be pursuant to the thickness of flange for pipe stipulated in previous or “Annex-L: Cover plate for pressure vessel” of JIS B8265-2003 “Construction of vessel-general principle”.

(2) In case of the flange which has the shape in “Annex-L fig-L.3: Structure of flange with dish-shaped cover b), c), d)” of “L.5.1: Structure of flange with dish-shaped cover” of JIS B8265-2003 “Construction of pressure vessel-general principles” stipulated in Article 23-8 paragraph-1 of this design guideline, it must be pursuant to “Annex-L: Cover plate for pressure vessel” of JIS B8265-2003 “Construction of vessel-general principle”.

Article 23-12. Cylindrical boiler

1. The tube sheet, fire box, furnace, stay and plates and fire tubes which are supported by them must conform to “6.3 Tube plate”, “6.4 Fire box and furnace”, “6.5 Stay and plate which supported by it” and “6.7.1: The minimum thickness of fire tube” of JIS B8201-2005 “Stationary steel boilers -construction “.

Article 24. Safety valve for boiler, etc.

1. The “**over-pressure**” stipulated in Article 24-1 of the design technical regulation means other than those listed in the following items:

(1) The ancillary equipment of boiler and steam accumulator, etc. which have no risk to exceed 1.06 times the maximum allowable operation pressure.

(2) The low pressure pipe stipulated in paragraph-2 item-(7) and the ancillary equipment of boiler, etc. and steam accumulator, stipulated in paragraph-2 item-(9) which have a pressure relief valve having the blow-off capacity and pressure equivalent of the safety valve prescribed in the respective items, in case these are not directly connected to the boiler, etc, and steam turbine.

(3) Addition to those listed in the preceding item-(2), those without exceeding the maximum working pressure in the view point of engineering.

2. The “**appropriate safety valve**” stipulated in Article 24-1 of the design technical regulation means the safety valve according to the following items.

(1) The safety valves must be the spring loaded safety valves or safety valves with a pilot valve which conforms to paragraph-3. When applying the spring safety valves with a spring loaded pilot valve, the total capacity of them must not exceed 1/2 of a total necessary capacity of safety valves stipulated in paragraph-2 item-(2) to (9).

(2) The circulation boiler with a super-heater must be pursuant to following items:

1) One or more safety valves must be provided on the drum and the super-heater outlet respectively.

2) The total capacity of safety valves must be not smaller than the maximum designed evaporation capacity of boiler. In this case, the total capacity of the safety valves to be installed on the drum must be not smaller than 75% of the maximum designed evaporation capacity of boiler and the total capacity of the safety valves to be installed at the super-heater outlet must be not smaller than the capacity required for keeping the temperature of the super-heater not higher than its design temperature. (In case it exceeds 15% of the maximum designed evaporation capacity of boiler, it is the 15% of the maximum designed evaporation capacity of boiler).

3) In connection with clause-2), in case of a boiler equipped with an automatic combustion control device and a device which cuts off fuel supply quickly with a pressure not higher than 1.06 times the maximum allowable working pressure of boiler, the capacity of a pressure relieving device which is actuated automatically by a pressure not higher than the maximum allowable working pressure of the boiler can be included in the capacity of the safety valves. (In case it exceeds 30% of the maximum designed evaporation capacity of the boiler, it is 30% of the maximum designed evaporation capacity of the boiler).

4) The set pressure of safety valves for drum must be pursuant to following:

a) In case of one safety valve: The pressure of the safety valve must be not higher than the maximum allowable working pressure of the boiler. However, in case the boiler is equipped with a pressure relieving device which is automatically actuated by a pressure not higher than the maximum allowable working pressure of the boiler, the set pressure can be reduced to not higher than 1.03 times the maximum allowable working pressure of the boiler.

b) In case of two or more safety valves: The set pressure of one of them must be pursuant to the provisions of the preceding clause-a) and the set pressure of the other safety valve or valves must be not higher than 1.03 times the maximum allowable working pressure of the boiler.

5) The set pressure of the safety valves installed on the super-heater must be lower than that of the safety valves installed on the drum.

(3) The circulation boiler without super-heater must be pursuant to the provisions of the preceding item-4) and to following items;

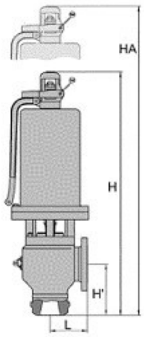
1) Two or more safety valves must be provided for on the drum. However, the number of safety valves may be reduced one or more in case of the boiler with heating area $50m^2$ or less.
2) The total capacity of safety valves calculated by the formula stipulated in paragraph-6 must be not smaller than the maximum designed evaporation capacity of the boiler.

(4) The once-through boiler must be pursuant to following items;

1) One or more safety valves must be provided for boiler in each outlet of the boiler and steam passing part (excluding re-heater) respectively. However, it may be provided one or more safety valves for outlet of the boiler in case of the boiler with heating area $50m^2$ or less.
2) The total capacity of safety valves which is calculated by the formula stipulated in paragraph-6 must be not less than the maximum designed evaporation capacity of boiler. In this case, if the boiler is equipped with a super-heater, the total capacity of the safety valves to be installed at the outlet of the boiler must be not smaller than the capacity required for keeping the temperature of the super-heater not higher than its design temperature. (In case it exceeds 15% of the maximum designed evaporation capacity of boiler, it is 15% of the maximum designed evaporation capacity of boiler).
3) In connection with clause-2): In case of a boiler equipped with an automatic combustion control device and a device which cuts off fuel supply quickly with a pressure not higher than 1.06 times the maximum allowable working pressure at the outlet of the boiler, the capacity of a pressure relieve device or starting bypass device which is actuated automatically by a pressure not higher than the maximum allowable working pressure at the outlet of the boiler can be included in the capacity of the safety valves. (In case it exceeds 30% of maximum designed evaporation capacity of the boiler, it is 30% of maximum designed evaporation capacity of the boiler.)
4) The set pressure of safety valves must be pursuant to followings;

   a) In case of installing one safety valve in a part where the maximum allowable pressure is same, its set pressure must be not higher than the maximum allowable working pressure in the part. However, in case of a boiler whose outlet pressure is lower than the critical pressure and which is equipped with a pressure relieving device or starting bypass device which is actuated automatically with a pressure not higher than the maximum allowable working pressure at the outlet of the boiler, the set pressure of the safety valve must be not higher than 1.03 times the maximum allowable working pressure in the part. In case of a boiler whose outlet pressure is not lower than the critical pressure and which is equipped with an automatic combustion control device, a device which cuts off fuel supply quickly with a pressure not higher than 1.06 times the maximum allowable working pressure at the outlet of the boiler, and one or more relieving devices or starting bypass devices which are actuated automatically by a pressure not higher than the maximum allowable working pressure at the outlet of boiler and having a capacity not smaller than 10% of the maximum design evaporation capacity of the boiler (in the case an isolating stop valve is installed on the pressure relieving device or starting bypass device, two or more)(hereinafter, this boiler must be referred to as supercritical pressure boiler), the set pressure of safety valve can be referred to not higher than 1.16 times the maximum allowable working pressure at the outlet of the boiler.

b) In case of installing two or more safety valves in a part where the maximum allowable working pressure is same, the set pressure of one of them must be in accordance with the clause-a) and that of the other safety valves must be not higher than 1.03 times the maximum allowable working pressure in the part. (In case of supercritical pressure boiler, 1.16 times the maximum allowable working pressure at its outlet)



Inlet	outlet flange	Installation size	maximum operation pressure (MPa)					Inlet diameter	throttle area mm²	outlet diameter	dimention		full length	over haul height	thread diameter		weight
			400℃	450℃	549℃	571℃	604℃	B			H'	L	H	HA	drain Rc	neede Rp	kg
welding type	ANSI 300Lb RF	2×J3×6	36. 8	34. 8	33. 8	31. 3	27. 0	50	1164. 1	150	280	220	1500	2050	3/4	3/4	580
		2-1/2×K3×8						65	1847. 4	200	325	250	1700	2400	3/4	3/4	830
		3×L×8						76	2010. 9	200	325	270	1720	2450	3/4	1	900
		3×M2×8						76	2587. 7	200	325	270	1850	2600	3/4	1	980

Name and Material of part for Supercritical Safety Valve

No.	Type	SL1033	SL1053	SL1073
	Name of Parts	400°C (750°F)	510°C (950°F)	604°C (1120°F)
1	seat	A105	A182-F12	A182-F91
2	body	A216 Gr.WCB	A217 Gr.WC6	A217 Gr.C12A
3	disk	B637 Alloy N07750 (Inconel X)		
4	disk collar	Stainless Steel		
5	holder	Cr-Ni-Si-S St		
6	cooling spool	A216 Gr.WCB	A217 Gr.WC6	A217 Gr.C12A
7	stem guide	Monel Alloy		
8	spring box	SCPH2 or A216 Gr.WCB		
9	stem	Cr-Ni-Si-S St		
10	guide	Cr-Ni-Si-S St		
11	upper adjust ring	Stainless Steel		
12	lower adjust ring	Stainless Steel		
13	upper lock bolt	Stainless Steel		
14	lower lock bolt	Stainless Steel		Inconel
15	spring shoe	Stainless Steel		
16	disc spring	Alloy Steel		
17	spring retainer	Stainless Steel		
18	bearing	Steel		
19	screw shell	Stainless Steel		
20	spring	Alloy Steel		
21	adjust screw	Stainless Steel		
22	adjust screw lock	Stainless Steel		
23	orifice piece	Stainless Steel		
24	stopper screw	Stainless Steel		
25	lift stopper	Stainless Steel		
26	center throttle	Stainless Steel		
27	step ring	Stainless Steel		
28	stud bolt &nut	A193 B7 / Carbon Steel		A193 B16/A194 Gr.4
29	hexagon bolt	Carbon Steel		
30	cap	Malleable Iron		
31	upper lever	Malleable Iron		
32	lower lever	Malleable Iron		
33	pin	Stainless Steel		

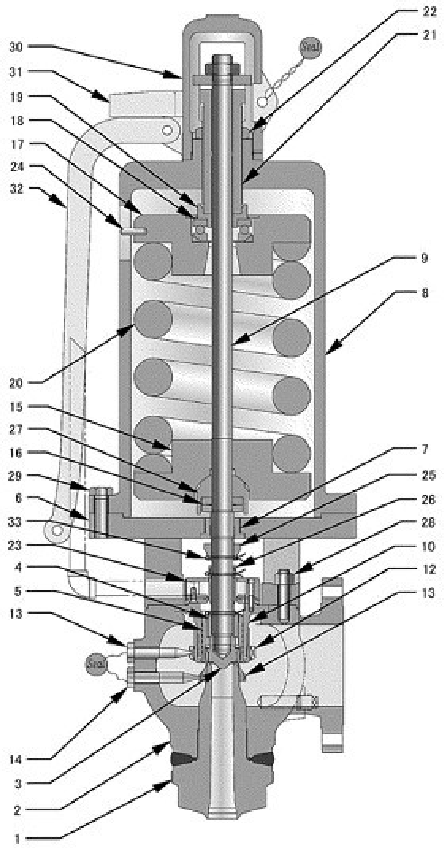


Fig- 92: Typical construction of supercritical safety valve

Reference: Safety & Relief Valve CATALOG No.SLH031117J: Fukui Seisakusho Co., LTD.

5) The supercritical pressure boiler with a stop valve for starting must be equipped with the device to record the pressure on the inlet side on the stop valve.

(5) The re-heater must be pursuant to following items;

1) At least one safety valve must be equipped at inlet and outlet respectively.
2) The total capacity of safety valves which is calculated by the formula stipulated in paragraph-6 must be not smaller than the maximum amount of steam passing through re-heater. In this case, the total capacity of safety valves installed at the outlet must be not smaller than the capacity required for keeping temperature of re-heater not higher than its design temperature. (In case it exceeds 15% of the maximum amount of steam passing through the re-heater, it is 15% of the maximum amount of steam passing through the re-heater).
3) In connection of clause-2): In case of the re-heater of boiler equipped with an automatic combustion control device and a device which cuts off fuel supply quickly with a pressure not higher than 1.06 times the maximum allowable working pressure of he re-heater, the capacity of a pressure relieving which is actuated automatically by a pressure not higher than the maximum working pressure of the

re-heater can be included in the capacity of the safety valves. (In case it exceeds 30% of maximum, quantity of passing steam through re-heater, it is30% of maximum, quantity of passing steam through re-heater.)

4) The set pressure of safety valve provided at inlet must be pursuant following items;

a) In case of installing one safety valve, the set pressure of safety valve must be not higher than the maximum allowable working pressure of the re-heater. In case the re-heater is equipped with a pressure relieving device which is actuated automatically by a pressure not higher than the maximum allowable working pressure of the re-heater, the set pressure of safety valve must be not higher than 1.03 times the maximum allowable working pressure of the re-heater.

b) In case of installing two or more safety valves, the set pressure of one of them must be in accordance with the provision in the preceding clause-a) and that of the other safety valves must be not higher than 1.03 times the maximum allowable working pressure of the re-heater.

5) The set pressure of the safety valves installed at the outlet must be lower than that of the safety valves installed at the inlet.

(6) For the independent super-heater, the provisions in the preceding item-(5) must apply correspondingly.

(7) For a pipe equipped with a pressure reducing valve and whose low pressure side and the equipment connected thereto are not designed at the pressure of the high pressure side, the provision of item-(2) clause-4) must apply correspondingly. Besides, the following provisions must be applied.

1) At least one safety valve must be installed on the low pressure side of pressure reducing valve and close to it.

2) The total capacity of safety valves must be not smaller than the capacity required for keeping the pressure on the low-pressure side of the pipe and the equipment close to the low-pressure side not higher than 1.06 times the maximum allowable working pressure of the respective parts when the pressure reducing valve is fully open.

(8) For the part where two or more safety valves are connected which have different maximum allowable working pressure and are equipped with safety valves respectively and in which the difference in set pressure between any two lowest set pressure safety valves of different boilers is not less than 0.06 time the set pressure of the lower one, the following provisions must be applied.;

1) At least one safety valve must be installed near the part where flows of steam from the two or more boiler join.

2) The total capacity of safety valves calculated by the formula stipulated in paragraph-6 must be not

smaller than the maximum amount of steam which is likely to flow from the high pressure side to the low pressure side.

3) The set pressure of safety valves must be pursuant following items;

a) In case of installing one safety valve, its set pressure must be not higher than the lowest among the maximum allowable working pressure of the two or more boilers concerned.

b) In case of installing two or more safety valves, the set pressure of one of them must be in accordance with the provisions of the preceding clause-a) and the that of the other safety valves must be not higher than 1.03 times the lowest among the maximum allowable working pressures of the two or more boilers concerned.

(9) For boiler accessories (excluding pipes and accessories stipulated in item-(6) and item-(8)) of whose pressure are apt to exceed 1.06 times their respective maximum allowable working pressures, must be pursuant to the following items.

1) At least one safety valve must be installed at proper place.

2) The total capacity of safety valves which is calculated by the formula stipulated in paragraph-6 must be not smaller than the amount of water or steam and gas which to be accumulated in that accessories concerned.

3) The set pressure of safety valves must be pursuant following items;

a) In case of installing one safety valve, its set pressure must be not higher than the maximum allowable working pressure of the accessories concerned.

b) In case of installing two or more safety valves, the set pressure of them must be in accordance with the provisions of the preceding clause-a) and that other of the other safety valves must be not higher than 1.03 times the maximum allowable working pressure of the accessories concerned.

3. The standard of spring safety valve stipulated in paragraph-2 item-(1) must be pursuant to the provisions of “4.6: Pressure resistance”, “5: Structure” and “8: Material” of JIS B8210-1994 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

4. The standard of spring safety valve stipulated in paragraph-2 item-(1) must be pursuant to following items:

(1) The structure of safety valve with pilot valve must be those operated by the pressure at the mounting place.

(2) The material of safety valve with pilot valve must be pursuant to the provisions of “8: Material” of JIS B8210-1994 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

(3) The material of safety valve with pilot valve must be pursuant to the provisions of “5: Structure” of JIS

B8210-1994 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

(4) The diameter of valve seat must be not less than 20mm.

(5) The safety valve and pilot valve must be connected by the pipe with inside diameter not less than 12mm.

(6) The safety valve must have the device can be opened manually when the inlet pressure reaches to the 70% and above of the blow-out pressure.

5. The pressure relief device stipulated in paragraph-2 from item-(2) to item-(7) and startup bypass equipment stipulated in paragraph-2 item-(4) must be pursuant to following items:

(1) It must be opened and closed by electricity, compressed air, steam, pressurized water and other, and must be opened automatically and immediately when the steam pressure at detecting point reached to the specified pressure.

(2) The valves must have a separate device which detects only variation of steam pressure.

(3) The pressure relief device must have the structure to release to the atmosphere, in case of startup bypass equipment to release exhaust to the low pressure vessel.

6. The calculation formula for safety valve capacity stipulated in paragraph-2 from item-(2) to (9) must be pursuant to following items;

(1) In case of safety valve for steam, it must be pursuant to “2: Nominal blow-out capacity for steam, appendix: The method for calculation of nominal blow-out capacity of safety valve” of JIS B8210-1994 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

(2) In case of safety valve for air and other gas, it must be pursuant to “JA.2: Nominal blow-out capacity for gas, appendix: The method for calculation of nominal blow-out capacity of safety valve” of JIS B8210-2009 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

(3) In case of spring safety valve with pilot valve for steam, the area of the passage of the steam at valve seat exceed 1.25 times or more of throat area, the area of the passage of steam at valve inlet and nozzle exceed 1.7 times or more, it must be pursuant to “JA.1: Nominal blow-out capacity for steam (2), appendix: the method for calculation of nominal blow-out capacity of safety valve” of JIS B8210-2009 “Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service”.

(4) In case of safety valve for water, it must be pursuant to “10.1.3: The size of relief valve or safety valve or hot water boiler” of JIS B8201-2005 “Stationary steel boilers-construction”.

7. The calculation formula for pressure relief device stipulated in paragraph-2 from item-(2) to (7) and startup bypass equipment stipulated in paragraph-4 item (4) must be pursuant to the formula “JA.1: Nominal

blow-out capacity for steam (1), appendix: the method for calculation of nominal blow-out capacity of safety valve" of JIS B8210-2009 "Safety devices for protection against excessive pressure-Direct spring loaded safety valves for steam and gas service". In this case, the nominal blowing factor must be 0.75, when the area of nozzle and passage of valve where the pressure relief device is equipped exceeds 1.7 times or more.

Article 25. Feed-water equipment for boiler, etc.

Article 25-1. Quantity of feed-water equipment

1. Quantity of feed-water equipment

1.1 Boilers must be provided two or more sets of pumps (including the injector) which are capable to supply feed-water to generate the maximum amount of evaporation alone from time to time. However, the second water supply capacity may be due to the followings.

1) It must be at least 25% of the maximum amount of boiler evaporation and at least equal to the first set of maximum pump when it is the combination of two or more pumps.
2) It must be at least 25% of the maximum amount of boiler evaporation when it is the combination of two or more pumps and is the boiler which applying pulverized coal, liquid fuel, gas fuel and pulp waste, the spreader stoker boiler, the heat recovery boiler.

The combination of capacity and number of water source can be concluded as following appendix according to the above recommendation.

Case	1st water supply	2nd water supply
1	40% + 25% + 25% + 10%	at least 40%
2	25% + 25% + 25% + 25%	at least 25%
3	50% + 25% + 25%	at least 50%
4	50% + 50%	at least 50%
5	100%	at least 100%

1.2 A set of feed-water supply equipment is acceptable if the boiler has the function to shut off fuel automatically when the water level reaches to the safety low water level of boiler. However, the boiler which use solid fuel and may have the residual heat damaging to the boiler must be excluded.

Article 25-2. Type of feed-water equipment

1. The feed-water supply equipment must be pursuant as follows.

1) The first one of those which is one set and two sets must be the feed-water pump which is operated by power or injector. However, this is not applied when the maximum operation pressure is less than 0.25MPa, the grate area is 0.6m^2 or less and the heat transfer area is 12m^2 or less.

2) The feed-water tank which is capable to supply feed-water with pressure 20% higher than the boiler maximum operation pressure or the water source which is capable to supply feed-water with 0.1MPa higher than the boiler maximum operation pressure may be applied to the feed-water equipment.

3) A feed-water equipment must be provided which is capable to operate by steam-engine, internal combustion engine or redundant electric power if the boiler which use solid fuel and may have the residual heat damaging to the boiler even after shutting off the fuel supply.

Article 25-3. Two or more feed-water equipment of boiler

1. The provision regarding feed-water equipment can be applied as considered one boiler if close two or more boilers are combined. In this case, the stop valves must be provided near the water source on the branch water supply pipe.

Article 25-4. Harmful heat

1. The case "**When harmful heat of boiler remains, even in the event of the fuel feed being turned off rapidly**" stipulated in Article 25-2. in the design technical regulation means the boiler, etc. which has not equipment to turn off fuel rapidly when the water level of circulation boiler and the flow rate of once-through boiler significantly decrease, which is not capable to halt heat supply rapidly and the stoker-fired boiler (excluding the spreader stoker-fired boiler).

Article 26. Isolation of steam and feed-water of boiler, etc.

Article 26-1. Main steam stop valve

1. Numbers of main steam stop valve

   The stop valve must be provided at each outlet of steam (excluding safety valve, outlet of super-heater, inlet of re-heater and outlet of re-heater). When the boiler which has manhole is connected for a common steam reservoir, 2 or more stop valves must be provided on the steam pipe that connects each boiler and the steam reservoir, or a check valve must be provided near the boiler, and the stop valve must be provided near the steam reservoir. Also, the drain valve which is large enough must be provided during these valves.

2. Stop valve

   The stop valve must withstand the maximum working pressure and temperature of boiler and at least withstand the pressure of 0.7MPa. The steam stop valve with nominal diameter of more than 65A mist have special construction or outside-screw shaped type construction and must be immediately obvious the valve opening.

3. Drain valve for stop valve

   When providing a drain valve on the super-heater or the place where the drain accumulates, drainage must be provided.

Article 26-2. Feed water valve and non-return valve

1. The feed-water valve close to the boiler and the non-return valve close to it must be provided on the feed-water pipe. However, the non-return valve may be omitted in case of the boiler under 0.1MPa operation pressure.

2. The feed-water valve and non-return valve mentioned in item-1. may be omitted if provided with a pump for each boiler, and if there is the feed-water valve and non-return valve at outlet of feed-water heater and feed-water pump.

3. The valve which is combined the feed-water valve and the non-return valve, and the disk and seat is common, is considered as the feed-water valve and is not allowed the non-return valve.

4. When installing the feed-water valve on the feed-water pipe, it must be installed as the feed-water pushes up the disk. The size of feed-water valve and non-return valve must be at least 15A for the boiler with transfer area $10m^2$ or less, at least 20A for the boiler with transfer area more than $10m^2$.

5. Water supply point: The water supply point must be pursuant to the followings except the special boilers.

5.1 The feed-water must be supplied away as possible from the heat transfer surface directly exposed to high temperature flame and exposed to heat radiation, and distributed as scattered. The boiler which the maximum operation pressure exceeds 2.8MPa must have the appropriate construction on the part where the feed-water pipe penetrates body plate or end plate and be reduce the effects of temperature differences.

5.2 The feed-water must not supply from the blow pipe except for the heating boiler to supply the condensate water.

5.3 When using the feed-water inner pipe, it must have the construction that can be removable.

5.4 In case of the horizontal external combustion fire-tube boiler with the inner diameter of body exceeding 1,000mm, generally the feed-water must be supplied in the place of about 3/5 of the length of boiler from the front end plate in the center column. The feed-water pipe must be supported firmly on the inside of body.

5.5 The feed-water must be supplied to following place in case of the vertical fire-tube boiler.

1) The place where the height is at least 1/4 of the tube length upward from the lower surface of tube sheet in case the length of fire-tube 1,200mm or less.
2) The place where the height is 300mm or more upward from the lower surface of tube sheet in case the

length of fire-tube 1,200mm or more.

Article 27. Blow-down equipment for boiler, etc.

Article 27-1. Blow-down equipment for circulating boiler

1. Purpose of blow

The purpose of blowing can be considered the following two.

1.1 To prevent excess concentration of boiler water

A variety of dissolved impurities in the boiler water make the formation of sludge and scale according to increasing concentration in the boiler and the carry over likely occurs. Therefore, it is necessary to discharge an appropriate amount of concentrated boiler water and dilute with fed-water. The needs for blowing is still remaining because the trace dissolved impurities are still surviving and chemicals for removal of dissolved oxygen and pH adjustment, although it comes to obtain high-purity water by developed water treatment facility recently.

1.2 To discharge deposited sediment in the boiler

It is necessary to discharge sludge which the rust or other insoluble impurities in the boiler feed-water, which is brought into boiler and is generated in the boiler will be deposited in the area where the circulation flow is relatively slow because the effects sludge deposit will have been promote corrosion.

2. Type of blow

The blowing is divided into two types from the following aspects of its operation.

2.1 Intermittent blow

A certain amount of boiler water per a certain time is blow out using the pressure rapidly. This will be done primarily for the purpose of discharging the sludge. Therefore, it is customary from bottom part of the boiler where the sludge is easy to accumulate or neat the water surface where large portion is floating. The former is called bottom blow and the latter is called as surface blow.

2.2 Continuous blow

This method is to discharge a small amount of boiler water constantly during boiler operation, the location to pick up is selected the most concentrated part, since it is conducted mainly to suppress the concentration of boiler water.

3. Amount of blow

As mentioned above, the blowing of boiler water means loss of the retain heat (in case of without heat exchanger) and loss of anti-scales or expensive make-up water itself, although it is the important operation of boiler. Therefore, the consideration to minimize to determine the amount of blow must be taken. The amount of blow described below is the total amount of all blows. It means the total when using a blow together continuous blow and intermittent blow, it means all amount blow when using only the intermittent blow.

3.1 Determination of the amount of blow

It is capable to calculate the amount of blowing by formula-(1) or formula-(2), assuming that ingredients in the feed-water goes into boiler and is concentrated without precipitation or deposition as scale.

$$\frac{\alpha}{\beta}\times 100 = B_1 \qquad \text{(based on amount of feed water)} \cdots\cdots (1)$$

$$\frac{\alpha}{\beta-\alpha}\times 100 = B_2 \qquad \text{(based on amount of evaporation)} \cdots\cdots (2)$$

Where

α	: concentrations of dissolved solids in the water or the component concentration in the feed-water	ppm
β	: concentrations of dissolved solids in the water or the component concentration in the boiler water	ppm
B_1, B_2	: amount of blow	%

The calculation formula (1) and (2) is the estimation formula and indicates the target amount of blowing because the ingredients in the water is actually precipitated as scale partly in the boiler and on the other hand dissolved solid increase by the addition of anti-scales. Therefore, it is necessary to increase or decrease the amount of blowing after blowing according to the calculated by formula-(1) or formula-(2) tentatively and measuring the concentration of the components of the boiler water to be restricted. The amount of each concentration of composition to be restricted is shown in Fig-93 as reference. In this figure, it was determined the target of the amount of blowing easily to corresponding to wide range of concentrations as if that can be applied to any component of the composition to be restricted.

3.2 Target component to be limited

The amount of blow must be determined according to the component which for is reached to a limit fastest, the component must be restricted following the normal component.

3.2.1 Dissolved solids

It is convenient to estimate the amount of blow by estimating the concentration of dissolved solids from measurements of electric conductivity usually, keep looking for the ratio of the measured concentration of dissolved solids and electric conductivity in advance because it takes a long time if applying the dissolved solids. The ration of the measured concentration of the dissolved solid and the electric conductivity is variable depending on the composition of the dissolved solids, it can be reduced the error relatively if employing the electric conductivity value after neutralization by phenolphthalein as an indicator of Gallic acid, although it easy has the error. When the concentration of chlorine in the feed-water is relatively high, it is convenient to estimate the amount of blow by estimating the concentration of dissolved solids from measurements of chlorine usually, keep looking for the ratio of the measured concentration of dissolved solids and chlorine in advance. In case of potassium salts is not performed, it is possible to estimates the dissolved solid concentration according to the following formula-(8).

$$TDS(ppm) = 1.32M - 0.52P + 0.61[PO_4] + 1.6[Cl] + 1.48[SO_4] + 1.57[SO_3] + [SiO_2] \cdots\cdots\cdots (3)$$

Where

TDS	: Total Dissolved Solid	ppm
M	: Methyl-orange alkalinity (CaCO3)	ppm
P	: Phenolphthalein alkalinity(CaCO3)	ppm
$[Cl]$	: Cl^-	ppm
$[PO_4]$	: PO_4^{3-}	ppm
$[SO_4]$	: SO_4^{2-}	ppm
$[SO_3]$	: SO_3^{2-}	ppm
$[SiO_2]$	: SiO_2	ppm

3.2.2 Silica

The blow of high pressure boiler is carried out to prevent the selective carry over according to the concentration of silica as the restriction item. The blow must be considered for such preventing siliceous scales to such limits in low-pressure boiler.

3.2.3 Alkalinity

The amount of blowing must be determined according to the alkalinity as the main restriction item, in case of boiler tends to concentrate too much alkaline in the boiler water depending on the type of feed-water treatment facility.

3.2.4 Others

Other than during normal operation, it is necessary to eliminate the cause of when oils, iroNOxide and organic matter adversely affect the boiler mixed in, while there is need to blow contamination as appropriate.

3.3 Concentration of target component to be limited

The limit of the concentration of component to be restricted must be referred JIS B8223-2006 "Quality of feed-water and boiler water for water tube boiler (circulation boiler)" and "Quality of feed-water and boiler water for HRSG" because they depend on the operation conditions such as pressure, type of water treatment.

4. Operation blow

4.1 Intermittent blow

The main purpose of intermittent blow is to discharge the sediment or suspended solids as described above, however, it is applied to suppress the concentration at the same time in case not blowing continuously and the quantity is determined as of the preceding paragraph. The intermittent blow is required even when carrying out continuous blowing and the amount may be any sufficient amount to discharge precipitates and suspended solids. The frequency of blow is about 1~3 times in 24 hours, the appropriate frequency and amount must be determined to be increased or decreased according to the result of investigation of sludge accumulation in the drum at boiler outage. The frequency of intermittent blow must be done to avoid exceeding the maximum allowable concentration of boiler water, if the intermittent blow is carried out for the suppression concentration of boiler water as shown in Fig-94. The timing of blow must be selected when the load is low, and extinguishing or buried timing is preferable.

When blowing during operation, it is conducted to blow raised water level after raising water level to about 25~50m gradually by means of adjusting the feed-water control equipment and combustion equipment in advance or to recover soon after it was blown from the standard water level. The information about the limit of water level and details on operation in this case must be followed the instructions of boiler manufacturer. It is better to blow in the tendency to increase the pressure even if the combustion rate slightly increased because it causes the heat loss by blowing in every case. If a single operation can not be performed the required amount of blowing, it is important to repeat the above mentioned additional operation. It is required attention because it may cause drastic changes in water with boiler carry-over, if a large amount of water is blown just disappear from the water level gauge at a time. In addition, when blowing from the thriving point of boiler water circulation, it must always be done without firing. The two blow valves are usually provided in series. In this case, it is usual to open the valve near boiler first and open to the next. When stop the blowing, the opposite procedure is applied. If the one of two blow valves is rapidly open and close type, the one must be opened rapidly after the other one is opened. The construction of blow valve such as a DC-type or piston-type is consistent with this purpose. It is desirable to blow out into blow tank or blow pit for silencing.

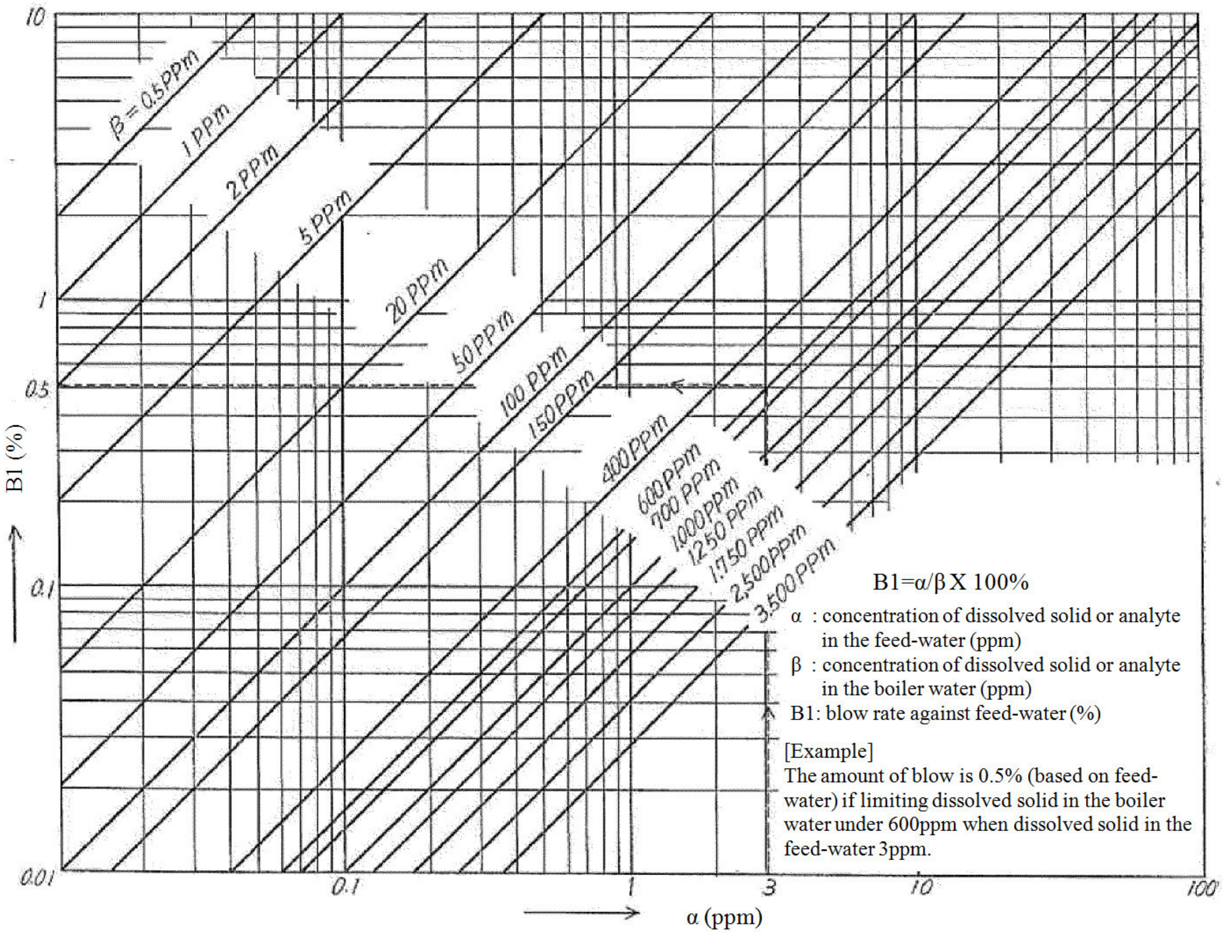
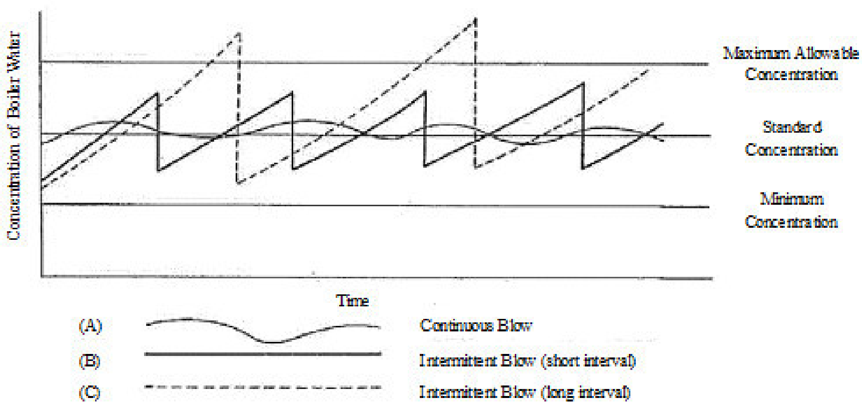


Fig- 93: Diagram for calculating the amount of blow (based on amount of feed water%)

Reference: P-38 of NO. 63 (May/1961) Journal of TENPES



The line-(A) shows the change of concentration in case of continuous blow, the line-(C) shows excess maximum allowable concentration due to the less frequency of blow-down. It is recommended to apply (B) to prevent concentration by intermittent blow.

Fig- 94: Change of the concentration of boiler water by blow-down

Reference: P-38 of NO. 63 (May/1961) Journal of TENPES

4.2 Continuous blow

It is necessary to limit to the minimum necessary amount of blow and to reduce heat losses due to the blowing by recovering heat which blowing water has because the continuous blowing discharge and damp a certain amount of boiler water at all times. There are various types of continuous blowing equipment and they can be divided into roughly following two types.

4.2.1 Flush type (Fig-95)

The blowing water is led to the flash tank which pressure is kept lower than the boiler pressure, extract a part of hot water as steam and dump the remaining hot water through the feed-water heat exchanger. The steam retrieved from flash tank is recovered into deaerator, heat exchanger or condenser. The make up water is usually used as the cooling water for heat exchanger. In case of the high-pressure boiler, pressure may be reduced sequentially by two or more flash tanks arranged series.

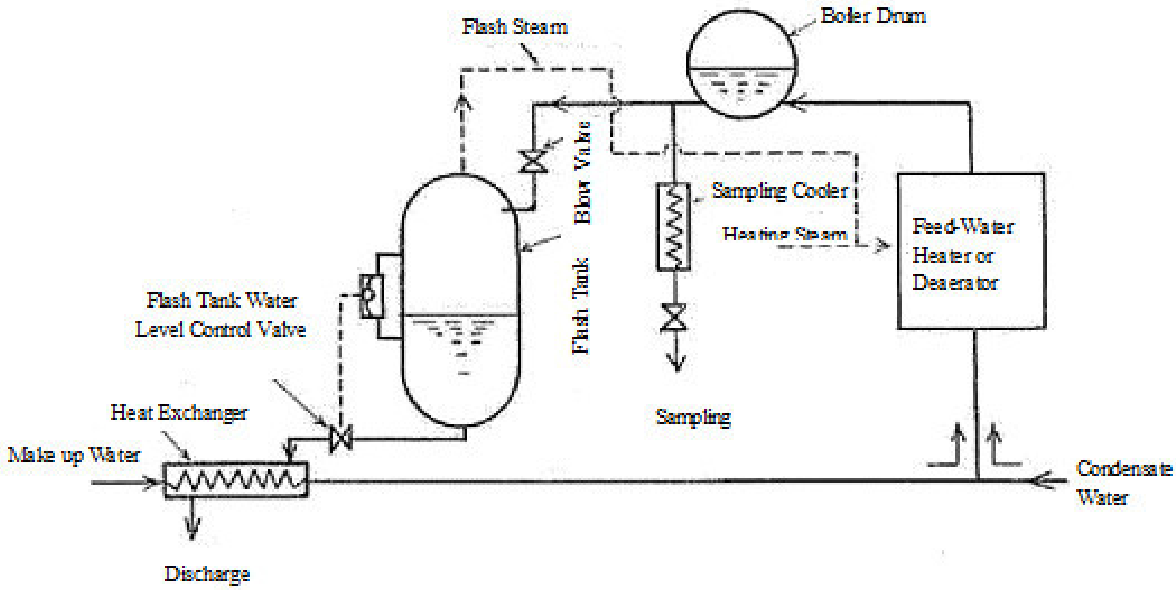


Fig- 95: Example of flush type continuous blow

Reference: P-39 of NO. 63 (May/1961) Journal of TENPES

4.2.2 Non-flush type (Fig-96)

The blowing water is led to heat exchanger directly and cooled down below 100°C, and depressurized and discharged. The heat exchanger would be expensive because it must be ordinary designed as same pressure as boiler, in this model does not required the flash tank and equipment becomes simple. Therefore, it is used to relatively low pressure boiler. The throttle valve construction is applied to the flow control valve for blowing because the adjustment of blow is carried out by the opening of valve in both cases. It is necessary to combine the orifice because it is impossible to reduce pressure by only the throttle valve in case of high pressure boiler. The full consideration must be paid against corrosion and erosion in both the throttle valve and orifice. If using make up water for heat recovery, it is necessary to pay attention to contamination of water by leakage. The amount of blow, the concentration of blow water or pH value, etc is desirable to be measured continuously and recorded by means of collecting a certain amount of sample through the cooler and measure the amount of blowing in order to measure boiler water concentration, pH as the basis of adjusting amount of blowing.

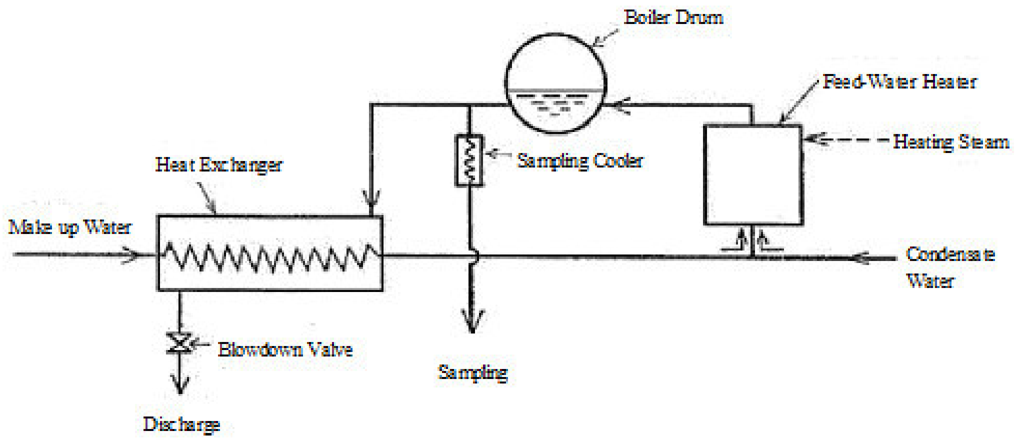


Fig- 96: Example of non-flush type continuous blow

Reference: P-39 of NO. 63 (May/1961) Journal of TENPES

Article 28. Instrument equipment for boiler, etc.

Article 28-1. Instrument to monitor operation status

1. The "**instrument equipment**" which is stipulated in Article28-1 of the design technical regulation is the equipment which measure following items.

1.1 In case of the circulation boiler, the following items;

1) Water level in the drum
2) Pressure in the drum
3) Steam temperature at super-heater and re-heater outlet

1.2 In case of the once-through boiler, the following items;

1) Steam pressure at super-heater outlet
2) Steam temperature at super-heater and re-heater outlet

2. Installation of instrument for boiler

2.1 Pressure gauge

The pressure gauge must be provided for steam boiler according to JIS B7505-1-2007 "Aneroid pressure gauge—Part-1.: Bourdon tube pressure gauges".

2.1.1 Size and scale of pressure gauge

The size of pressure gauge which is equipped on steam boiler must have at least 100mm outside diameter, and be installed so that easy to see needle depending on its height. However, it is capable to apply the gauge which has not less than 60mm outside diameter for following boiler.

1) maximum operation pressure is 0.5MPa or less and inner diameter of body is 500mm or less, length of body is 1000mm or less
2) maximum operation pressure is 0.5MPa or less and heat transfer are is $2m^2$ or less
3) once-through boiler which maximum evaporation is 5t/h or less

The maximum scale must be not less than 1.5 times and not greater than 3 times of maximum boiler operation pressure. The appropriated indication must be provided on the scale of maximum boiler operation pressure.

2.1.2 Installation of pressure gauge

The installation of pressure gauge must be pursuant as follows.

1) The pressure gauge must be installed so that easy to see scale in the boiler room and preventing freezing. And the temperature of surroundings in operation status must be in the range which is stipulated in JIS B7505-1-2007.
2) The connection pipe to the pressure gauge must withstand the maximum operation pressure, and the size must be at least 6.6mm inner diameter for brass pipe, copper pipe or stainless pipe, at least 12.7mm inner diameter for steel pipe. The brass and copper pipe must not be used when steam temperature exceeds 208^oC.
3) The pressure gauge must have the siphon pipe which is filled with water or equivalent equipment to prevent so that not steam coming into the gauge. The siphon pipe must have at least 0.5mm inner diameter.
4) The cock of pressure gauge must be open when the direction of handle is same as steam pipe. When applying valve, it must be those which easy to know the open situation at a glance.
5) When it is easy to clean up the inside of connection pipe regardless of 1) to 4),

2.1.3 Installation of manometer

1) The maximum scale of the manometer must be not less than 1.5 times and not greater than 3 times of

maximum boiler operation pressure.

2.1.4 Thermometer

1) The thermometer must be provided in outlet of the super-heater and re-heater of steam boiler.

2.1.5 Level gauge

1) The two or more glass level gauges must be provided for steam boiler (except once-through boiler). A glass level gauge may be the other type of level gauge in case the body is 750mm or less. And if providing two or more remote level gauge, it may provide one or more glass level gauge.
2) The level gauge glass must have glass stipulated in JIS B8211-2007 “Boilers gauge glasses” and valve or cock in up and down, must have the function working under the maximum operation pressure and temperature, must be so that testing and cleaning easily. The construction of valve and cock must be easy to clean.
3) The level gauge for water tube boiler must be installed in safety and appropriate location.

Article 28-2. Boiler trip item and application

1. It is recommended to provide above mentioned monitoring instruments and conduct safety operation. When the following major trip items as shown in Table-25 occurred, the boiler must be trip immediately eliminating severe damage of boiler.

Table- 25: Boiler trip item and application

No.	Trip item	item				Basic concept	Following protection	remarks
		Drum boiler		Once through boiler				
		essential	recommendation	essential	recommendation			
1	Drum pressure or MS pressure high	O		O		To provide trip circuit to avoid over pressure exceeding 1.16 times of boiler design pressure.	Boiler safety valve operation	
2	1st SH outlet pressure high			O		To stop BFP to avoid safety valve working during start-up by-pass operation due to high pressure.	Boiler safety valve operation	Supercritical boiler
3	1st SH outlet pressure low			O		When pressure drops below from supercritical to subcritical pressure, flow become unstable. To stop boiler to prevent burning.	—	—
4	Low Feed-water flow l				O	To stop boiler to prevent burnout due to poor heating of film boiling in the water wall tube.	—	—

No.	Trip item	item				Basic concept	Following protection	remarks
		Drum boiler		Once through boiler				
		essential	recommendation	essential	recommendation			
5	Drum water level low		O			To trip boiler to prevent water wall burnout due to deterioration of boiler water circulation.	—	—
6	Furnace pressure high		O		O	To trip boiler to protect furnace in the view point of design strength and due to the prospect of abnormality of air and gas pass.	—	—
7	Furnace pressure low		O		O	It is caused abnormal draft control of furnace or furnace pressure drop due to loss of fire. To trip boiler to protect furnace water wall or to prevent hopper-seal break.	—	Balanced draft boiler (coal fired)
8	Fuel pressure low Gas pressure low	O		O		To close all shut-off valves below the pressure limit of stable combustion for burner.	Boiler trip due to loss of all flames	—
9	Loss of all fuel	O		O		To stop boiler to prevent low temperature steam flow into steam turbine.	—	—
10	Loss of all frame	O		O		To trip boiler considering occurrence of abnormal combustion in the furnace and extremely unstable combustion.	—	—
	Critical frame out	O		O		To trip boiler after counting misfire burner within a time due to the occurrence of an abnormal combustion in the furnace.	—	—
11	Fuel supply exceeding re-heater protection range		O		O	To trip boiler if there may be burnout of re-heater because it is impossible to reduce fuel when shut-off steam for turbine.	—	Detection method different from fuel
12	Low steam pressure for burner atomizing	O		O		To trip boiler due to the pressure drop of atomizing medium to prevent combustion in stability.	Boiler trip due to loss of all flames	—
13	Halt of all BFP				O	It is impossible to continue operation. To trip boiler to protect burnout.	—	—
14	Drum water level high		O			To prevent low temperature steam flow into steam turbine. Generally, only ANN without trip.	—	—
15	Halt of all IDF	O		O		To trip FDF as well as boiler trip to prevent furnace pressure rise.	—	Balanced draft boiler (coal fired)
16	Halt of all FDF	O		O		To trip boiler because of loss of air to combustion.	—	
17	Halt of all coal mill	O		O		To stop boiler to prevent low temperature steam flow into steam turbine when all fuel are lost.	—	

No.	Trip item	item				Basic concept	Following protection	remarks
		Drum boiler		Once through boiler				
		essential	recommendation	essential	recommendation			
18	Halt of all PAF	**O**		**O**		To stop boiler to prevent low temperature steam flow into steam turbine when all fuel are lost.	—	
19	Halt of all coal feeder	**O**		**O**		Ditto. After stopping of coal feeder, coal mill will stop in a while. It is the difference just either directly or indirectly.	—	
20	Actuation of fire fighting equipment		**O**		**O**	To trip boiler due to the occurrence of fire when a fire extinguishing equipment is worked.	—	
21	Two times failure of ignition		**O**		**O**	To trip boiler for purging in case of failing ignition twice of ignition burner even before ignition of main burner for boiler start-up.	—	Depend on the decision by boiler maker

Reference: P-58 of No. 632 (May/2009) Journal of TENPES

Chapter-3. Reference International Technical Standards

The reference international standards for designing boiler are organized in Table-26.

Table- 26: Reference international technical standards

Number	Rev.	Title	Content
ASME Section-1	2010	Construction of Power Boilers	Rules for Construction of Power Boilers (ASME X00010)
ASME Section-2	2010	Materials--Part-A: Ferrous Material Specifications	Ferrous Material Specifications (two volumes) (ASME X0002A)
ASME Section-2	2010	Materials--Part-B: Nonferrous Material Specifications	Nonferrous Material Specifications (ASME X0002B)
ASME Section-2	2010	Materials--Part-C: Specifications for Welding Rods, Electrodes and Filler Metals	Specifications for Welding Rods, Electrodes, and Filler Metals (ASME X0002C)
ASME Section-2	2010	Materials--Part-D: Properties	Properties, Customary Version (ASME X0002D)
ASME Section-5	2010	Nondestructive Examination	Nondestructive Examination (ASME X00050)
ASME Section-7	2010	Recommended Guideline for the Care of Power Boilers	Recommended Guidelines for the Care of Power Boilers (ASME X00070)
ASME Section-8	2010	Rules for Construction of Pressure Vessels Devision-1:	Rules for Construction of Pressure Vessels (ASME X00081)
ASME Section-8	2010	Devision-2: Alternative Rules	Alternative Rules (ASME X00082)
ASME Section-8	2010	Devision-3: Alternative Rules for the Construction of High Pressure Vessels	Alternative Rules for Construction of High Pressure Vessels (ASME X00083)
ASME Section-9	2010	Welding and Brazing Qualifications	Welding and Brazing Qualifications (ASME X00090)
ISO 16528	2007	Boilers and pressure vessels -- Part 1: Performance requirements	This defines the performance requirements for the construction of boilers and pressure vessels

Number	Rev.	Title	Content
ISO 16528-1	2007	Boilers and pressure vessels -- Part 1: Performance requirements	This defines the performance requirements for the construction of boilers and pressure vessels. It is not the intent of ISO 16528-1:2007 to address operation, maintenance and in-service inspection of boilers and pressure vessels. In relation to the geometry of the pressure-containing parts for pressure vessels, ISO 16528-1:2007 includes welding end connection for the first circumferential joint for welded connections, first threaded joint for screwed connections, face of the first flange for bolted, flanged connections, first sealing surface for proprietary connections or fittings and safety accessories, where necessary. In relation to the geometry of pressure-containing parts for boilers, ISO 16528-1:2007 covers feedwater inlet (including the inlet valve) to steam outlet (including the outlet valve), including all inter-connecting tubing that can be exposed to a risk of overheating and cannot be isolated from the main system, associated safety accessories and connections to the boilers involved in services such as draining, venting, desuperheating, etc. ISO 16528-1:2007 does not apply for nuclear components, railway and marine boilers, gas cylinders or piping systems or mechanical equipment, e.g. turbine and machinery casings.
ANSI/ASME PTC 25.3	1994	Safety and Relief Valves - performance test codes	
API RP 520	2000	Sizing selection and installation of pressure relieving devices in refineries, Part 1 Design, Part 2 Installation	This recommended practice covers methods of installation for pressure-relief devices for equipment that has a maximum allowable working pressure (MAWP) of 15 psig (1.03 bar g or 103 kPA) or greater. Pressure-relief valves or rupture disks may be used independently or in combination with each other to provide the required protection against excessive pressure accumulation. As used in this recommended practice, the term pressure-relief valve includes safety relief valves used in either compressible or incompressible ßuid service, and relief valves used in incompressible ßuid service. This recommended practice covers gas, vapor, steam, two-phase and incompressible ßuid service; it does not cover special applications that require unusual installation considerations.
API RP 521	1997	Guide for pressure relieving and depressurizing systems	This recommended practice is applicable to pressure-relieving and vapor depressuring systems. The information provided is designed to aid in the selection of the system that is most appropriate for the risks and circumstances involved in various installations. This recommended practice is intended to supplement the practices set forth in API Recommended Practice 520, Part 1, for establishing a basis of design. This recommended practice provides guidelines for examining the principal causes of overpressure; determining individual relieving rates; and selecting and designing disposal systems, including such component parts as vessels, flares, and vent stacks.

Number	Rev.	Title	Content
			Piping information pertinent to pressure-relieving systems is presented in 5.4.1, but the actual piping should be designed in accordance with ASME B31.3 or other applicable codes. Health risks may be associated with the operation of pressure-relieving equipment. The discussion of specific risks is outside the scope of this document.
API STD 526	2002	Flanged steel pressure relief valves	This standard is a purchase specification for flanged steel pressure-relief valves. Basic requirements are given for direct spring-loaded pressure-relief valves and pilot-operated pressure-relief valves as follows:
API STD 527	2007	Seat tightness of pressure relief valves	This standard describes methods of determining the seat tightness of metal- and soft-seated pressure relief valves, including those of conventional, bellows, and pilot-operated designs. The maximum acceptable leakage rates are defined for pressure relief valves with set pressures from 15 pounds per square inch gauge (103 kilopascals gauge) to 6,000 pounds per square inch gauge (41,379 kilopascals gauge). If greater seat tightness is required, the purchaser shall specify it in the purchase order. The test medium for determining the seat tightness of air, steam, or water shall be the same as that used for determining the set pressure of the valve. For dual-service valves, the test medium for determining the seat tightness air, steam, or water shall be the same as the primary relieving medium. To ensure safety, the procedures outlined in this standard shall be performed by persons experienced in the use and functions of pressure relief valves.
ISO 4126-1	2004	Safety devices for protection against excessive pressure Part-1: Safety valves	This specifies general requirements for safety valves irrespective of the fluid for which they are designed. It is applicable to safety valves having a flow diameter of 6 mm and above which are for use at set pressures of 0,1 bar gauge and above. No limitation is placed on temperature. This is a product standard and is not concerned with applications for safety valves.
ISO 4126-2	2003	Safety devices for protection against excessive pressure Part-2: Bursting disc safety devices	This specifies the requirements for bursting disc safety devices. ISO 4126-2:2003 includes the requirements for the design, manufacture, inspection, testing, certification, marking, and packaging. The requirements for the application, selection and installation of bursting disc safety devices are given in ISO 4126-6.

Number	Rev.	Title	Content
ISO 4126-3	2006	Safety devices for protection against excessive pressure Part-3: Safety valves and bursting disc safety devices in common	This specifies the requirements for a product assembled from the in-series combination of safety valves or CSPRS (controlled safety pressure relief systems) according to ISO 4126-1, ISO 4126-4 and ISO 4126-5, and bursting disc safety devices according to ISO 4126-2 installed within no more than five pipe diameters from the valve inlet. It specifies the design, application and marking requirements for such products, which are used to protect pressure vessels, piping or other enclosures from excessive pressure, and which comprise the bursting disc safety device, a safety valve or CSPRS and, where applicable, a short length of connecting pipe or spool piece. In addition, it gives a method for establishing the combination discharge factor used in sizing combinations.
ISO 4126-4	2004	Safety devices for protection against excessive pressure Part-4: Pilot-operated safety valves	This specifies general requirements for pilot operated safety valves, other than those covered in ISO 4126-1, irrespective of the fluid for which they are designed. In all cases, the operation is carried out by the fluid in the system to be protected. ISO 4126-4:2003 is applicable to pilot operated safety valves having a valve flow diameter of 6 mm and above which are for use at set pressures of 0,1 bar gauge and above. No limitation is placed on temperature. This is a product standard and it is not concerned with applications for pilot operated safety valves
ISO 4126-5	2004	Safety devices for protection against excessive pressure Part-5: Controlled safety pressure relief system (CSPRS)	This specifies the requirements for controlled safety pressure relief systems, irrespective of the fluid for which they are designed. It is applicable to main valves having a flow diameter of 6 mm and above for use at pressures of 0.1 bar (= 0.01 MPa) gauge and above. No limitation is placed on temperature. This is a product standard and is not concerned with applications.
ISO 4126-6	2003	Safety devices for protection against excessive pressure Part6-: Application, selection and installation of bursting disc safety devices	This gives guidance on the application, selection and installation of bursting disc safety devices used to protect pressure equipment from excessive pressure and/or excessive vacuum.
ISO 4126-7	2004	Safety devices for protection against excessive pressure—Prat-7: Common data	This contains data common to other parts of ISO 4126, thus avoiding unnecessary repetition, and is referenced in those other parts as appropriate.

Number	Rev.	Title	Content
ISO 4126-9	2008	Safety devices for protection against excessive pressure—Prat-9: Application and installation of safety devices excluding stand-alone bursting disc safety devices	This covers the application and installations of safety devices such as safety valves, safety valves and bursting disc safety devices in combination, pilot-operated safety valves and controlled safety pressure-relief systems for the protection of pressure equipment. ISO 4126-6 covers the selection, application and installation of bursting disc safety devices. ISO 4126-9:2008 describes the normative requirements for applications and installations of safety devices to protect static pressure equipment. The information contained in ISO 4126-9:2008 assumes single-phase flow of the fluid discharged from the safety device. ISO 4126-10 provides guidance specific to two-phase flow conditions. Equipment connected together in a system by piping of adequate capacity, which is free from potential blockages and does not contain any valve that can isolate any part, can be considered to be a safety system for the application of pressure relief. ISO 4126-9:2008 does not deal with other safety devices, such as safety related monitoring, control and regulation devices and other limiting devices allowed by some national regulations.
ISO 4126-10	2010	Safety devices for protection against excessive pressure—Part-10: Sizing of safety valves for gas/liquid two-phase flow	This specifies the sizing of safety valves for gas/liquid two-phase flow in pressurized systems such as: reactors, storage tanks, and columns, heat exchangers, piping systems or transportation tanks/containers.
A. D. Merkblatt A2	2001	Pressure Vessel Equipment safety devices against excess pressure - safety valves	German standard
ARI-SAFE-TRD 421	1982	Technical Equipment for Steam Boilers Safeguards against excessive pressure - safety valves for boilers of groups I, III & IV	German standard
ARI-SAFE-TRD 721	2011	Technical Equipment for Steam Boilers Safeguards against excessive pressure-safety valves for steam boilers group II	German standard
BS 6759	1999	Part 1 specification for safety valves for steam and hot water Part 2 specification for safety valves for compressed air and inert gas Part 3 specification for safety valves for process fluids	UK standard
AFNOR NFE-E -29-411 to 416		Safety and relief valves	French standard
AFNORNFE-E -29-421		Safety and relief valves	French standard
KS B6216	1998	Spring loaded safety valves for steam boilers and pressure vessels	Korean standard
SAA AS1271	2003	Safety valves, other valves, liquid level gauges and other fittings for boiler and unfired pressure vessels	Australian standard

Chapter-4. Reference Japanese Technical Standards

The reference Japanese industrial standards for designing boiler are organized in Table-27.

Table- 27: Reference Japanese technical standards

Number	Rev.	Title	Content
JIS B0126	2010	Glossary of terms for thermal power plants - Boilers and auxiliary equipment	This stipulates definitions of key terms and rules for boiler and associate equipment use in thermal power generation.
JIS B0130	2006	Glossary of terms for thermal power plants-general	This stipulates terms used in thermal power generation, main provisions relating to overall, environment, operation and maintenance.
JIS B0131	2007	Glossary of terms for turbo-pumps	This stipulates terms and definitions related to hydropower and the main terms used in their products and turbo pumps that are commonly used.
JIS B2312	2009	Steel butt-welding pipe fittings	This stipulates about seamless pipe fittings made of steel and nickel chromium alloy steel mainly butt welded with pressure pipe, high pressure pipe, high temperature pipe, alloy steel pipe, stainless steel pipe and low temperature pipe.
JIS B2313	2009	Steel plate butt-welding pipe fittings	This stipulates about fittings with longitudinal joint made of steel and nickel chromium alloy steel mainly butt welded with pressure pipe, high pressure pipe, high temperature pipe, alloy steel pipe, stainless steel pipe and low temperature pipe.
JIS B7505-1	2007	Aneroid pressure gauges—Part-1.: Bourdon tube pressure gauges	This stipulates about circular single-needle elastic element pressure gauge of aneroid type pressure gauge.
JIS B7528	2010	Mercury filled thermometers	This stipulates about circular single-needle pressure type thermometer applied to -30~500^{o}C that is composed Bourdon pipe and temperature sensor by connecting pipe and filled by mercury.
JIS B8201	2010	Stationary steel boilers-construction	This stipulates about steel boiler for land use for hot steam, hot water and it’s auxiliary.
JIS B8203	2010	Cast iron boilers-construction	This stipulates about construction of cast iron steam boiler, hot water boiler and it’s auxiliary to be used as a heat source such as heating supplying hot water.
JIS B8210	2009	Safety devices for protection against excessive pressure-direct spring loaded safety valves for steam and gas service	This stipulates about steam safety valves and gas safety valve directing acting by cylindrical coil spring.
JIS B8211	2007	Boilers-gauge glasses	This stipulates about water gage glass of boiler.
JIS B8213	2006	Boilers-reflex type water gauges	This stipulates about boiler reflective level gauge used for maximum operating pressure 2.5MPa or less.
JIS B8215	2006	Boilers-transparent type water gauges	This stipulates about boiler transparent level gauge used for maximum operating pressure 4.5MPa, 6.0MPa and 8.0MPa.

Number	Rev.	Title	Content
JIS B8216	2006	Boilers-1MPa tubular type water gauges	This stipulates about boiler round level gauge used for maximum operating pressure 1MPa or less.
JIS B8222	2007	Land boilers-heat balancing	This stipulates about general procedure of heat account for practical examination of land boiler (including hot water boiler) that use solid, liquid and gaseous fuel.
JIS B8223	2006	Water conditioning for boiler feed water and boiler water	This stipulates about feed-water and boiler water quality standard for steam boiler and steam boiler for marine use.
JIS B8224	2009	Boiler feed water and boiler water-testing methods	This stipulates about testing method of boiler feed-water, boiler water and steam.
JIS B8225	2007	Safety valves-measuring methods for coefficient of discharge	This stipulates about procedure for measuring the coefficient of safety valve blow-off for steam and gas.
JIS B8247	2010	Formed head for pressure vessel	This stipulates about head plate produced by press-molded and spinning to weld with pressure vessel.
JIS B8248	2008	Cylindrical layered pressure vessels	This stipulates about cylindrical multilayer pressure vessel with body composed by more than 2 steel layers that holds internal pressure above atmospheric pressure.
JIS B8249	2009	Shell and tube heat exchangers	This stipulates about evaporator, heater, and condenser, cooler and other metal cylindrical multi-tube heat exchanger.
JIS B8265	2010	Construction of pressure vessel-general principles	This stipulates construction and attached structure for pressure vessel with design pressure less than 30MPa. Pressure vessel means a vessel or container that holds pressure, holds pressure fluid inside or maintain outside pressure.
JIS B8266	2006	Alternative standard for construction of pressure vessels	This stipulates about safety equipment such as rupture disc, holder and vacuum support which composed by annex to prevent damage due to excess pressure and negative pressure.
JIS B8267	2008	Construction of pressure vessel	This stipulates construction and an attached structure for pressure vessel with design pressure less than 30MPa.
JIS B8274	2008	Flat tube-sheet for pressure vessels	This stipulates design method of tube plate for multi-tube cylindrical heat exchanger.
JIS B8277	2008	Expansion joint for pressure vessels	This stipulates about design, manufacturing and inspection method of expansion joint to absorb heat expansion caused on heat exchanger or vessel with jacket by heat expansion.
JIS B8279	2010	Jacket for pressure vessels	This stipulates construction about pressure chamber (jacket) welded on pressure vessel.
JIS B8280	2010	Pressure vessels of noncircular cross section	This stipulates construction about pressure vessel of rectangular or oval cross-section.
JIS B8285	2010	Welding procedure qualification test for pressure vessels	This stipulates about verification testing of pressure vessel welding procedure.
JIS B8286	2009	Sight glasses for pressure vessels	This stipulates construction and about porthole window to be used for pressure vessel with design pressure less than 30MPa.

Number	Rev.	Title	Content
JIS G3103	2007	Carbon steel and molybdenum alloy steel plates for boilers and pressure vessels	This stipulates about carbon and molybdenum steel hot plate used for boiler and pressure vessel at medium and high temperature.
JIS G3106	2008	Rolled steels for welded structure	This stipulates about hot rolled steel used for bridge, ship, oil tank, vessel and other welded structure especially with excellent good weldability.
JIS G3119	2007	Manganese-molybdenum and manganese-molybdenum-nickel alloy steel plates for boilers and pressure vessels	This stipulates about manganese molybdenum, manganese molybdenum nickel hot rolled steel plate used for boiler and pressure vessel at medium and high temperature.
JIS G3124	2009	High strength steel plates for pressure vessel for intermediate and moderate temperature service	This stipulates about high strength steel plate for boiler and pressure vessel used at medium and high temperature.
JIS G3206	2008	High strength chromium-molybdenum alloy steel forgings for pressure vessels under high-temperature service	This stipulates about high strength chrome molybdenum forgings used for pressure vessel at high temperature.
JIS G3214	2009	Stainless steel forgings for pressure vessels	This stipulates about stainless forgings used for pressure vessel and their component for anti-corrosion and high temperature.
JIS G3462	2009	Alloy steel tubes for boiler and heat exchanger	This stipulates about alloy steel pipe used for heat transfer in and out of tub.
JIS G3463	2010	Stainless steel boiler and heat exchanger tubes	This stipulates about stainless steel pipe used for heat transfer in and out of tub.
JIS G3601	2007	Stainless-clad steels	This stipulates about stainless steel as cladding material used in pressure vessel, boiler, nuclear reactor and tank.
JIS G3602	2008	Nickel and nickel alloy clad steels	This stipulates about cladding material together with nickel and nickel alloy used in pressure vessel, boiler, nuclear reactor and tank.
JIS G4109	2008	Chromium-molybdenum alloy steel plates for boilers and pressure vessels	This stipulates about chrome molybdenum hot rolled steel plate for boiler and pressure vessel that are used at high temperature from room temperature.
JIS G4311	2011	Heat-resisting steel bars and wire rods	This stipulates about heat resistant steel rod and wire.
JIS G4312	2011	Heat-resisting steel plate, sheet and strip	This Provides heat resistant steel plate and steel band.
JIS G7102	2010	Continuously hot-rolled steel sheet of structural quality with improved atmospheric corrosion resistance	This stipulates about weather resistant structural hot-rolled steel plate and steel band.
JIS G7220	2008	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part2:Unalloyed and alloyed steels with specified elevated temperature properties	This stipulates technical delivery conditions for seamless pipe with circular cross section that is manufactured from carbon steel and alloy steel and defined high temperature characteristics.
JIS G7222	2008	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part4:Austenitic stainless steels	This stipulates technical delivery condition for seamless pipe with circular cross section that is manufactured from austenite stainless steel and application to pressure and anti-corrosion at room temperature, low temperature and high temperature.

Number	Rev.	Title	Content
JIS G7224	2008	Welded steel tubes for pressure purposes - Technical delivery conditions - Part2:Electric resistance and induction welded unalloyed and alloyed steel tubes with specified elevated temperature properties	This stipulates technical delivery conditions for electric resistance welding pipe with circular cross section that is manufactured from carbon steel and alloy steel and defined temperature characteristics.
JIS G7225	2008	Welded steel tubes for pressure purposes - Technical delivery conditions - Part3:Electric resistance and induction welded unalloyed and alloyed steel tubes with specified low temperature properties	This stipulates technical delivery conditions for electric resistance welding pipe with circular cross section that is manufactured from carbon steel and alloy steel and defined low temperature toughness.
JIS G7226	2008	Welded steel tubes for pressure purposes - Technical delivery conditions - Part6:Longitudinally welded austenitic stainless steel tubes	This stipulates technical delivery condition for seamless pipe with circular cross section that is manufactured from austenite stainless steel and application to pressure and anti-corrosion at room temperature, low temperature and high temperature.
JIS Z2287	2008	Method for steam oxidation test of boiler tube metallic materials	This stipulates about test method of steam oxide of boiler tube metal at high temperature.
JIS Z2290	2009	General rules for high-temperature corrosion test of metallic materials	This stipulates about common matters about test method of high temperature corrosion to quantitive evaluate hot corrosion of metal.
JIS Z2315	2007	Test methods for performance characteristics of eddy current flaw detecting system	This stipulates about measuring method and how to display overall performance of the test equipment used when performing eddy current test such as steel pipe.
JIS Z2314	2008	Test methods for performance characteristics of eddy current testing	This stipulates about performance measuring method of eddy current flaw detector with a phase analysis function.
JIS Z3121	2010	Methods of tensile test for butt welded joints	This stipulates about tensile strength test method of butt welding joint of plate and pipe of metal material.
JIS Z3122	2010	Methods of Bend Test for Butt Welded joint	This stipulates bending test method of butt welding joint of plate and pipe of metal material.
JIS Z3153	2008	Method of T-joint weld cracking test	This stipulates T-type cracking test to investigate hot crack that occurs in the welding part of carbon steel, alloy steel and stainless steel.
JIS Z3154	2008	Method of controlled thermal severity weld cracking test	This stipulates lap joint cracking test method to investigate low temperature crack that occurs in the welding part of carbon steel, alloy steel and stainless steel.
JIS Z3155	2008	Method of FISCO test	This stipulates C-type jig restraint joint cracking test method to investigate high temperature crack that occurs in the welding part of carbon steel, alloy steel and stainless steel.
JIS Z3157	2008	Method of U-groove weld cracking test	This stipulates U-type cracking test method to investigate low temperature crack that occurs in the welding part of carbon steel, alloy steel.
JIS Z3158	2008	Method of y-groove weld cracking test	This stipulates Y-type cracking test method to investigate low temperature crack that occurs in the welding part of carbon steel, alloy steel.

Number	Rev.	Title	Content
JIS Z3183	2008	Classification and testing methods for deposited metal of submerged arc welding for carbon steel and low alloy steel	This stipulates quality classification and test method of deposited metal obtained by submerged arc welding material.

Chapter-5. Reference TCVN

The reference Vietnamese national standards for designing boiler are organized in Table-28.

Table- 28: Reference TCVN

Number	Rev.	Title	Content
TCVN 2549	1978	Steam and hot water boilers. Symbols of control devices	Ap dụng cho các nồi hơi, nồi chưng nước đặt cố định và qui định các ký hiệu tượng trưng bố trí trên bảng bàn điều khiển nhằm làm rõ chức năng thực hiện của các cơ cấu điều khiển của nồi hơi và nồi chưng nước
TCVN 4878	2009	Fire protection. Classification of fires.	Tiêu chuẩn này quy định việc phân loại các đám cháy thành năm loại theo bản chất của chất cháy
TCVN 4945	2008	Industrial valves. Pressure testing of valves	Tiêu chuẩn này quy định các phép thử để khẳng định khả năng chịu áp lực của vỏ van công nghiệp chịu áp lực và kiểm tra độ kín và duy trì được áp suất thích hợp của mặt tựa van và cơ cấu làm kín.
TCVN 5346	1991	Boilers. General requirement for calculation of stability	Ap dụng cho nồi hơi có áp suất làm việc lớn hơn 0,7MPa và nồi nước nóng có nhiệt độ nước lớn hơn 115oC
TCVN 5893	1995	Steel tubes for boilers, super-heaters and heat exchangers. Dimensions, tolerances and convectional masses per unit length	Qui định đường kính, chiều dày, dung sai và khối lượng qui ước trên đơn vị chiều dài của các loại ống chịu nhiệt (bao gồm cả các ống của thiết bị tăng nhiệt và thiết bị trao đổi nhiệt). Ống kim loại qui định trong tiêu chuẩn này để dẫn nước của nồi hơi hoặc thiết bị nước nhiệt độ cao. Tiêu chuẩn này không áp dụng cho các loại ống theo ISO 6758 đến ISO 6759
TCVN 5894	1995	Steel tubes. Tolerance systems	Qui định hệ thống dung sai để tiêu chuẩn hoá các loại ống thép
TCVN 6008	2010	Pressure equipment. Welded. Technical requirements and testing methods	Qui định các yêu cầu kỹ thuật về hàn, nhiệt luyện, phương pháp thử đối với các mối hàn của thiết bị áp lực.
TCVN 6101	1996	Fire protection equipment. Carbon dioxide extinguishing systems for use on premises. Design and installation.	Qui định những yêu cầu về thiết kế và lắp đặt những hệ thống chữa cháy cacbon dioxit cố định sử dụng trong nhà. Không áp dụng đối với các hệ thống chữa cháy trên tàu thuỷ, máy bay, trên xe chữa cháy lưu động hoặc cho các hệ thống dưới lòng đất trong công nghiệp khai mỏ cũng như đối với các hệ thống làm trơ trước bằng cacbon dioxit
TCVN 6155	1996	Pressure vessels. Safety engineering requirements of erection, use, repair	Qui định những yêu cầu kỹ thuật an toàn về lắp đặt, sử dụng, sửa chữa đối với các bình chịu áp lực thuộc phạm vi hiệu lực của TCVN 6153-1996

Number	Rev.	Title	Content
TCVN 6156	1996	Pressure vessels. Safety engineering requirements of erection, use, repair. Testing method	áp dụng cho các bình chịu áp lực thuộc phạm vi hiệu lực của TCVN 6153:1996. Tất cả các bình đều phải được cơ quan nhà nước có thẩm quyền tiến hành khám nghiệm kỹ thuật trước khi đưa vào sử dụng, trong quá trình sử dụng và điều tra khi xẩy ra sự cố theo đúng qui định của tiêu chuẩn này
TCVN 6158	2010	Pipe lines for vapour and hot water. Technical requirements	Qui định những yêu cầu kỹ thuật trong thiết kế, chế tạo và lắp đặt các đường ống dẫn hơi nước và nước nóng bằng kim loại có áp suất làm việc bằng và lớn hơn 0,07 MPa, nhiệt độ lớn hơn 115oC cũng như các bộ phận của đường ống dẫn như các thiết bị giảm áp, giảm nhiệt, ống góp. Không áp dụng cho các ống dẫn nồi hơi, ống dẫn trên đầu máy xe lửa.
TCVN 6305-1	2007	Fire protection. Automatic sprinkler systems. Part-1: Requirement and test methods for sprinklers	Tiêu chuẩn này quy định các đặc tính, phương pháp thử và ghi nhãn đối với sprinkler thông thường, sprinkler phun sương, sprinkler phun sương thẳng và sprinkler bên vách.
TCVN 6305-2	2007	Fire protection. Automatic sprinkler systems. Part-2: Requirement and test methods for wet alarm valves, retard chambers and water motor alarm	Tiêu chuẩn này quy định tính năng, các yêu cầu, phương pháp thử và các yêu cầu về ghi nhãn đối với van báo động kiểu ướt, bình làm trễ, chuông nước và thiết bị bổ sung sử dụng trong hệ thống prinkler tự động chữa cháy theo quy định của nhà sản xuất.
TCVN 6305-3	2007	Fire protection. Automatic sprinkler systems. Part-3: Requirement and test methods for dry pipe valves	Tiêu chuẩn này quy định tính năng, các yêu cầu, phương pháp thử và các yêu cầu về ghi nhãn đối với van ống khô và thiết bị bổ sung có liên quan do nhà sản xuất quy định được sử dụng trong các hệ thống phòng cháy chữa cháy tự động ống khô.
TCVN 6305-4	1997	Fire protection. Automatic sprinkler systems. Part-4: Requirement and test methods for quick-open devices	Tiêu chuẩn này qui định đặc tính và yêu cầu thử đối với cơ cấu mở nhanh dùng với van ốc khô trong hệ thống phòng cháy chữa cháy, làm đẩy nhanh sự hoạt động của van khi một hoặc một số sprinkler hoạt động. Cơ cấu mở nhanh bao gồm máy gia tốc và máy hút khí dùng với van ống khô đặc biệt. Giá trị đo áp suất trong tiêu chuẩn được tính bằng bar
TCVN 6305-5	2009	Fire protection. Automatic sprinkler systems. Part-5: Requirement and test methods for deluge valve	Tiêu chuẩn này quy định các yêu cầu về đặc tính, phương pháp thử, ghi nhãn đối với van tràn, thiết bị bổ sung có liên quan của nhà sản xuất dùng trong hệ thống tràn và hệ thống phòng cháy chữa cháy tự động tác động trước.
TCVN 6305-7	2006	Fire protection. Automatic sprinkler systems. Part-7: Requirements and test methods for early suppression fast response (ESFR) sprinkler	Tiêu chuẩn này qui định các yêu cầu về tính năng, phương pháp thử và ghi nhãn đối với các prinkler phản ứng nhanh ngăn chặn sớm (ESFR) có phần tử dễ nóng chảy và bầu thuỷ tinh.

Number	Rev.	Title	Content
TCVN 6503-1	1999	Gas turbines. Exhaust gas emission. Part-1 : Measurement and evaluation	Tiêu chuẩn này thiết lập các phương pháp dùng để đo và đánh giá sự phát tán của các khí thải từ tuốc bin khí và định nghĩa các thuật ngữ về phát tán thích hợp. Tiêu chuẩn đưa ra những yêu cầu về môi trường thử và thiết bị cũng như chất lượng của các phép đo và hiệu chỉnh các dữ liệu đo được
TCVN 6503-2	1999	Gas turbines. Exhaust gas emission. Part-2: Automated emission monitoring	Tiêu chuẩn này thiết lập chương trình quan trắc giám sát và các yêu cầu cho việc lựa chọn và hoạt động của phần cứng dùng để đo liên tục một thời gian kéo dài không giới hạn
TCVN 6553-1	1999	Explosion protection systems. Part-1: Method for determination of explosion indices of combustible dust in air	Phần này của tiêu chuẩn qui định phương pháp xác định các chỉ số nổ của bụi cháy lơ lửng trong không khí trong không gian kín. Nó đưa ra chuẩn cứ mà theo đó những kết quả nhận được khi sử dụng các qui trình thử nghiệm khác có thể so sánh với các chỉ số nổ giới hạn đã được xác định thep phương pháp qui định trong phần này của tiêu chuẩn
TCVN 6553-2	1999	Explosion protection systems. Part-2: Method for determination of explosion indices of combustible gases in air	Phần này của tiêu chuẩn qui định phương pháp xác định các chỉ số nổ của khí cháy lơ lửng trong không khí trong không gian kín. Nó đưa ra chuẩn cứ mà theo đó các kết quả nhận được khi sử dụng các qui trình thử nghiệm khác có thể so sánh với các chỉ số nổ giới hạn đã được xác định theo phương pháp qui định trong phần này của tiêu chuẩn
TCVN 6553-3	1999	Explosion protection systems. Part-3: Method for determination of explosion indices of fuel/air mixture other than dust/air and gas/air mixture	Phần này của tiêu chuẩn qui định phương pháp xác định các chỉ số của các nhiên liệu trong không khí, trừ hỗn hợp bụi với không khí và khí cháy với không khí trong không gian kín
TCVN 6553-4	1999	Explosion protection systems. Part-4: method of determination of efficacy of explosion suppression systems	Phần này của tiêu chuẩn qui định phương pháp đánh giá hiệu quả của hệ thống triệt nổ chống lại các sự nổ đã xác định trong thể tích kín. Nó đưa ra chuẩn cứ để lựa chọn các thiết bị thử nghiệm sao cho bảo đảm dùng được các thử nghiệm hiệu quả triệt nổ và làm chuẩn cứ để áp dụng trong việc xác định đặc tính của chế độ vận hành an toàn của hệ thống triệt nổ
TCVN 7194	2002	Thermal insulation materials. Classification	Tiêu chuẩn này quy định cách phân loại vật liệu cách nhiệt dùng trong xây dựng và thiết bị công nghiệp
TCVN 7336	2003	Fire protection. : Automatic sprinkler system. Design and installation requirements	Tiêu chuẩn này quy định các yêu cầu đối với việc thiết kế, lắp đặt hệ thống chữa cháy sprinkler tự động bằng nước, bọt (sau đây gọi là hệ thống sprinkler) trong các toà nhà và công trình xây dựng mới hoặc cải tạo.
TCVN 7568-1	2006	Fire detection and alarm system. Part-1: General and definitions	Tiêu chuẩn này đưa ra các hướng dẫn và định nghĩa chung được sử dụng để mô tả thiết bị của hệ thống báo cháy, các thử nghiệm và yêu cầu kỹ thuật trong các phần khác của TCVN 7568.

Number	Rev.	Title	Content
TCVN 7634	2007	Safety of machinery. Fire prevention and protection	Tiêu chuẩn này quy định các phương pháp để nhận biết nguy hiểm cháy do máy và thực hiện việc đánh giá rủi ro tương ứng.
TCVN 7704	2007	Boilers. Technical requirement of design, construction, manufacture, installation, operation, maintenance	Tiêu chuẩn này quy định các yêu cầu về thiết kế, chế tạo, lắp đặt sử dụng và sửa chữa các thiết bị nồi hơi có áp suất làm việc của hơi lớn hơn 0,07 MPa và các nồi đun nước nóng có nhiệt độ của nước lớn hơn 115 độ C.
TCVN 7915-1	2009	Safety devices for protection against excessive pressure. Part-1: Safety valve	Tiêu chuẩn này quy định các yêu cầu chung đối với các van an toàn được thiết kế để sử dụng cho môi chất lỏng hoặc khí.
TCVN 7915-2	2009	Safety devices for protection against excessive pressure. Part-2: Bursting disc safety devices	Tiêu chuẩn này quy định các yêu cầu cho các đĩa nổ. Tiêu chuẩn này bao gồm các yêu cầu về thiết kế, chế tạo, kiểm tra, thử nghiệm, giấy chứng nhận, ghi nhãn và bao gói.
TCVN 7915-3	2009	Safety devices for protection against excessive pressure. Part-3: Safety valves and bursting disc safety devices in combination	Tiêu chuẩn này quy định các yêu đối với sản phẩm thực phẩm được lắp ráp từ sự tổ hợp trong sản xuất hàng loạt của các van an toàn hoặc CSPRS (hệ thống an toàn xả áp có điều khiển) theo TCVN 7915-1, TCVN 7915-4, TCVN 7915-5, và đĩa nổ theo TCVN 7915-2 được lắp đặt trong khoảng cách không lớn hơn năm lần đường kính ống tính từ cửa vào của van.
TCVN 7915-4	2009	Safety devices for protection against excessive pressure. Part-4: Pilot operating safety valve	Tiêu chuẩn này quy định các yêu cầu chung cho các van an toàn có van điều khiển, khác với van an toàn được nêu trong TCVN 7915-1, không phụ thuộc vào môi chất dùng để thiết kế van.
TCVN 7915-5	2009	Safety devices for protection against excessive pressure. Part-5: Controlled safety pressure relief systems (CSPRS)	Tiêu chuẩn này quy định các yêu cầu đối với các hệ thống an toàn xả áp có điều khiển không phụ thuộc và môi chất dùng để thiết kế hệ thống này.
TCVN 7915-6	2009	Safety devices for protection against excessive pressure. Part-6: Application, selection and installation of bursting disc safety devices	Tiêu chuẩn này hướng dẫn việc ứng dụng, lựa chọn và lắp đặt các đĩa nổ dùng để bảo vệ thiết bị chịu áp lực khỏi sự quá áp và/hoặc quá chân không.
TCVN 7915-7	2009	Safety devices for protection against excessive pressure. Part-7: Common data	Tiêu chuẩn này quy định các dữ liệu chung cho các phần của TCVN 7915 để tránh sự lặp lại không cần thiết, và được viện dẫn trong các phần của TCVN 7915.
TCVN 8366	2010	Pressure vessels. Requirements of design and manufacture	Tiêu chuẩn này quy định các yêu cầu tối thiểu về vật liệu, thiết kế, chế tạo, thử nghiệm, giám sát, chứng nhận và chuyển giao các bình chịu áp lực có đốt nóng hoặc không đốt nóng cấu tạo từ kim loại đen hoặc kim loại màu bằng cách hàn, hàn vảy cứng, đúc, rèn, phủ, lót và bao gồm cả việc sử dụng các thiết bị ngoại vi cần thiết cho sự hoạt động chuẩn xác và an toàn của bình chịu áp lực.

Chapter-6. Referenced Literature and Materials

The referenced books, literatures, standards to establishing this guide line are organized as follows.

1. Interpretation of technical regulation for thermal power facility(10/Jul/1007): NISA (Nuclear and Industrial Safety Agency) of METI (Ministry of Economy, Trade and Industry Japan)
2. The outline—boiler (Journal No.583: Apr./2006): TENPS (Thermal and Nuclear Engineering Society of Japan)
3. The construction of boiler (Journal No.584: Apr/2005): TENPES (Thermal and Nuclear Engineering Society of Japan)
4. The construction of boiler (Journal No.585: Jun/2005): TENPES (Thermal and Nuclear Engineering Society of Japan)
5. The features of various boilers (Journal No.587: Aug/2005): TENPES (Thermal and Nuclear Engineering Society of Japan)
6. Application study of international standards for thermal power generation facilities—Part-4 regarding overall evaluation: (Journal No.629: Sept/2008): TENPES (Thermal and Nuclear Engineering Society of Japan)
7. Equipment for GTCC—HRSG ((Journal No.647: Aug/2010): TENPES (Thermal and Nuclear Engineering Society of Japan)
8. Standard for boiler blow (Journal No.63: May/1961): TENPES (Thermal and Nuclear Engineering Society of Japan)
9. Thermal and nuclear generation handbook (Ver.7: Mar./2008): TENPES (Thermal and Nuclear Engineering Society of Japan)
10. JIS B8223-2006 “Water conditioning for boiler feed water and boiler water”
11. JIS B8201-2005 “Stationary steel boilers-Construction”
12. “Characteristics of the internally circulating fluidized bed boiler” (T.Hirota and others of Ebara corporation)
13. P-11 of “Standardization in the design of medium size of CFB boilers in industrial and IPP application” (PPT material of Formosa Heavy Industries Co-Gen Department)
14. Safety & Relief Valve CATALOG No.SLH031117J: Fukui Seisakusho Co., LTD.
15. “800MWe Circulating Fluidized Bed Boiler with 1300^{o}F Supercritical Steam” (June/ 2008: Z.Fan and others of Foster Wheeler)