10.2 Boiler Trouble Prevention

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

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

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

The points remarked to prevent trouble are as follows:

10.2.1 Preparation of Operation and Inspection Manuals and Training

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

10.2.2 Safety Device

The boilers should pass a predetermined inspection and be equipped with a relief valve, a high and low water level alarm, a flame detector as a necessary instrument and a safety device. Furthermore, the boilers should be designed to operate fail-safely against misoperation through automation. These must be inspected periodically. Table 10.2 shows the routine check items for boilers.

Table 10.2 Daily Inspection of Boiler (1/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Routine inspection	1. Pressure of boiler	O				1. Reading. Pointer movement	1. Smooth moving without catching
					O	2. Surface temperature. Leakage	
				O		3. Initial and stop temperatures of pressure controller.	3. No disorder. See item 9.
					O	4. Particularly take care to popping pressure at operation of the safety valve.	4. Check disorder by comparison with pressure gages of three or more.

Table 10.2 Daily Inspection of Boiler (2/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Routine inspection	2. Water level of boiler	O				1. Movement of water level of a water gage.	1. A little movement of the water level is normal. If the hole is clogged, the movement becomes dull. Compare the water levels of two water gages which height changes.
			O			2. Normality of water level at start and stop of the feed water pump.	2. A detection by bellows varies with the level and the operation range by fluctuation of pressure. When the pressure goes to higher, the level goes to down and the operation range comes to wider. Check the operation level and range in an average pressure.
					O	3. Special care must be taken to the working at a lower and higher level alarm.	3. Find out the cause and take a countermeasure. (See items 5 and 6.)
	3. Combustion state	O				1. Change of burning sound.	1. Take care to abnormal sound at the start of combustion and during the switching from low to high.
			O			2. Shape and color of flame.	2. Proper flame without touch to furnace wall and with no rough particle.
		O				3. Generation of smoke and its time.	3. Check the internal pressure of furnace, exhaust gas analysis and the quantity of air and oil. Care must be used to a long time operation under a low load.

Table 10.2 Daily Inspection of Boiler (3/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	4. Gage glass	O				1. Check of gage glass.	1. Make sure the open and close condition and any leakage of each cock. Clean the inside.
			O		O	2. Open a drain cock, close a steam cock and blow out boiler water sufficiently. And then close the water cock, open the steam cock, check the steam side, then close the drain cock, open the water cock and watch forcible rising of water level.	2. Repair to any leakage from the out of glasses. Check a disorder of the mounting core of the upper and lower cocks and the length of glass. 3. Clean the glass. Use a predetermined length of glass if exchanged. Use care not to tighten too much the glass. Namely, first, open the drain cock to warm with steam and close the drain cock. Open the water cock and open fully the steam cock. After using a little, do retightening.
	5. Water column (floatless)	O				1. Drain water in the column and remove sludge and scale.	1. Make sure the open and close condition of the interconnecting line and clean the inside.
					O	2. Built-in water level detector. Inspect the electric wiring terminal, any contamination of the insulation of the electrode holder, contamination and crack of the electrode.	2. Check the electric wiring (heat resistance wiring). Measuring of insulation resistance—remove the wiring for the electrode holder and the resistance between the electrode and the earth shall be more than 100 MΩ. Cleaning of electrode. Clean contamination of the electrode holder, check any crack or exchange it.

Table 10.2 Daily Inspection of Boiler (4/19)

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

Table 10.2 Daily Inspection of Boiler (5/19)

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

Table 10.2 Daily Inspection of Boiler (6/19)

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

Table 10.2 Daily Inspection of Boiler (7/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection Automatic equipment (accessory of the body)	12. Oil temperature switch				O	1. Check the setting value.	1. Set to a proper oil temperature.
					O	2. Check contamination and installing dimension of the heat sensitive cylinder and the detecting part.	2. Clean contamination. Investigate the length and replace. Investigate the installing location.
					O	3. Check the configuration of detecting part.	
	13. Latch switch. Low and high interlock, damper lock and burner lock				O	1. Check the settings of each latch switch.	1. Check that it is set in a proper position.
					O	2. Check loosening of the setting of installed position.	2. Check and adjustment.
					O	3. Check a normal operation of the interlock.	3. Check the operation, inspect and repair.
	14. Control motor			O		1. Check the movement.	
					O	2. Check an inferior contact of the balancing relay.	2. Check arc and clean the contact. Investigate the installing position not to be influenced by vibration.
					O	3. Check contamination and contact defect of the potentiometer.	3. Inspection and cleaning.

Table 10.2 Daily Inspection of Boiler (8/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection Firing equipment	15. Pilot burner			O		1. Check the gas pressure.	
					O	2. Check a deterioration of the ignition transformer.	2. Check a spark between the electrode and the earth to be 7 to 8 mm in atmosphere.
					O	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
					O	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper low combustion.
					O	5. Check the clearance between the nozzle and the electrode.	5. Adjust an interval suitable.
	16. Electric pilot firing device				O	1. Check an electric spark state.	1. Blue color is normal. If reddish, cleaning is necessary. Short spark is a narrow interval.
					O	2. When a frequent cleaning is required, inferior electrode setting.	2. If the electrode is set within the jetting angle, the electrode is wetted with oil and don't spark. The electrode should be set to the setting value.
					O	3. Transformer insulation defect. Deteriorated lead	3. Check the transformer and clean the insulator. Check any damage of the lead.

Table 10.2 Daily Inspection of Boiler (9/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection Firing equipment	15. Pilot burner			O		1. Check the gas pressure.	
					O	2. Check a deterioration of the ignition transformer.	2. Check a spark between the electrode and the earth to be 7 to 8 mm in atmosphere.
					O	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
					O	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper low combustion.
					O	5. Check the clearance between the nozzle and the electrode.	5. Adjust an interval suitable.
	16. Electric pilot firing device				O	1. Check an electric spark state.	1. Blue color is normal. If reddish, cleaning is necessary. Short spark is a narrow interval.
					O	2. When a frequent cleaning is required, inferior electrode setting.	2. If the electrode is set within the jetting angle, the electrode is wetted with oil and don't spark. The electrode should be set to the setting value.
					O	3. Transformer insulation defect. Deteriorated lead	3. Check the transformer and clean the insulator. Check any damage of the lead.

Table 10.2 Daily Inspection of Boiler (10/19)

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

Table 10.2 Daily Inspection of Boiler (11/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection Firing equipment	19. Oil pump			O		1. Check the oil pressure.	1. Set to a proper oil pressure.
					O	2. Clean the strainer.	2. Drain and remove sludge.
					O	3. Check oil leakage.	3. Repair the leaking place. Replace the oil seal.
					O	4. Check overheat and overcurrent.	4. Replace the bearing.
	20. Oil preheater			O		1. Check a proper oil temperature.	1. Adjustment of the thermostat. Check a gasification by the air chamber.
					O	2. Drain	2. Drain and remove sludge.
					O	3. Check oil leakage.	3. Repair the leaking place.
					O	4. Check the sheath heater.	4. Sludge removing.
	21. Service tank. Storage tank.			O		1. Make sure the oil level control.	1. Make sure the operation of the float switch and other controller.
					O	2. Temperature control. Operation of the control valve and the steam solenoid valve.	2. Check leakage and operation.
					O	3. Clean the oil strainer.	
				O		4. Check the receiving quantity and the residual quantity.	
					O	5. Check a leakage and the piping line.	
					O	6. Drain and remove sludge.	

Table 10.2 Daily Inspection of Boiler (12/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection Firing equipment	22. Oil meter		O			1. Check the oil meter indication record.	1. Disassemble and clean the meter and replace the parts.
					O	2. Grasp the oil temperature passing through the meter.	2. Since the efficiency calculation is based on the specific gravity at passing through the meter, the oil temperature should be grasped.
	23. Oil quantity controller			O		1. Check the link mechanism to the controller.	1. Adjust the link mechanism compared with the air volume, check loosening and play.
					O	2. Check the oil quantity by a meter measurement. (Every load)	2. Check by operation and oil quantity and disassemble and clean it.
	24. Oil strainer			O		1. In autocleaner, turn the handle. In a change type strainer, a prepared one should be always cleaned.	
					O	2. Remove drain and sludge. Grasp a good rating of cleaning by a differential pressure between the inlet and the outlet.	

Table 10.2 Daily Inspection of Boiler (13/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection	25. Forced draft fan			O		1. Check abnormal sound and overcurrent.	1. If abnormal, disassemble and service it, and replace the bearing.
					O	2. Check foreign matter in the suction port.	2. Mount a wire gauze not to suck foreign matter.
					O	3. Check vibration. Check and replace the belt.	3. Loosening of installed bolts. Loosening of the runner. Remove any deposit to the runner. Replace the bearing.
	26. Damper			O		1. Check the link mechanisms of the primary and main dampers.	1. The damper should be adjusted to be opened slowly.
				O		2. Check the opening of damper.	2. Check distortion or loosening.
					O	3. Adjust the damper draft in the outlet of boiler.	3. 0 ± 2 mm Aq in a pressurized combustion of rated operation.
				O		4. Check leakage of dampers and deteriortion in operation.	
	27. Internal pressure gage of boiler			O		1. Make sure the indication of internal pressure gage of boiler.	1. Check a clogging in lead pipe. Check the opening and closing of valve cock. Check and repair a leaking point due to corrosion.
	28. Smoke indicator					1. Check a difference between the indication and the smoke concentration.	1. Cleaning of glass. Adjust a lamp and a light receiver. Blow air from a compressor.
						2. Adjust the zero point.	2. Set the zero point.

Table 10.2 Daily Inspection of Boiler (14/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	29. Exhaust gas analyzer			O		1. Make sure the operation of pointer.	1. Check a clogging and leakage in the lead. Cleaning or replacement of the filter and tightness test of the lead.
					O	2. Adjustment.	2. Adjustment of the water quantity in aspirator. Comparison of a normal operation through passing air to the transmitter with the Orsat analyzed value.
	30. Flue and stack				O	1. Check leakage and corrosion.	1. Inspection and repairing.
					O	2. Remove soot in the flue and the stack.	
					O	3. Discharge of rain water.	
	31. Water softening equipment			O		1. Check of the water pressure. 1.5 to 2 kg/cm^2 (G)	
					O	2. Check of hardness. Check in the secondary side.	2. Check from 70 to 80 % of cycle.
					O	3. Leakage from the perforated valve.	3. Use care to leak from the fitting part of the packing.
					O	4. Care must be taken to leak during a stop of the pump operation.	

Table 10.2 Daily Inspection of Boiler (15/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	32. Feed water tank		O			1. Check of the level gage.	
			O			2. Make sure the operation of low level alarm lamp.	2. Test in an actual level drop or test by an electric wiring.
			O			3. Make sure the level control.	3. Make sure a manual operation of controller.
			O			4. Check of temperature.	4. Check of abnormality of trap.
					O	5. Check the painting on the tank inside and corrosion. Clean the inside.	5. Check, repair and cleaning.
	33. Chemicals pouring device			O		1. Check a proper chemicals pouring.	1. Check contamination in the tank and the flow rate.
				O		2. Check a linkage to the feed water pump.	2. Check the operation.
					O	3. Check leakage or clogging.	3. Inspection and repair.
	34. Feed water pump			O		1. Check overcurrent.	1. Adjust the valve.
					O	2. Check leakage from the gland.	2. Replace and tighten a packing.
					O	3. Check an oil servicing.	3. Apply oil and grease.
					O	4. Check play to the coupling.	4. Repair and replacement.

Table 10.2 Daily Inspection of Boiler (16/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	35. Injector				O	1. Check a normal operation.	1. Impossible to feed when the steam pressure lowers, the feed water temperature rises, air is sucked, the feed water pressure is too much higher.
					O	2. Check the check valve. Attachment of scale.	2. Check, disassemble and clean.
	36. Water flow meter strainer		O		O	1. Check the operation.	1. Record, check operation.
					O	2. Check clogging in the strainer.	2. Disassemble and clean.
	37. Feed water check valve				O	1. Check back flow.	1. Water hammer. Hand touch feels hot to the feed water pipe. Overhaul or replacement.
	38. Feed water inlet pipe				O	1. Check clogging in the inlet pipe.	1. Insufficient feed water quantity. Overhaul.
					O	2. Inferior or falling of the gasket for installation of the inlet pipe.	2. Water hammer. Replace the gasket.
	39. Relief valve		O			1. Check leakage of steam.	1. Repair the leaked place and overhaul.
					O	2. Check the popping and blowdown pressures in operation.	
					O	3. Check the popping volume.	3. When the pressure rising in a rated combustion is 6 % or more, it is not acceptable.

Table 10.2 Daily Inspection of Boiler (17/19)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	40. Blow off valve			O		1. Check leakage. Check heat by hand touch.	1. Overhaul or replacement.
				O		2. Blow off as a quick opening valve in the body side and as a slow opening valve in the secondary side.	2. For 10 kg/cm^2 (G) or more, two valves.
					O	3. Check the discharge port.	
	41. Manhole			O		1. Check leakage from the manhole.	1. Tightening, replacement of gasket.
					O	2. Keep a mating surface of the gasket in no contamination.	2. Apply graphite to facilitate a replacement.
	42. Casing for insulation				O	1. Check gas leakage.	1. Gas leakage should be checked and repaired as soon as possible.
					O	2. Check discolored place.	2. Find out the cause of overheat, check and repair.
	43. Refractory material				O	1. Check damage, falling and abnormality.	1. Repair the refractory materials as soon as possible.
					O	2. Check gas leakage and short pass.	2. Repairing.
	44. Inspection port. Cleaning port. Mounting part of accessory.				O	1. Check leakage of steam and water.	1. Repair the leaked place. Tightening, replacement of gasket.

Table 10.2 Daily Inspection of Boiler (18/19)

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

Table 10.2 Daily Inspection of Boiler (19/19)

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

10.2.3 Consideration on Operation

(1) Igniting operation

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

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

(2) Monitor of water level

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

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

a. After the boiler is started.

b. When the operators are shifted.

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

d. When some foaming occurs in the boiler water.

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

(3) Water treatment and blow

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

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

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

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

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

For prevention of the trouble mentioned above, Japanese Industrial Standard (JIS) has provided the standard value for water quality as shown in Table 10.3 and Table 10.6.

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

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

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

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

Table 10.3 Quality of Feed Water and Boiler Water for Cylindrical Bolier

Classification					
	Max. Servicing Pressure MPa	Below 1			From 1 to 2
	Max. Servicing Pressure kg/cm² (G)	Below 10			From 10 to 20
	Rate of Evaporation of heating surface (kg/m²·h)	Below 30[1]	From 30 to 60	Over 60	–
	Type of make-up water	raw water[2]	softened water		
Feed water	pH (at 25 °C)	7-9	7-9	7-9	7-9
	Hardness (mg$CaCO_3$/ℓ)	Below 60	Below 1	Below 1	Below 1
	Fat and Oil (mg/ℓ)[3]	[4]	[4]	[4]	[4]
	Dissolved Oxygen (mgO/ℓ)	[4]	[4]	[4]	[4]
Boiler water	Treatment Method	Alkali treatment			
	pH (at 25 °C)	11.0-11.8	11.0-11.8	11.0-11.8	11.0-11.8
	Alkalinity (pH 4.8)[5] (mg$CaCO_3$/ℓ)	100-800	100-800	100-800	Below 600
	Alkalinity (pH 8.3)[6] (mg$CaCO_3$/ℓ)	80-600	80-600	80-600	Below 500
	Total solids (mg/ℓ)	Below 4000	Below 3000	Below 2500	Below 2300
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 6000	Below 4500	Below 4000	Below 3500
	Chloride ion (mgCl^-/ℓ)	Below 600	Below 500	Below 400	Below 350
	Phosphate ion[7] (mgPO_4^{3-}/ℓ)	20-40	20-40	20-40	20-40
	Sulfite Ion[8] (mgSO_3^{2-}/ℓ)	10-50	10-50	10-50	10-50
	Hydrazine[9] (mgN_2H_4/ℓ)	0.1-1.0	0.1-1.0	0.1-1.0	0.1-1.0

Notes

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

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

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

(4) It is desirable to keep it low.

(5) It is commonly called M-alkalinity.

(6) It is commonly called P-alkalinity.

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

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

(9) It is applied when hydrazine is added as an oxygen scavenger in feedwater boiler or a cylindrical boiler or a water-tube boiler with the maximum servicing pressure of 2 MPa (20 kgf/cm²) or less.
When a deaerater is to be used, it should preferably be adjusted to 0.1 - 0.5 mg N_2H_4/ℓ.

Table 10.4 Quality of Feed Water and Boiler Water for Water Tube Boiler (1/2)

Classification	Item									
	Max. Servicing Pressure MPa	Below 1			From 1 to 2		From 2 to 3		From 3 to 5	
	Max. Servicing Pressure kg/cm² (G)	Below 10			From 10 to 20		From 20 to 30		From 30 to 50	
	Rate of Evaporation of heating surface (kg/m²·h)	Below 50	Over 50	–	–		–		–	
	Type of make-up water	Softened water			Ion exchange water (1)		Ion exchange water (1)		Ion exchange water (1)	
Feed Water	pH (at 25 °C)	7-9	7-9	7-9	8.0-9.5		8.0-9.5		8.0-9.5	
	Hardness (mgCaCO$_3$/ℓ)	Below 1	Below 1	Below 1	0		0		0	
	Fat and Oil (mg/ℓ) (2)	(3)	(3)	(3)	(3)		(3)		(3)	
	Dissolved Oxygen (mgO/ℓ)	(3)	(3)	Below 0.5	Below 0.5		Below 0.1		Below 0.03	
	Total iron (mgO/ℓ)	–	Below 0.3	Below 0.3	Below 0.1		Below 0.1		Below 0.1	
	Total copper (mgCu/ℓ)	–	–	–	–		–		Below 0.05	
	Hydrazine (mgN$_2$H$_4$/l) (4)	–	–	–	–		Over 0.2		Over 0.06	
	Electrical conductivity (25 °C) (μS/cm) (at 25 °C)	–	–	–	–		–		–	
Boiler water	Treatment Method	Alkali treatment				Phosphate	Alkari	Phosphate	Alkari	Phosphate
	pH (at 25 °C)	11.0-11.8	11.0-11.8	11.0-11.8	10.5-11.5	9.8-10.8	10.0-11.0	9.4-10.5	9.6-10.8	9.4-10.5
	Alkalinity (pH 4.8) (mgCaCO$_3$/ℓ) (5)	100-800	100-800	Below 600	Below 250	Below 130	Below 150	Below 100	–	–
	Alkalinity (pH 8.3) (mgCaCO$_3$/ℓ) (6)	80-600	80-600	Below 500	Below 200	Below 100	Below 120	Below 80	–	–
	Total solids (mg/ℓ)	Below 3000	Below 2500	Below 2000	–	–	–	–	–	–
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 4500	Below 4000	Below 3000	Below 1500	Below 1200	Below 1000	Below 800	Below 800	Below 600
	Chloride ion (mgCl-/ℓ)	Below 500	Below 400	Below 300	Below 150	Below 150	Below 100	Below 100	Below 80	Below 80
	Phosphate ion (mgPO$_4^{3-}$/ℓ) (7)	20-40	20-40	20-40	10-30	10-30	5-15	5-15	5-15	5-15
	Sulfite ion (mgSO$_3^{2-}$/ℓ)	10-50 (8)	10-50 (8)	10-20	10-20	10-20	5-10	5-10	5-10	5-10
	Hydrazine (mgN$_2$H$_4$/ℓ) (9)	0.1-1.0	0.1-1.0	0.1-0.5	0.1-0.5	0.1-0.5	–	–	–	–
	Silica (mgSiO$_2$/ℓ)	–	–	–	Below 50	Below 50	Below 50	Below 50	Below 20	Below 20

Table 10.4 Quality of Feed Water and Boiler Water for Water Tube Boiler (2/2)

Classification	Item									
	Max. Servicing Pressure MPa	From 5 to 7.5			From 7.5 to 10		From 10 to 15		From 15 to 20	
	Max. Servicing Pressure kg/cm² (G)	From 50 to 75			From 75 to 100		From 100 to 150		From 150 to 200	
	Rate of Evaporation of heating surface (kg/m²·h)	-			-		-		-	
	Type of make-up water	Ion exchange water [1]			Ion exchange water [1]		Ion exchange water [1]		Ion exchange water [1]	
Feed Water	pH (at 25 °C)	8.5-9.5 [10]			8.5-9.5 [10]		8.5-9.5 [10]		8.5-9.5 [10]	
	Hardness (mgCaCO$_3$/ℓ)	0			0		0		0	
	Fat and Oil (mg/ℓ) [2]	[3]			[3]		[3]		[3]	
	Dissolved Oxygen (mgO/ℓ)	Below 0.007			Below 0.007		Below 0.007		Below 0.007	
	Total iron (mgO/ℓ)	Below 0.05			Below 0.03 [11]		Below 0.03 [11]		Below 0.02 [12]	
	Total copper (mgCu/ℓ)	Below 0.03			Below 0.02		Below 0.01		Below 0.005	
	Hydrazine (mgN$_2$H$_4$/l) [4]	Over 0.01			Over 0.01		Over 0.01		Over 0.01	
	Electrical conductivity (25 °C) (μS/cm) (at 25 °C)	-			-		Below 0.5 [13]		Below 0.5 [13]	
Boiler water	Treatment Method	Alkali treatment	Phosphate treatment	Volatile material treatment	Phosphate treatment	Volatile material treatment	Phosphate treatment	Volatile material treatment	Phosphate treatment	Volatile material treatment
	pH (25 °C)	9.6-10.5	9.2-10.2 [14]	8.5-9.5	9.0-10.0 [14]	8.5-9.5	8.5-9.8	8.5-9.6	8.5-9.8	8.5-9.6
	Alkalinity (pH 4.8) (mgCaCO$_3$/ℓ) [5]	-	-	-	-	-	-	-	-	-
	Alkalinity (mgCaCO$_3$/ℓ) [6]	-	-	-	-	-	-	-	-	-
	Total solids (mg/ℓ)	-	-	-	-	-	-	-	-	-
	Electrical Conductivity (μS/cm) (at 25 °C)	Below 500	Below 400	Below 60 [13]	Below 150	Below 60 [13]	Below 60	Below 20 [13]	Below 60	Below 20 [13]
	Chloride ion (mgCl-/ℓ)	Below 50	Below 50	Below 2	Below 10	Below 2	Below 2	Below 1	Below 2	Below 1
	Phosphate ion (mgPO$_4^{3-}$/ℓ) [7]	3-10	3-10 [14]	[15]	2-6 [14]	[15]	0.1-3	[15]	0.1-3	[15]
	Sulfite ion (mgSO$_3^{2-}$/ℓ) [8]	-	-	-	-	-	-	-	-	-
	Hydrazine (mgN$_2$H$_4$/ℓ) [9]	-	-	-	-	-	-	-	-	-
	Silica (mgSiO$_2$/ℓ)	Below 5 [16]	Below 5 [16]	Below 5 [16]	Below 2 [16]	Below 2 [16]	Below 0.3 [16]		Below 0.2 [16]	

Notes
(1) Water refined by an ion exchange equipment using strong acid cation-exchange resin and strong basic anion-exchange resin. This water is commonly called desalted water. It also includes the refined condensed water treated by evaporator.
(2) It means hexane extract or carbon tetrachloride extract. (See JIS B8224)
(3) It is desirable to keep it low.
(4) It is applied when hydrazine is added into feedwater as an oxygen scavenger.
(5) It is commonly called M-alkalinity.
(6) It is commonly called P-alkalinity.
(7) It is applied when phosphate is added in water.
(8) It is applied when sulfite is added in water as an oxygen scavenger.
When a deaerator is to be used, it is preferably adjusted to 10 - 20 mg SO32-/l.
(9) It is applied when hydrazine is added as an oxygen scavenger in feedwater boiler or cylindrical boiler or a water-tube boiler with the maximum servicing pressure of 2 MPa (20 kgf/cm2) or less. When a deaerater is to be used, it should preferably be adjusted to 0.1 - 0.5 mg N2H4/l.
(10) When the pipe material in the feedwater heater is steel, pH is preferably adjusted to a higher value.
(11) It is preferably maintained at 0.02 mg Fe/ℓ or below.
(12) It is preferably maintained at 0.01 mg Fe/ℓ or below.
(13) For measurement, pass the sample through the column filled with hydrogen ion type strong acid cation-exchange resin.
(14) In the case of waste-heat boiler, pH is preferably adjusted within the range from 9 to 10.5, and phosphate ion within the range from 2 to 20 mg PO$_4^{3-}$/ℓ.
(15) If a substance which will decrease calcium, magnesium and pH should be mixed because of the leakage of seawater from the condenser, add a required amount of phosphate as the temporary measure in accordance with the mixed amount of the substance.
(16) The concentration of the silica in the boiler water should be so kept that the concentration of silica in the steam will be 0.02 mg SiO$_2$/ℓ or below based on the relationship between the silica concentration in the boiler water and that in the steam.

Table 10.5 Quality of Feed Water and Boiler Water for Low Circulation Ratio Water Tube Boiler

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

Notes

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

(2) It is applied to the feed water before return water is added.

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

(4) It is desirable to keep it low.

(5) It is commonly called M-alkalinity.

(6) It is commonly called P-alkalinity.

(7) It is applied when hydrazine is added into feedwater as an oxygen scavenger.

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

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

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

Table 10.6 Quality of Feed Water for Once-through Boiler

Classification	Max. Servicing Pressure MPa	From 7.5 to 10		From 10 to 15		From 15 to 20		Over 20	
	kg/cm² (G)	From 75 to 100		From 100 to 150		From 150 to 200		Over 200	
	Treatment Method	Volatile matter treatment	Oxygen treatment	Volatile matter treatment	Oxygen treatment	Volatile matter treatment			
Feed water	pH (at 25 °C) [1]	8.5-9.6[2]	6.5-9.0[3]	8.5-9.6[2]	6.5-9.0[3]	8.5-9.6[2]	6.5-9.0[3]	9.0-9.6[2]	6.5-9.1[3]
	Electrical conductivity (at 25 °C) (μS/cm)	Below 0.3	Below 0.2	Below 0.3	Below 0.2	Below 0.3	Below 0.2	Below 0.25	Below 0.2
	Dissolved Oxygen (mgO/ℓ)	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]	Below 0.007	0.02-0.2[4]
	Total iron (mgFe/ℓ)	Below 0.03[5]	Below 0.02	Below 0.02	Below 0.01	Below 0.02[6]	Below 0.01	Below 0.01	Below 0.01
	Total copper (mgCu/ℓ)	Below 0.01	Below 0.01	Below 0.005	Below 0.01	Below 0.003	Below 0.005[7]	Below 0.002	Below 0.002
	Hydrazine (mgN_2H_4/ℓ) [8]	Over 0.01	–	Over 0.01	–	Over 0.01	–	Over 0.01	–
	Silica ($mgSiO_2/\ell$)	Below 0.04[9] Below 0.02[10]	Below 0.02	Below 0.03[9] Below 0.02[10]	Below 0.02	Below 0.02	Below 0.02	Below 0.02	Below 0.02

Notes

(1) Add ammonia or volatile amine for pH adjustment.

(2) Where the pipe material in the heater for feedwater is steel, pH is preferably adjusted to a higher value.

(3) When copper alloy is used in this system, pH is preferably maintained within the range of from 8.0 to 8.5.

(4) Use a minimum value within this range which will be appropriate for minimizing the corrosion product.

(5) It is preferably maintained at 0.02 mg Fe/ℓ or below.

(6) It is preferably maintained at 0.01 mg Fe/ℓ or below.

(7) It is preferably maintained at 0.003 mg Cu/ℓ or below.

(8) The concentration of hydrazine should be within the range where pH value will not exceed its upper limit.

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

(10) It is applied to a bolier without a separator.

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

To prevent an accumulation of the impurities in the boiler water, the blow is an important operation. A continuous blow with linking an amount of feed water is preferably economical owing to an easier adjustment of the amount and possibility of heat recovery compared with a periodic blow-down. The blow amount can be obtained by the following equation from the feed water quantity and the boiler water standard shown in Tables 10.3 to 10.6.

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

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

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

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

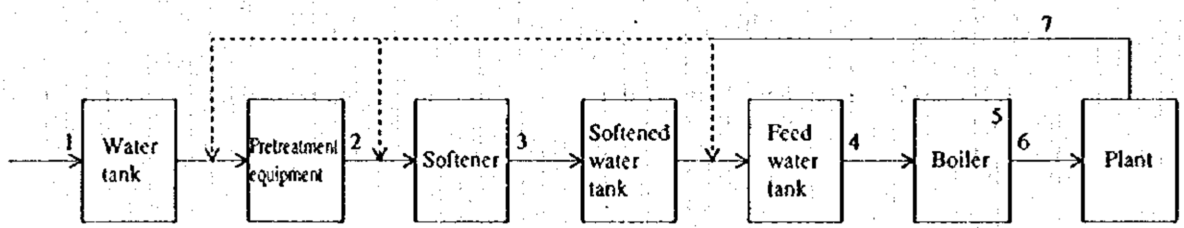
Although an M-alkalinity, total solids, silica and chloride ion are taken as the control subject, the analyses of those are not easy in practice and the electrical conductivity is sometimes taken as a good measure. It is desirable to control through premeasurement of a relation between the chloride ion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

Table 10.7 is a standard of the water quality measuring frequency shown as reference in JIS.

Table 10.7 Standard for Water Quality Measuring Frequency (Cylindrical Boiler)

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

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



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

10.3 Expression of Boiler Capacity

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

10.3.1 Rated Evaporation

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

10.3.2 Equivalent Evaporation

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

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

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

In addition, the boiler capacity may sometimes be expressed by a heating surface area (m^2) based on the combustion side. A small sized boiler in U.S. and British has been often expressed by boiler horse power. This expression was established in 1876 and was based on the value which was taken as one horse power per 30 lb/h of saturated steam in 70 lb/in^2 of gauge pressure. Nowadays this is not familiar with the actual specification. The equivalent evaporation of 15.65 kg/h corresponds to one horse power.

10.4 Heat Balance of Boilers

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

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

At the start, a limit of heat balance should be fixed as shown in Figure 10.7. The heat balance shall be performed on heat output and heat input across the battery limit. If equipped with waste heat recovery equipment, take care not to mistake the measuring points.

The specification of equipment for a subject boiler should be examined according to the items shown in Table 10.8 and the operation record should be described on the items of Table 10.9. The results of the heat balance should be entered into the formula of Table 10.10. Referred items are indicated for calculation below.

Figure 10.7 Standard Range of Boiler Heat Balance

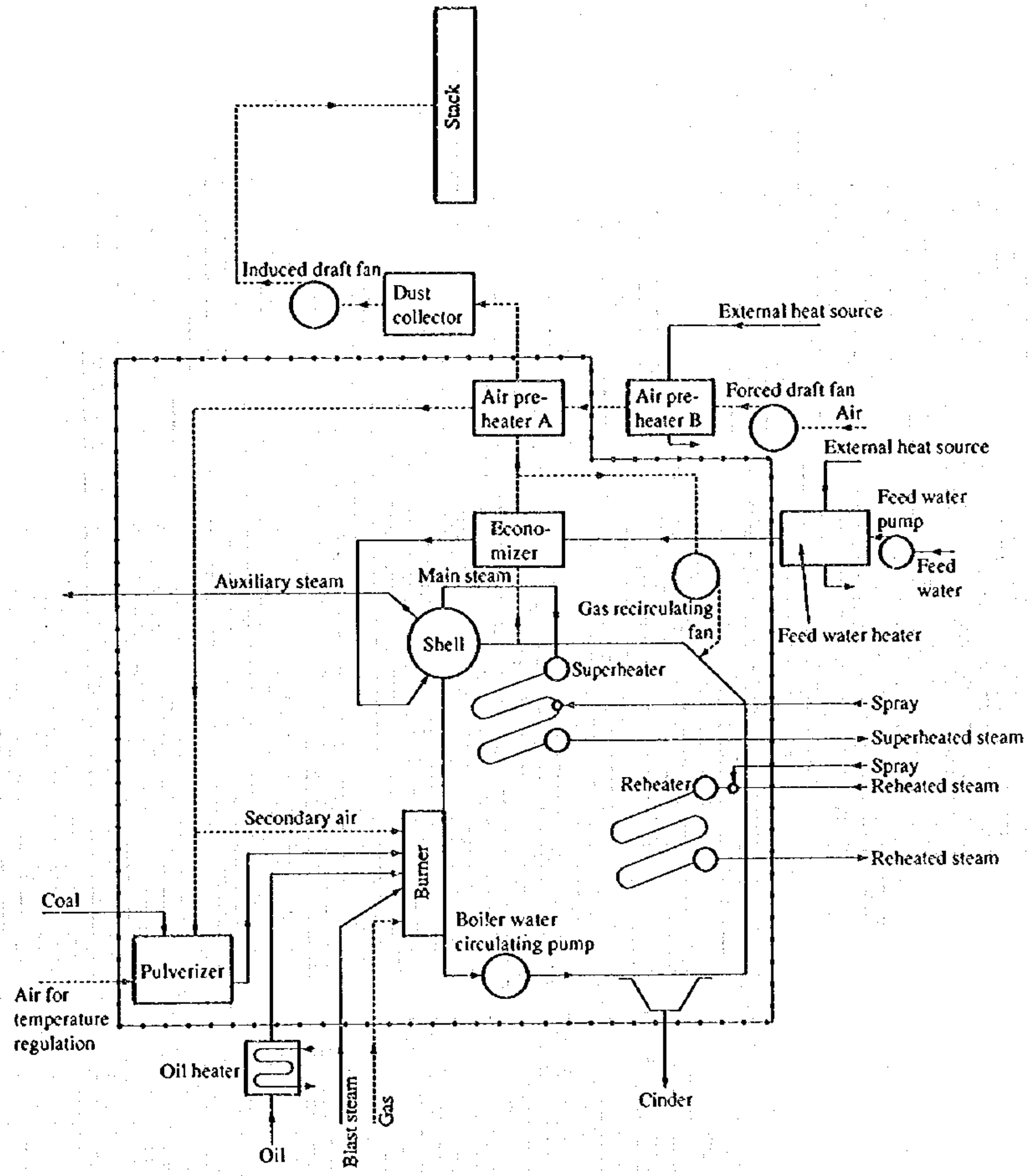


Table 10.8 Outline of Equipment

Outlines of the installation shall be indicated as follows.

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

Note(1) The pressure is a gage pressure.

Table 10.9 Results of Measurement (1/2)

The test results shall be indicated as follows.

			Unit	Remarks
Date and time of test				
Personnel in charge				
Weather, atmospheric pressure, wind velocity			°C	
Ambient temperature, dry bulb and wet bulb temperatures			°C	
Duration of test			h	
Load factor			%	
Fuel	Type of fuel			
	Mixing ratio			
	Temperature as used		°C	
	Total moisture		%	
	Proximate analysis	Analysed value	%	
		As used	%	Correct by moisture.
	Ultimate analysis	Analysed value	%	
		As used	%	Correct by moisture.
	Lower calorific value of fuel used	Analysed value	kcal/kg (m_n^3)	Measure a high calorific value by a calorimeter and obtain a low calorific value by calculation. Correct by moisture.
		As used	kcal/kg (m_n^3)	
	Fuel consumption Total		kg (m_n^3)	
	Fuel consumption per hour		kg (m_n^3)/h	
	Firing quantity per burner		kg (m_n^3)/h	
	Combustion chamber heat generation		kcal/m^3h	
Condition of firing equipment				
Condition of control device				
Condition of drafting equipment				
Condition of water feeding equipment				
Condition of dust catcher				
Feed water	Quantity of feed water	Total (corrected value)	kg	
		Per hour	kg/h	
		Per unit volume of fuel	kg/kg (m_n^3)	
	Temperature	Economizer inlet	°C	
		Boiler proper inlet	°C	
	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum	kg/cm^2 (G)	
		Superheater outlet	kg/cm^2 (G)	
		Reheater inlet	kg/cm^2 (G)	
		Reheater outlet	kg/cm^2 (G)	
	Temperature	Superheated outlet	°C	
		Reheater inlet	°C	
		Reheater outlet	°C	
	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (i.e. 98%)
	Evaporation	Total (corrected value)	kg	
		Per hour	kg/h	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
		Equivalent evaporation per hour	kg/h	
		Reheated steam	kg/h	
Steam jetting into furnace	Source of steam or hot steam			If impossible to measure, use an approximate figures.
	Quantity of steam or hot steam		kg/h	
	Pressure and temperature		kg/cm^2 (G), °C	

Table 10.9 Results of Measurement (2/2)

Air for combustion	Air quantity per unit volume of fuel		m_n^3/kg (m_n^3)
	Tempe-rature and pressure	Air preheater inlet	°C, mmAq
		Air preheater outlet	°C, mmAq
		Outlet of forced draft fan	°C, mmAq
		Inlet of chamber	°C, mmAq
	Air ratio	Outlet of boiler proper	
		Outlet of economizer	
		Outlet of air preheater	
Exhaust (combustion) gas	Exhaust gas quantity per unit volume of fuel		m_n^3/kg (m_n^3)
	Temper-rature and pressure	Furnace inside	°C, mmAq
		Outlet of boiler proper	°C, mmAq
		Economizer inlet	°C, mmAq
		Economizer outlet	°C, mmAq
		Air preheater inlet	°C, mmAq
		Air preheater outlet	°C, mmAq
		Induced fan suction	°C, mmAq
		Induced fan delivery	°C, mmAq
	Gas analysis	Outlet of boiler proper (CO_2, O_2, CO)	%
		Outlet of economizer (CO_2, O_2, CO)	%
		Outlet of air preheater (CO_2, O_2, CO)	%
	Unburned component		%
	Refuse quantity per unit volume of fuel		kg/kg
Condition of smoke			
Auxiliary	Steam consumption		kg
	Electric power consumption		kWh
Remark			

Remarks

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

2. Load factor shall be as follows.

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

3. Condition of firing equipment means as follows.
   - Hand firing — method and interval of feeding coal, damper opening
   - Stoker firing — speed of stoker or coal feeder, thickness of coal layer, damper opening, etc.
   - Pulverized coal firing — working number and speed of coal feeders, pulverizers, exhausters and fans, damper opening, working number and condition of burners
   - Oil firing — oil pressure, and working number and condition of burner
   - Gas combustion — gas pressure. Number and condition of operating burners

4. Condition of water feeding equipment means as follows.
   - Intermittent feeding — number of feeding per hour, etc.
   - Continuous feeding — working number, revolution, valve opening, etc. of pumps

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

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

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

Table 10.10 Heat Balance Table

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

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

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

Note (1) (2), (3) and (4) are due to the external heat source.
(2) In case of a high heating value basis, it shall be taken as $H_h(H_h')$.
(3) In case of a high heating value basis $L_{1l}\{L_{1l}'\}$ shall be taken as L_{1h} $\{L_{1h}'\}$ and L_l $\{L_l'\}$ be taken as shall be taken as L_h $\{L_h'\}$.

10.4.1 Method to Obtain Lower Combustion Heat from Higher Combustion Heat

Solid fuel and liquid fuel: $H_l = H_h - 5.9\ (9h + w)$ kcal/kg-fuel

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

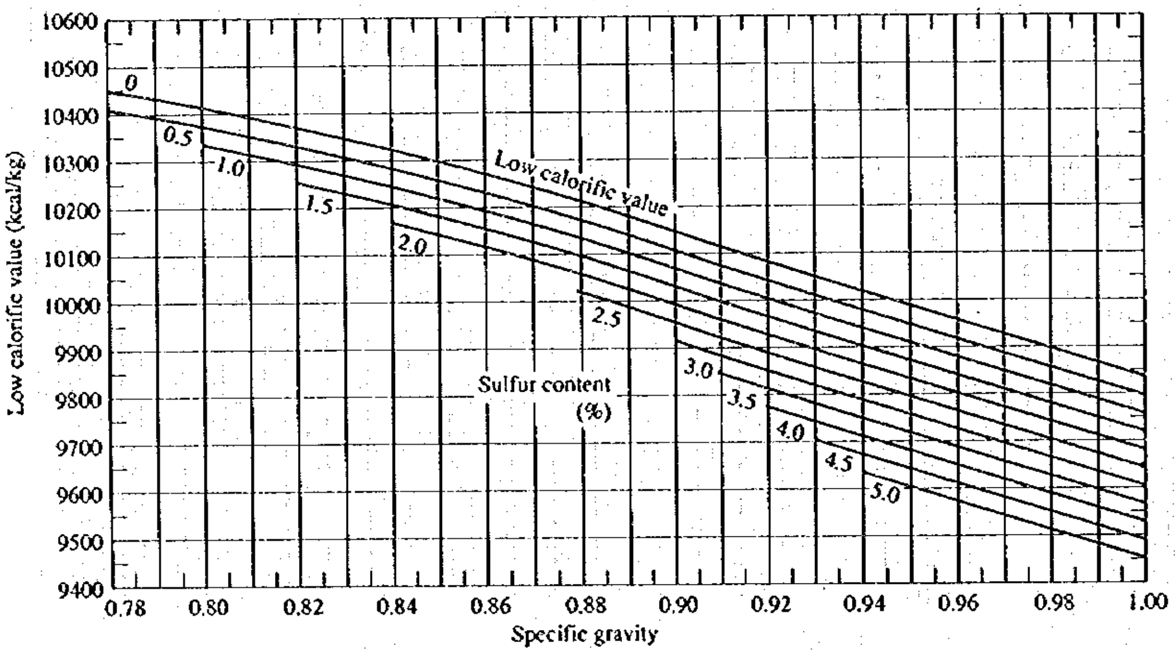
When omitting elementary analysis, h shall take the following value.

Kerosene, light oil, crude oil and fuel oil A; h = 13 %
Fuel oil B: h = 12 %
Fuel oil C: h = 11 %

Apart from this, on petroleum fuel, the graph and chart which show the relation between specific gravity and calorific value have been published. (See Figure 10.8). When a specific gravity measured at t°C is d_t, the specific gravity d_{15} at 15 °C can be obtained by the following equation.

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

Figure 10.8 Relation between Calorific Value (Low) and Specific Gravity of Petroleum Fuel



Even if the following equation is applied, error is not so much. (See Table 10.11)

Gaseous fuel: $H_l = 25.9\ (H_2) + 30.1\ (CO) + 86.1\ (CH_4)$
$+ 142\ (C_2H_4) + 154\ (C_2H_6) + 210\ (C_3H_6)$
$+ 223\ (C_3H_8) + 282\ (C_4H_8)$
$+ 295\ (C_4H_{10})$ kcal/m^3_N Fuel

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

Table 10.11 Specific Gravity, Sulfur Content and Mean Calorific Value of Petroleum Fuel

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

10.4.2 Specific Heat of Fuel and Air

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

10.4.3 Air Amount

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

$$A_0 = \frac{1}{100}[8.89c + 26.7(h - \frac{o}{8}) + 3.3s] m^3{}_N/\text{kg-fuel}$$

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

Case of coal

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

Case of fuel oil

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

Case of gaseous fuel

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

(Case of hydrocarbon-mixed gas)

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

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

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

The value of z can be obtained from Figure 10.9.

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

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

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

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

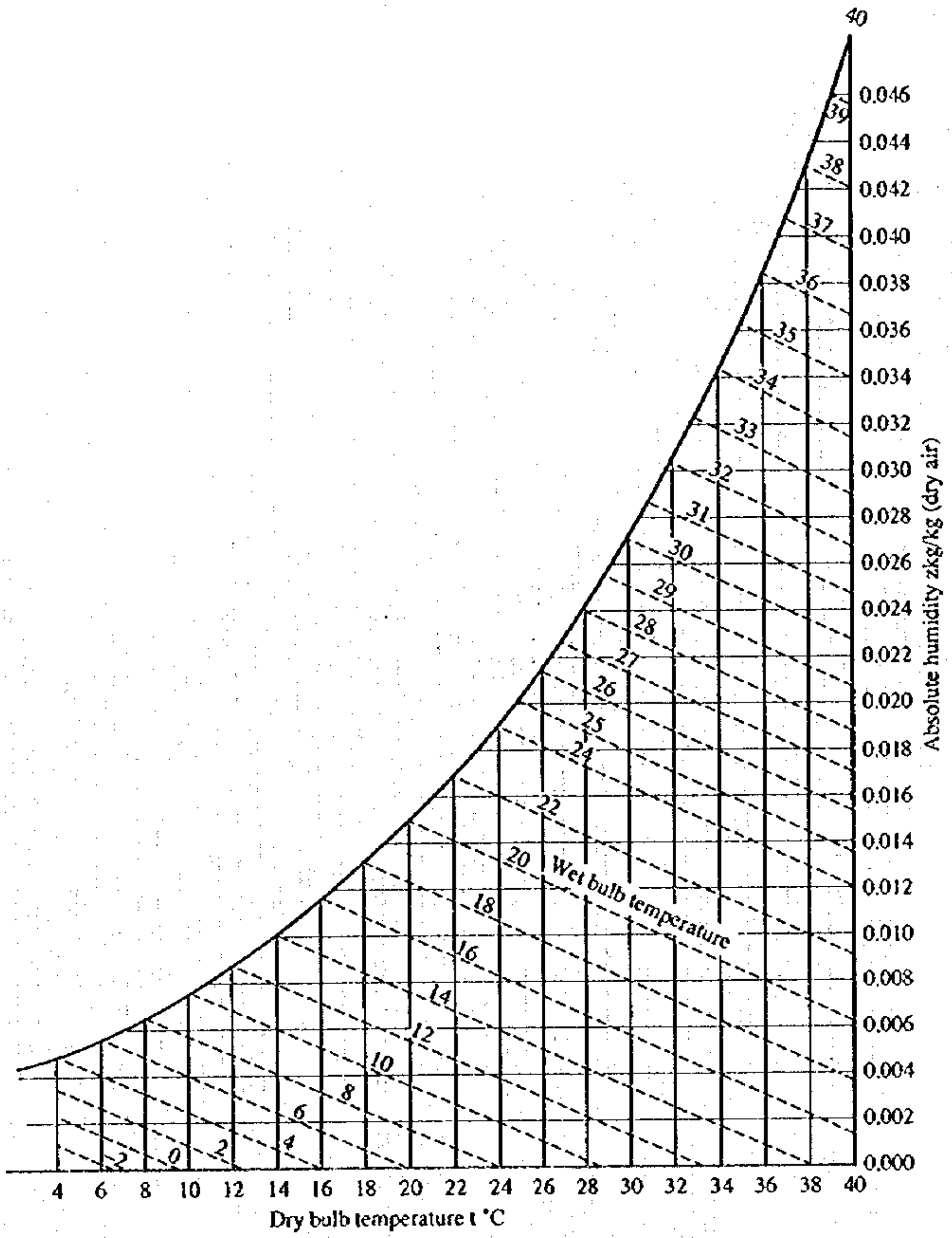
When there is little hydrogen in the fuel:

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

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

The following values may be used for the value of $CO_{2\ max}$: Coal: 18.5 %, fuel oil: 15.7 %, natural gas: 12 %, LPG: 14.5 %.

Figure 10.9 Absolute Humidity of Air



10.4.4 Heat Absorbed by Generated Steam

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

If a reheater is used, the heat obtained by the steam and the sprayed water is added to it. The enthalpy of steam is shown in Tables 10.12 and 10.13.

Table 10.12 Thermodynamic Properties of Saturated Water and Saturated Steam (Temperature reference)

Temperature	Saturation pressure		Specific volume (m^3/kg)		Specific enthalpy (kcal/kg)		
(°C)	(kg/cm^2)	(mmHg)	v'	v''	h'	h''	r = h'' − h'
0.01	0.00623	4.6	0.0010002	206.16	0.00	597.5	597.5
5	0.00889	6.5	0.0010000	147.16	5.02	599.7	594.7
10	0.01251	9.2	0.0010003	106.43	10.03	601.9	591.8
15	0.01738	12.8	0.0010008	77.98	15.03	604.1	589.0
20	0.02383	17.5	0.0010017	57.84	20.03	606.2	586.2
25	0.03228	23.7	0.0010029	43.40	25.02	608.4	583.4
30	0.04325	31.8	0.0010043	32.93	30.01	610.6	580.6
35	0.05732	42.2	0.0010060	25.24	35.01	612.7	577.7
40	0.07520	55.3	0.0010078	19.55	40.00	614.9	574.9
45	0.09771	71.9	0.0010099	15.28	44.99	617.0	572.0
50	0.12578	92.5	0.0010121	12.05	49.98	619.1	569.2
55	0.16051	118.1	0.0010145	9.579	54.98	621.2	566.3
60	0.20313	149.4	0.0010171	7.679	59.97	623.3	563.3
65	0.2550	187.6	0.0010199	6.202	64.97	625.4	560.4
70	0.3178	233.7	0.0010229	5.046	69.98	627.4	557.5
75	0.3931	289.1	0.0010259	4.134	74.98	629.5	554.5
80	0.4829	355.2	0.0010292	3.409	79.99	631.5	551.5
85	0.5894	433.6	0.0010326	2.829	85.01	633.4	548.4
90	0.7149	525.9	0.0010361	2.361	90.03	635.4	545.3
95	0.8619	634.0	0.0010399	1.982	95.06	637.3	542.2
100	1.0322	760.0	0.0010437	1.673	100.1	639.2	539.1
110	1.4609		0.0010519	1.210	110.2	642.8	532.6
120	2.0246		0.0010606	0.8915	120.3	646.3	526.0
130	2.7548		0.0010700	0.6681	130.5	649.6	519.2
140	3.685		0.0010801	0.5085	140.7	652.8	512.1
150	4.854		0.0010908	0.3924	151.0	655.7	504.7
160	6.303		0.0011022	0.3068	161.3	658.4	497.1
170	8.076		0.0011145	0.2426	171.8	660.9	489.1
180	10.224		0.0011275	0.1938	182.3	653.1	480.8
190	12.799		0.0011415	0.1563	192.9	665.0	472.1
200	15.855		0.0011565	0.1272	203.6	666.6	463.0
210	19.454		0.0011726	0.10424	214.4	667.9	453.4
220	23.656		0.0011900	0.08604	225.4	668.8	443.4
230	28.528		0.0012087	0.07145	236.5	669.2	432.7
240	34.138		0.0012291	0.05965	247.8	669.3	421.5
250	40.560		0.0012513	0.05004	259.3	668.9	409.5
260	47.869		0.0012756	0.04213	271.1	667.9	396.8
270	56.144		0.0013025	0.03559	283.1	666.4	383.3
280	65.468		0.0013324	0.03013	295.4	664.1	368.7
290	75.929		0.0013659	0.02554	308.1	661.0	352.9
300	87.621		0.0014041	0.02165	321.3	657.1	335.8
310	100.65		0.0014480	0.01833	335.0	652.1	317.1
320	115.12		0.0014995	0.01548	349.3	645.8	296.4
330	131.16		0.0015615	0.01299	364.6	637.8	273.2
340	148.93		0.0016387	0.01078	381.1	627.3	246.2
350	168.61		0.0017411	0.00880	399.3	613.3	213.9
360	190.43		0.0018959	0.006940	421.4	593.6	172.3
374.15	225.56		0.0031700	0.003170	503.3	503.3	0

Table 10.13 Thermodynamic Properties of Saturated Water and Saturated Steam (Pressure reference)

Pressure P (kg/cm²)	Saturation temparature (°C)	Specific volume (m³/kg)		Specific enthalpy (kcal/kg)			Specific entropy (kcal/kg·K)	
		v'	v"	h'	h"	r = h" − h'	s'	s"
0.01	6.699	0.0010001	131.6	6.72	600.4	593.7	0.0243	2.1458
0.03	23.775	0.0010026	46.52	23.80	607.9	584.1	0.0836	2.0506
0.05	32.55	0.0010051	28.72	32.56	611.7	579.1	0.1126	2.0070
0.10	45.45	0.0010101	14.95	45.44	617.2	571.8	0.1539	1.9485
0.20	59.66	0.0010170	7.791	59.64	623.2	563.5	0.1975	1.8908
0.30	68.68	0.0010221	5.326	68.65	626.9	558.2	0.2242	1.8573
0.5	80.86	0.0010298	3.300	80.86	631.8	550.9	0.2593	1.8156
0.7	89.45	0.0010357	2.408	89.47	635.2	545.7	0.2833	1.7882
1.0	99.09	0.0010430	1.725	99.17	638.8	539.6	0.3097	1.7594
1.033	100.00	0.0010437	1.673	100.09	639.2	539.1	0.3121	1.7568
1.2	104.25	0.0010471	1.454	104.37	640.7	536.4	0.3235	1.7448
1.4	108.74	0.0010508	1.259	108.91	642.4	533.5	0.3355	1.7324
1.6	112.73	0.0010542	1.111	112.94	643.8	530.8	0.3460	1.7217
1.8	116.33	0.0010573	0.9952	116.59	645.0	528.5	0.3554	1.7122
2.0	119.61	0.0010603	0.9018	119.92	646.2	526.3	0.3639	1.7038
2.2	122.64	0.0010631	0.8248	123.00	647.2	524.2	0.3717	1.6961
2.6	128.08	0.0010682	0.7053	128.53	649.0	520.5	0.3855	1.6828
3.0	132.88	0.0010728	0.6168	133.42	650.6	517.2	0.3976	1.6713
4	142.92	0.0010831	0.4708	143.70	653.7	510.0	0.4226	1.6483
5	151.11	0.0010920	0.3816	152.13	656.0	503.9	0.4426	1.6303
6	158.08	0.0011000	0.3213	159.34	657.9	498.6	0.4594	1.6156
7	164.17	0.0011072	0.2778	165.67	659.5	493.8	0.4739	1.6031
8	169.61	0.0011140	0.2448	171.35	660.8	489.5	0.4867	1.5922
9	174.53	0.0011203	0.2188	176.51	661.9	485.4	0.4983	1.5826
10	179.04	0.0011262	0.1980	181.25	662.9	481.7	0.5087	1.5739
11	183.20	0.0011319	0.1807	185.65	663.7	478.1	0.5184	1.5660
12	187.08	0.0011373	0.1663	189.77	664.5	474.7	0.5273	1.5588
13	190.71	0.0011425	0.1540	193.63	665.1	471.5	0.5356	1.5521
14	194.13	0.0011476	0.1434	197.29	665.7	468.4	0.5434	1.5458
15	197.37	0.0011524	0.1342	200.75	666.2	465.5	0.5507	1.5400
16	200.43	0.0011572	0.1260	204.05	666.7	462.6	0.5577	1.5345
17	203.36	0.0011618	0.1189	207.21	667.1	459.9	0.5642	1.5293
18	206.15	0.0011663	0.1124	210.23	667.4	457.2	0.5705	1.5244
19	208.82	0.0011706	0.1067	213.14	667.7	454.6	0.5765	1.5197
20	211.39	0.0011749	0.1015	215.94	668.0	452.1	0.5822	1.5152
30	232.76	0.0012142	0.06794	239.62	669.3	429.7	0.6295	1.4788
40	249.18	0.0012494	0.05076	258.38	668.9	410.6	0.6654	1.4514
50	262.69	0.0012826	0.04025	274.28	667.6	393.3	0.6949	1.4288
60	274.28	0.0013149	0.03313	288.32	665.5	377.2	0.7203	1.4092
70	284.47	0.0013469	0.02798	301.04	662.8	361.8	0.7427	1.3915
80	293.61	0.0013791	0.02406	312.80	659.7	346.9	0.7631	1.3752
90	301.91	0.0014119	0.02098	323.83	656.2	332.4	0.7818	1.3598
100	309.53	0.0014458	0.01848	334.30	652.3	318.0	0.7993	1.3451
120	323.15	0.0015177	0.01466	354.04	643.5	289.4	0.8316	1.3170
140	335.10	0.0015985	0.01183	372.83	632.8	260.0	0.8616	1.2890
160	345.75	0.0016935	0.009615	391.3	619.7	228.4	0.8905	1.2595
180	355.35	0.001814	0.007795	410.8	603.7	192.9	0.9205	1.2274
200	364.07	0.001990	0.00619	431.6	582.8	151.2	0.9520	1.1892
220	372.05	0.002369	0.00442	462.7	545.8	83.2	0.9988	1.1276
225.56	374.15	0.00317	0.00317	503.3	503.3	0	1.0612	1.0612

10.4.5 Exhaust Gas Loss

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

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

Case of coal

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

Case of fuel oil

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

Case of gaseous fuel

$$G_l = \frac{12.25H_\ell}{10,000} m^3{}_N/\text{kg-fuel}$$

(Case of hydrocarbon-mixed gas)

Actual exhaust gas quantity is as the following equation.

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

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

10.4.6 Heat Loss Due to Furnace Blast Steam

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

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

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

10.4.7 Heat Loss Due to Incompletely Burning Gas

It is calculated according to the following equation.

Heat loss = 30.1 [G_0 + (m – 1) A_0] (CO) kcal/kg (m^3_N)-fuel

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

10.4.8 Heat Loss Due to Combustible Refuse in Cinder

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

c = au/(100 – u)

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

Heat loss is 81c kcal/kg-fuel.

10.4.9 Heat Loss Due to Heat Release

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

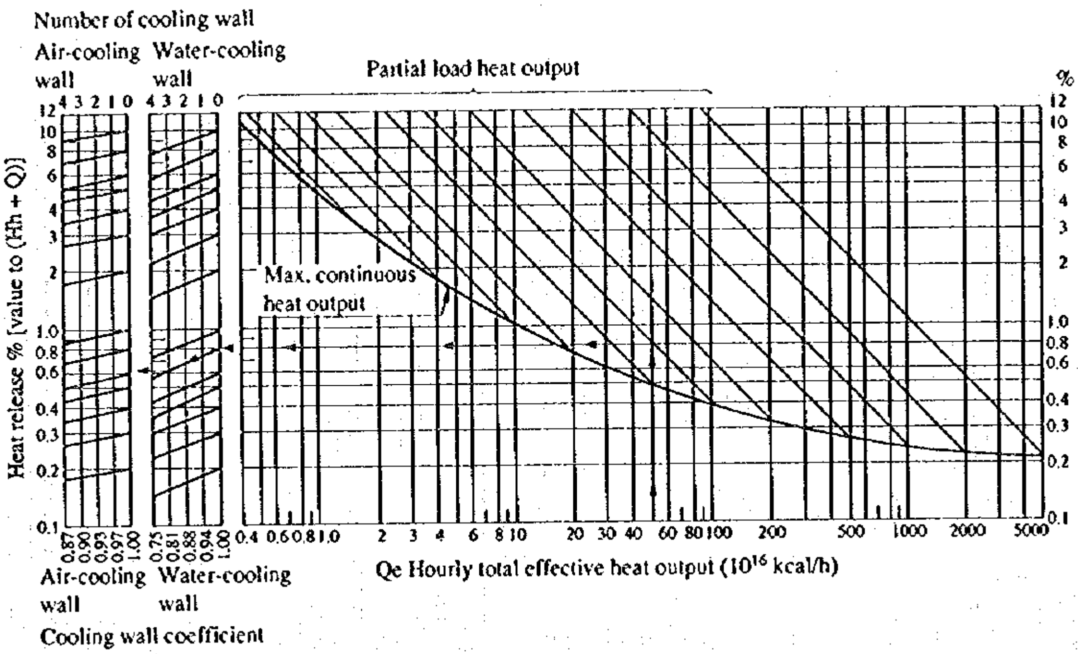
The following values are shown as round figures for heat loss. (Table 10.14)

For reference, the diagram shown in the Power Test Code of the ASME (American Society of Mechanical Engineering) is shown in Figure 10.10. This diagram is a case of the difference between the temperature of the warm surface and the ambient temperature is 28 °C and the air flow velocity on the surface is 0.5 m/s. For other conditions, it should be corrected by a multiple of Figure 10.11. This diagram is for a high calorific value. For a low calorific value it should be multiplied by H_h/H_ℓ.

Table 10.14 Radiant Heat Loss

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

Figure 10.10 Heat Loss Chart (From ABMA chart in power test code of ASME)

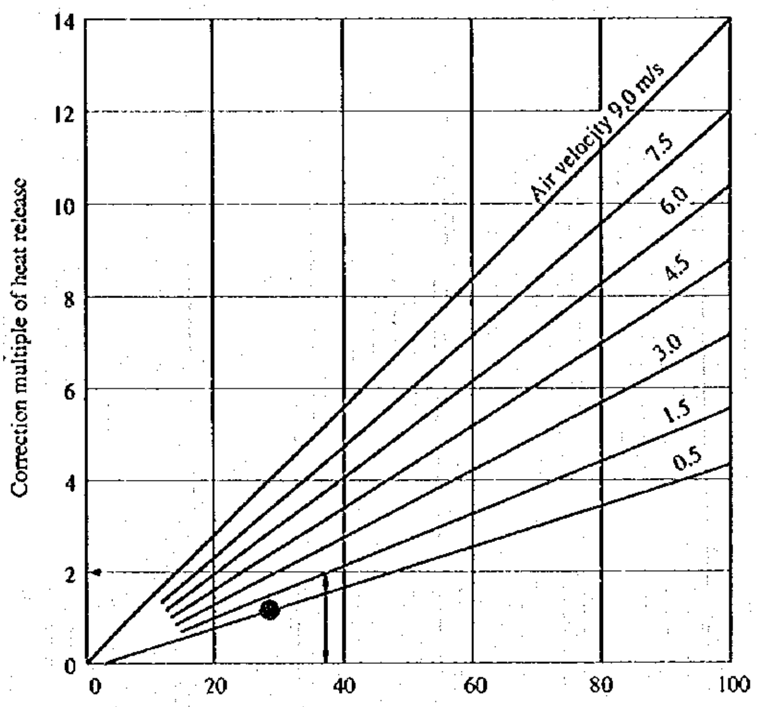


(The figure shows the case that the temperature difference between the heat release surface and the ambient air is 28 °C and the wind velocity on the heat release surface is 0.5 m/s. Correction multiples in other condition are based on that of Figure 10.11.)

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

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

Figure 10.11 Correction Multiple of Temperature Difference and Air Velocity to Figure 10.10



Temperature difference between heat release surface and ambient air (Δt °C)

10.4.10 Other Heat Losses

They are error terms.

10.5 Boiler Performance Indication

The boiler efficiency is indicated by an input-output method which is represented by a ratio of the available output heat to the total input heat as shown in Table 10.10 or by a heat loss method which subtracts the heat loss rate.

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

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

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

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

10.6 Consideration in Installation Steps

10.6.1 Cogeneration

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

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

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

Accordingly, a higher T_1 is a higher efficiency.

Cogeneration gives a work (electric power) by utilization of the higher temperatures when fuel is burned and utilizes the remaining exhaust heat as heat (see Figure 10.12). And various systems are considered as follows.

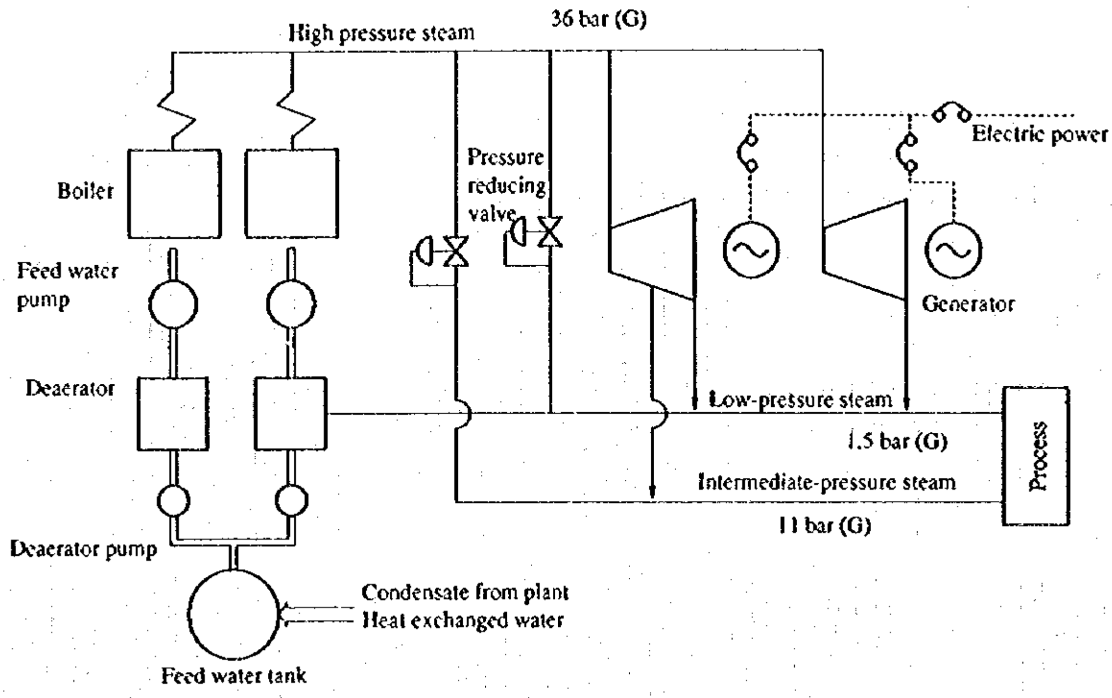
(1) (Gas turbine power generation) + (Steam turbine power generation)

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

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

In the plants of a steam consumption type, the last system (3) is usually used in such as a petroleum refinery, a paper and pulp plant, or a chemical plant. From the point of view of efficiency, the steam pressure is desirable in 30 kg/cm² (G) or more and it is almost 100 kg/cm² (G). And the capacity is 50 t/h or more. With the sharp advance of an energy price, the economical efficiency is improved even in further lower pressure and a lower capacity boiler and the case equipped with a generator instead of the pressure reducing valve has increased.

Figure 10.12 An Example of Cogeneration System



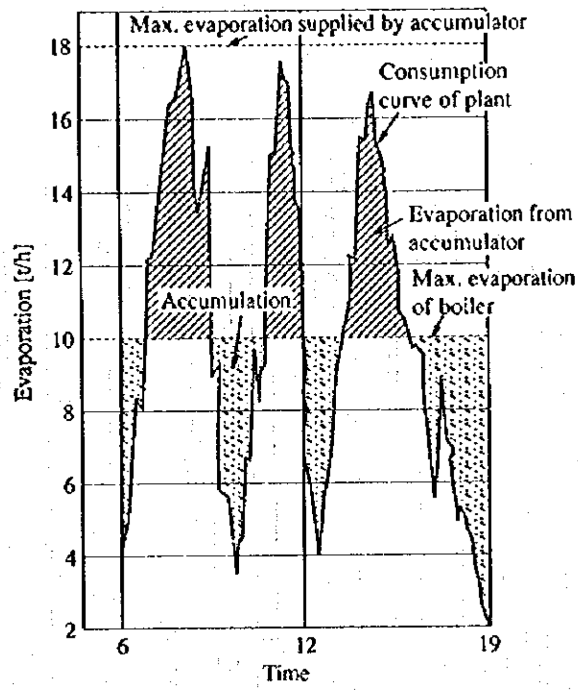
10.6.2 Coping with Steam Demand Variation

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

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

As a method, the steam accumulator should be equipped to store some excess steam which is used when short of steam (See Figure 10.13). If an accumulator is accompanied when the boiler is installed, a boiler of the capacity near to the average load is able to cover sufficiently the demand.

Figure 10.13 Effect of Steam Accumulator



In another method, several small size one-through boilers which are quick start-up are installed and the operating number of boilers is controlled automatically according to load (see Figure 10.14). Since this method increases the efficiency in a lower load compared with the case of a single boiler (see Figure 10.15), energy conservation can be taken as a whole with a counterbalance of some loss increase due to the start-up and shut-off operation.

Figure 10.14 Operation Number Control

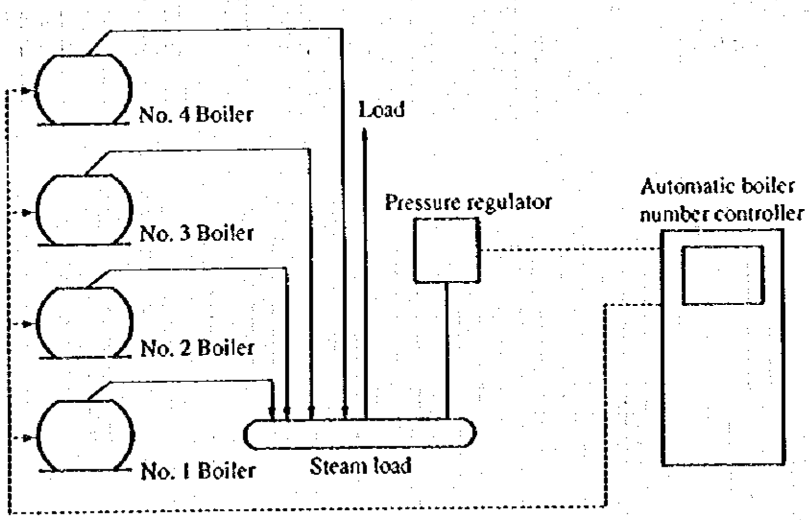
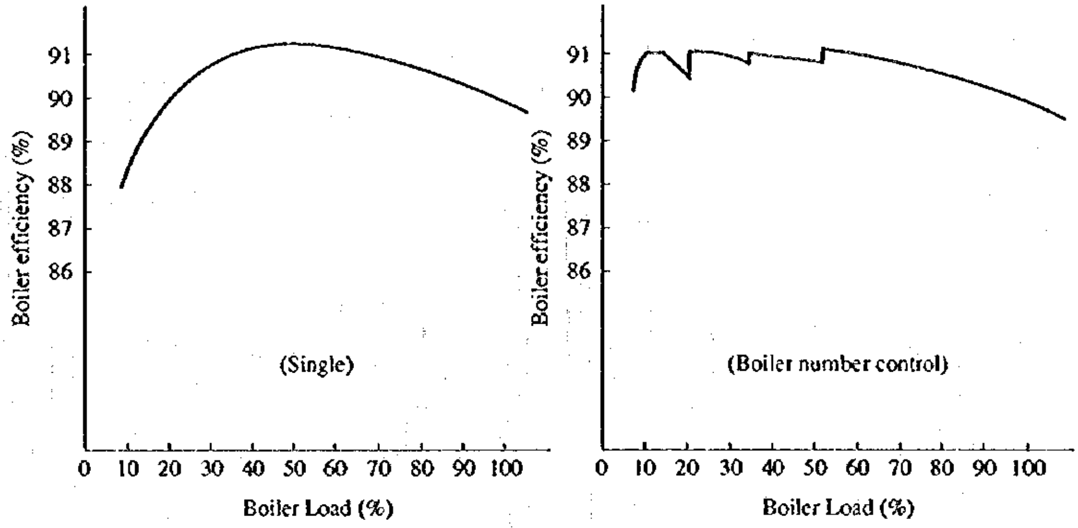


Figure 10.15 Boiler Efficiency Improvement by Operation Number Control



10.6.3 Installation of Proper Capacity Boiler

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

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

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

10.7 Energy Conservation Measure of Boilers

There are various items for the energy conservation in the boilers as shown in Figure 10.16, the characteristic factor chart. The important points of these items are described below.

10.7.1 Air Ratio

The largest heat loss of boilers is an exhaust gas loss (see Figure 10.17). The exhaust gas loss is decided by an exhaust gas volume and an exhaust gas temperature. A proper air ratio must be kept to minimize the exhaust gas volume.

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

Figure 10.16 Energy Conservation Items of Boiler

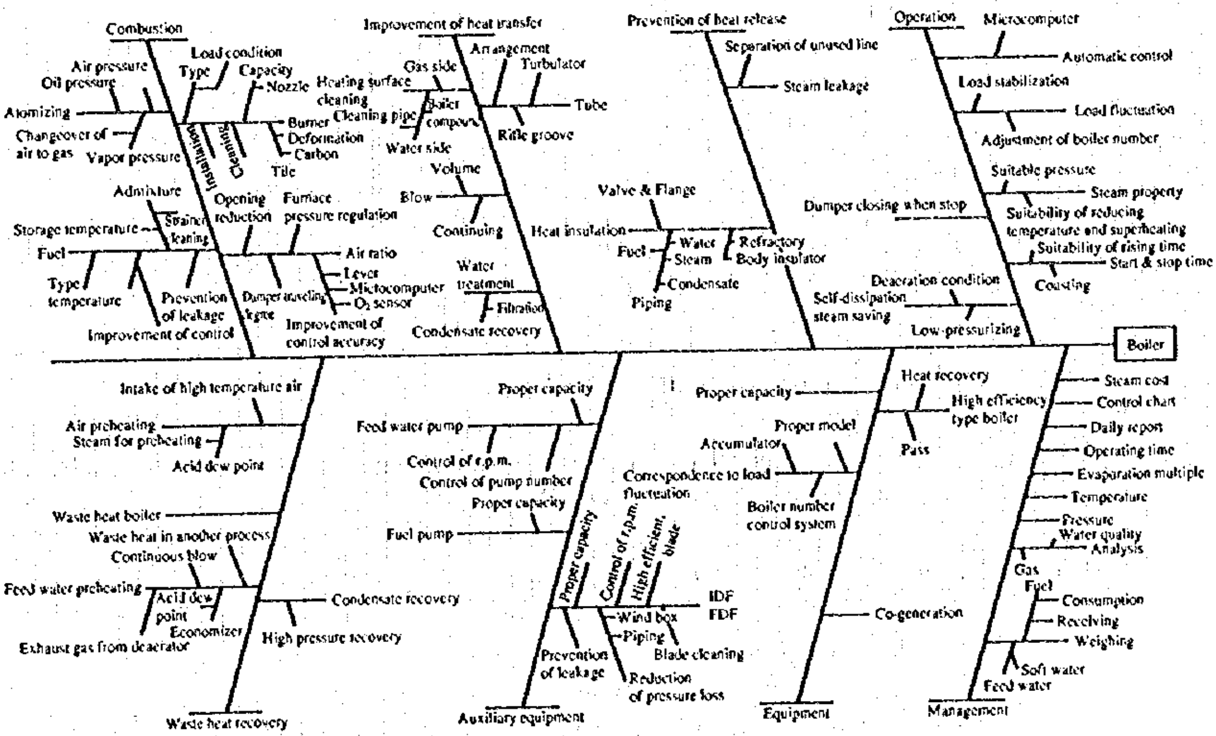
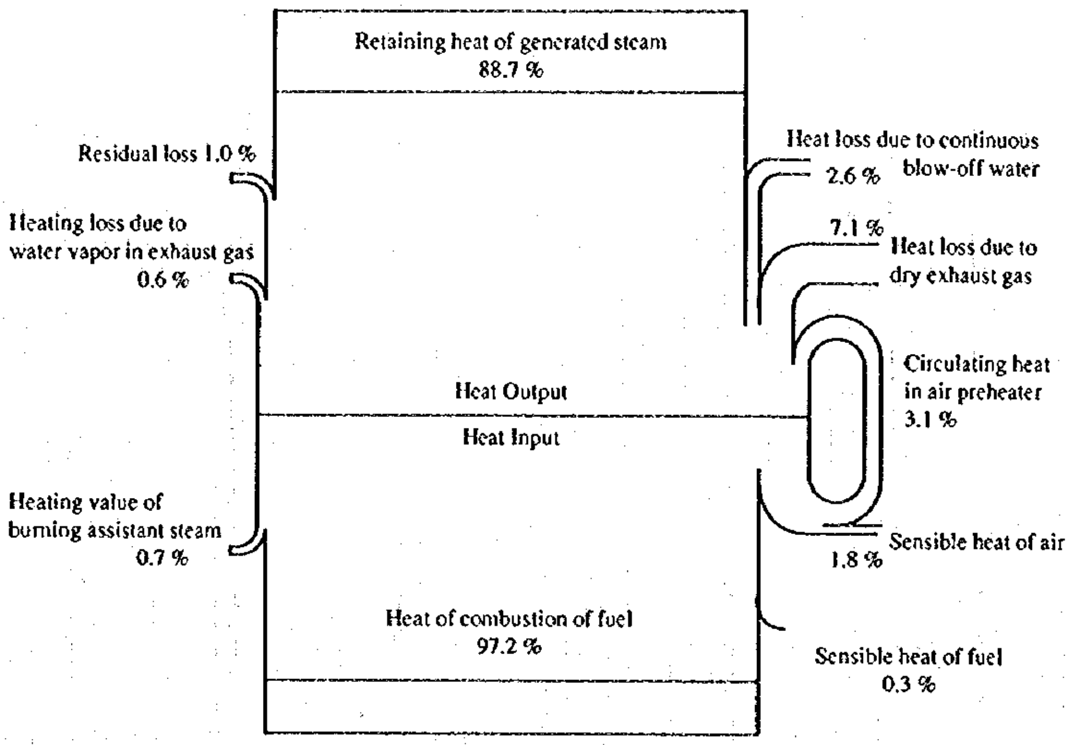


Figure 10.17 Example of 20 T/H Boiler Heat Balance



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

(1) Maintaining of proper fuel oil temperature

Fuel oil should be preheated to 80 – 100 °C to maintain the viscosity of fuel oil within the range of 20 to 45 cSt. (See Figure 10.18).

(2) Inspection and tuning up of burner

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

(3) Maintaining of steam pressure for atomization

The steam pressure, air pressure or fuel oil pressure should be maintained to the specified value by the manufacturer to be atomized sufficiently. The characteristics of oil burners should be referred to Table 10.15.

(4) Prevention of air invasion

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

Figure 10.18 Viscosity of Fuel Oil

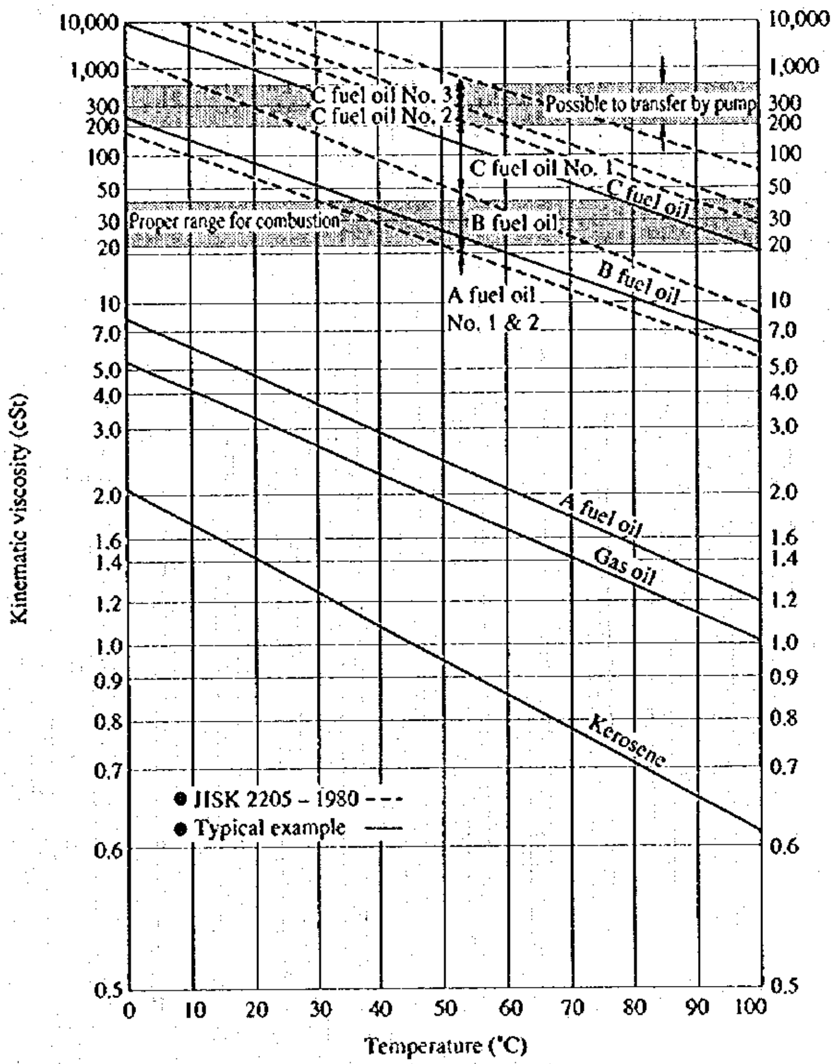


Table 10.15 Characteristics and Application of Oil Burner

	Low pressure air system		High pressure atomizing system		Oil pressure system	
	Interlocking type	Non-interlocking type	Internal mixing type	External mixing type	Return oil type	Non-return oil type
Fuel oil amount	1.5 ~ 120	4 ~ 180	10 ~ 5,000	10 ~ 600	50 ~ 10,000	50 ~ 10,000
Oil pressure	0.4 ~ 1	0.1 ~ 0.3	2 ~ 9	0.2 ~ 1	5 ~ 40	5 ~ 70
Atomizing pressure	mm H_2O (400 ~ 2,000)	mm H_2O (400 ~ 2,000)	3 ~ 10 bar	2 ~ 8 bar	–	–
Atomizing medium amount	2 ~ 3 m^3_N kg	1 ~ 3 m^3_N kg	A 0.2 m^3_N kg S 0.25 kg/kg	A 0.26 m^3_N kg S 0.33 kg/kg	–	–
Atomizing medium	Air	Air	Air or steam	Air or steam		
Combustion air pressure	400 ~ 2,000	100 ~ 2,000	0 ~ 250	0 ~ 50	100	100
Combustion regulation range	4 ~ 6 : 1	4 ~ 8 : 1	8 : 1	6 : 1	3 : 1	3 : 1
Flame characteristic	Short flame	Slightly short flame, Long flame	Short flame, Long flame	Slightly long flame	Short flame	Short flame
Merit	Possible for proportional control by one lever. Low cost of installation and operation	Easy handling. Same as left.	Good atomizing. Small clogging	Same as left	Low combustion noise. Low cost of operation	Same as left
Weakness	Blower required	Same as left	Power cost required	Power cost required	Not respond to load fluctuation High pressure pump required	Same as left
Boiler application	O	O	O	O	O	O
			O	O	O	O
	O	O		O		
	O		O	O	O	O

(5) Regulation of air

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

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

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

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

(6) Automatic control

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

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

The example shown in Figure 10.19 has a ratio setting mechanism in the linkage and the O_2 content in the exhaust gas is fed back to adjust the air damper to the O_2 setting by fine adjustment.

The example shown in Figure 10.20 remains the function of linkage and the controller of the revolution of the blower is added to it to adjust the O_2 concentration in the exhaust gas using a setting value suitable to the load.

For a large capacity boiler, a flow controller should be installed for fuel and air respectively to perform a parallel or series cascade control by the steam pressure signal as shown in Figure 10.21.

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

To dissolve this defect, the example in Figure 10.22 is applied with a cross limit to check fuel or air flow whether to conform to the actual flow of each other: for fuel, the master signal coming from the steam pressure meter is compared with the smoke limit fuel quantity signal obtained by a calculation from the actual air flow, then smaller value is selected as a fuel value. In the air side, contrary to this, the air flow is set to a larger value between the master signal and the smoke limit air quantity signal obtained from the actual fuel flow. Thus, since a control of the air preceding type is done in a load increasing and a control of the fuel preceding type is done in the load decreasing, the air ratio is not required at a large margin.

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

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

Figure 10.19 Boiler Air Ratio Controller (1)

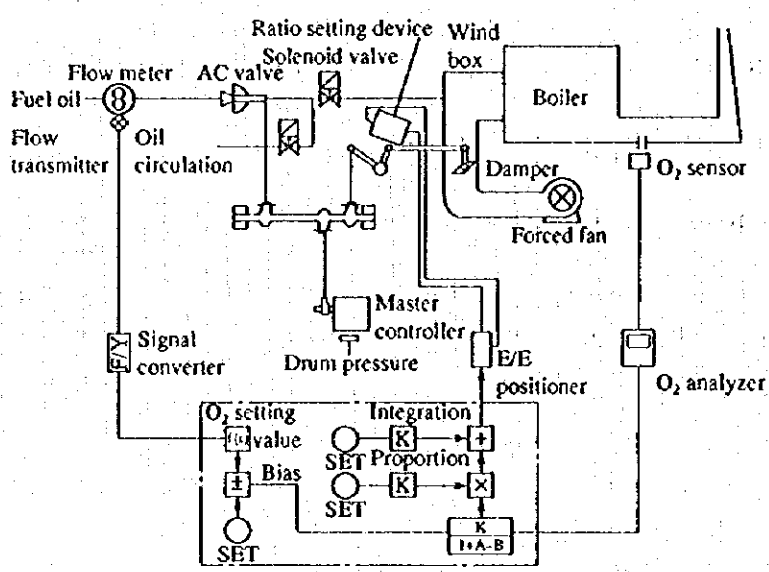


Figure 10.20 Boiler Air Ratio Controller (2)

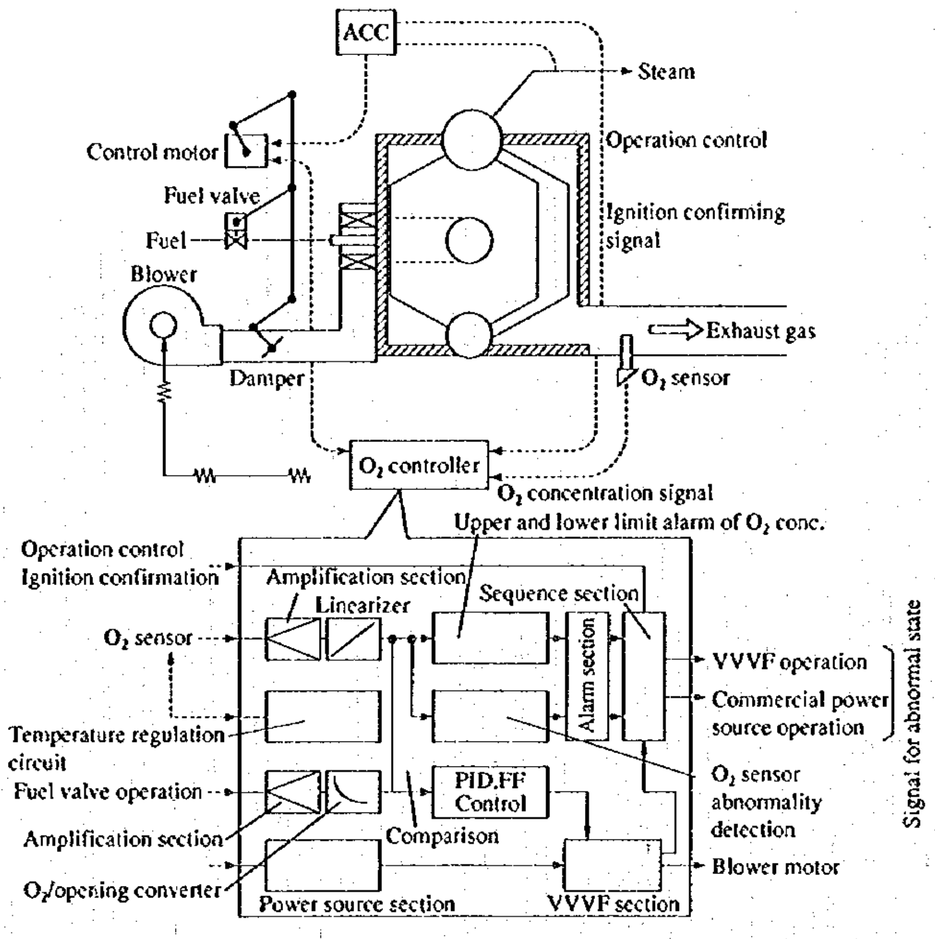


Figure 10.21 Basic Combustion Control System

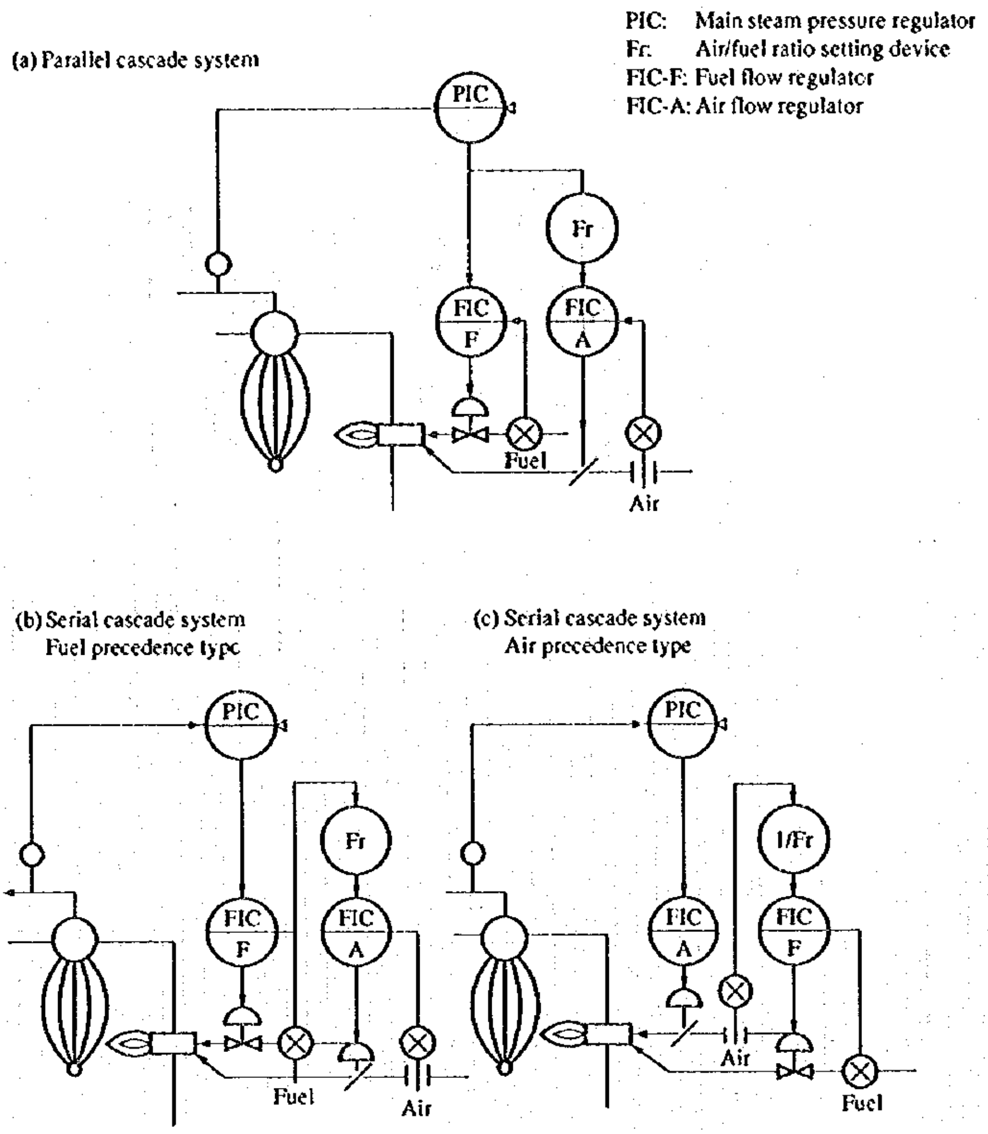
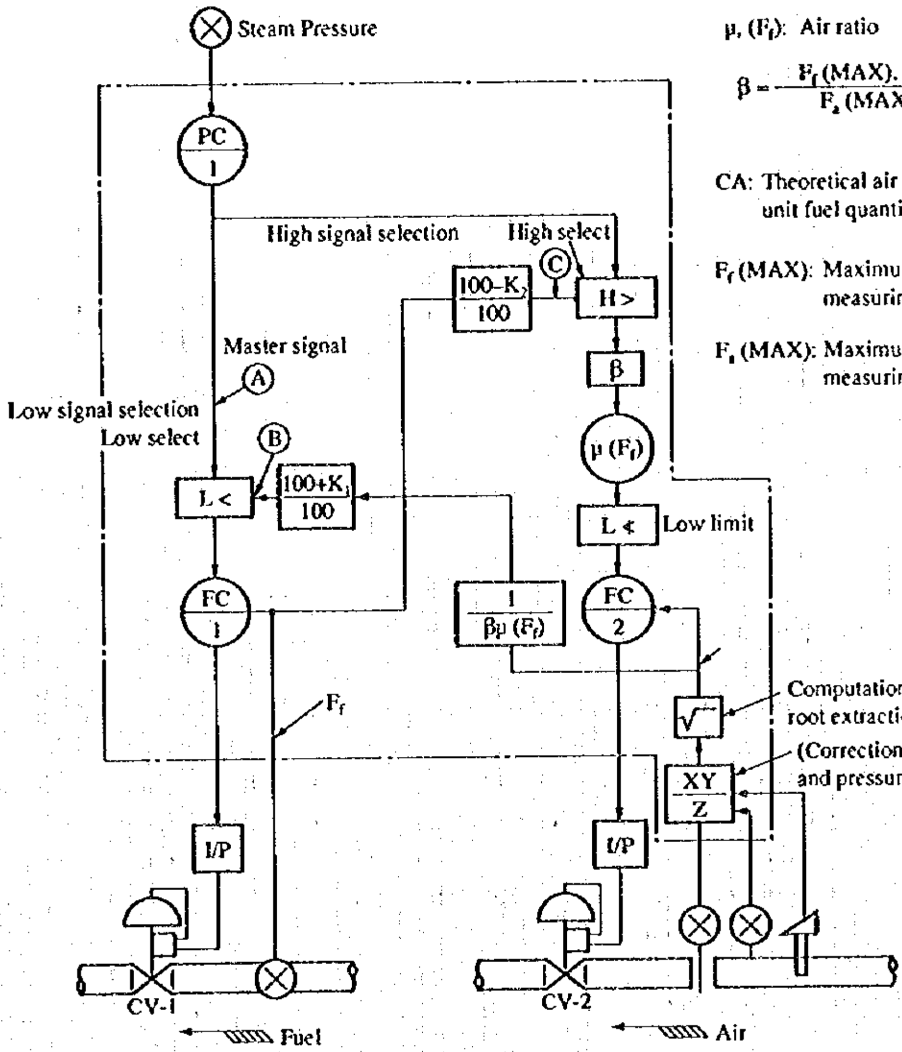


Figure 10.22 Block Diagram of Single Cross Limit Combustion Control System



PC-1: Main Steam pressure regulation
FC-1: Fuel oil flow control
FC-2: Air flow control

μ, (F_f): Air ratio

$$\beta = \frac{F_f(MAX).CA}{F_a(MAX)}$$

CA: Theoretical air quantity per unit fuel quantity

F_f(MAX): Maximum value in the measuring range of fuel flow

F_a(MAX): Maximum value in the measuring range of air flow

(7) Standard of air ratio

Since the air ratio is influenced by the type of fuel, the load factor and the composition of control devices, these points must be considered for setting of the standard. The values of Japanese standard are shown in Table 10.16 as reference.

Table 10.16 Standard Air Ratio of Boiler

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

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

10.7.2 Exhaust Gas Temperature

(1) Improvement of heat transfer

The thermal conductivities of soot and scale depend on their composition and the deposit situation, and they are of values of no more than 1/100 to 1/1,000 of those of mild steel as shown in Table 10.17. Accordingly, these deposits make the thermal efficiency of boilers decline remarkably similar to some insulation on the heating surface (see Figure 10.23 and Figure 10.24).

Table 10.17 Thermal Conductivity of Scale and Other Substance

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

Figure 10.23 Example of Fuel Loss due to Soot on Heating Surface

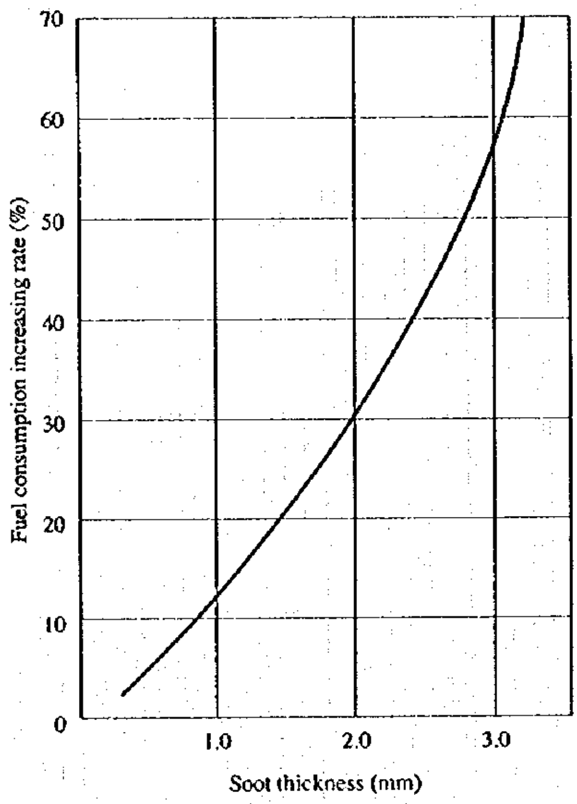
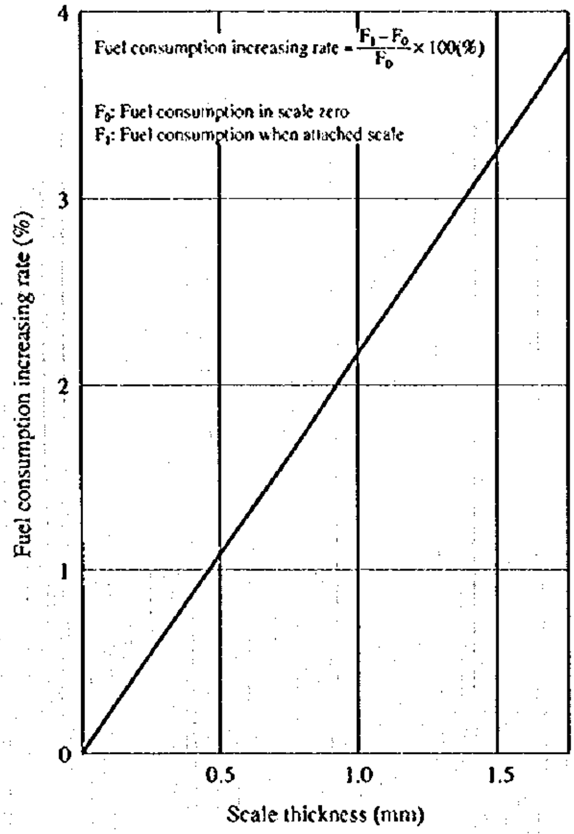


Figure 10.24 Example of Relation between Scale Thickness and Fuel Loss



In order to avoid any hindrance due to the scale, it is required to perform properly a water treatment and a blow and to clean periodically as described in item (3) of paragraph 10.2.3.

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

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

When a flue smoke tube boiler has an enough capacity, a special steel turbulator in the smoke tube is inserted to improve the coefficient of heat transfer by bringing turbulent flow in the gas flow (see item (3) of paragraph 10.7.7).

(2) Recovery of waste heat in exhaust gas

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

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

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

The relation between the sulfur content in fuel and the SO_2% in exhaust gas is shown in Figure 10.25, the conversion of SO_2 to SO_3 is shown in Figure 10.26 and the relation between the SO_3 concentration and the dew point of acid is shown in Figure 10.27. In the vicinity of the inlet for a low temperature fluid of the heat exchanger, a low temperature part exists partially. Therefore, the gas temperature must be kept at a higher level than the dew point of acid shown in the figure.

Figure 10.25 Relation between Sulfur Content in Fuel and SO_2 Content in Fuel Gas

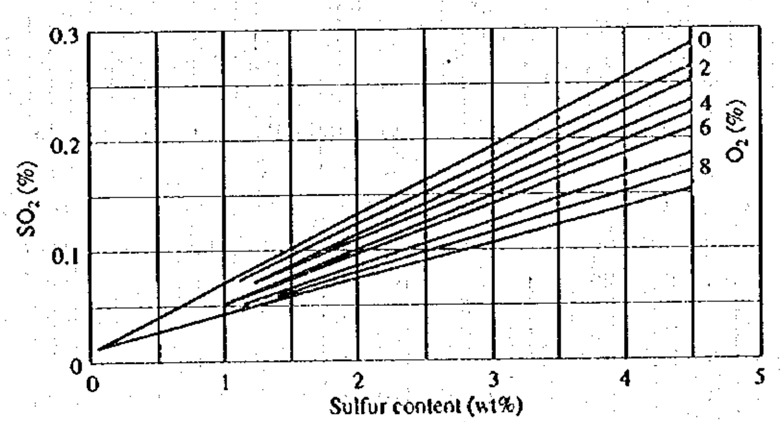


Figure 10.26 Relation between Sulfur Content in Fuel and Conversion Ratio from SO_2 to SO_3

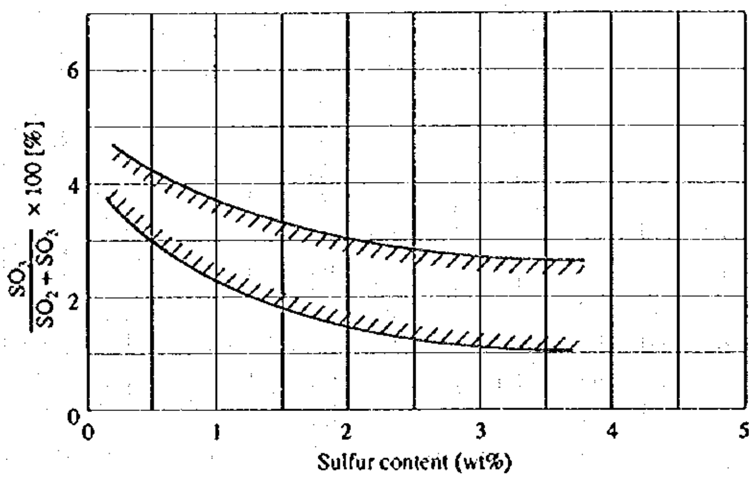
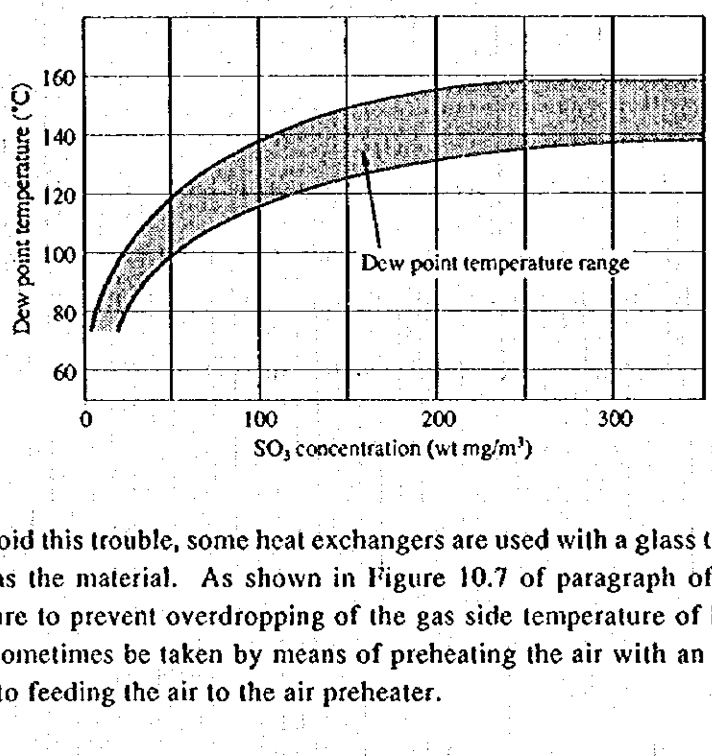


Figure 10.27 Relation between SO_3 Concentration in Exhaust Gas and Dew Point Temperature



To avoid this trouble, some heat exchangers are used with a glass tube or a lead coating tube as the material. As shown in Figure 10.7 of paragraph of the heat balance, a measure to prevent overdropping of the gas side temperature of heat transfer surface may sometimes be taken by means of preheating the air with an external heat source prior to feeding the air to the air preheater.

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

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

Where,

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

In a case, where air is not preheated

$H_A = F - Q$

In a case of preheating air

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

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

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

When air is preheated:

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

Accordingly, the fuel saving rate is as follows:

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

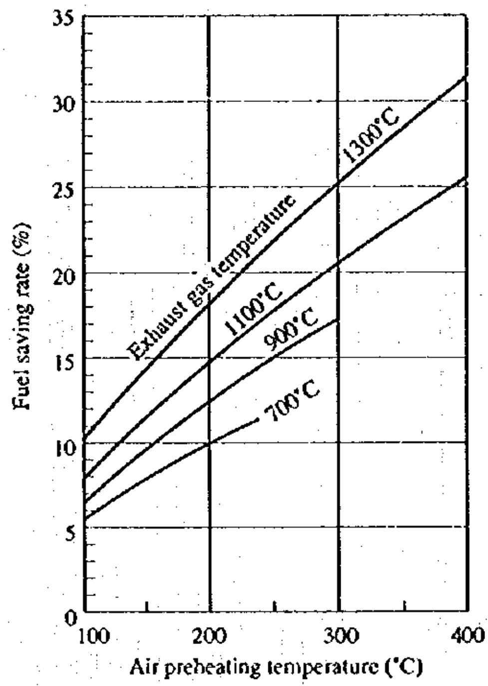
The fuel saving rate in case of 1.2 in the air ratio is shown in Figure 10.28.

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

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

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

Figure 10.28 Fuel Saving Rate due to Air Preheating



(3) Exhaust gas temperature standard

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

In the Japanese exhaust gas temperature standard, the standard of an exhaust gas temperature by capacity and by fuel is determined in consideration of these points as shown in Table 10.18.

Table 10.18 Standard Exhaust Gas Temperature of Boiler (unit: °C)
(Load factor: 100 % at the outer termperature of 20 °C)

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

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

10.7.3 Prevention of Heat Release

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

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

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

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

10.7.4 Energy Conservation of Accessory

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

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

10.7.5 Operation

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

10.7.6 Routine Management

To advance the energy conservation of boilers, it must be settled first to provide required instruments and grasp the daily operating situations. Especially the relation between the evaporation and the fuel consumption, that is the evaporation multiple (see paragraph 10.5), should be observed. If a declining of the performance is recognized, its cause should be investigated immediately and an appropriate measure must be taken.

Table 10.19 is a sample of operation records. These items must be recorded for the boiler management. The items such as the evaporation multiple, the feed water temperature, the exhaust gas temperature and O_2% in the exhaust gas should be prepared in chart to know a long-term tendency and these data make use of detection in its early stage of any abnormality. The indication of data is useful to promote the operator's interest to energy conservation.

Table 10.19 Daily Report of Boiler Operation

Manager	Chief operator	Early attendance	Day service	Night service

Date   Weather   Ambient temperature inside °C   Outside °C

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

Hours	Pressure	Feed water temperature	Feed water quantity		Fuel oil quantity		Fuel oil temp.		Oil pressure		Exhaust gas temperature	Exhaust gas	Furnace pressure	WB static pressure	Outlet static pressure
			Meter reading	Consumption	Consumption	Meter reading	Service tank	Heater outlet	Primary	Secondary					
	bar	°C		lit.	lit.		°C	°C	bar	bar	°C	% CO_2	mmAq	mmAq	mmAq
				(A)	(B)										

(Take care to the ratio. Example: 13:1)

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

Boiler water blowdown (Reading in previous day)

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

Water softener (Reading in previous day)

Previous meter reading	t
Today's meter reading	t
Treating water quantity	ton
Basic cycle	ton
NaCl quantity	kg
Hardness analysis	Good or no

Cleaning agent

Chemical name	Input g	Input hour

Boiler water

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

Check & supplying

Previous day	Today	Pour

Water quality test

Feed water	pH		—
	Conductivity		μΩ/cm
	Chloride ion		ppm
	Hardness		ppm
Boiler water	pH		—
	Conductivity		μΩ/cm
	Chloride ion		ppm
	Hardness Phosphate ion		ppm

Description:

10.7.7 Example

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

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

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

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

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

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

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

• Boiler efficiency	90%
• Exhaust gas loss	5%
• Steam loss for atomization	1%
• Heat release and others	4%

Various tests were carried out by changing the air ratio automatic controller to a manual operation in order to try to reduce the exhaust gas loss. The result proved to be possible to reduce from 2.5 % of the conventional O_2% limit to 0.6 %. As a result, O_2 has been reduced to 1.0 %

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

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

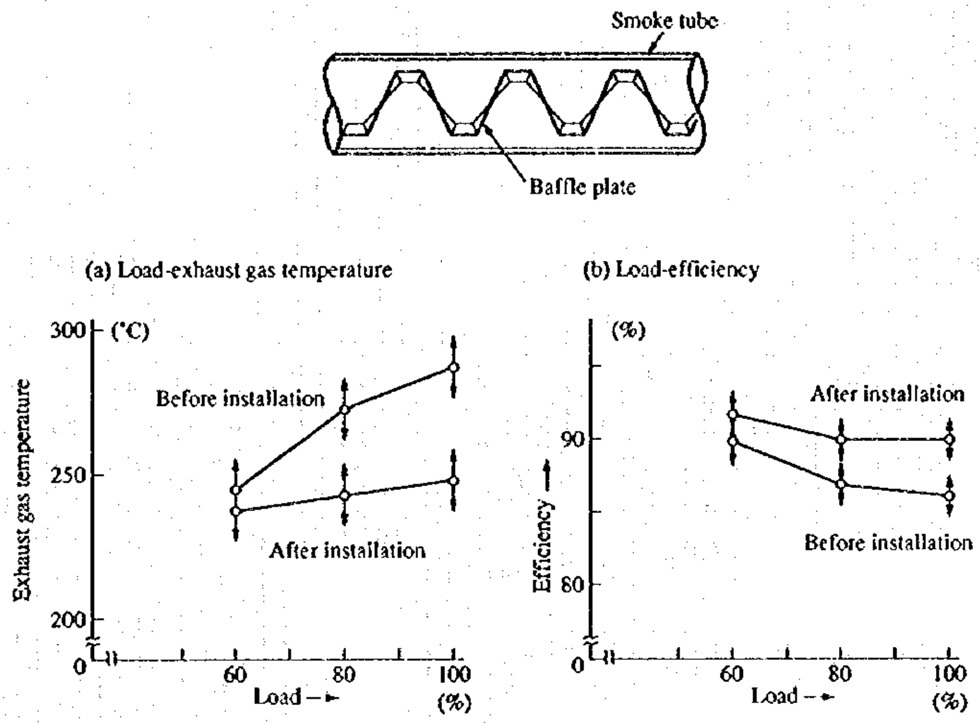
Since the opening of the damper for the forced draft fan was a low degree of 10 to 20 %, the revolution control by inverter was carried out.

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

(3) Heat transfer improvement of smoke tube (See Figure 10.29)

A special steel turbulator was inserted in the smoke tube of a flue smoke tube boiler (6 kg/cm² (G), 7 t/h) which burns fuel oil and the heat transfer was improved by giving a turbulent flow to the gas flow in the smoke tube. As a result, the boiler efficiency was improved from 87.5 % to 89.7 %.

Figure 10.29 Turbulator Insertion Effect



11. ENERGY CONSERVATION IN THE UTILIZATION OF STEAM

11. ENERGY CONSERVATION IN THE UTILIZATION OF STEAM

11.1 Utilization of Steam

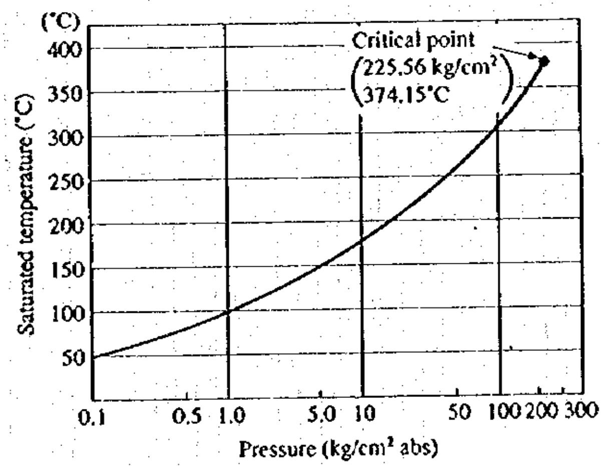
Steam is widely used in factories, buildings and so on as an energy source because of its excellent physical and chemical properties. Available utilization of steam with a thorough comprehension of its properties is related to an effective energy conservation.

The general characteristics of steam are as follows:

(1) Saturated steam is always in a constant relationship between the pressure and the temperature and by keeping steam in a constant pressure it is possible to set a constant temperature. (See Figure 11.1)

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

Figure 11.1 Relation between Pressure and Temperature of Saturated Steam



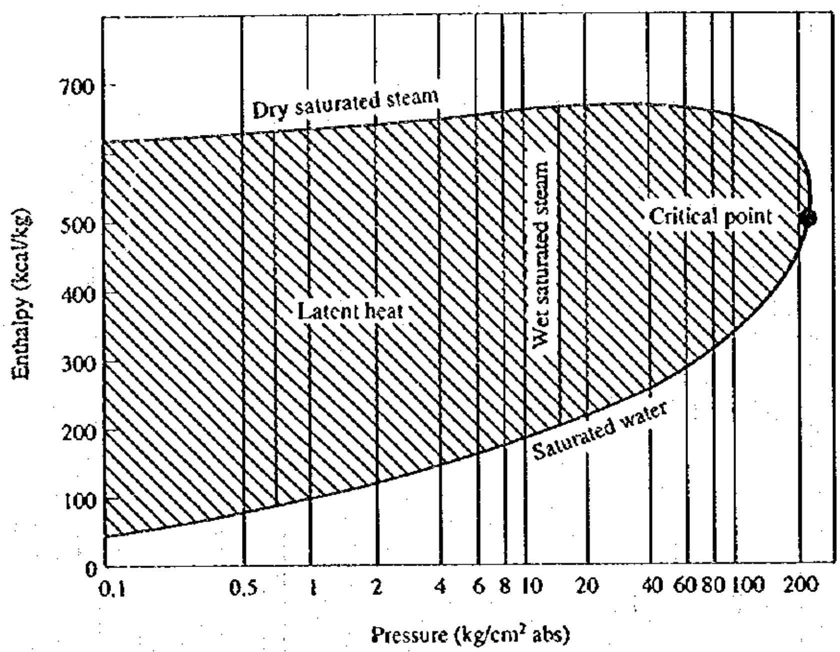
(3) The latent heat of evaporation of steam is larger as the pressure decreases and it is reduced as the pressure rises. (See Figure 11.2)

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

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

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

Figure 11.2 Relation between Pressure and Latent Heat of Staturated Steam



11.2 Effectiveness of Steam Setting Pressure

11.2.1 Effectiveness of Boiler Steam Pressure

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

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

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

Table 11.1 Difference of Steam Effective Heat by Pressure

Steam pressure (kg/cm^2 G)	Saturation temperature (°C)	Specific enthalpy of steam (kcal/kg)	Condensation latent heat (kcal/kg)
7	170	660.8	489.5
5	159	657.9	498.6

If the steam pressure is reduced from 7.2 kg/cm^2 (G) to 5.2 kg/cm^2 (G), the latent heat of condensation rises to approximately 9 kcal/kg from Table 11.1. If steam consumption per month is taken as 5,400 metric tons, the steam consumption due to reduction of the steam pressure is

$$5,400 \times \frac{489.5}{498.6} = 5,300 \text{ t/month}$$

If the calorific value of fuel is taken as 10,000 kcal/kg, the feed water temperature as 20 °C and the boiler efficiency as 85 %. The saving of the fuel due to the reduction of steam pressure is as follows:

$$\frac{5,400 \times 10^3 \times (660.8 - 20)}{40,000 \times 0.85} - \frac{5,300 \times 10^3 (657.9 - 20)}{10,000 \times 0.85} = 9,347 \text{ kg/month}$$

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

11.2.2 Pressure Reducing Effect of Steam

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

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

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

If a steam 9.3 kg/cm^2 (G) of steam pressure and 0.95 of dryness is reduced to 2 kg/cm^2 (G), the latent heat of saturated steam before pressure reduction is

$$481.65 \times 0.95 = 457.74 \text{ kcal/kg}$$

and the enthalpy of wet steam is

$$181.25 + 457.57 = 638.82 \text{ kcal/kg.}$$

The latent heat after pressure reduction is

$$638.83 - 133.41 = 505.41 \text{ kcal/kg.}$$

Accordingly, the latent heat amount due to pressure reduction is increased by

$$505.41 - 457.57 = 47.84 \text{ kcal/kg.}$$

In other words, the excessive heat quantity of $(47.84/457.57) \times 100 = 10.6\%$ is possible for utilization through pressure reduction. The dryness after pressure reduction results in the following:

$$638.82 = 133.41 + x \times 517.9$$
$$x = 0.98.$$

11.3 Steam Transport

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

11.3.1 Piping Plan

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

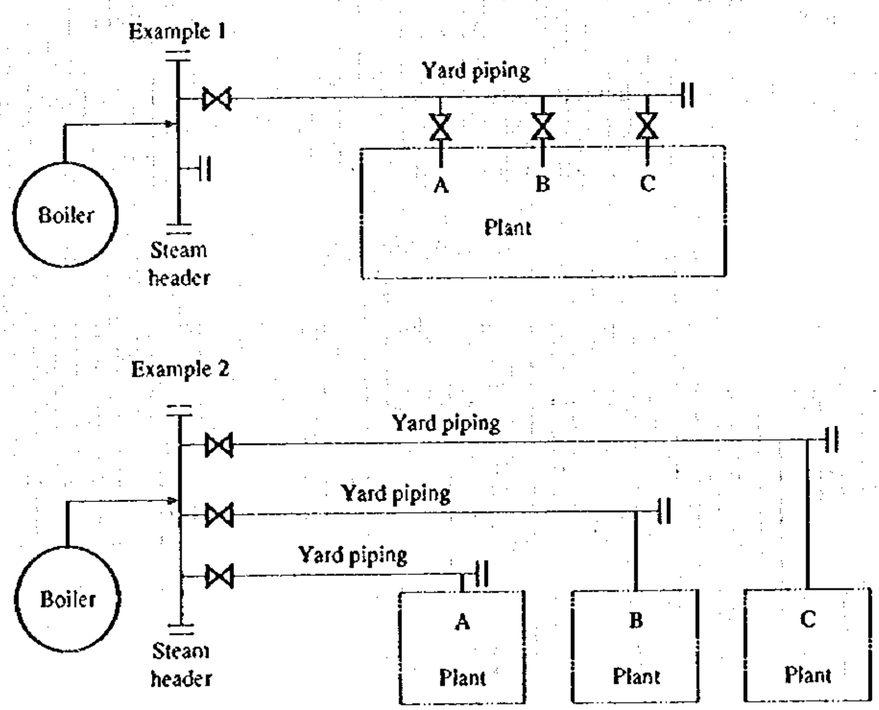
a. Servicing time and hours

b. Batch or continuance

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

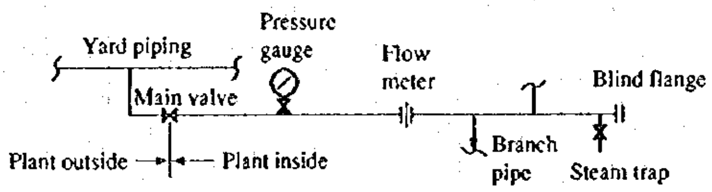
With a plant plan of piping, the relation between the yard piping and the plant piping should be defined. The yard piping system diagram is shown in Figure 11.3. Decision of either the example 1 or 2 should be taken into consideration for various factors such as the area of factory, the length of yard piping, the time of expansion plant, the operating process of each plant, the initial cost and the heat loss. It is also required to investigate for an exclusive piping for the daytime and the night time, and a separation of the high pressure line and the low pressure line.

Figure 11.3 Yard Piping System Diagram



To take the piping from the yard piping into the plant, a main valve should be installed as shown in Figure 11.4 to lessen the influence on the work for the plant extension or to avoid heat loss by closing the main valve at a dead time. A pressure gauge and a flow meter must be installed. Also it is a method that a blind flange is mounted to some terminals of the heater for future usage.

Figure 11.4 Plant Steam Piping System Diagram



11.3.2 Heat Insulation of Steam Piping

In steam transport, part of the steam gets condensed by heat dissipation from the pipe and is discharged as condensate with energy loss. Accordingly, the steam piping should be given a proper heat insulation to reduce heat loss.

(1) Type and selection of heat insulating materials

a. Properties required of heat insulating materials

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

The thermal conductivity of insulating materials has the following characteristics:

1) increasing generally with the density;

2) increasing with absorption of moisture;

3) increasing with raising of the temperature.

b. Type of insulating materials

The insulating material used for steam piping is mostly an inorganic materials. Table 11.2 shows the kinds and features of inorganic insulating materials.

Table 11.2 Heat Insulator Type and Its Feature

Heat insulator	Raw material and manufacturing process	Product	Property	Safety service temp.
Rock wool insulator	• Andesite, basalt, igneous rock, serpentinite, peridotite, chlorite-schist, slag of nickel ore and manganese ore and limestone • Compound the above materials in a proper ratio, melt in a temperature of 1,500 ~ 1,600 °C and form it to a thin fiber shape by blowing of compressed air/steam. SiO_2 : 40 ~ 50 % Al_2O_3: 10 ~ 20 % CaO : 20 ~ 30 % MgO : 3 ~ 7 % Fe_2O_3 : 2 ~ 5 %	• Attacked by weak acid but not weathered. • Various shape products such as plate, cylinder, band and blanket. • Blanket is formed by set metal on both sides of the stratified rock wool and sew up with a wire. Good acoustic absorption effect.	Density: < 0.3 g/cm³ Thermal conductivity (70 °C): < 0.042 kcal/m·h·°C	600 °C or less
Glass wool insulator	• Manufactured by the similar manner to the rock wool.	• Plate, cylinder, blanket and band	Density: < 0.1 g/cm³ Thermal conductivity (70 °C): < 0.042 kcal/m·h·°C	400 °C or less
Calcium silicate insulator	• Add fiber into silicate powder (mainly diatom earth) and slaked lime to reinforce, allow it to swell enough and mold in a metal mold to allow produce calcium silicate by steaming.	• Low price, good workability and durability. • Typical insulator used not only piping but a general machine.	Density: less 0.22 g/cm³ Thermal conductivity (70 °C): < 0.053 kcal/m·h·°C	1000 °C or less
Perlite insulator	• Calcinate ignition rock such as pearlite or obsidian at 800 ~ 1,200 °C in kiln. • White or gray white color fine particle and very light particle having fine bubble. Not change in quality and not fade in the color. Not absorb moisture in atmosphere.	• Less 1 mm for moulding insulator	Density: less 0.2 g/cm³ Thermal conductivity: < 0.065 kcal/m·h·°C	900 °C or less
Preformed cellular plastics	• Polystyrene, polyurethane, polyethylene or phenol resin	• Preformed plate or cylinder having many isolated air cell. Used for cold insulation	Density: more than 2.7 g/cm³ Thermal conductivity: < 0.037 kcal/m·h·°C	-200 °C 100 °C

c. Selection of heat insulating materials

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

1) Low thermal conductivity

2) Small specific weight

3) Low water absorption

4) High strength and durability

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

6) Good workability

(2) Heat insulation works

Although an excellent heat insulation material is used, an incomplete work allows the heat insulation to worsen through intrusion of rainwater and the energy loss due to heat dissipation. Care must be exercised for works.

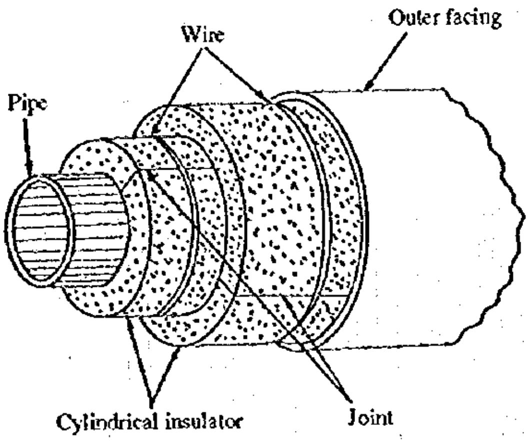
a. Works

1) Use a molded product as far as possible.

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

The thermal expansion of piping and the shrinkage of the insulator cause some gasp. In case of two layers or more (if a required thickness is more than 75 mm, the works should be two layers as much as possible), the longitudinal and the lateral joints in each layer should be installed, in shifting, not to be put at the sample part, and the joint should be packed with a compressed fiber (Figure 11.5).

Figure 11.5 Insulation of Pipe



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

The valve portions and the flange parts may sometimes not be insulated by reason of maintenance or inspection and complexity of the works, but these also should be insulated. Figure 11.6 shows the works of heat insulation for valves, Figure 11.7 shows the works of heat insulation for flange portions, and Figure 11.8 shows an example of the works of a heat insulation for hangers.

Figure 11.6 Valve Insulation Work

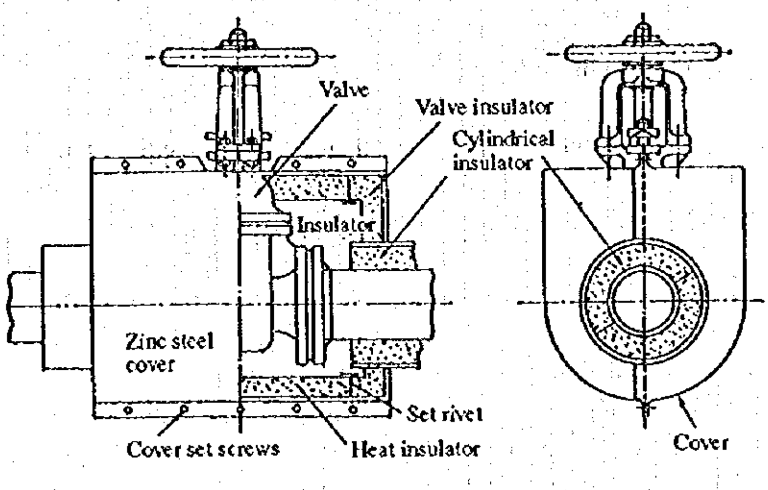


Figure 11.7 Flange Insulation Work

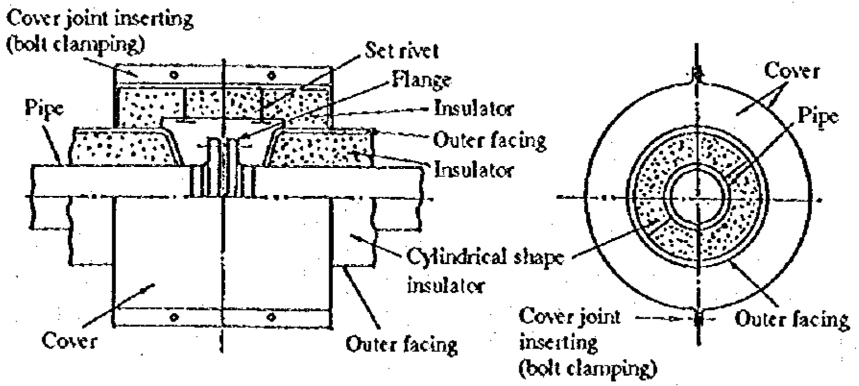
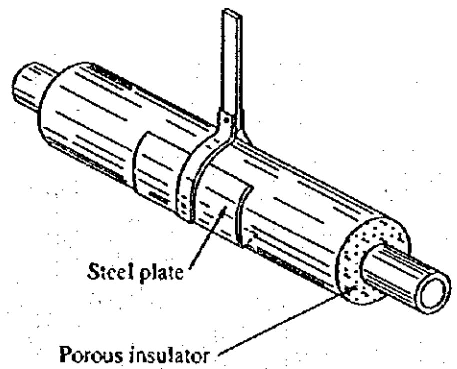


Figure 11.8 Hanger Installation Work



(4) Consideration of vibration

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

(5) Consideration of rainwater resistance and chemical resistance

To prevent the heat insulation against rainwater or corrosive chemicals, the heat insulating material should be covered with steel sheet, aluminium sheet or mastic gum. When the heat insulating material absorbs moisture, because the thermal conductivity of water is approximately 0.5 kcal/m·h·°C which is larger by about 10 times than that of the insulating material, heat loss increases. Care must be taken against moisture. The mastic gum is a liquid or a paste containing asphalt or plastics as the main component and is excellent for workability, antirainwater and chemical resistance.

b. Maintenance and inspection of heat insulation

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

Special attention should be paid to the following points:

1) Deformation and damage of the outer jacketing

2) Decoloration of the outer jacketing and peeling of the painting

3) Mark of steam leakage or falling of drops

4) Shifting of the cover joint parts of outer jacketing or falling-off of the caulking.

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

If no abnormality is found in the above points, the insulating performance is considered to be maintained sufficiently.

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

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

The heat insulation efficiency and heat loss after heat insulation are shown in Figure 11.9 to 11.14.

Figure 11.9 1" Piping

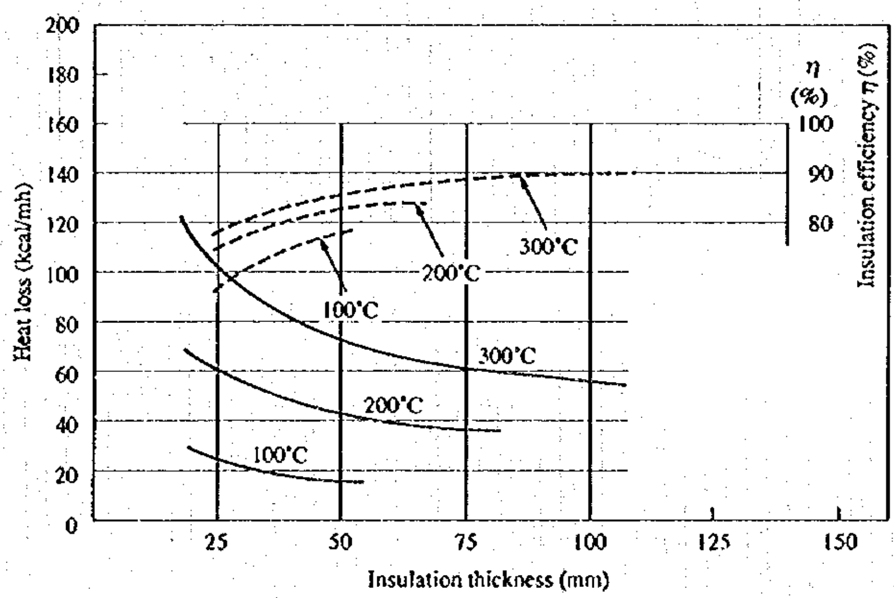


Figure 11.10 2" Piping

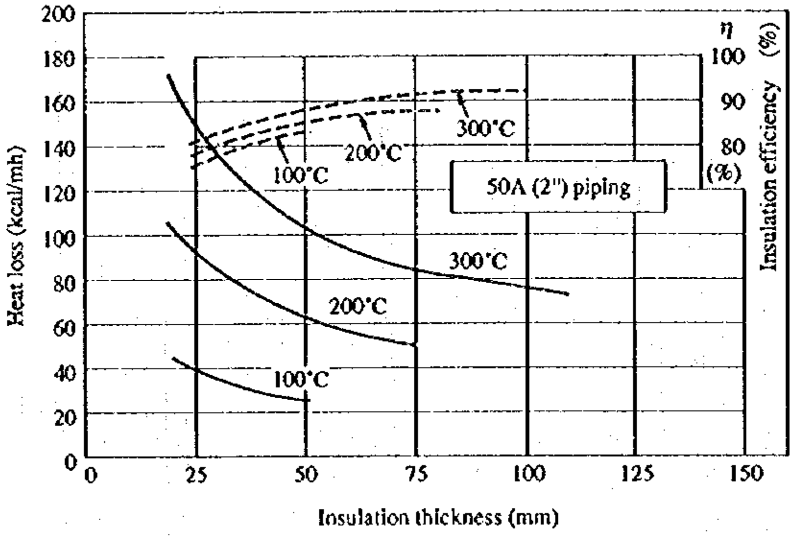


Figure 11.11 3" Piping

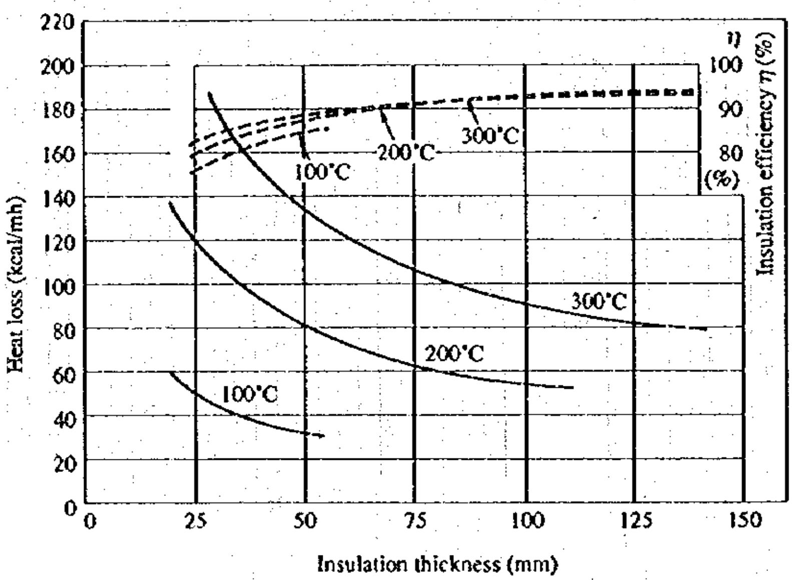


Figure 11.12 4" Piping

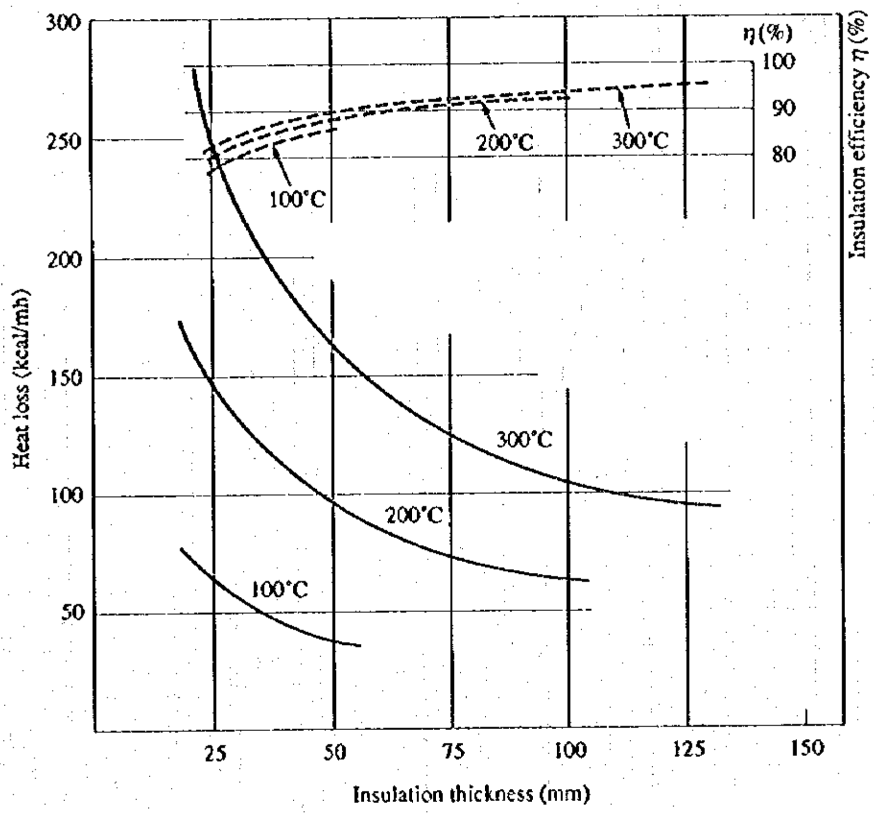


Figure 11.13 6" Piping

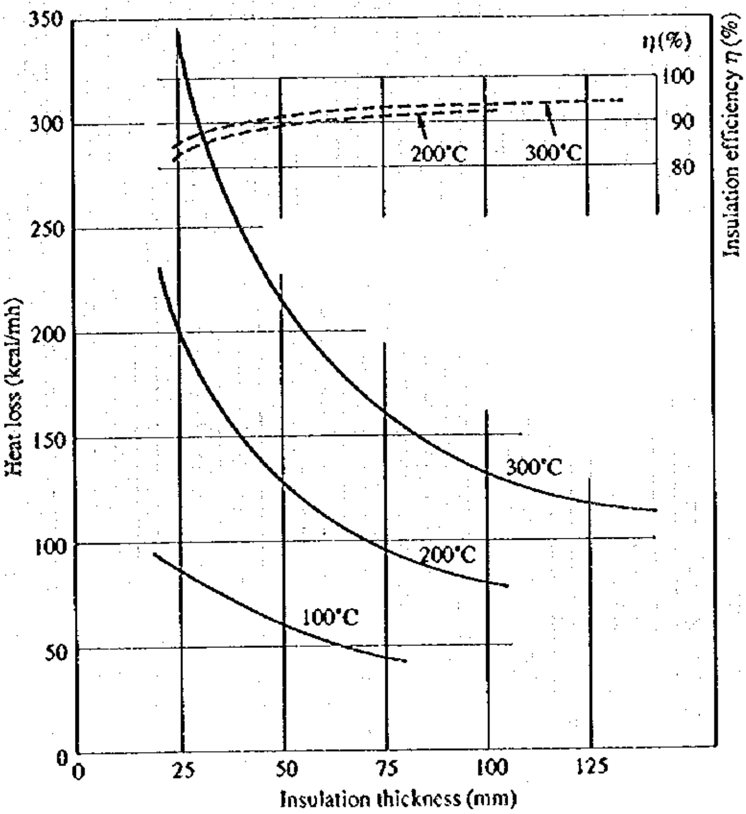
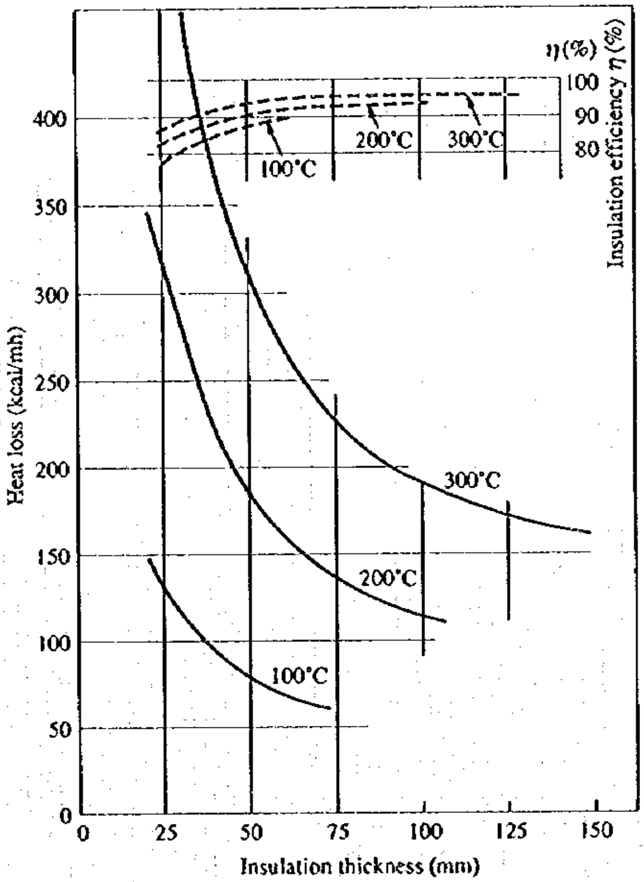


Figure 11.14 10" Piping



11.4 Steam Traps

When steam is fed into a steam servicing equipment, the potential heat of steam is conducted to the subject for heating. As a result, the whole quantity of steam forms a condensate through condensation. The steam servicing equipment shows the maximum heating effect when the steam space is filled completely with steam. With a residence of condensate in the steam space, the effective heating surface area decreases and the heating effect of the equipment lowers. Accordingly, to maintain the equipment capacity at a maximum, the generated condensate should be discharged as soon as possible. In addition to preventing inflow of condensate occurring in the steam supply tube to the equipment, the occurrence of water hammer also must be prevented.

A steam trap is applied for this purpose.

11.4.1 Classification and Characteristic

The three most important functions of steam traps are described below.

- Discharge quickly the generated condensate.
- Do not leak steam.
- Discharge non-condensable gas such as air.

At the present time, many kinds of steam trap have been manufactured.

These are classified roughly into the following three types by their operating principles.

(1) Mechanical steam traps

(2) Thermostatic steam traps

(3) Thermodynamic steam traps

Each type has various models and their classifications and characteristic are shown in Table 11.3.

Table 11.3 Classification and Characteristic of Steam Trap

Large classification	Operation principle	Middle classification	Characteristic
Mechanical	Utilize the density difference between the steam and the condensate.	Lever float type Free float type Open bucket type Inverted bucket type Free ball bucket type	The presence of condensate drives directly a trap valve. It is not necessary to wait a temperature drop of the condensate for actuation. The actuation is quick and secure and has a high reliability.
Thermostatic check	Utilize the temperature difference between the steam and the condensate.	Bimetal type Bellows type (steam expansion type)	Actuation does not depend on directly the presence of condensate. Since actuation is done through the change of temperature, response is slow. Accordingly the actuation cycle is longer. A large air exhaust capacity.
Thermodynamic	Utilize the difference of thermodynamic property between the steam and the condensate.	Impulse type (orifice type) Disc type	The configuration is small and the reliability is next to the mechanical. The trap back pressure is limited to less 50% of the inlet pressure.

(1) Mechanical steam traps

These types of traps function by opening and closing the valve by motions of the backet or the float due to the difference of the densities between steam and condensate.

a. Lever float type trap

This type is a trap to open or close the valve through the lever, utilizing the buoyance of a closed float (See Figure 11.15). Deformation due to abrasion or shock of the lever mechanism might cause warpage or incompetency of the valve seat.

b. Free float type trap

The float itself serves as valve to open or close the valve port (See Figure 11.16). This trap has a high reliability because there is little mechanical trouble. It has a continuous discharging characteristic of condensate.

Figure 11.15 Float with Level Type Trap

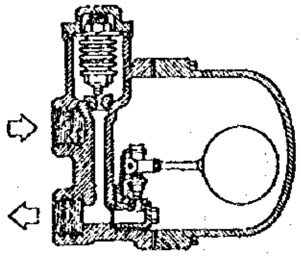
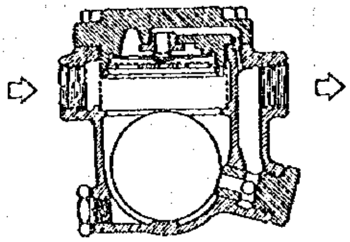


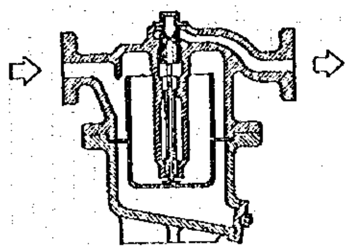
Figure 11.16 Free Float Type Trap



c. Open bucket type trap

The trap is equipped with a valve on the valve stick which is fixed in the center of the upward opened bucket (See Figure 11.17).

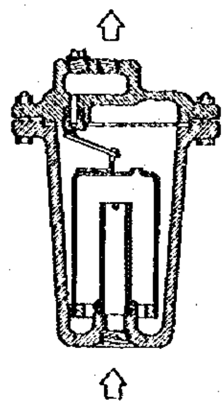
Figure 11.17 Open Bucket Type Trap



d. Inverted bucket type trap

The trap has a hanging mechanism of a downward opening bucket by the lever and the valve mounted to the lever opens or closes the orifice located in the upper (See Figure 11.18). Deformation or abrasion of the lever might cause trouble.

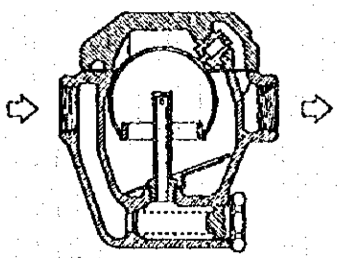
Figure 11.18 Inverted Bucket Type Trap



e. Free ball bucket type trap

The trap does not have the lever as in the inverted bucket type trap and its actuating principle is the same as the inverted bucket type trap (Figure 11.19). The bucket is a globe and its outer surface actuates as a valve. The trap actuates intermittently for a small quantity of condensate and discharges continually condensate for a large quantity.

Figure 11.19 Free Ball Bucket Type Trap



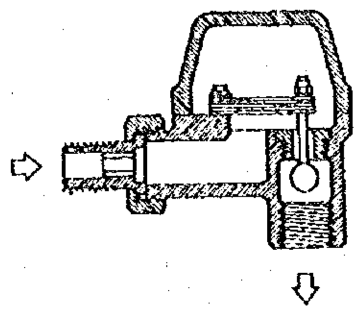
(2) Thermostatic steam traps

The condensate is at a saturation temperature of steam just after the generation of condensate. The subsequent heat loss lowers the temperature, thereby causing a temperature difference between condensate and steam. This temperature differene is utilized for opening or closing the valve.

a. Bimetal type trap

The power generated by bimetal is in a linear relation to the temperature. This relation is utilized for opening and closing of the valve. But the steam pressure has not a linear relation to the temperature and so the servicing pressure range of the trap is restricted (See Figure 11.20).

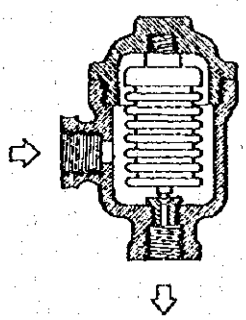
Figure 11.20 Bimetal Type Trap (Strip Type)



b. Bellows type trap

A low boiling point liquid is sealed in an expandible hermetically sealed enclosure and the valve can be opened or closed through utilization of expansion and contractions of the enclosure due to the change of the liquid vapor pressure by temperature variation (See Figure 11.21).

Figure 11.21 Bellows Type Trap



(3) Thermodynamic steam traps

The valve can be opened or closed utilizing the difference of the thermodynamic properties between the condensate and the steam.

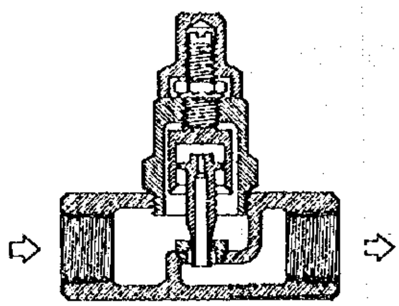
The trap performance is restricted by the pressure such that the trap's back pressure is less than 50 % of the inlet pressure. If the pressure goes to 50 % or more, the trap results in a blow-off condition and is impossible to actuate normally.

When air or steam exists at the steam trap inlet, air locking or steam locking may occur easily and the condensate outflow may be impaired, so that care is required.

a. Impulse type trap

It is a trap utilized with fluid characteristics (when the condensate passes the orifice, some pressure drop is caused.) (Figure 11.22). Although the trap has an advantage of smaller size compared to other types, it has disposition of easy trouble, because it has mechanism that some steam leaks when valve shuts and precision fitting part.

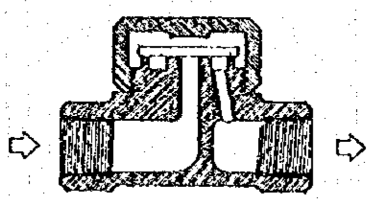
Figure 11.22 Impulse Type Trap



b. Disk type trap

The trap is equipped with a variable pressure chamber having a disc valve between the inlet and the outlet port and the disc valve opens or closes through the pressure change in the variable pressure chamber (See Figure 11.23).

Figure 11.23 Disc Type Trap



The trap has a simple structure of only a disc valve in the moving part and can actuate in a wide pressure range without adjustment. But since its actuation depends on the ambient temperature and the pressure drop in the transformer room due to the outside air cooling, the trap actuates in spite of condensate in case of rain and causes some heat loss.

11.4.2 Steam Trap Selection

The following items must be considered for the steam trap selection.

(1) Condensate load of the steam use equipment and load characteristics

For decision of the steam trap size, the condensate quantity must be investigated and the steam trap tube diameter must be decided.

Simplified calculation of the condensate quantity is possible according to the following equation.

$$W_p = \frac{C \times G \times (T_2 - T_1)}{r}$$

where

Wp	: Condensate generation quantity	kg/h
C	: Specific heat of the heated fluid	kcal/(kg·°C)
G	: Weight of the heated fluid	kg/h
$(T_2 - T_1)$	: Temperature rise	°C
r	: Latent heat of the steam	kcal/kg

Besides, in consideration of the amount carried in from the piping line and condensate amount generated by the radiation from the equipment, the generated condensate amount is made 1.5 to 2 times of the calculated value.

In case of continuous operation of the equipment, there are generally few load fluctuations. However, in the case of a batch process, start-up is executed several times per day, and with each start-up, large quantities of air and condensate must be discharged. In addition, from the point of view of productivity, the start-up time must be kept as short as possible, so that a trap with a sufficient discharge capacity must be selected. In the case of a bore of 1" and an operation pressure differential of 1.5 to 16 kg/cm² (G), the condensate discharge quantity is about 100 to 200 kg/h for a mechanical trap, 300 to 700 kg/h for a thermodynamic trap, and around 100 kg/h for a thermostatic trap.

(2) Steam conditions (pressure, temperature, dryness)

For smooth condensate discharge, the following pressure differential is required over the steam trap.

- Mechanical or thermostatic trap: 0.1 kg/cm² (G) or more
- Thermodynamic trap : 0.3 kg/cm² (G) or more

On the other hand, blocking phenomena may occur with use at a pressure in excess of the max. use pressure.

(3) Back pressure conditions

When condensate recovery is executed, the condensate is evaporated again, and a back pressure acts onto the trap.

$$\text{Permissible backpressure} = \frac{\text{Steam trap outlet pressure}}{\text{Steam trap inlet steam pressure}} \times 100\ \%$$

When the permissible back pressure is defined according to the above equation, the permissible back pressure differs according to the trap.

Mechanical trap : 90 % or less
Thermostatic, thermodynamic trap: 30 to 50 % or less

(4) Maintenance conditions: Is there little trouble and is the life long? Are disassembly and inspection easy?

The following troubles can be considered for steam traps.

Blowing : Valve closing has become impossible for the trap. The trap continues to discharge a large quantity of steam together with the condensate. In this case, the production is not impaired, so that there is a tendency towards doing nothing, but the steam loss is large.

Blocking : The strainer is clogged by rust, scale, etc., the valve has become locked and can not open, and neither condensate nor air is discharged. As the trap has become cold, this can be confirmed easily.

When this condition occurs, a bypass valve must be opened in order to maintain the production, and a gigantic steam loss may be caused.

Steam leakage: Leakage is caused by damage to valve, valve seat, or float. The trap operates, but in comparison to normal operation, the steam leakage is notably high.

As traps with a simpler construction have less trouble, simpler traps should be selected as far as possible.

(5) Body material

Select a steam trap of a suitable material according to the used steam pressure.

- Up to 16 kg/cm^2 (G), 220 °C: Cast iron (FC)
- Up to 20 kg/cm^2 (G), 350 °C: Black heart malleable cast iron (FCMB)
- Up to 45 kg/cm^2 (G), 425 °C: Cast steel (SCPH)

Table 11.4 shows the general caution items for steam trap selection.

Table 11.4 Steam Trap Selection

○ Appropriate △ Some problems × Problematic

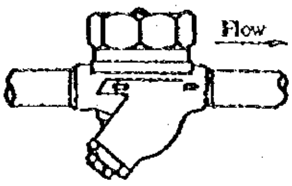
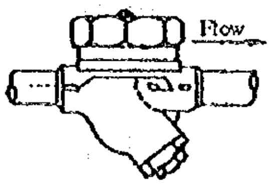
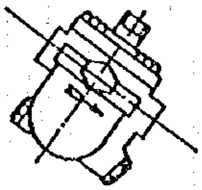
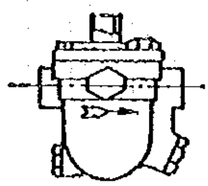
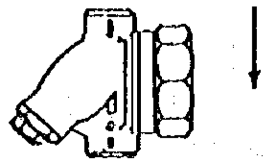
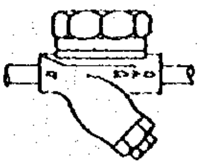
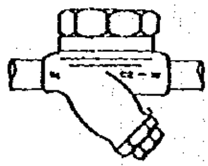
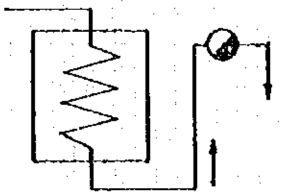
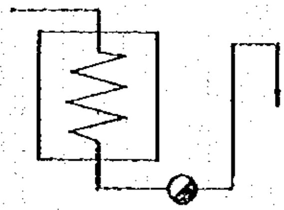
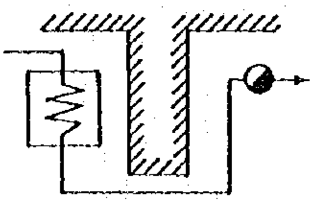
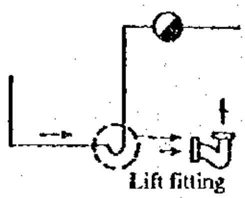
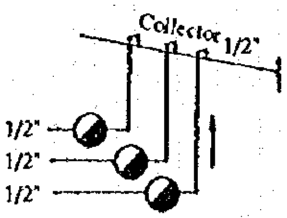
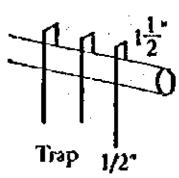
	Control method		Processing method		Backpressure conditions	Air trouble	Pressure fluctuations	Others
	2-position control (ON/OFF)	Continuous control (P,PI, PID)	Continuous processing	Batch processing				
Downward bucket type	○ However, there is the problem of steam locking by reevaporation of drain in the trap at the time of control valve closing.	○ This is an intermittent discharge method, but as the inflowing drain is discharged quickly, there is little drain stoppage and the equipment efficiency is high. The permissible back pressure is high, and discharge is possible even at low pressure.	○ Structurally, the steam consumption amount is small, and the leakage steam amount also is small.	△ The drain discharge capacity is slightly low, so that the trap becomes large in order to maintain the equipment capacity. Large equipment expenses.	○ Permissible back pressure about 90%	○	△ When the use pressure range is exceeded, drain discharge becomes impossible.	• Large size → Large radiation • Strictly horizontal installation
Float type	× Float deformation damage from drain water hammer can occur at the time of control valve opening.	○ As this is a continuous discharge method, there is no drain stoppage and the equipment efficiency becomes high. The permissible back pressure is high.	○ As the discharge valve is below the water level, water sealing takes place, and the steam leakage amount principally is zero. However, the lever float type has loss from valve closing delay.	△ Same as above. There is the problem of air trouble at the time of start-up.	○ Same as above.	× However, there is no trouble when air blow equipment is installed.	△ Same as above.	Same as above.
Disk type	△ As the control valve opening/closing timing and the trap opening/closing timing are not the same, the control accuracy is bad.	× As this is an intermittent discharge method, drain stoppage increases, the equipment efficiency drops. The permissible back pressure is low, and blow-out occurs when the control valve is throttled.	× In many cases, steam leakage occurs at the time of steady operation (little drain generation).	△ The drain discharge capacity is high and the equipment start-up time becomes short, but steam entrainment occurs at the time of start-up, and in many cases, steam leakage occurs at the time of steady operation.	△ Permissible back pressure: 30 to 50% (Spouting occurs when the backpressure becomes high.)	×	○	• Small size and light weight • Vertical installation is possible.

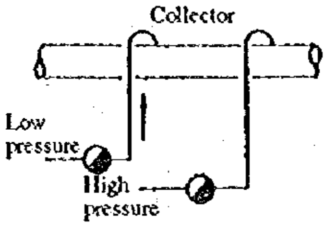
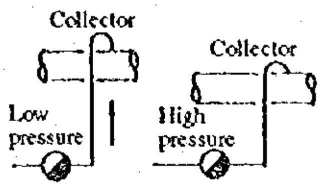
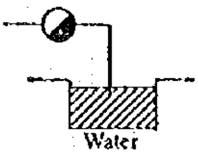
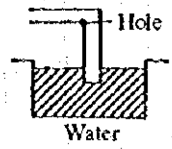
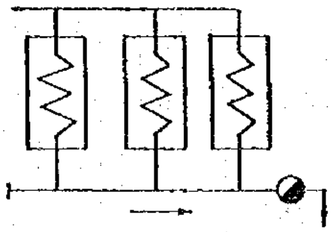
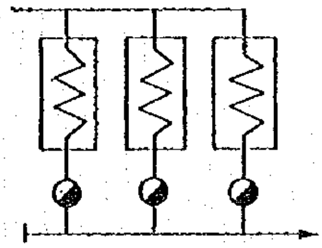
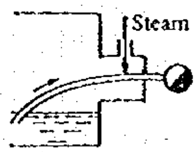
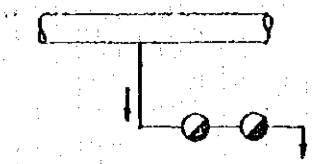
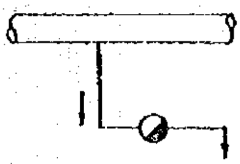
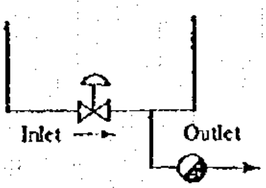
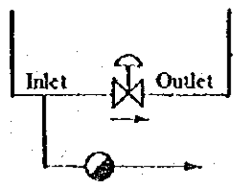
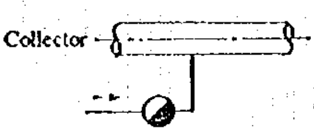
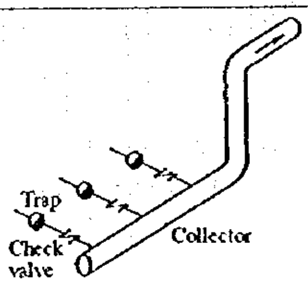
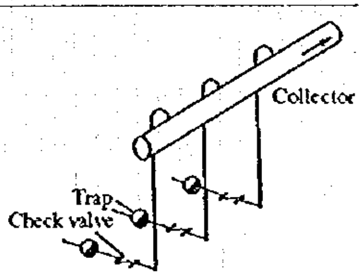
11.4.3 Steam Trap Installation Method

The installation place can be the lowest part of a riser, in front of a pressure-reducing valve or any other valve with automatic control, the drain separator, etc.

As the steam flow velocity in a steam transport pipe may be 20 to 30 m/s, a short pipe is connected to the lower part of the piping for removal so that the condensate can be separated easily. The basic rules for steam trap installation are that the condensate from the steam heating equipment shall flow smoothly by gravity flow to the trap, and that the condensate leaving the trap shall be sent by the steam pressure to the collection place. Figure 11.24 shows good and bad installation examples.

Figure 11.24 Correct Example and Wrong Example of Installation

Wrong installation	Description	Correct installation
	Steam trap should be fitted in the direction of flow. All steam traps bear on the body stamp or mark showing flow direction.	
	Free float type steam trap should be fitted horizontally.	
	Thermodynamic steam traps have no limitation as to position. It can be fitted vertically.	
	Never use an inlet pipe smaller than trap size. Steam locking and air locking are apt to occur when inlet pipe is too small.	
	Never install steam trap at a higher level than the drainage point. The inlet pipe should be one that allows water to flow into the trap by gravity.	
	If the trap has to be installed at level higher than the draining point, use a lift-fitting.	
	Size of collector must be larger than trap size. The collector should have a sectional area above sum of those for all traps connected to it.	

Wrong installation	Description	Correct installation
	Condensate discharged through two traps which operate at different pressures should not be collected to a common collector.	
	Outlet pipe should not be submerged into trenches. Provide small hole to break vacuum.	
	Each steam unit should always have individual steam trap. (Individual trapping) To fit one trap to several steam equipment is a bad practice. (Group trapping)	
	In siphon type cylinder, steam locking is liable to occur.	
	Double trapping is a bad practice. An efficient one trap is enough.	
	Steam trap must be fitted at the inlet side to discharge condensate before the regulating valve.	
	To collect condensate, the trap outlet pipe must not be connected to the bottom of collector.	
	Collector should not have a riser. The head of condensate in the collector exerts on the traps as a back pressure.	

11.4.4 Steam Trap Maintenance

(1) Inspections

When steam traps are used for a long time, the internal mechanical parts like valve, valve seat, etc. become worn, the function is impaired, and they will not stand up to use. Also, the life of each steam trap becomes uncertain.

Accordingly, careful inspections must be executed at all times, and when trouble is detected, exchange or repair must be executed to maintain the equipment in good condition and to maintain highly efficient operation for the equipment using steam. Inspections are divided into periodic and daily inspections.

The inspection is divided into periodic inspection and daily inspection. The intervals of periodic inspection should be decided in consideration of the inspection effect and cost. The inspection effect is expressed as steam consumption per unit production (steam consumption rate). For periodic inspection, the following items must be prepared.

(a) Steam trap plot plan

(b) Steam trap register book

(c) Steam trap check list

Daily inspection must be carried out to maintain the condition at the finishing time of the periodic inspection as far as possible and should be done not to worsen the steam consumption rate.

(2) Inspection method

a. Visual inspection

When condensate is discharged from a steam trap into the atmosphere, or when a side glass is mounted in the outlet of the steam trap, visual inspection is available.

b. Auditory inspection

This inspection is a method by listening to the actuating sound by a stethoscope, but much experience is necessary.

c. Touch inspection

Grip the inlet pipe and the outlet pipe of the steam trap with hands wearing gloves and make sure of the actuating condition through the temperature difference.

d. Instrument measuring inspection

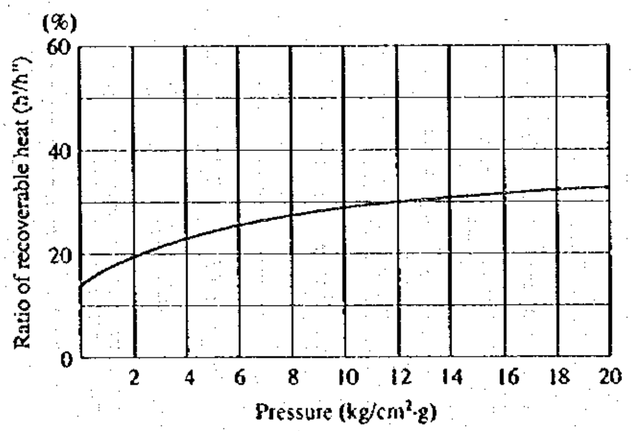
This inspection is a method to measure the actuating sound by an ultrasonic measuring instrument and thermometer and can be simply checked without experience.

11.5 Condensate Recovery

11.5.1 Significance of Condensate Recovery

Heat utilized actually in the steam servicing equipment is only the latent heat out of the total quantity of heat. The sensible heat of steam, namely the quantity of heat of condensate, is almost wasted. The heat content of condensate amounts to approximately 20 to 30 % of the total heat content of steam as shown in Figure 11.25. If this heat contents of condensate is recovered 100 % and utilized effectively, the fuel consumption can be saved by approximately 10 to 13 %. This will result in large energy conservation.

Figure 11.25 Ratio of Recoverable Heat (Enthalpy of Condensate/Enthalpy of Saturated Steam)



11.5.2 Utilization of Recovered Condensate

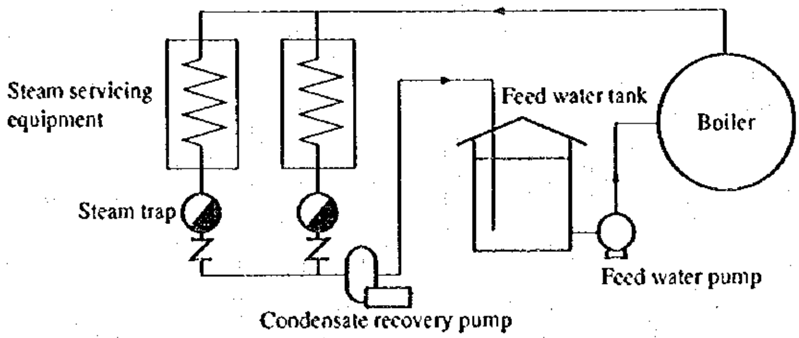
The recovered condensate is generally utilized as feed water of the boiler. Consideration of the pressure and the quantity of condensate and the layout of the steam equipment is necessary to more effectively recover the condensate. The utilization of condensate is classified into the following three methods.

(1) Direct utilization

The condensate discharged from the steam trap is recovered directly to the boiler or the feed water tank by a condensate recovery pump (See Figure 11.26).

In this case, high-pressure condensate is discharged to the atmosphere, so that flash steam is generated, and care is required as this will escape into the atmosphere and cause a loss when it is not finely dispersed and absorbed in water.

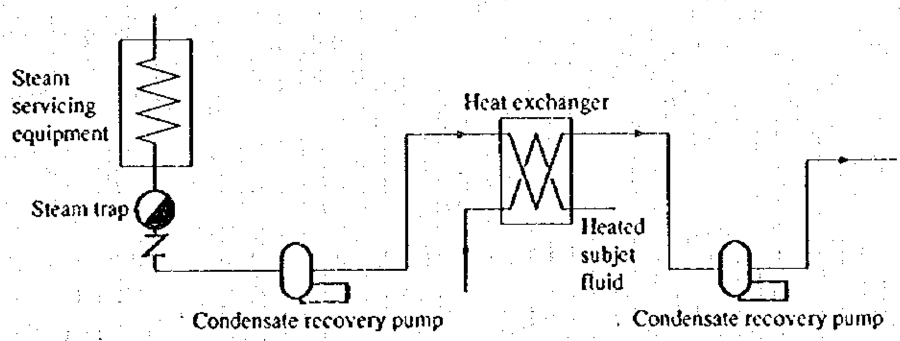
Figure 11.26 Direct Utilization to Feed Water



(2) Indirect utilization

If condensate is contaminated, only the potential heat of condensate should be recovered by heat exchange to other fluids in the heat exchanger (Figure 11.27).

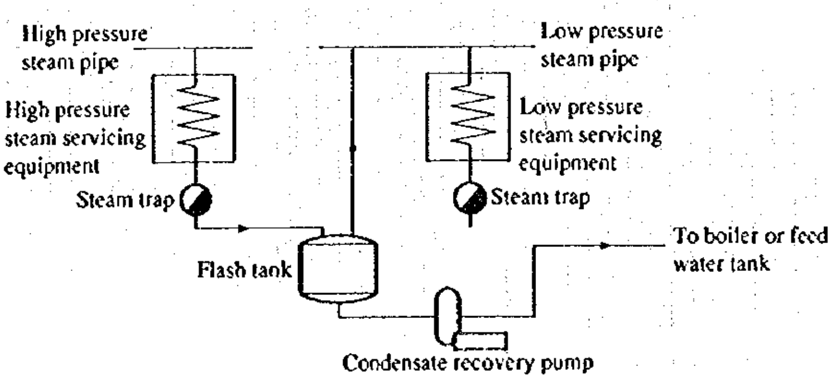
Figure 11.27 Indirect Utilization through Heat Exchanger



(3) Utilization of flash steam

If the pressure of condensate is high, it is effective that the condensate be recovered into the flash tank and a part of it be utilized as low pressure steam (See Figure 11.28).

Figure 11.28 Flash Steam Utilization



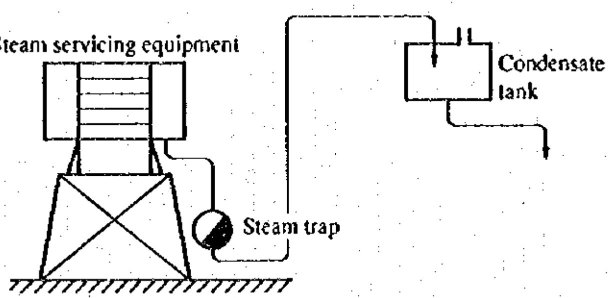
11.5.3 Condensate Recovery Method

Recovery of condensate from the generating source to re-utilization has the following three methods depending on the pressure of condensate and the recovery distance. These methods have characteristics respectively.

(1) Method by only steam trap

Condensate can be recovered to a flash tank or a condensate tank by the steam pressure acting on the steam trap. This can be applied to the case of a short distance between the condensate generating place and the utilizing place (See Figure 11.29).

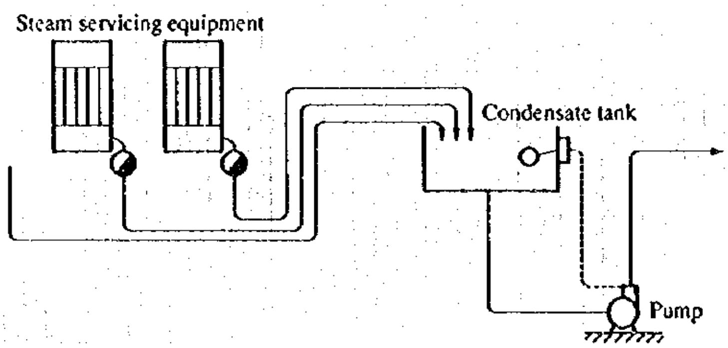
Figure 11.29 Recovery by Steam Trap Only



(2) Method by centrifugal pump

The condensate discharged from the steam trap is once gathered in a condensate tank and then is sent pressurized by a centrifugal pump. This is applied to the case when the steam traps are installed in a wide area. Each condensate tank is installed by an area or by a process and then the condensate is recovered by sending it pressurized by a pump in a central tank (See Figure 11.30).

Figure 11.30 Recovery by Centrifugal Pump

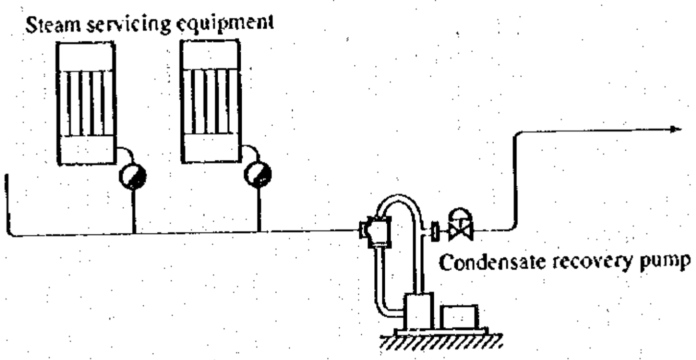


In this case, care must be used for ensuring the water head of the pump, a level control of condensate tank, and a pump capacity as well as a back pressure limit of the steam trap. Especially when the temperature in the tank is 80 °C or more, a positive water head of 4 to 5 m is required to prevent a cavitation of the pump.

(3) Method by condensate recovery pump

Recently, a condensate recovery pump, which combines with an ejector to make up for the weak points of centrifugal pump, has been used. Since the suction side of this pump is operated under a pressurized condition, no cavitation is caused and its positive water head is sufficient with about one meter. In the case of a closed system of the condensate recovery line, even a condensate of about 180 °C can be sent pressurized with a large effect of energy conservation (Figure 11.31).

Figure 11.31 Recovery by Condensate Recovery Pump



For this method, a mechanical steam trap should be applied.

11.5.4 Caution Items for Condensate Recovery

(1) Steam trap back pressure limit

When a back pressure acts onto the steam trap and when the conditions change, select a mechanical trap with little trouble. The back pressure of the recovery piping should be 40 to 45% of the min. pressure of the used steam or less.

(2) Condensate treatment

The recovered condensate may be considered as pure distilled water because practically only a very small amount of various impurities are dissolved in it. Can the recovered condensate itself be used as boiler feed water? If it is impossible to use, what is the condensate treatment method? Or, for a severe contaminated condensate, is heat quantity alone recovered? These questions should be investigated.

- pH control of condensate

The pH of condensate declines due to dissolution of carbon dioxide. In consequence, this increases the total iron concentration in the condensate. At the time of condensate recovery, some chemicals are required to be poured into the condensate to control the dissolved oxygen and the pH.

(3) Appropriate selection of the condensate recovery pipe

In case of piping systems with different back pressure, separate condensate recovery pipes must be installed for each pressure system.

In case of occurrence of flash steam, two-phase flow occurs, so that the pipe diameter must be set so that the flow velocity is within max. 15 m/s, and excessive pressure loss and water hammer must be prevented.

The pipe diameter for the recovery piping can be obtained from the following equation.

$$d^2 = \frac{3.53 \times W \times v_e}{V}$$

where

d : Piping inside diameter, cm
W: Condensate quantity, kg/h
V : Flow velocity in the pipe, m/s
Open recovery : 10 to 15 m/s,
Closed recovery: 5 to 10 m/s
v_e: Equivalent specific volume

$$v_e = v' (1 - f) + v''f$$

v' : Specific volume of saturated water at the pressure inside the recovery pipe, m^3/kg
v'': Specific volume of saturated steam at the pressure inside the recovery pipe, m^3/kg
f : Reevaporation ratio

$$f = \frac{h_1 - h_2}{r}$$

h_1: Condensate enthalpy at the trap inlet side, kcal/kg
h_2: Condensate enthalpy at the pressure inside the recovery pipe, kcal/kg
r : Evaporation latent heat at the pressure inside the recovery pipe, kcal/kg

When the recovery pipe is long, the pressure loss becomes large, so that the pressure inside the recovery pipe must be decided under consideration of the pressure loss, especially in case of self-pressure recovery.

Example for calculation of the pipe diameter:

$W = 300$ kg/h

$V = 10$ m/s

$h_1 = 160.2$ kcal/kg (6.1 kg/cm² (G))

$h_2 = 111.1$ kcal/kg (1.5 kg/cm² (G))

$r = 531.8$ kcal/kg (1.5 kg/cm² (G))

$v' = 0.00105$ m³/kg

$v'' = 1.159$ m³/kg

$$f = \frac{160.2 - 111.1}{531.8} = 0.091$$

$v_c = 0.00105 \times (1 - 0.091) + (1.159 \times 0.091) = 0.1065$ m³/kg

$d = (3.53 \times 300 \times 0.1065/10)^{1/2} = 3.4$ cm

Accordingly, a 1-1/2" pipe is used.

(4) Insulation

Thermal insulation shall be executed for the recovery piping. The piping shall be routed so that it will not get wet easily.

(5) Flash loss prevention

Discharge of the flash steam generated when the condensate is depressurized to atmospheric pressure shall be prevented. When the condensate is led into liquid in the recovery tank, cooling shall be executed so that the temperature in the recovery tank does not exceed 90 °C, and water shall be replenished.

As vibrations or noise may be caused when the temperature in the tank exceeds 80 °C, a large number of small holes shall be provided and the condensate shall be dispersed widely.

The method with direct recovery of the condensate into the boiler, without depressurization, is most effective to prevent this loss.

(6) Sight glass installation

A sight glass shall be installed in the recovery piping for monitoring of trap steam leakage.

(7) Design of the total system

The condensate recovery system is a series of closed systems from the boiler through the steam servicing equipment to return to the boiler again. Therefore, the recovery system should be designed as a whole instead of a design for every equipment.

11.5.5 Utilization of Flash Steam

In the paragraph 11.5.2 (3), it is described to recover the high pressure condensate into the flash tank and to utilize a part of the condensate as low pressure steam. However, since this method actually has various problems, its economical effect should be investigated.

(1) When the condensate quantity discharged from the steam trap is extremely small, the flash steam is also small and is scarcely worth using. There are many steam traps which discharge a small quantity of condensate in a factory. The total of these condensates result in a fair amount. But it is necessary to manage to gather these small quantity condensates with a cost as small as possible.

(2) The distance between the place generating condensate and the servicing place of flash steam is desired to be short. Because the flash steam is of a low pressure, the pressure loss is required to be minimized. If the distance is long, the piping increases in diameter and the piping cost becomes rather expensive, its merit may be offset. For this case, the utilization of flash steam must be given up.

Figure 11.32 shows an example of using the flash steam in the front stage of an air heater with steam of 8 kg/cm^2 pressure.

When a steam of 8 kg/cm^2 (G) is used by 2,500 kg/h and condensate is discharged into a flash tank of 0.5 kg/cm^2 (G) of internal pressure, the quantity of flash steam is generated with 12.3 % (wt.) by Table 11.5 and a steam quantity of 307.5 kg/h is obtained.

A flash tank is a sort of pressure vessel to recover flash steam from the condensate. The flash tank capacity is decided on the basis of this large flash steam generating volume (m^3/s). When the flash steam goes up in the tank, reasonable velocity of the flash steam may be required not to involve condensate. The inside diameter of the tank should be decided to be a rising speed of steam of 1 to 2 m/s. But as a variation of the operating condition may carry out entrainment, a separator should be mounted to the steam outlet pipe.

Figure 11.33 shows a chart to decide the inside diameter of the flash tank.

Obtain the inside diameter of the tank through the example shown in Figure 11.32.

Obtain the intersection of the steam pressure of 8 kg/cm^2 (G) in the high pressure side and the internal pressure of 0.5 kg/cm^2 (G) in the flash tank from the chart A. Move horizontally to chart B and obtain the intersection with a high pressure condensate quantity of 2.5 t/h. The diameter of the tank is obtainable as 0.55 m. If the tank capacity is 40 liters or more, a safety valve must be installed so that the pressure in the tank does not become excessive by a variation of the supplied condensate quantity and the flash steam demand.

Table 11.5 Flash Steam Generating Rate (wt. %)

Pressure in high pressure side (kg/cm^2 (G))	Low pressure side (kg/cm^2 (G))															
	0	0.3	0.5	1	1.5	2	3	4	5	6	8	10	12	14	16	18
1	3.7	2.5	1.7	—	—	—	—	—	—	—	—	—	—	—	—	—
2	6.2	5.0	4.2	2.6	1.2	—	—	—	—	—	—	—	—	—	—	—
3	8.1	6.9	6.1	4.5	3.2	2.0	—	—	—	—	—	—	—	—	—	—
4	9.7	8.5	7.7	6.1	4.8	3.6	1.6	—	—	—	—	—	—	—	—	—
5	11.0	9.8	9.1	7.5	6.2	5.0	3.1	1.4	—	—	—	—	—	—	—	—
6	12.2	11.0	10.3	8.7	7.4	6.2	4.3	3.0	1.3	—	—	—	—	—	—	—
8	14.2	13.1	12.3	10.8	9.5	8.3	6.4	4.8	3.4	2.2	—	—	—	—	—	—
10	15.9	14.8	14.2	12.5	11.2	10.1	8.2	6.6	5.3	4.0	1.9	—	—	—	—	—
12	17.4	16.3	15.5	14.0	12.7	11.6	9.8	8.2	6.9	5.7	3.5	1.7	—	—	—	—
14	18.7	17.6	16.9	15.4	14.1	13.0	11.2	9.6	8.3	7.1	5.0	3.2	1.5	—	—	—
16	19.0	18.8	18.1	16.6	15.3	14.3	12.4	10.9	9.6	8.4	6.3	4.5	2.9	1.4	—	—
18	21.0	19.9	19.2	17.7	16.5	15.4	13.6	12.1	10.8	9.6	7.5	5.7	4.1	2.7	1.3	—
20	22.0	20.9	20.2	18.8	17.5	16.5	14.7	13.2	11.9	10.7	8.7	6.9	8.3	3.8	2.5	1.2

Figure 11.32 Example of Flash Steam Use in Air Heater

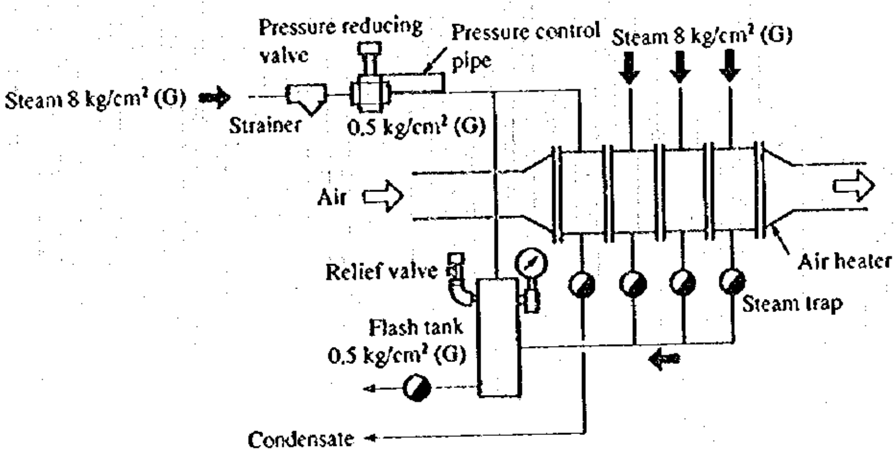
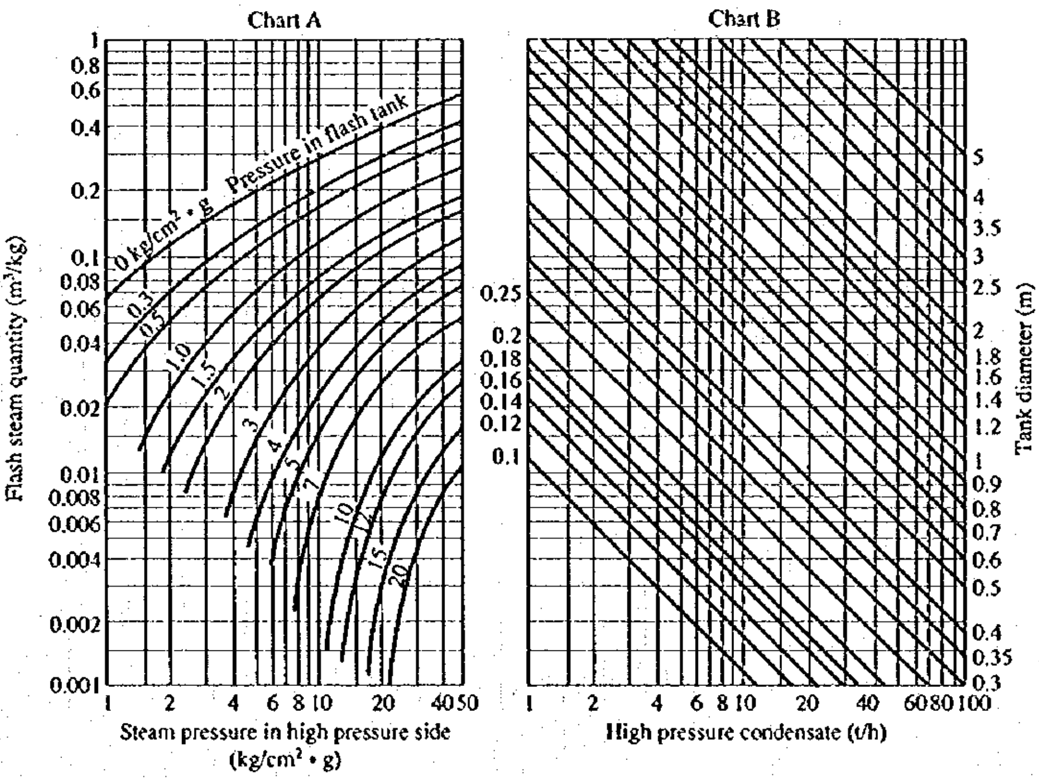


Figure 11.33 Chart of Flash Tank Diameter



11.5.6 Utilization of Thermocompressors

The structure of thermocompressors is composed of three basic parts, body, a steam nozzle and diffuser as shown in Figure 11.34. When a driving steam is expanded through the steam nozzle, a supersonic jet having an extremely low static pressure is generated. When its speed is reduced by the diffuser, the pressure is recovered. That is, when a low pressure steam is sucked into the Venturi throat section, it becomes high pressure steam.

Figure 11.35 shows an example of a chemical plant. The bottom liquid in a stripping tower is introduced to a flash tank and the low pressure of a generated flash steam is raised to a proper pressure by the thermocompressor to save additional steam.

Figure 11.34 Thermocompressor

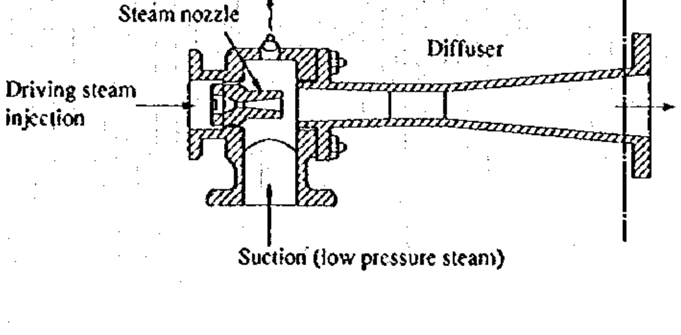
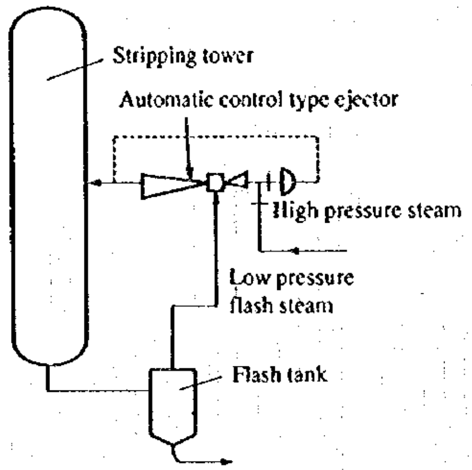


Figure 11.35 Example of Thermocompressor Use for Stripping Tower



11.6 Utilization of Direct Heating by Steam

Heating by steam direct contact has advantages such as simple and low cost equipment, quick work, and a constant temperature.

Direct heating by steam has the following two methods

11.6.1 Direct Heating in a Closed Vessel

A direct heating vessel such as an autoclave and a steamer is mounted with an airtight door and is applied to treat a settled quantity of goods in batch.

In the case of the steam direct heating, a constant temperature is accurately obtained by adjustment of steam pressure. This is suitable to heating in the case than a product quality may deteriorate at higher than a certain temperature or a process requiring a very narrow temperature range.

But, the relation that the steam temperature depends on the pressure holds true only in the case when air is not contained in the steam. In an air containing steam, the temperature is a saturation temperature equivalent to the partial pressure of steam in the mixture and is lower than the saturation temperature of steam alone. Therefore, sufficient air elimination is required at the start up. For reference, the relation between the air mixing ratio and the steam temperature is shown in Table 11.6.

Table 11.6 Relation between the Air Mixing Ratio and Steam Temperature

Steam Pressure kg/cm^2 (G) Air mixing ratio %	2	3	5	9
0	119.6	132.9	151.1	174.5
10	116.3	129.3	147.2	169.6
20	112.7	125.5	142.9	165.3
40	104.3	116.3	132.9	154.0

11.6.2 Direct Steam Blow Heating Method

A direct steam blowing operation is often carried out in some processes such as when hot water is required or when heating a raw material solution. For steam blowing, there are various methods, such as installation of a silencer to the tip of steam pipe, or a steam blowing pipe with a number of small holes (See Figure 11.36 and Figure 11.37).

Figure 11.36 Silencer

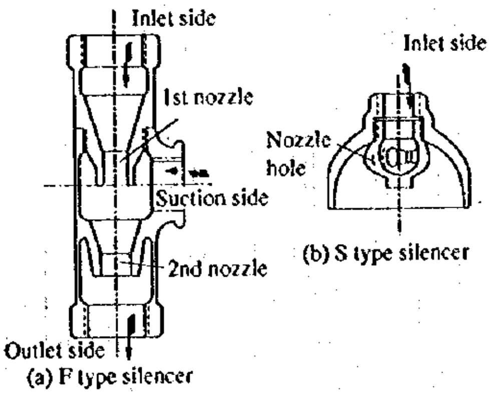
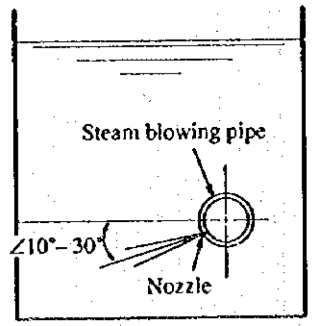


Figure 11.37 Steam Blowing Angle from Nozzle



Either method is important to condense effectively the steam blown in the liquid and to devise not to leak the live steam to atmosphere, and great consideration is necessary.

(1) Reduce the velocity of steam bubbles blown into liquid.

(2) Give a longer time to condensate the steam bubbles. Select a proper depth and location, and install a blow nozzle downward at an angle of 10° to 30° to the level (See Figure 11.37).

(3) Install the blow nozzle under a large water head.

(4) Because the heat exchange from the steam bubble to the liquid is done on the contact surface, the blow nozzle size should be designed to form a number of small bubbles in order to increase the surface area of steam bubbles.

(5) Reduce the blowing pressure of steam. A low pressure is advantageous with small steam bubbles. Since the steam blowing pipe is always inserted in the liquid bath, a stop of steam supply brings about vacuum in the pipe and causes backflow of the liquid into the pipe. A preventing measure for this is required. Install a check valve operable in a very low pressure to the pipe as shown in Figure 11.38. When the steam side comes in a vacuum, the valve opens by a pressure difference to atmospheric pressure, the vacuum is destroyed and the back flow of liquid can be prevented.

Figure 11.38 Steam Direct Blowing Heater