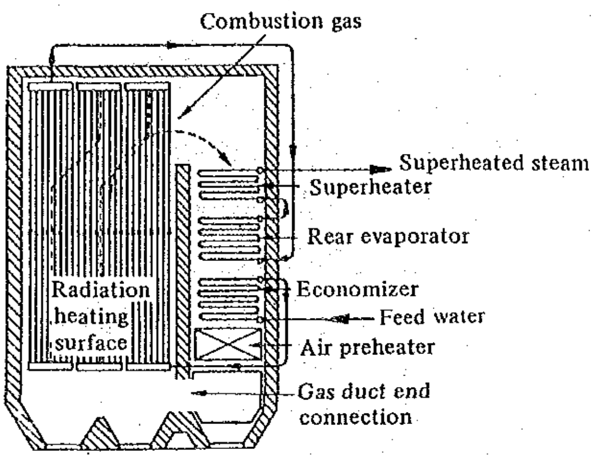


Figure 13−6 Schematic Flow Diagram of Benson Boiler

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

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

13.1.1.3 Other Boilers

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

13.1.2 Boiler Trouble Prevention

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

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

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

The points remarked to prevent trouble are as follows:

13.1.2.1 Preparation of Operation and Inspection Manuals and Training

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

13. 1.2.2 Safety Device

The boilers should pass a predetermined inspection and be equipped with a relief valve, a high and low water level alarm, a flame detector as a necessary instrument and a safety device. Furthermore, the boilers should be designed to operate failsafely against miss operation through automation. These must be inspected periodically. Table 13-2 shows the routine check items for boilers.

Table 13–2 Daily Inspection of Boiler 1 ~ 8

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
Constantly inspection	1. Pressure of boiler	O				1. Reading. Pointer movement	1. Smooth moving without catching.
					O	2. Surface temperature. Leakage.	
				O		3. Initial and stop temperatures of pressure controller.	3. No disorder. See item 9.
					O	4. Particularly take care to popping pressure at operation of the safety valve.	4. Check disorder by comparison with pressure gages of three or more
	2. Water level of boiler	O				1. Movement of water level of a water gage.	1. A little movement of the water level is normal. If the hole is clogged, the movement becomes dull. Compare the water levels of two water gage which the height changes.
			O			2. Normality of water level at start and stop of the feed water pump.	2. A detection by bellows vary 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 come 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 and with no rough particle.
		O				3. Generation of smoke and its time.	3. Check the internal pressure of furnace, exhaust gas analysis and the quantity of air and oil. Care must be used to a long time operation under a low load.
Daily inspection	4. Gage glass	O				Check of gage glass. Open a drain cock, close a steam cock and blow out boiler water sufficiently. 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.	1. Make sure the open and close condition and any leakage of each cock. Clean the inside.
					O		2. Repair to any leakage from the out of glasses. Check a disorder of the mounting core of the upper and lower cocks and the length of glass.
			O				3. Clean the glass. Use a predetermined length of glass if exchanged. Use care not to tighten too much the glass. Namely, first, open the drain cock to warm with steam and close the drain cock. Open the water cock and open fully the steam cock. After use 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. Build-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 100MΩ. Cleaning of electrode. Clean contamination of the electrode holder, check any crack or exchange it.

Table 13 − 2 ②

Type of inspection		Place of inspection	Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessary of the body)	6. Automatic feed water adjustable device. Low level breaker. High and low water level alarm.		O			1. Purge scale and sludge in the interconnecting pipe.	1. Make sure the open and close condition of the interconnecting line. Clean the inside (blow enough) in a condition of lower pressure if possible.
				O			2. Make sure the operation with lowering of the water level by blowing.	2. Make sure the operation with blowing. If impossible to blow, remove the electric wire to make sure the operation (burner cut).
						O	3. Check the internal mercury switch and bellows.	3. Check a scattering of mercury and balance. Check leakage from the bellows.
						O	4. Check the electric wiring.	4. Check damage due to heat. Rewire with a heat resistance wire.
						O	5. Check a wrong operation due to vibration.	5. Mount a stay in a change orientation.
						O	6. Check contamination, crack and leakage of the electrode holder.	6. Replace the cracked and leaking insulator with a new one and clean the electrode. Insulation shall be more than 100MΩ.
		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.
		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 delayes 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 schield 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. Stop down it when excessive current is detected (the life be shortened.).
						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 are defective.

Table 13 − 2 ③

Type of inspection		Place of inspection	Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessary of the body)	9. Pressure restriction device.				O	1. Check the operation stop pressure and the setting of differential gap.	1. Clean and check the siphone pipe, meter cock and the detective part of the bellows. Change the setting of differential gap.
						O	2. Check leakage and concave in the bellows of the detector. Check the mounted position and orientation.	
						O	3. Check the two step setting values for control of high and low-off.	
						O	4. Check damage of the electric wire.	4. Check and replacement.
		10. Pressure controller				O	1. Check the width of proportional band.	1. Change the width of proportional band.
						O	2. Check inferior contact, contamination and disconnection of resistance of the potentiometer.	2. Check, clean and replace it.
						O	3. Check clogging of the detecting part.	
		11. Wind pressure switch				O	1. Check the setting value.	1. Set to a proper value.
						O	2. Check clogging and leakage of the pipe.	2. Disassembly, check and cleaning.
		12. Oil temperature switch				O	1. Check the setting value.	1. Set to a proper oil temperature.
						O	2. Check contamination and installing dimension of the heat sensitive cylinder and the detecting part.	2. Clean contamination. Investigate the length and replace. Investigate the installing location.
						O	3. Check the configuration of detecting part.	
		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.
		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 8mm in atomosphere.

Table 13 − 2 ④

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					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 redish, 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.
		17. Burner			O		1. Remove carbon and sludge.	1. Check and Repair of burner tile.
					O		2. Check the atomizing cap and the shape of tip bleeding part. Clean contamination.	
						O	3. Clean the shaft and the lubricating pipe.	3. Remove sludge and oil.
						O	4. Apply grease the bearing. Check seal leakage.	4. Apply grease and check the bearing.
					O		5. Check any damage of the diffuser and carbon deposit.	5. Cleaning and adjustment of the interval.
						O	6. Gun type burner. Check and clean the chip and strainer.	6. Disassembly and cleaning. Check the chip hole.
						O	7. Check the gun type electrode insulator.	7. Clean and set the specified dimension.
					O		8. Check abnormal sound and overcurrent.	8. Research of its cause and assembly servicing. Replace the bearing.
						O	9. Oil leakage	9. Repair leaking place.
						O	10. Burner belt	10. Replace cracked burner.
		18. Fuel cutout valve (main valve)			O		1. Check leakage of the cutout valve.	1. A fire is extinguished entirely after cutout.
					O		2. Make sure cutout due to a low level and no ignition.	
						O	3. Check the electric wiring.	3. Check damage due to heat.
		19. Oil pump			O		1. Check the oil pressure.	1. Set to a proper oil pressure.
						O	2. Clean the strainer.	2. Drain and remove sludge.
						O	3. Check oil leakage.	3. Repair the leaking place. Replace the oil seal.
						O	4. Check over heat 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 shieth heater.	4. Sludge removing.

Table 13 − 2 ⑤

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	21. Service tank. Storage tank.			O		1. Make sure the oil level control.	1. Make sure the operation of the float switch and other controller.
						O	2. Temperature control. Operation of the control valve and the steam solenoid valve.	2. Check leakage and operation.
						O	3. Clean the oil strainer.	
					O		4. Check the receiving quantity and the residual quantity.	
						O	5. Check a leakage and the piping line.	
						O	6. Drain and remove sludge.	
		22. Oil meter		O			1. Check the oil meter indication record	1. Disassemble and clean the meter and replace the parts.
						O	2. Grasp the oil temperature passing through the meter.	2. Since the efficiency calculation is based on the specific gravity at passing through the meter, the oil temperature should be roughly grasped.
		23. Oil quantity controller.			O		1. Check the link mechanism to the controller.	1. Adjust the link mechanism compared with the air volume, check loosening and play.
						O	2. Check the oil quantity by a meter measurement. (Every load)	2. Check by operation and oil quantity and disassemble and clean it.
		24. Oil strainer			O		1. In autocleaner, turn the handle. In an change type strainer, a prepared one should be always cleaned.	
						O	2. Remove drain and sludge. Graspe a good rating of cleaning by a differential pressure between the inlet and the outlet.	
		25. Forced draft fan			O		1. Check abnormal sound and overcurrent.	1. If abnormal, disassemble and service it, and replace the bearing.
						O	2. Check foreign matter in the suction port.	2. Mount a wire gauze not to suck foreign matter.
						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 mmAq in a pressurized combustion of rated operation.
						O		
						O		
		27. Internal pressure gage of boiler.			O		1. Make sure the indication of internal pressure gage of boiler.	1. Check a clogging in lead pipe. Check the opening and closing of valve cock. Check and repair a leaking point due to corrosion.

Table 13－2 ⑥

Type of inspection	Place of inspection	Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
	28. Smoke indicator.			O		1. Check a difference between the indication and the smoke concentration.	1. Cleaning of glass. Adjust a floodlamp and a light receiver. Blow air from a compressor.
						2. Adjust the Zero point.	2. Set the zero point.
	29. Exhaust gas analyser.			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/cm².	
					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.	
	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 ground.	2. Replace and tighten a packing.
					O	3. Check an oil servicing.	3. Apply oil and grease.
					O	4. Check play in the coupling.	4. Repair and replacement.
	35. Injector.				O	1. Check a normal operation.	1. Impossible to feed when the steam pressure lowers, the feed water temperature rises, air is sucked, the feed water pressure is too much higher.
					O	2. Check the check valve. Attachment of scale.	2. Check, disassemble and clean.
					O		

Table 13 − 2 ⑦

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
	36. Water flow meter strainer		O		O	1. Check the operation. 2. Check clogging in the strainer.	1. Record, check operation. 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 internal pipe.				O O	1. Check clogging in the internal pipe. 2. Inferior or falling of the gasket for installation of the internal pipe.	1. Insufficient feed water quantity. Overhaul. 2. Water hammer. Replace the gasket.
	39. Relief valve			O	O O O	1. Check leakage of steam. 2. Check the popping and blowdown pressures in operation. 3. Check the popping volume.	1. Repair the leaked place and overhaul. 3. When the pressure rising in a rated combustion is 6% or more, it is not acceptable.
	40. Blowoff valve.			O O		1. Check leakage. Check heat by hand touch. 2. Blow off as a quick opening valve in the body side and as a slow opening valve in the secondary side. 3. Check the discharge port.	1. Overhaul or replacement. 2. For 10 kg/cm^2 or more, two valves. 3. Check the size of pit. Should arresting measure and water control.
	41. Manhole			O	O	1. Check leakage from the manhole. 2. Keep a mating surface of the gasket in no contamination.	1. Tightening, replacement of gasket. 2. Apply graphite to facilitate a replacement.
	42. Casing for insulation					1. Check gas leakage. 2. Check discolored place.	1. Gas leakage should be checked and repaired as soon as possible. 2. Find out the cause of overheat, check and repair.
	43. Refractory material.				O O	1. Check damage, falling and abnormality. 2. Check gas leakage and short pass.	1. Repair the refractory material as soon as possible. 2. Repairing.
	44. Inspection port. Cleaning port. Mounting part of accessary.				O	1. Check leakage of steam and water.	1. Repair the leaked place. Tightening, replacement of gasket.
	45. Explosion door.			O	O	1. Check gas leakage. 2. Check the spring.	1. Repair the leaking place. 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 O O	1. Check the contact of relay. 2. Check loosening of the terminal.	1. Replace the contact and relay. 2. Tighten the terminal.

Table 13 − 2 ⑧

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
	47. Timer. Time limit relay.				O O	1. Check the setting of the timer. 2. Check the setting of the cam mechanism.	1. Y-Δ starting. Starting current. Change to Δ after dropping to rated value by Y. 2. Check by sequence.
	48. Actuation lamp.			O	 O	1. Check a disconnection and luminosity. 2. Inferior contact.	1. Replace the lamp. 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	 O O	1. Check the operation. 2. Check the fixing and tightening of relay and the contact. 3. Check voltage drop.	1. Check the sequence. Replace if inferior. 2. Check the operation. 3. Check the voltage in the operating circuit.
	51. Terminal.				O O	1. Check loosening of the terminal. 2. Cleaning.	1. Tightening. Apply a detent paint if possible. 2. Suck dust by a vacuum cleaner.
	52. Insulation resistance				O	1. Measuring by 500V megger. Measure in a removing condition of a low voltage equipment.	1. If panel and secondary side has resistance less than 5MΩ, inspection or repair are required.
	53. Electric wiring				O O O	1. Check overheat, damage and discoloration. 2. Check damage of coating. 3. Check of phase.	1. Check the wiring. 2. Use care to a discolorization of the wiring around the terminal.

13. 1.2.3 Consideration on Operation

(1) Igniting operation

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

Heating just after ignition is done to make temperature raise 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 is occurred 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 scale occurs, 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 13-3 and Table 13-4.

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

In the boiler external treatment, there is elimination of suspended solid by sedimentation and filtration and salt elimination by ion exhange resin and a deaeration. For a low pressure boiler of 20 kg/cm^2 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 acculumation of these impurities.

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

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

Table 13–3 Quality of Feed Water and Boiler Water for Circulating Boiler

Classification	Type of boiler	Cylindrical boiler			Water-tube boiler													
Classification	Max. servicing pressure (kgf/cm2)				Below 10		From 10 to 20	From 20 to 30	From 30 to 50	From 50 to 75	From 75 to 100		From 100 to 125		From 125 to 150		From 150 to 200	
	Max. servicing pressure (MPa)				Below 1		From 1 to 2	From 2 to 3	From 3 to 5	From 5 to 7.5	From 7.5 to 10		From 10 to 12.5		From 12.5 to 15		From 15 to 20	
	Rate of evaporation of heating surface (kg/m²·h)	Below 30(1)	From 30 to 60	Over 60	Below 50	Over 50	–	–	–	–	–		–		–		–	
Feed water	pH (25°C)	7~9	7~9	7~9	7~9	7~9	7~9	7~9	8~9.5	8.5~9.5(9)	8.5~9.5(9)		8.5~9.5(9)		8.5~9.5(9)		8.5~9.5(9)	
	Hardness (mgCaCO₃/ℓ)	Below 60	Below 2	Below 1	Below 1	Below 1	Below 1	0	0	0	0		0		0		0	
	Fat and oil(2) (mg/ℓ)	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible		Maintain zero as much as possible		Maintain zero as much as possible		Maintain zero as much as possible	
	Dissolved oxygen (mgO/ℓ)	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Below 0.5	Below 0.1	Below 0.03	Below 0.007	Below 0.007		Below 0.007		Below 0.007		Below 0.007	
	Total iron (mgFe/ℓ)	–	–	–	–	–	–	–	Below 0.1	Below 0.05	Below 0.03(10)		Below 0.03(10)		Below 0.02(11)		Below 0.02(11)	
	Total copper (mgCu/ℓ)	–	–	–	–	–	–	–	Below 0.05	Below 0.03	Below 0.02		Below 0.01		Below 0.01		Below 0.005	
	Hydrazine(3) (mgN₂H₄/ℓ)	–	–	–	–	–	–	Over 0.2	Over 0.06	Over 0.01	Over 0.01		Over 0.01		Over 0.01		Over 0.01	
	Electrical conductivity (25°C)(μS/cm)	–	–	–	–	–	–	–	–	–	–		–		Below 0.3(12)		Below 0.3(12)	
Boiler water	Treatment method	Alkali treatment							Alkali treatment or phosphating		Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment
	pH (25°C)	11.0~11.8	11.0~11.8	11.0~11.8	11.0~11.8	11.0~11.8	10.8~11.3	10.5~11.0	9.4~11.0(13)	9.2~10.8(13)	9.0~9.8	8.5~9.5	8.7~9.7	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5
	M-Alkalinity(4) (mgCaCO₃/ℓ)	100~800	100~800	100~800	100~800	100~800	Below 600	Below 150	–	–	–	–	–	–	–	–	–	–
	Alkalinity(5) (mgCaCO₃/ℓ)	80~600	80~600	80~600	80~600	80~600	Below 500	Below 120	–	–	–	–	–	–	–	–	–	–
	Total solids (mg/ℓ)	Below 4000	Below 3000	Below 2500	Below 3000	Below 2500	Below 2000	Below 700	Below 500	Below 300	Below 100	Below 20	Below 30	Below 5	Below 20	Below 3	Below 10	Below 2
	Electrical conductivity (μS/cm)	Below 6000	Below 4500	Below 4000	Below 4500	Below 4000	Below 3000	Below 1000	Below 800	Below 500	Below 150	Below 60(12)	Below 60	Below 20(12)	–	–	–	–
	Chloride ion (mgCl⁻/ℓ)	Below 600	Below 500	Below 400	Below 500	Below 400	Below 300	Below 100	Below 80	Below 50	Below 10	–	Below 3	–	–	–	–	–
	Phosphate ion(6) ($mgPO_4^{3-}/ℓ$)	20~40	20~40	20~40	20~40	20~40	20~40	5~15	5~15	3~10	2~6	(11)	1~5	(11)	0.5~3	(11)	0.5~3	(11)
	Sulfite ion(7) ($mgSO_3^{2-}/ℓ$)	10~20	10~20	10~20	10~20	10~20	10~20	5~10	5~10	–	–	–	–	–	–	–	–	–
	Hydrazine(8) (mgN₂H₄/ℓ)	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	–	–	–	–	–	–	–	–	–	–	–
	Silica (mgSiO₂/ℓ)	–	–	–	–	–	–	Below 50	Below 20	Below 5	Below 2		Below 0.5		Below 0.3		Below 0.2	

Notes
(1) Apply it when use live steam and use constantly make-up water in a cast iron boiler.
(2) It means hexane extract (see JIS B 8224).
(3) Apply it when hydrazine may be poured in the feed water as an oxygen scavenger.
(4) It means an acid consumption (pH 4.8)
(5) It means an acid consumption (pH 8.3)
(6) Apply it when phosphate may be poured in water.
(7) Apply it when sulfite may be poured in water as an oxygen scavenger.
(8) Apply it when hydrazine may be poured as an oxygen scavenger in a cyrindrical boiler or a water-tube boiler in a pressure less than 20 kgf/cm² [2MPa] of the maximum servicing pressure.
(9) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.
(10) It is desirable to maintain below 0.02 mgFe/lit.
(11) It is desirable to maintain below 0.01 mgFe/lit.
(12) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.
(13) The pH lower limit indicates a lower limit when a phosphating is applied and shall be taken as a pH corresponding to the lower limit of the PO_4^{3-} concentration of boiler water. (See paragraph 1.3.1 of the description).
(14) If hardness components and pH lowering components are leaked in the boiler water due to sea water leakage from the sample vessel, some type and quantity of phosphate required to the emergency treatment against the leaked components and quantity should be poured.

Remarks.
1. The concentration unit of mg/lit. shall be regarded as the same as ppm.
2. For a make-up water to a water-tube boiler of the maximum servicing pressure of 20 kgf/cm², desalted water shall be applied.
3. Hydrazine or sulfite as an oxygen scavenger, as a rule, either one of them shall be poured.

the following equation from the feed water quantity and the boiler water standard shown in Tables 13-3, 13-4.

Table 13–4 Quality of Feed Water for Once-Through Boiler

Classification	Max. servicing pressure							
		kgf/cm²	Below 25	From 75 to 100	From 100 to 125	From 125 to 150	From 150 to 200	Over 200
		(MPa)	Below 2.5	From 7.5 to 10	From 10 to 12.5	From 12.5 to 15	From 15 to 20	Over 20
Feed water	pH (25°C)		10.5~11.0	8.5~9.5(2)	8.5~9.5(2)	8.5~9.5(2)	8.5~9.5(2)	9.0~9.5
	Hardness ($mgCaCO_3/\ell$)		Below 1*	0	0	0	0	0
	Dissolved oxygen (mgO/ℓ)		Below 0.5	Below 0.007	Below 0.007	Below 0.007	Below 0.007	Below 0.007
	Total iron ($mgFe/\ell$)		–	Below 0.03(3)	Below 0.03(3)	Below 0.02(4)	Below 0.02(4)	Below 0.01
	Total copper ($mgCu/\ell$)		–	Below 0.01	Below 0.01	Below 0.005	Below 0.003	Below 0.002
	Hydrazine(1) (mgN_2H_4/ℓ)		–	Below 0.01	Below 0.01	Below 0.01	Below 0.01	Below 0.01
	Silica ($mgSiO_2/\ell$)		–	Below 0.04(5) Below 0.02(6)	Below 0.04(5) Below 0.02(6)	Below 0.03(5) Below 0.02(6)	Below 0.02	Below 0.02
	Total solids (mg/ℓ)		Below 700	–	–	–	–	–
	Electrical conductivity (25°C)($\mu S/cm$)		Below 1000	Below 0.3(7)	Below 0.3(7)	Below 0.3(7)	Below 0.3(7)	Below 0.25(7)
	Phosphate ion ($mgPO_4^{3-}/\ell$)		20~40	–	–	–	–	–

Note (1) The concentration of hydrazine shall be limited with a concentration not exceeded the upper limit of pH.
(2) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.
(3) It is desirable to maintain below 0.02 mgFe/lit.
(4) It is desirable to maintain below 0.01 mgFe/lit.
(5) It is applied to a boiler with separator.
(6) It is applied to a boiler without separator.
(7) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.

Remarks 1. Since the concentration of the total solids in the feed water for a high pressure once-through boiler is very low and can not be nearly measured, the measured value of electrical conductivity should be used to estimate a concentration of soluble solids in the total solids.
2. The maximum servicing pressure of 25 kgf/cm² [2.5 MPa] or less shall be applied to an once-through boiler returned by 30% of the boiler water into the feed water. Since the water returned from the boiler is added into the feed water is again fed to the boiler with addition of some chemicals, the water quantity shall be controlled by the method similar to it for a circulating boiler.
The mark of * shall be applied to the feed water prior to addition of a returned water.

y: Blow amount

k: Blow rate (%)

x: Evaporation

a: Impurity concentration in feed water

b: Impurity concentration standard in boiler water

$$a(x+y) = b\,y$$

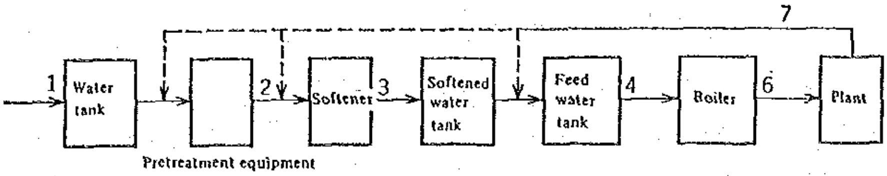
$$\therefore y = \frac{a}{b-a}\,x$$

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

Although a total dissolved salt or a chloride ion in the impurities 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 total salt concentration and the electrical conductivity.

Table 13–5 is a standard of the water quality measuring frequency shown as reference in JIS.

Table 13–5 Standard for Water Quality Measuring Frequency



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

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

13. 1.3 Expression of Boiler Capacity

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

13. 1.3.1 Rated Evaporation

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

13. 1.3.2 Equivalent Evaporation

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

13.1.4 Heat Balance of Boilers

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

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

At the start, a limit of heat balance should be fixed as shown in Figure 13-7. 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 13-6 and the operation record should be described on the items of Table 13-7. The results of the heat balance should be entered into the formula of Table 13-8. Referred items are indicated for calculation below.

a. Method to obtain lower combustion heat from higher combustion heat.

Solid fuel and liquid fuel: $Hi = Hh - 6(9h + w)$ 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 13-8). 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 $+ 0.00065 (t - 15)$

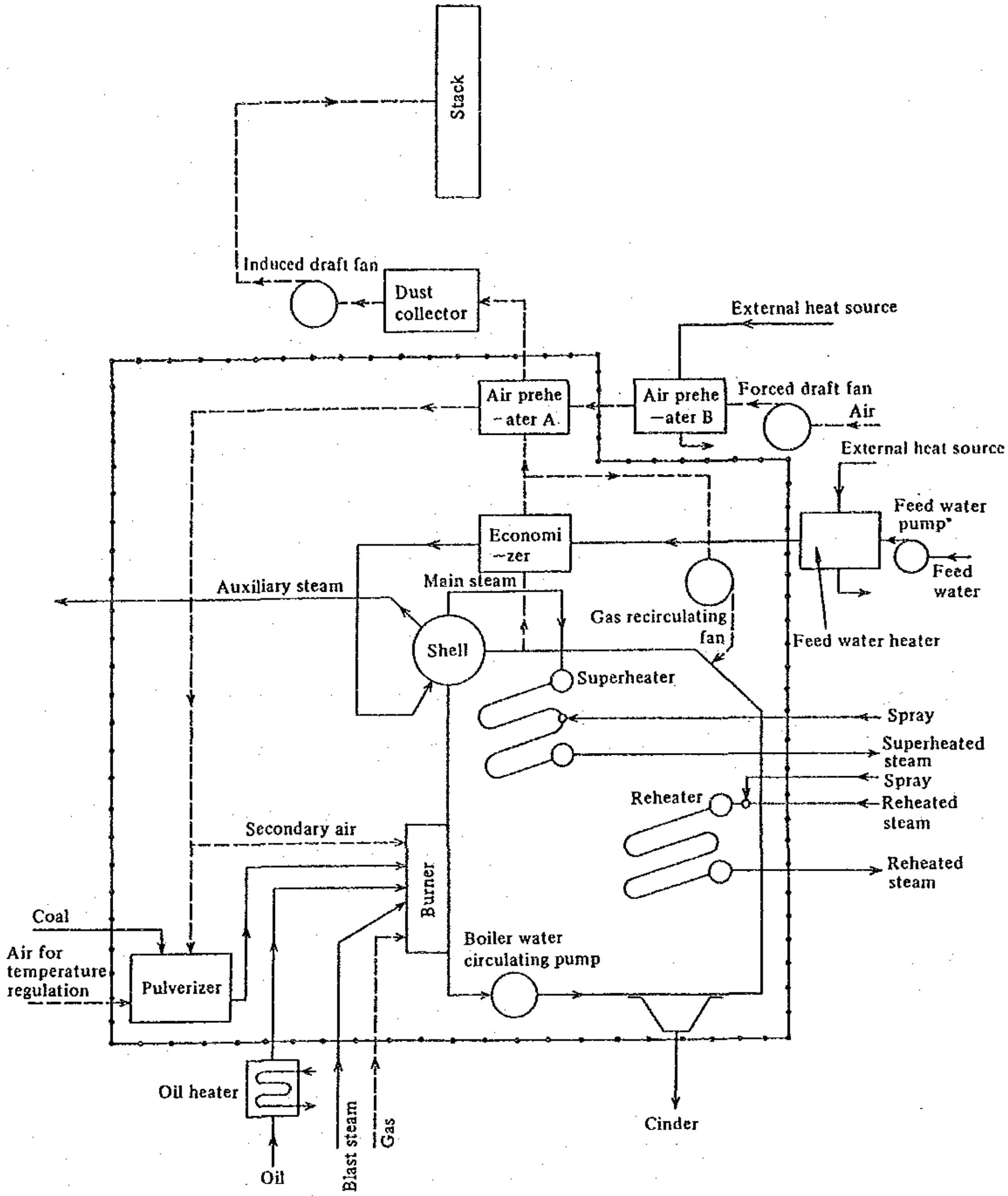


Figure 13–7 Standard Range of Boiler Heat Balance

Table 13−6 Oneline of Equipment

Outlines of the installation shall be indicated as follows.

Name of plant, Address			
Name of boiler maker			
Number of boiler, date of manufacture			
Boiler proper	Kind · Type		
	Maximum continuous evaporation t/h Maximum working pressure (¹) kg/cm² Normal operating pressure (¹) kg/cm² Superheated (reheated) temperature °C Calorific value of standard fuel kcal/kg(m_n^3)[kJ/kg(m_n^3)]		
	Heating surface area	Boiler m² Water wall m² Total m²	
Super-heater	Type Heating surface area m²		
Re-heater	Type Heating surface area m²		
Econo-mizer	Type Heating surface area m²		
Airpre-heater	Type Heating surface area m²		
Firing equip-ment	Type (¹) Burner capacity, number and grate area kg(m_n^3)/h, m²		
Comb-ustion chamber	Furnace volume m³ Standard heat generation kcal/m³ h		
Control device	Pressure Water level Superheating temp. Others		
Drafting equipment	Drafting		
	Forced fan	Type Capacity m³/min(°C) pressure mmAq	
	Induced fan	Type Capacity m³/min(°C) pressure mmAq	
	Other fan	Type Capacity m³/min(°C) pressure mmAq	
	Chimney	Size (diameter x height) m x 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 13-7 Results of Measurement

The test results shall be indicated as follows.

			Unit	Remarks
Date and time of test				
Personnel in charge				
Weather, atmostpheric pressure, wind velocity			°C	
Ambient temperature, dry bulb and wet bulb temperatures			°C	
Duration of test			h	
Load factor			%	
Fuel	Brand and characteristic of fuel			
Fuel	Mixing ratio			
Fuel	Temperature as used		°C	
Fuel	Total moisture		%	
Fuel	Proximate analysis	Analysed value	%	
Fuel	Proximate analysis	As used	%	Correct by moisture.
Fuel	Ultimate analysis	Analysed value	%	
Fuel	Ultimate analysis	As used	%	Correct by moisture.
Fuel	Lower calorific value of fuel used (high)	Analysed value	kcal/kg(m_n^3)	Measure a high combustion heat by a calorimeter and obtain a low combustion heat by calculation. Correct by moisture.
Fuel	Lower calorific value of fuel used (high)	As used	kcal/kg(m_n^3)	
Fuel	Fuel consumption Total		kg(m_n^3)	
Fuel	Fuel consumption Per hour		kg(m_n^3)/h	
Fuel	Firing quantity per burner		kg(m_n^3)/h	
Fuel	Combustion chamber heat generation		kcal/m³ h	
Condition of firing equipment				
Condition of control device				
Condition of drafting equipment				
Condition of water feeding equipment				
Feed water	Quantity of feed water	Total (corrected value)	kg	
Feed water	Quantity of feed water	Per hour	kg/h	
Feed water	Quantity of feed water	Per unit volume of fuel	kg/kg(m_n^3)	
Feed water	Temperature	Economizer inlet	°C	
Feed water	Temperature	Boiler proper inlet	°C	
Feed water	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum	kg/cm²	
Steam generated	Pressure	Superheater outlet	kg/cm²	
Steam generated	Pressure	Reheater inlet	kg/cm²	
Steam generated	Pressure	Reheater outlet	kg/cm²	
Steam generated	Temperature	Superheated outlet	°C	
Steam generated	Temperature	Reheater inlet	°C	
Steam generated	Temperature	Reheater outlet	°C	
Steam generated	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (i.e. 98%)
Steam generated	Evaporation	Total (corrected value)	kg	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
Steam generated	Evaporation	Per hour	kg/h	
Steam generated	Evaporation	Equivalent evaporation per hour	kg/h	
Steam jetting into furnace	Source of steam			If impossible to measure, use an approximate figures.
Steam jetting into furnace	Quantity of stem		kg/h	
Steam jetting into furnace	Pressure and temperature		kg/cm², °C	
Air for combustion	Air quantity per 1 kg of fuel		m_n^3/kg(m_n^3)	Calculate from the composition of fuel and combustion gas.
Air for combustion	Temperature and pressure	Air preheater inlet	°C, mmAq	
Air for combustion	Temperature and pressure	Air preheater outlet	°C, mmAq	
Air for combustion	Temperature and pressure	Outlet of forced draft fan	°C, mmAq	
Air for combustion	Temperature and pressure	Inlet of chamber	°C, mmAq	

Table 13 - 7 ②

Air for combustion	Air ratio	Outlet of boiler proper Outlet of economizer Outlet of air preheater	
Exhaust (combustion) gas	Exhaust gas quantity per unit volume of fuel $m_n^3/kg(m_n^3)$		
	Temperature and pressure	Furnace inside °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		Caluculate from the fuel consumption,ash in fuel, unburned fuel in cinder.
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 refuse and exhaust gas, pressures, temperatures and etc. of the steam, air and gas shall be the averages.
2. Load factor shall be as follows.

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

3. Condition of firing equipment means as follows.

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

4. Condition of water feeding equipment means as follows.

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

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

Table 13–8 Heat Balance Table

Heat input		kcal/kg(m_n^3)	%	
(1) Calorific value of fuel	H_l[3]			
(2)[2] Sensible heat of fuel	Q_1			(2)Mean specific heat of fuel x (Fuel temp. after heating–ambient temp.)
(3)[2] Sensible heat of air	Q_2			(3)Air quantity (including moisture) per 1 kg (Nm³) of fuel x Mean specific heat of air x (Air temp. after heating—combient temp.)
(4)[2] Carrying heat of furnace blast steam.	Q_3			(4)Blast steam quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam—Enthalpy of steam in ambient temp.) (Only in case of steam from another soruce)
Total	H_l[3] + Q		100	

Note [2] (2), (3) and (4) are due to the external heat source. (5) is not usually considered.
[3] In case of a high heating value basis, it shall be taken as $H_h(H_h')$.

	Heat output		kcal/kg(m_n^3)	%	
Effective heat	(1) Heat content of generated steam				(1) (a)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of boiler–Enthalpy in outlet of economizer)
	(a) Heat absorbed at the boiler proper	Q_b			
	(b) Heat absorbed by economizer	Q_{ec}			(b)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of feed water in outlet of economizer–Enthalpy of feed water)
	(c) Heat absorbed by superheater	Q_{sh}			(c)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of superheater–Enthalpy of steam in outlet of boiler) + Spray quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of superheater–Enthalpy of spray water).
	(2) Heat absorbed by reheater	Q_{rh}			(2)Steam quantity in inlet of reheater per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of reheater–Enthalpy of steam in inlet of reheater) + Spray quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of reheater–Enthalpy of spray water)
	Subtotal	Q_s			
Heat loss	(1) Heat loss due to moisture in exhaust gas	L_1l[4]			(1)Actual exhasut gas quantity (including moisture) per 1 kg (Nm³) of fuel x Mean specific heat of exhaust gas x (Temp. of exhaust gas—ambient temp.)
	(2) Heat loss due to furnace blast steam	L_2			See item (f)
	(3) Heat loss due to incomplete burning exhaust gas	L_3			See item (g)
	(4) Heat loss due to combustible in refuse	L_4			See item (h)
	(5) Heat loss due to release	L_5			See item (i)
	(6) Heat loss due to others	L_6			See item (j)
	Subtotal	$L\ell$[4]			
Total				100	

Note [4] In case of a high heating value basis L_1l {L_1l'} shall be taken as L_{1h} {L_{1h}'} and $L\ell$ {$L\ell'$} be taken as shall be taken as L_h {L_h'}

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

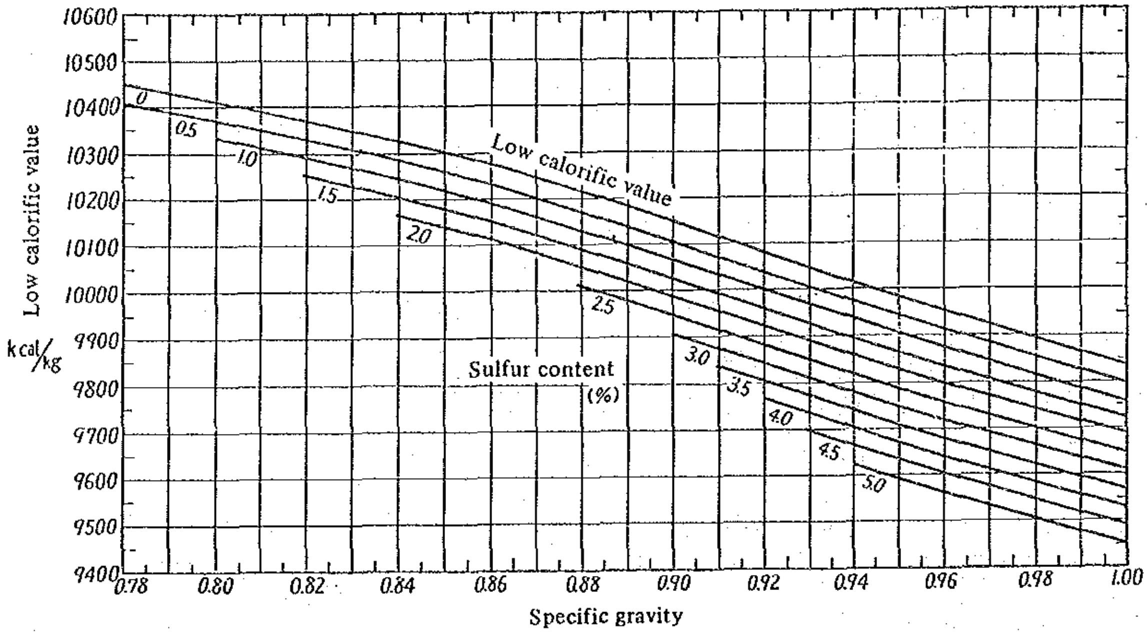


Figure 13–8 Relation between Calorific Value (Low) and Specific Gravity of Petroleum Fuel

Even if the following equation is applied, error is not so much. (See Table 13-9)

Gaseous fuel: $Hl = 25.7\,(H_2) + 30.2\,(CO) + 85.5\,(CH_4)$

$+ 143\,(C_2H_4) + 154\,(C_2H_6) + 211\,(C_3H_6)$

$+ 224\,(C_3H_8) + 272\,(C_4H_8)$

$+ 295\,(C_4H_{10})$ kcal/m³$_N$ Fuel

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

Table 13–9 Specific Gravity, Sulfur Content and Mean Calorific Value of Petroleum Fuel

	Specific gravity	Sulfur content (%)	Mean calorific value (low)
Kerosene	0.79 ~ 0.85	0.5 Below	kcal/kg 10400
Light oil	0.82 ~ 0.86	1.2以下	10300
Whole fuel oil			9850
A fuel oil	0.84 ~ 0.86	0.5 ~ 1.5	10200
B fuel oil	0.88 ~ 0.92	0.5 ~ 3.0	9900
C fuel oil	0.90 ~ 0.95	1.5 ~ 3.5 (Over)	9750

b. Specific heat of fuel and air

Coal: 0.25 kcal/kg. °C

Fuel oil: 0.45 kcal/kg. °C

Natural gas: 0.38 ~ 0.42 kcal/m³$_N$ °C

LPG: 0.7 ~ 1.0 kcal/m³$_N$ °C

Air: 0.31 kcal/m³$_N$ °C (Influence of humidity in air can be neglected.)

c. Air amount

The theoretical air (A_o) 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.

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

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

$$A_0 = 1.01\frac{Hl + 550}{1{,}000}\ m^3N/kg\ Fuel$$

Case of fuel oil

$$A_0\ 12.38\frac{Hl - 1{,}100}{10{,}000}\ m^3N/kg\ Fuel$$

Case of gaseous fuel

$$A_0 = 11.20\ \frac{Hl}{10{,}000}\ m^3N/m3N\ Fuel$$

(Case of hydrocarbon-mixed gas)

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

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

m: Air ratio

z: Absolute humidity of atmosphere kg/kg Dry air

The value of z can be obtained from Figure 13-9.

Figure 13-9

Absolute humidity z kg (steam)/kg (dry air)

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

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

$$m = \frac{21}{21 - (O_2)} = \frac{(CO_2)max}{(CO_2)}$$

(O_2): Oxygen concentration in exhaust gas %

(CO_2): Carbon dioxide concentration in exhaust gas %

(CO_2) max: Maximum carbon dioxide concentration in theoretical dry exhaust gas

The value of (CO_2) max may use the following values.

Coal: 18.5%, Fuel oil: 15.7%, Natural gas: 12% and LPG: 14.5%

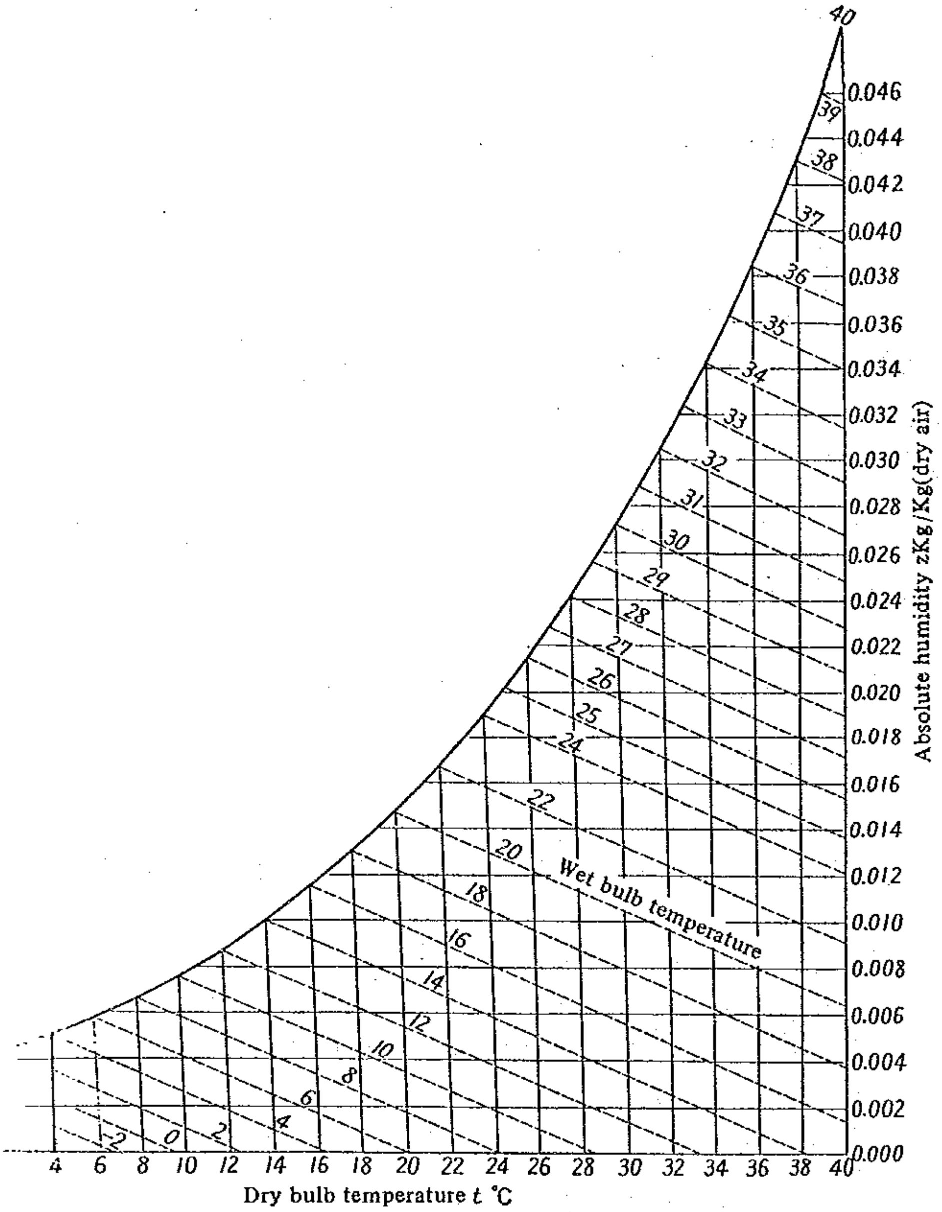


Figure 13–9 Absolute Humidity of Air

d. Heat absorbed by generated steam

The heat absorbed by the generated steam is shown by the value that substracts the sensible heat of feed water from the retaining heat of generated steam. If water is sprayed in 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 retaining heat of steam is shown in Tables 13-10 and 11.

e. Exhaust gas loss

The average specific heat of combustion exhaust gas is 0.33 kcal/m^3N°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 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

$$G_0 = \frac{0.904\ Hl}{1,000} + 1.67\ m^3 N/kg\ Fuel$$

Case of fuel oil

$$G_0 = \frac{15.75\ Hl}{10,000} 3.91\ m^3 N/kg\ Fuel$$

Case of gaseous fuel

$$G_0 = \frac{12.25\ Hl}{10,000}\ m^3 N\ Fuel$$

(Case of hydrocarbon-mixed gas)

Actual exhaust gas quantity is as the following equation.

$G = G_0 + (m - 1) A_0$ + water vapor quantity due to moisture in air

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

f. Steam into boiler

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 1k g of fuel x [(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 (600 kcal/kg), and an output heat and input heat are calculated in enthalpies in each condition.

g. Heat loss due to unburned gas

It is calculated according to the following equation.

Heat loss = 30.5 $[G_0 + (m - 1) A_0]$ (CO) kcal/kg ($m^3 N$) Fuel

(CO) is a carbon monoxide content (%) in dry exhaust gas.

h. Heat loss due to combustible refuse in cinder.

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

$c = au/(100 - u)$

here, a: Ash content % in fuel

u: Average unburned content % in cinder

Heat loss is 81c kcal/kg Fuel.

i. Heat loss due to heat release

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

The following values are shown as round figures for heat loss. (Table III-7-12)

For reference, the diagram shown in the Power Test Code of the ASME (American Society of Mechanical Engineering) is shown in Figure 13-10. 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 condi-

Table 13−10 Thermodynamic Properties of Saturated Water and Saturated Steam (Temperature Reference)

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

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

Table 13−11 Thermodynamic Properties of Saturated Water and Saturated Steam (Pressure Reference)

Pressure	Saturation temperature		Specific volume (m³/kg)		Specific enthalpy (kJ/kg)			Specific entropy (KJ/(kg·K))	
P (MPa)	t_s (℃)	t_s (K)	v'	v''	h'	h''	$r=h''-h'$	s'	s''
0.001	6.9828	280.1328	0.0010001	129.20	29.34	2514.4	2485.0	0.1060	8.9767
0.002	17.513	290.663	0.0010012	67.01	73.46	2533.6	2460.2	0.2607	8.7246
0.003	24.100	297.250	0.0010027	45.67	101.00	2545.6	2444.6	0.3544	8.5785
0.004	28.983	302.133	0.0010040	34.80	121.41	2554.5	2433.1	0.4225	8.4755
0.005	32.898	306.048	0.0010052	28.19	137.77	2561.6	2423.8	0.4763	8.3960
0.006	36.183	309.333	0.0010064	23.74	151.50	2567.5	2416.0	0.5209	8.3312
0.007	39.025	312.175	0.0010074	20.53	163.38	2572.6	2409.2	0.5591	8.2767
0.008	41.534	314.684	0.0010084	18.10	173.86	2577.1	2403.2	0.5925	8.2296
0.009	43.787	316.937	0.0010094	16.20	183.28	2581.1	2397.9	0.6224	8.1881
0.010	45.833	318.983	0.0010102	14.67	191.83	2584.8	2392.9	0.6493	8.1511
0.02	60.086	333.236	0.0010172	7.650	251.45	2609.9	2358.4	0.8321	7.9094
0.03	69.124	342.274	0.0010223	5.229	289.30	2625.4	2336.1	0.9441	7.7695
0.04	75.886	349.036	0.0010265	3.993	317.65	2636.9	2319.2	1.0261	7.6709
0.05	81.345	354.495	0.0010301	3.240	340.56	2646.0	2305.4	1.0912	7.5947
0.06	85.954	359.104	0.0010333	2.732	359.93	2653.6	2293.6	1.1454	7.5327
0.08	93.512	366.662	0.0010387	2.087	391.72	2665.8	2274.0	1.2330	7.4352
0.10	99.632	372.782	0.0010434	1.694	417.51	2675.4	2257.9	1.3027	7.3598
0.101325	100.00	373.15	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
0.12	104.81	377.96	0.0010476	1.428	439.36	2683.4	2244.1	1.3609	7.2984
0.14	109.32	382.47	0.0010513	1.236	458.42	2690.3	2231.9	1.4109	7.2465
0.16	113.32	386.47	0.0010547	1.091	475.38	2696.2	2220.9	1.4550	7.2017
0.18	116.93	390.08	0.0010579	0.9772	490.70	2701.5	2210.8	1.4944	7.1622
0.2	120.23	393.38	0.0010608	0.8854	504.70	2706.3	2201.6	1.5301	7.1268
0.3	133.54	406.69	0.0010735	0.6056	561.43	2724.7	2163.2	1.6716	6.9909
0.4	143.62	416.77	0.0010839	0.4622	604.67	2737.6	2133.0	1.7764	6.8943
0.5	151.84	424.99	0.0010928	0.3747	640.12	2747.5	2107.4	1.8604	6.8192
0.6	158.84	431.99	0.0011009	0.3155	670.42	2755.5	2085.0	1.9308	6.7575
0.7	154.96	438.11	0.0011082	0.2727	697.06	2762.0	2064.9	1.9918	6.7052
0.8	170.41	443.56	0.0011150	0.2403	720.94	2767.5	2046.5	2.0457	6.6596
0.9	175.36	448.51	0.0011213	0.2148	724.64	2772.1	2029.5	2.0941	6.6192
1.0	179.88	453.03	0.0011274	0.1943	762.61	2776.2	2013.6	2.1382	6.5828
1.2	187.96	461.11	0.0011386	0.1632	798.43	2782.7	1984.3	2.2161	6.5194
1.4	195.04	468.19	0.0011489	0.1407	830.08	2787.8	1957.7	2.2837	6.4651
1.5	198.29	471.44	0.0011539	0.1317	844.67	2789.9	1945.2	2.3145	6.4406
1.6	201.37	474.52	0.0011586	0.1237	858.56	2791.7	1933.2	2.3436	6.4175
1.8	207.11	480.26	0.0011678	0.1103	884.58	2794.8	1910.3	2.3976	6.3751
2.0	212.37	485.52	0.0011766	0.09954	908.59	2797.2	1888.6	2.4469	6.3367
2.2	217.24	490.39	0.0011850	0.09065	930.95	2799.1	1868.1	2.4922	6.3015
2.4	221.78	494.93	0.0011932	0.08320	951.93	2800.4	1848.5	2.5343	6.2690
2.5	223.94	497.09	0.0011972	0.07991	961.96	2800.9	1839.0	2.5543	6.2536
2.6	226.04	499.19	0.0012011	0.07686	971.72	2801.6	1825.0	2.5831	6.2315
2.8	230.05	503.20	0.0012088	0.07139	990.48	2802.0	1811.5	2.6106	6.2104
3.0	233.84	506.99	0.0012163	0.06663	1008.4	2802.3	1793.9	2.6455	6.1837
3.5	242.54	515.69	0.0012345	0.05703	1049.8	2802.0	1752.2	2.7253	6.1228
4.0	250.33	523.48	0.0012521	0.04975	1087.4	2800.3	1712.9	2.7965	6.0685
4.5	257.41	530.56	0.0012691	0.04409	1122.1	2797.7	1675.6	2.8612	6.0191
5.0	263.91	537.06	0.0012858	0.03943	1154.5	2794.2	1639.7	2.9206	5.9735
5.5	269.93	543.08	0.0013023	0.03563	1184.9	2789.9	1605.0	2.9757	5.9309
6.0	275.55	548.70	0.0013187	0.03244	1213.7	2785.0	1571.3	3.0273	5.8908
6.5	280.82	553.97	0.0013350	0.02972	1241.1	2779.5	1538.4	3.0759	5.8527
7.0	285.79	558.94	0.0013513	0.02737	1267.4	2773.5	1506.0	3.1219	5.8162
7.5	290.50	563.65	0.0013677	0.02533	1292.7	2766.9	1474.2	3.1657	5.7811
8.0	294.97	568.12	0.0013842	0.02353	1317.1	2759.9	1442.8	3.2076	5.7471
9	303.31	576.46	0.0014179	0.02050	1363.7	2744.6	1380.9	3.2867	5.6820
10	310.96	584.11	0.0014526	0.01804	1408.0	2727.7	1319.7	3.3605	5.6198
11	318.05	591.20	0.0014887	0.01601	1450.6	2709.3	1258.7	3.4304	5.5595
12	324.65	597.80	0.0015268	0.01428	1491.8	2689.2	1197.4	3.4972	5.5002
13	330.83	603.98	0.0015672	0.01280	1532.0	2667.0	1135.0	3.5616	5.4408
14	336.64	609.79	0.0016106	0.01150	1571.6	2642.4	1070.7	3.6242	5.3803
15	342.13	615.28	0.0016579	0.01034	1611.0	2615.0	1004.0	3.6859	5.3178
16	347.33	620.48	0.0017103	0.009308	1650.5	2584.9	934.3	3.7471	5.2531
17	352.26	625.41	0.0017696	0.008371	1691.7	2551.6	859.9	3.8107	5.1855
18	356.96	630.11	0.0018399	0.007498	1734.8	2513.9	779.1	3.8765	5.1128
19	361.43	634.58	0.0019260	0.006678	1778.7	2470.6	692.0	3.9429	5.0332
20	365.70	638.85	0.0020370	0.005877	1826.5	2418.4	591.9	4.0149	4.9412
21	369.78	642.93	0.0022015	0.005023	1886.3	2347.6	461.3	4.1048	4.8223
22	373.69	646.84	0.0026714	0.003728	2011.1	2195.6	184.5	4.2947	4.5799
22.12	374.15	647.30	0.00317		2107.4		0.0	4.4429	

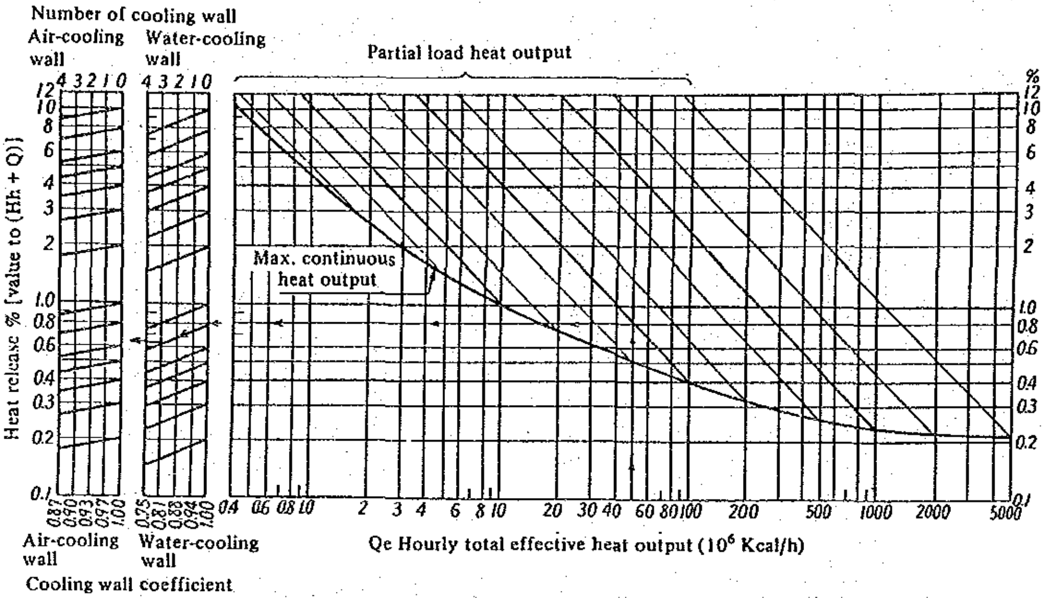
Table 13–12 Radiant Heat Loss

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

tions, it should be corrected by a multiple of Figure 13-11. This diagram is for a high calorific value. For a low calorific value is should be multiplied by Hh/H*l*.

j. Other heat losses

They are error terms.



(The figure shows the case that the temperature difference between the heat release surface and the ambient air is 28°C and the wind velocity on the heat release surface is 0.5 m/s. Correction multiples in other condition are based on it of Fig. III-7-11.)

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 13–10 Heat Loss Chart (From ABMA Chart in Power Test Code of ASME)

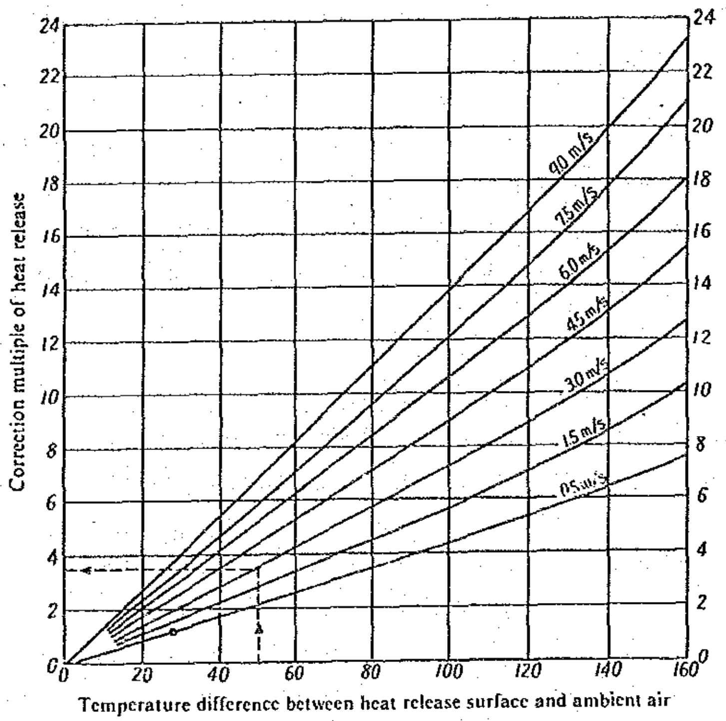


Figure 13-11 Correction Multiple of Temperature Difference and Air Velocity to Figure **III-7-10**

13.1.5 Boiler Performance Indication

The boiler efficiency is indicated by an input-output method which is represented by a ratio of the available output heat to the total input heat as shown in Table 13-8 or by a heat loss method which subtracts the heat loss rate. The latter should be applied to a boiler of 10 t/h or more.

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

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

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

13.1.6 Consideration in Installation Steps

13.1.6.1 CO-Generation

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 heât 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_1 K from a high temperature heat source and releases the heat at the temperature of T_2 K 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.

CO-generation 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 13-12). 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 vapor pressure is desirable in 30 kg/cm² or more and it is almost 100 kg/cm². 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.

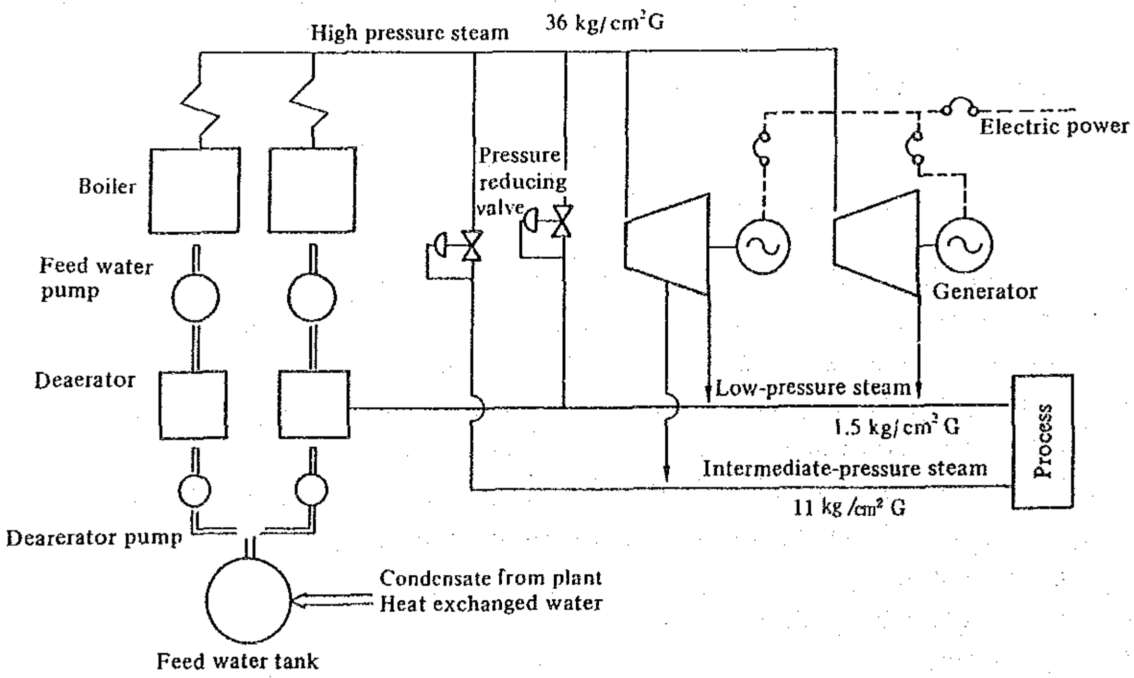


Figure 13–12

13.1.6.2 Coping with Steam Demand Variation

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

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

As a method, the steam accumulator should be equipped to store some excess steam which is used when short of steam (See Figure 13-13). 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.

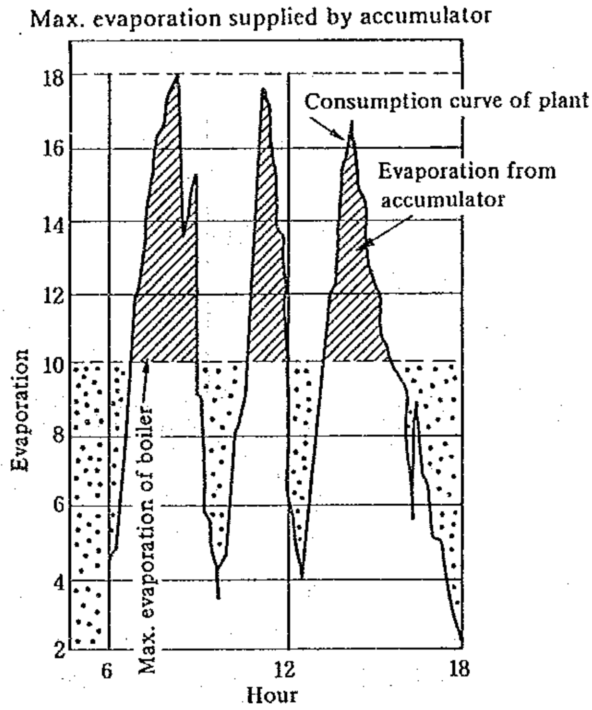


Figure 13–13

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 13-14). Since this method increases the efficiency in a lower load compared with the case of a single boiler (see Figure 13-15), energy conservation can be taken as a whole with a counterbalance of some loss increase due to the start-up and shut-off operation.

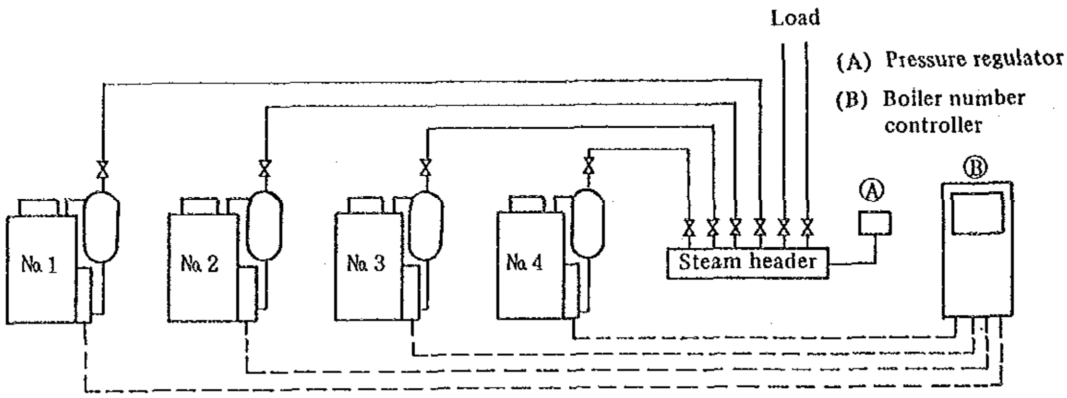


Figure 13–14

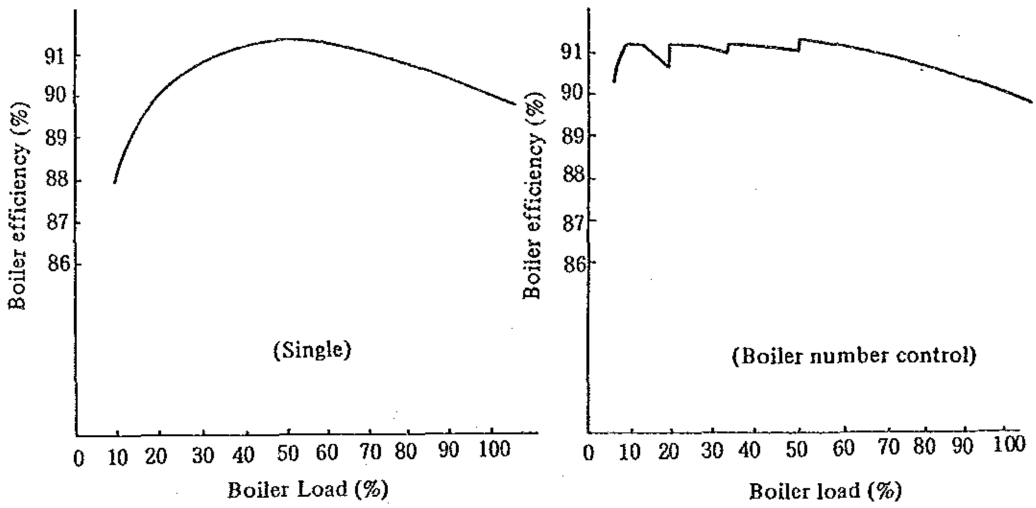


Figure 13–15

13.1.6.3 Installation of Proper Capacity Boiler

Installation of an excess capacity boiler causes not only a higher investment but also requires a relatively longer start-up time to the required steam quantity and for much heat loss. In addition to this, when the number of ON-OFFs in operation is increased, the exhaust gas loss due to purge at each operation is increased. In a high-low combustion change-over 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.

13.1.7 Energy Conservation Measure of Boilers

There are various items for the energy conservation in the boilers as shown in Figure 13-16;, the characteristic factor chart. The important points of these items are described below.

13. 1.7.1 Air Ratio

The largest heat loss of boilers is an exhaust gas loss (see Figure 13-17). 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:

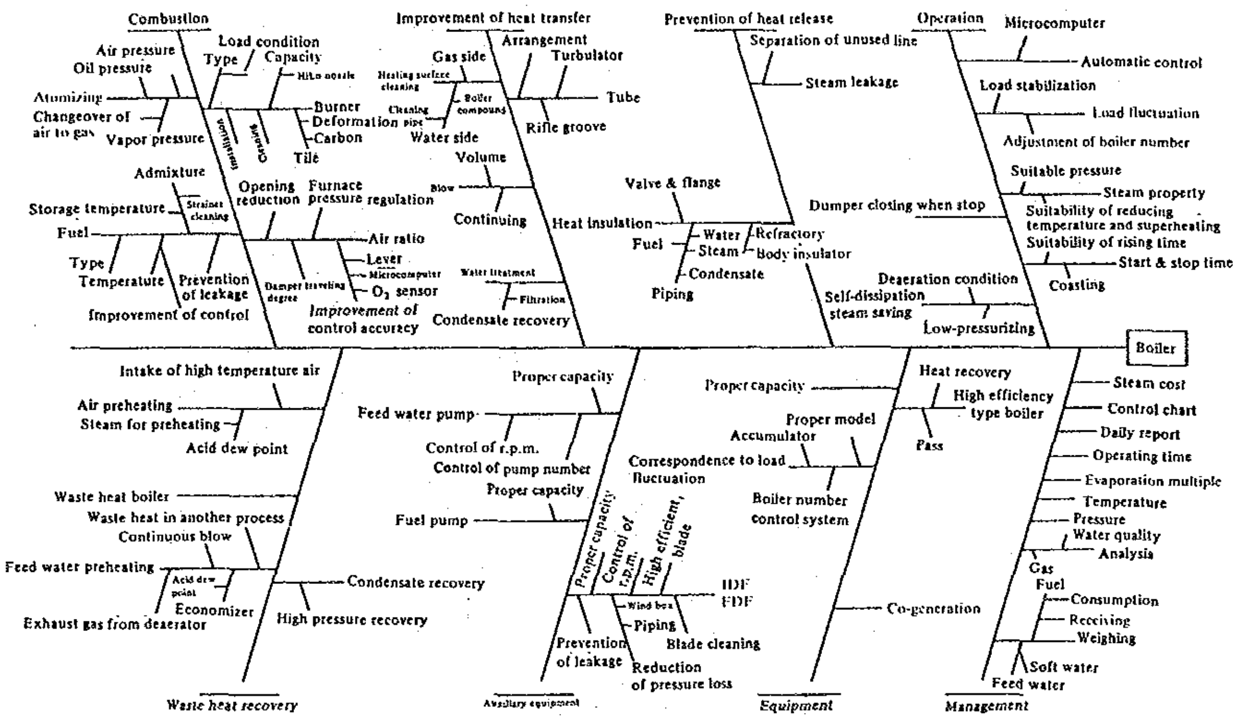
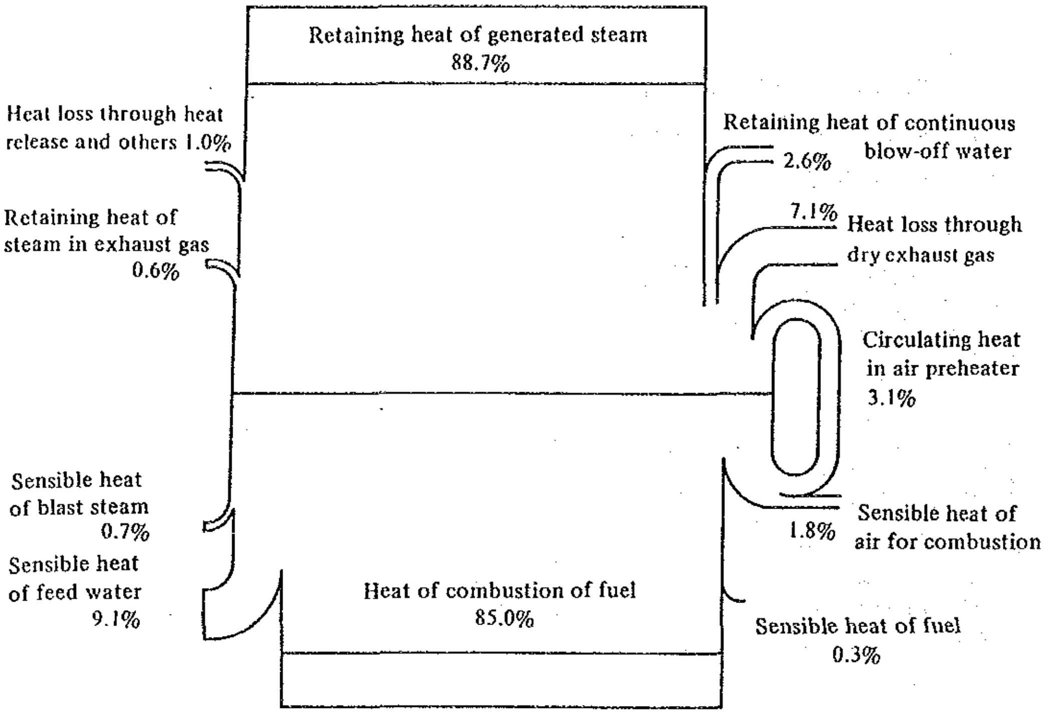


Figure 13–16 Energy Conservation Items of Boiler



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

Figure 13–17 Example of 20 T/H Boiler Heat Balance

(1) Maintaining of proper fuel oil temperature

Fuel oil should be preheated to 80 - 100°C to maintain the viscosity of fuel oil within the range of 20 to 45 cst. (See Figure 13-18)

(2) Inspection and tuningup 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 13-13.

(4) Prevention of air invasion

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

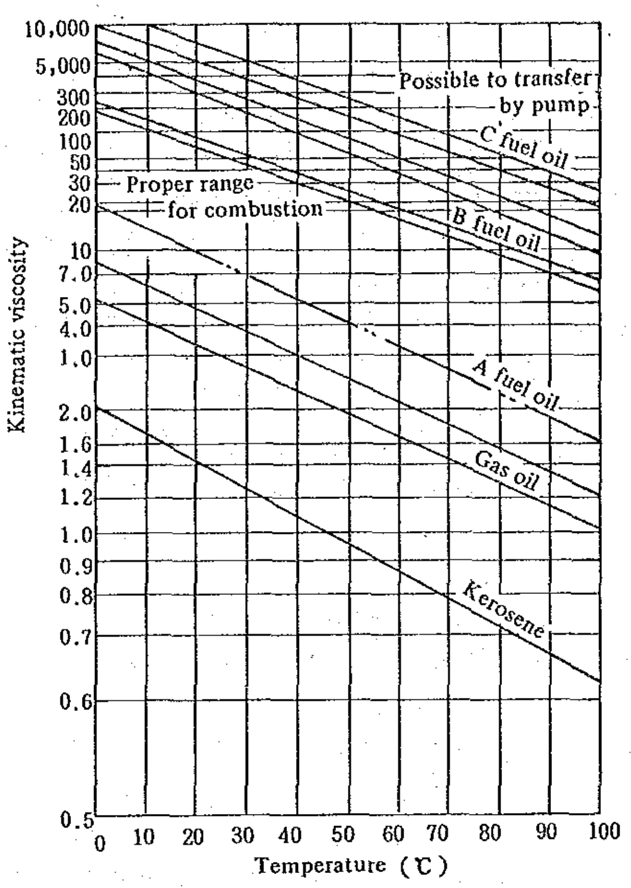


Figure 13–18

Table 13–13 Characteristics and Application of Oil Burner

		Low pressure air system		High pressure atomizing system		Oil pressure system		Rotary burner
		Interlocking type	Non-interlocking type	Internal mixing type	External mixing type	Return oil type	Non-return oil type	
Fuel oil amount	ℓ/h	1.5～120	4～180	10～5,000	10～600	50～10,000	50～10,000	10～300
Oil pressure	kg/cm²	0.4～1	0.1～0.3	2～9	0.2～1	5～40	5～70	0.5～10
Atomizing pressure	kg/cm² (mmH₂O)	mmH₂O (400～2,000)	mmH₂O (400～2,000)	3～10kg/cm²	2～8kg/cm²	—	—	1～3 kg/cm²
Atomizing medium amount	A Nm³/kg, S kg/kg	2～3m³/kg	1～3m³/kg	A 0.2m³/kg, S 0.25 kg/kg	A 0.26m³/kg, S 0.33 kg/kg	—	—	
Atomizing medium		Air	Air	Air or steam	Air or steam			Air, rotation of cup
Combustion air pressure	mmH₂O	400～2,000	100～2,000	0～250	0～50	100	100	0～100
Combustion regulation range		4～6 : 1	4～8 : 1	8 : 1	6 : 1	3 : 1	3 : 1	2～10 : 1
Flame characteristic		Short flame	Slightly short flame, Long flame	Short flame, Long flame	Slightly long flame	Short flame	Short flame	Short flame
Merit		Possible for proportional control by one lever. Low cost of installation and operation	Easy handling. Same as left	Good atomizing. Small clogging	Same as left	Low combustion noise. Low cost of operation	Same as left	Low cost, Easy handling
Weakness		Blower required	Same as left	Power cost required	Power cost required	Not respond to load fluctuation. High pressure pump required	Same as left	Result in large size
Boiler application	Flue smoke tube	○	○	○	○	○	○	○
	One-through			○	○	○	○	
	Vertical	○	○		○			○
	Water-tube	○		○	○	○	○	○

(5) Regulation of air

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

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

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

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

(6) Automatic control

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

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

The example shown in Figure 13-19 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 13-20 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 13-21.

These controls have little problem under the steady operation, but they do not have a mechanism to prevent black smoke generation which control 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 13-22 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

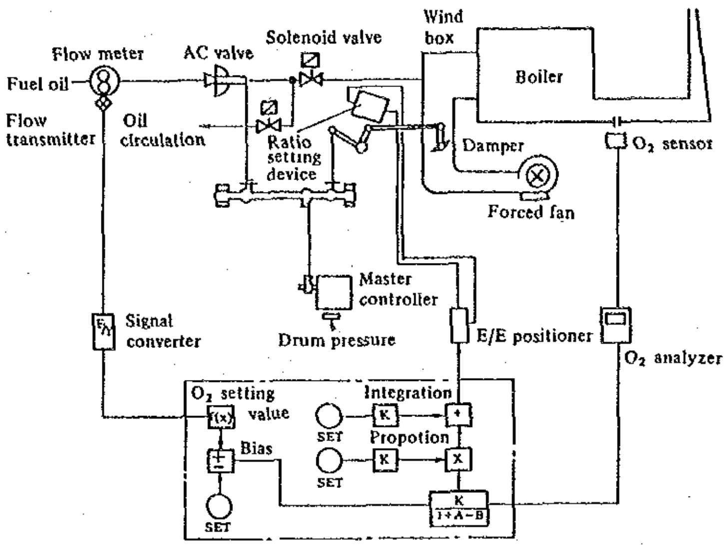


Figure 13–19

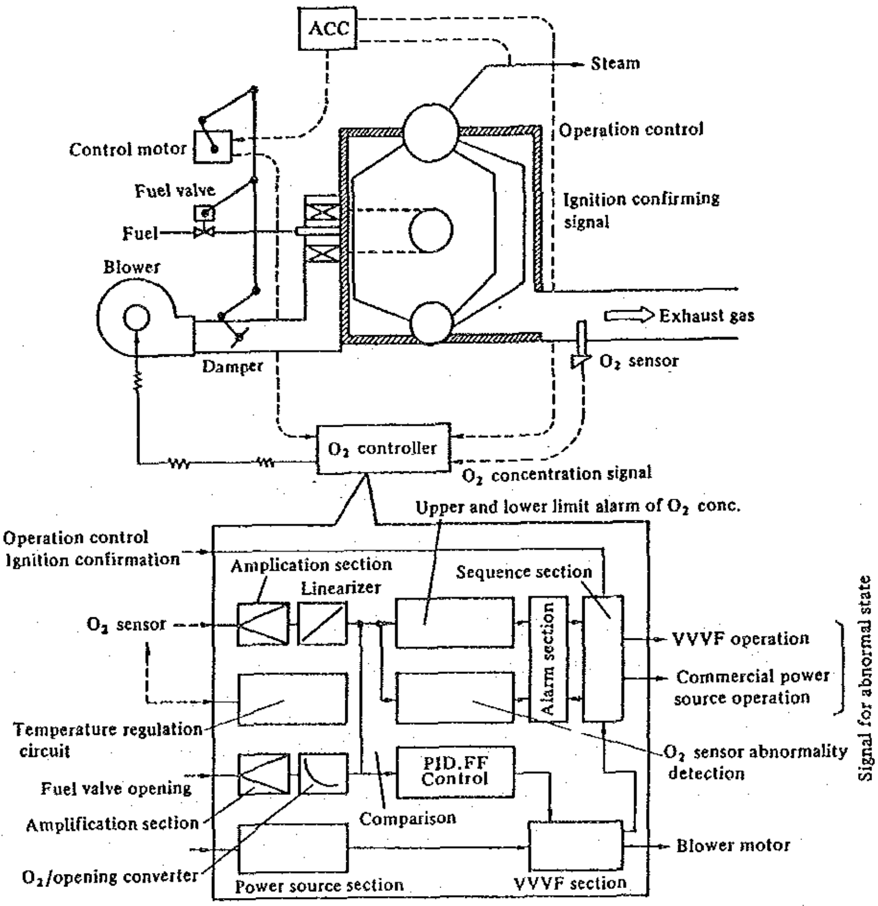


Figure 13–20

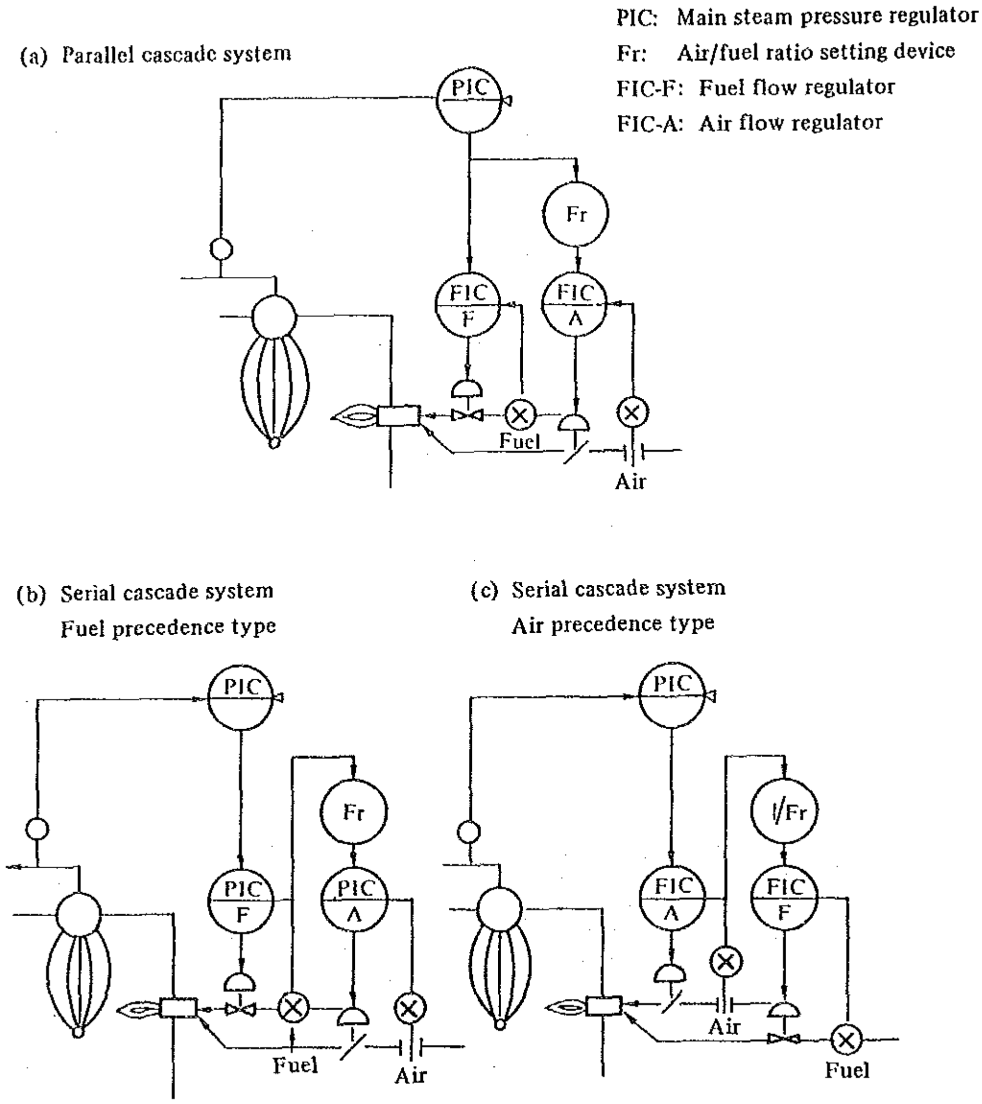


Figure 13–21 Basic Combustion Control System

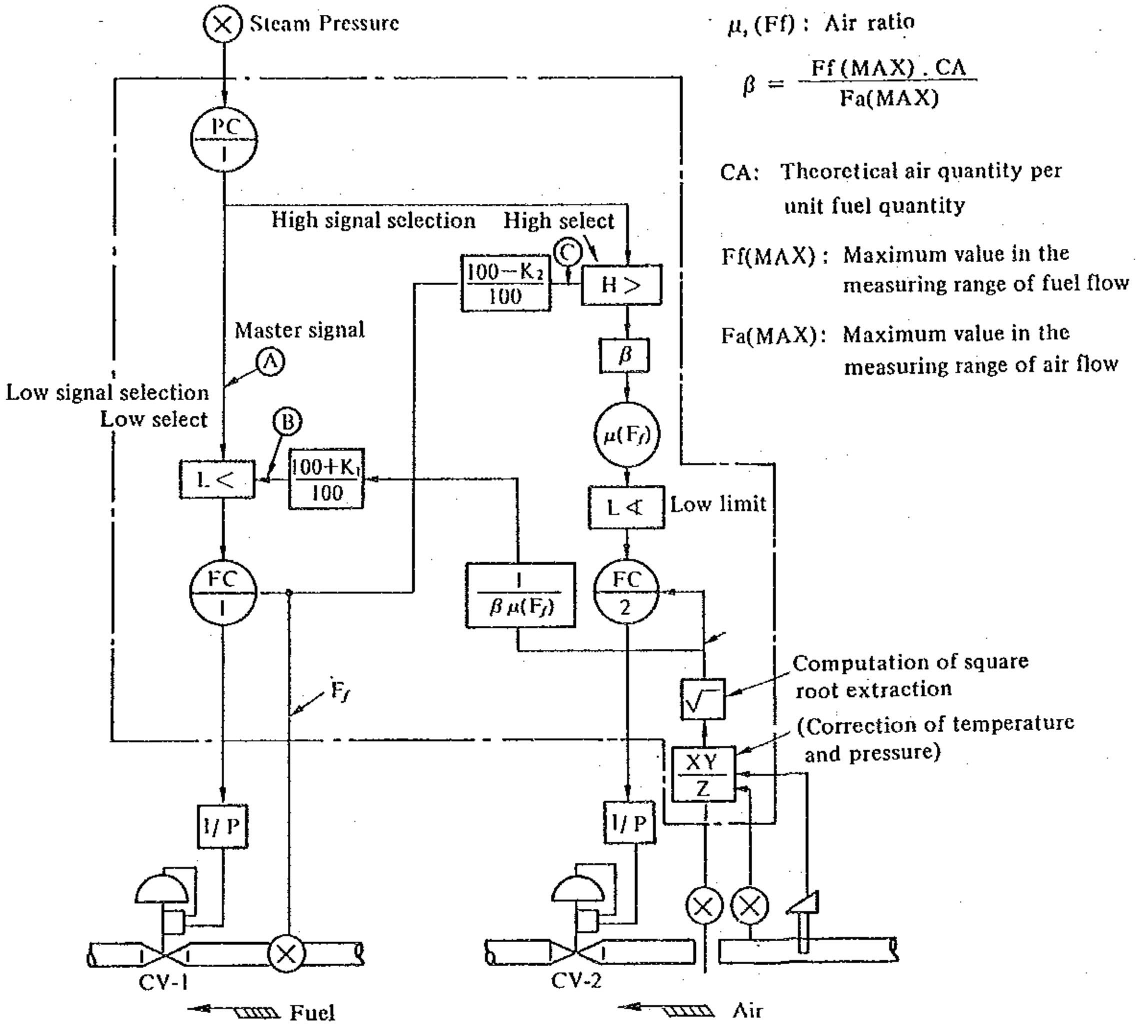
air ratio is not required at a large margin.

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 analyser in exhaust gas.

(7) Standard of air ratio

Since the air ratio is influenced by the type of fuel, the load factor and the composition of control devices, these points must be considered for setting of the standard. The values of Japanese standard are shown in Table 13-14 as reference.



PC-1 : Main Steam pressure regulation

PC-1 : Fuel oil flow control

PC-2 : Air flow control

μ, (Ff) : Air ratio

$$\beta = \frac{Ff(MAX) \cdot CA}{Fa(MAX)}$$

CA: Theoretical air quantity per unit fuel quantity

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

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

Figure 13–22 Block Diagram of Single Cross Limit Combustion Control System

Table 13–14 Standard Air Ratio of Boiler

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

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

The example in Figure 13-23 is the result of Japanese boilers researched by the Energy Conservation Center. The figures shown in the standard correspond to the value in the highest frequency of distribution.

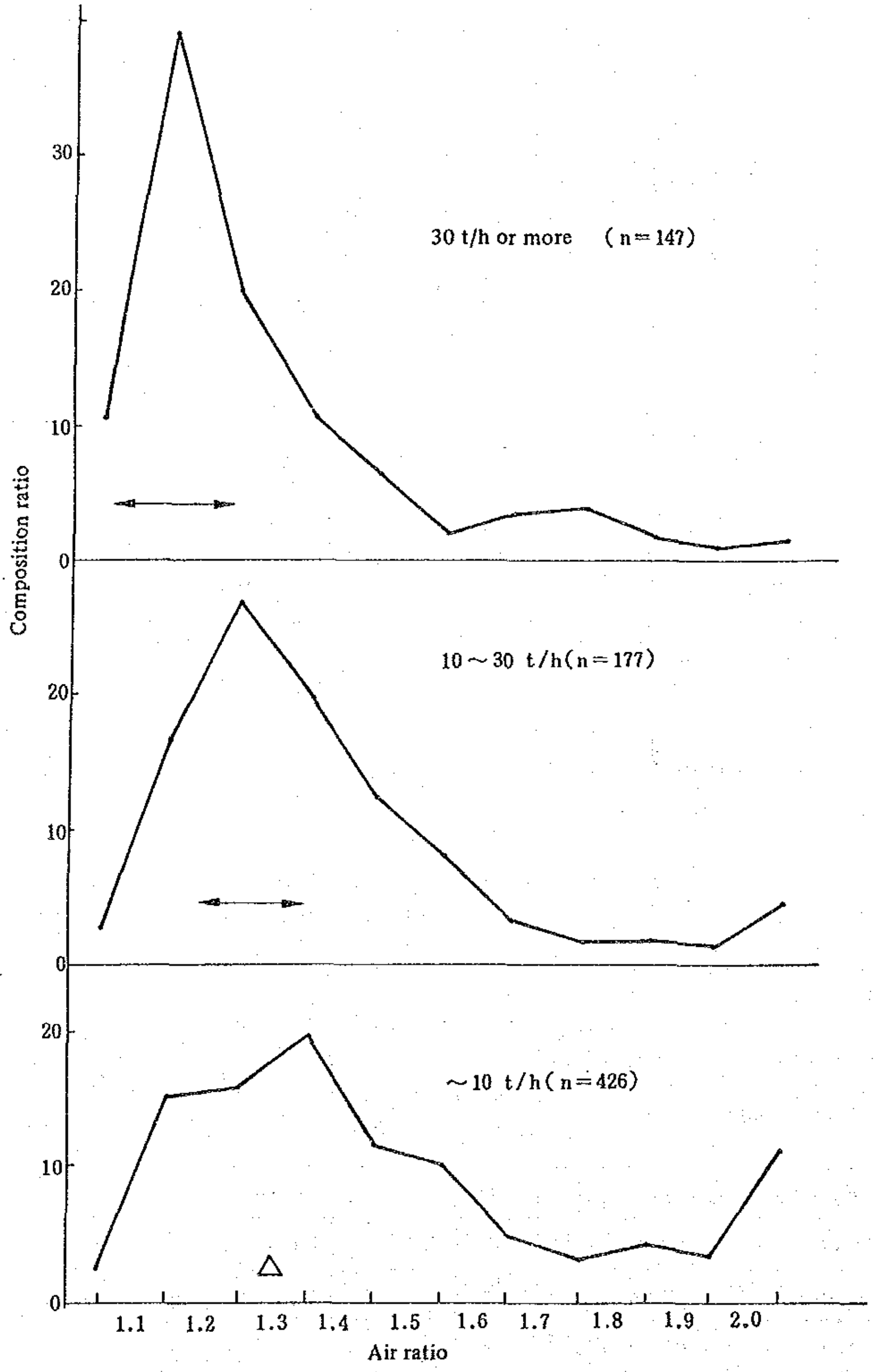


Figure 13–23 Boiler Air Ratio Distribution Example

13. 1.7.2 Exhaust Gas Temperature

(1) Improvement of heat transfer

The thermal conductivities of soot and scale depend on their composition and the deposit situation, and they are of values of no more than 1/100 to 1/100 of those of mild steel as shown in Table 13-15. Accordingly, these deposits make the thermal efficiency of boilers decline remarkably similar to some insulation on the heating surface (see Figure 13-24 and Figure 13-24).

Table 13–15 Thermal Conductivity of Scale and Other Substance

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

In order to avoid any hindrance due to the scale, it is required to perform properly a water treatment and a blow and to clean periodically as described in item (3) of paragraph 1.2.3.

Cleaning of the heating surface for the water side should be carried out commonly once per year, though it depends on the degree of the wate 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. 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.

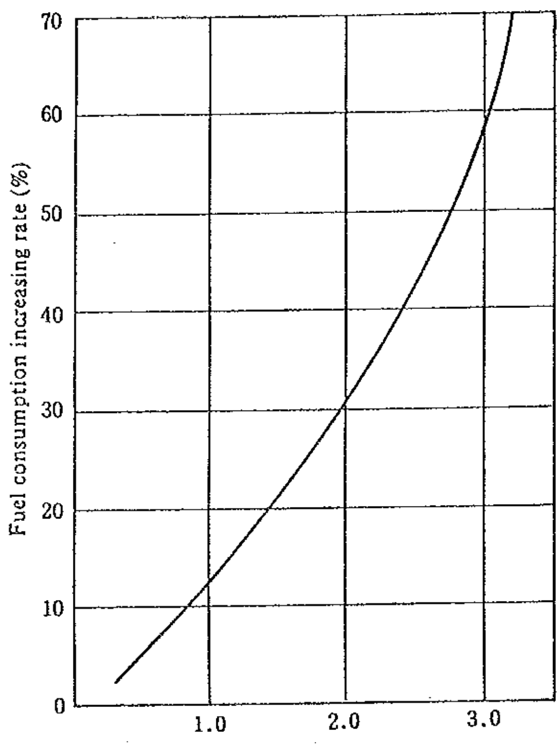
When a flue smoke tube boiler has a enough capacity, a special steel turbulator in the smoke tube is inserted to improve the coefficient of heat transfer by bringing turbulent flow in the gas flow (see item (3) of paragraph 1.7.7).

(2) Recovery of waste heat in exhaust gas

In boilers, it is basic that the exhaust gas temperature does not raise 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



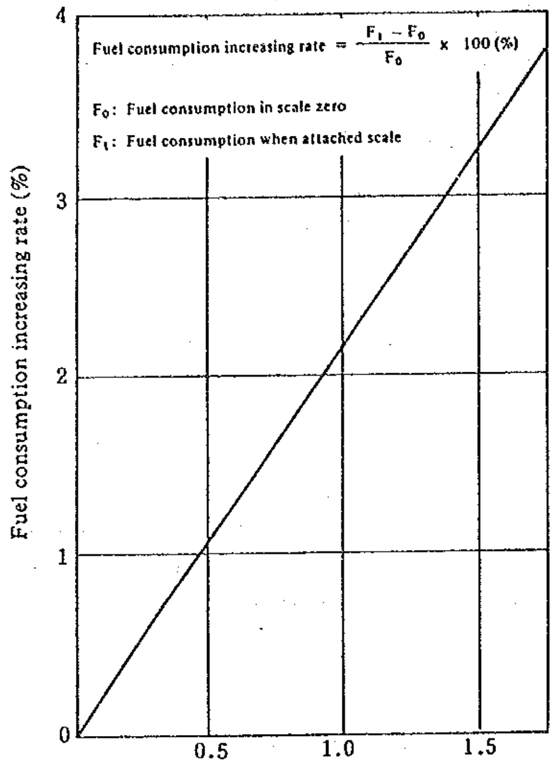


Figure 13–24
Example of Fuel Loss Due to Soot on Heating Surface

Figure 13–25
Example of Relation between Scale Thickness and Fuel Loss

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 13-26, the conversion of SO_2 to SO_3 is shown in Figure 13-27 and the relation between the SO_3 concentration and the dew point of acid is shown in Figure 13-28. 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.

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 13-7 of paragraph of the heat balance, a measure to prevent overdropping of the exhaust gas temperature 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 make the thermal stress generated in the drum very

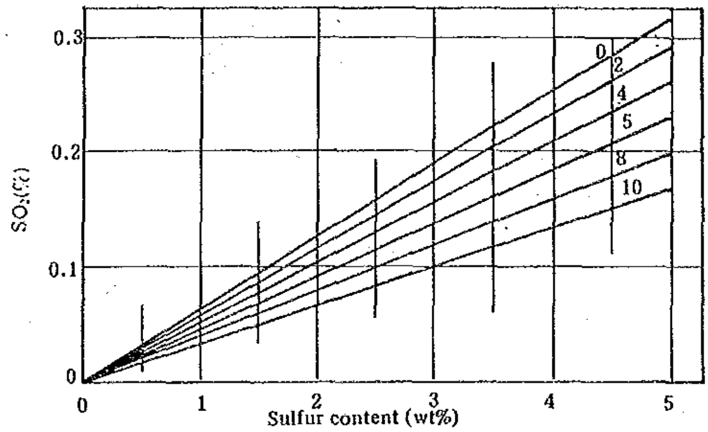


Figure 13–26 Relation between Sulfur Content in Fuel and SO_2 Content in Fuel Gas

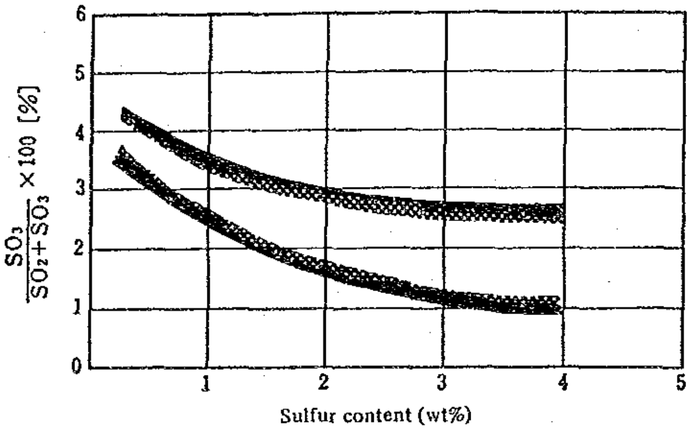


Figure 13–27 Relation between Sulfur Content in Fuel and Conversion Ratio from SO_2 to SO_3

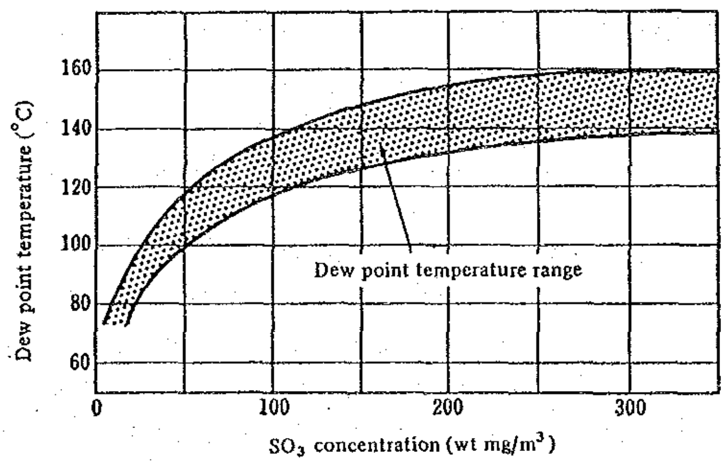


Figure 13–28 Relation between SO_3 Concentration in Exhaust Gas and Dew Point Temperature

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:	Carring-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 13-29.

The preheating of air brings an energy conservation effect by increasing of the carrying-in heat, an 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 NO_x 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.

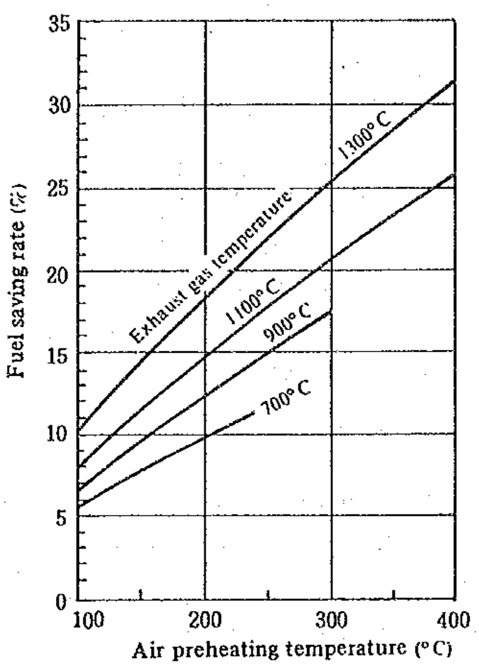


Figure 13–29 Fuel Saving Rate Due to Air Preheating

(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 III-7-16.

Table 13–16 Standard Exhaust Gas Temperature of Boiler

Division		Standard exhaust gas temperature (°C)			
		Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other byproduced gas
For electric industry		145	145	110	200
Others	Evaporation; More than 30 t/h	200	200	170	200
	Evaporation: 10 to 30 t/h	—	200	170	—
	Evaporation: Less than 10 t/h	—	320	300	—

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

But the existing boiler without a waste heat recovery unit out of the boilers of 10 to 30 t/h in the evaporation is taken as the same value as the boiler of 10 t/h or less.

The results in Japan, researched by the Energy Conservation Center, are shown in Figure 13-30 and the highest frequency value is less than the value of the standard. The value of the margin is the installation situation of a waste heat recovery unit and half of the boilers of 30 t/h or more are provided with both an air preheater and economizer. Moreover, most of the small size boilers are equipped with only an air preheater. The boilers without a waste heat recovery unit in either case are only about 3%.

13. 1.7.3 Prevention of Heat Release

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

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

13. 1.7.4 Energy Conservation of Accessory

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

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

13. 1.7.5 Operation

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

13. 1.7.6 Routine Management

To advance the energy conservation of boilers, it must be settled first to provide required instruments and grasp the daily operating situations. Especially the relation between

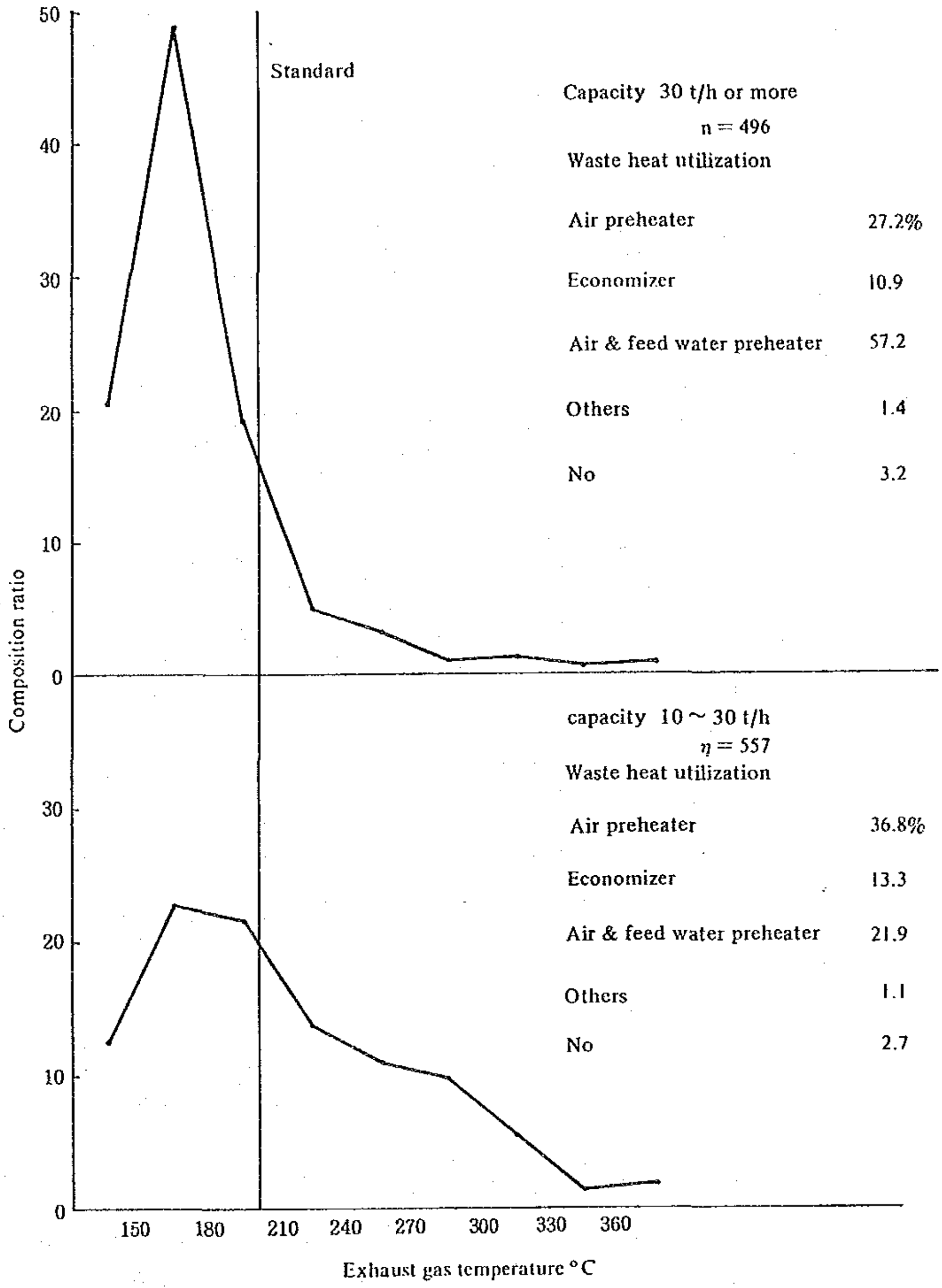


Figure 13–30 Boiler Exhaust Gas Temperature Distribution

the evaporation and the fuel consumption, that is the evaporation multiple (see paragraph 1.5), should be observed. If a declining of the performance is recognized, its cause should be investigated immediately and an appropriate measure must be taken.

Table 13-17 is a sample of operation records. These items must be recorded for the boiler management. The items such as the evaporation multiple, the feed water temperature, the exhaust gas temperature and O_2% in the exhaust gas should be prepared in chart to know a long-term tendency and these data make use of detection in its early stage of any abnor-

Table 13-17 Daily Report of Boiler Operation

Manager	Chief operator	Early attendance	Day service	Night service

Date Weather Ambient temperature inside °C Outside °C

Every hour measured matters (Hours should be entered from the bottom to the upper.)	Hours	Pressure kg/cm²	Feed water temperature °C	Feed water quantity: Meter reading	Feed water quantity: Consumption lit.	Fuel oil quantity: Consumption lit.	Fuel oil quantity: Meter reading	Fuel oil temp.: Service tank °C	Fuel oil temp.: Heater outlet °C	Oil pressure: Primary kg/cm²	Oil pressure: Secondary kg/cm²	Exhaust gas temperature °C	Exhaust gas % CO_2	Furnace pressure mmAq	WB static pressure mmAq	Outlet static pressure mmAq	
									(A)	(B)							
					(Take care to the ratio. Example: (3:1))												
	Reading in previous day				Reading in previous day												

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

Reference

Boiler efficiency $\frac{Gs(i''-i')}{Lf.r.Hl} \times 100$

Gs = Evaporation kg/h ≒ Feed water quantity lit./h lit./d Blow quantity is reduced.

i'' = Specific enthalpy of generated steam Kcal/kg Dryness 98%

i' = Specific enthalpy of feedwater Kcal/kg

Lf = Fuel oil quantity lit./h. lit./d

r = Meter passing specific gravity Specific gravity converted with the meter passing temperature.

Hl = Hh − 6 × 9 × h Kcal/kg According to the Hh analysis table. h: Kerosine, Light oil, A grade fuel oil 13%, B grade fuel oil 12%, C grade fuel oil 11%

- Factor $\alpha = \frac{i''-i'}{r.\ Hl} \times 100$

The factor can be calculated from the average pressure, feedwater temperature, fuel oil temperature, fuel oil specific gravity and low calorific value.

- Evaporation multiple = $\frac{Gs}{Lf} = \frac{\text{Feedwater quantity lit./h. lit./d}}{\text{Fuel oil quantity lit./h. lit./d}}$
- Boiler efficiency = $\frac{Gs}{Lf} \times \alpha\%$
- Steam unit price = $\frac{\text{Fuel unit price Bt/kl}}{\text{Evaporation ratio Ton/kl}}$ Bt/Ton

Boiler water blowdown	Blowing time	Pressure kg/cm²	Blowing quantity l
	Continuing blow		
	Total blowing quantity		

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

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

Boiler water	Sampling	Pressure kg/cm²	State of boiler, Before and after blowing.
	Yes		
	No		

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

Description)

mality. The indication of data is useful to promote the operator's interest to energy conservation.

13. 1.7.7 Example

(1) Feed water 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 pre heater 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. The investment fund recovery period was 3 months.

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

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

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

Various tests were carried out by changing the air ratio automatic controller to a manual operation in order to try to reduce the exhaust gas loss. The result proved to be possible to reduce from 2.5% of the conventional O_2% limit to 0.6%. As a result, O_2 has been reduced to 1.0% by replacing to a microcomputor control system which can cope with a load fluctuation and by installation of a zirconia system O_2 analyzer which is a low time delay.

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

As a result, fuel oil was reduced by 37.5 kl/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 13-31)

A special steel turbulator was inserted in the smoke tube of a flue smoke tube boiler (6 kg/cm^2, 8.4 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 88.5% to 90.5% and the fuel cost was saved by 4.3 million yen. The investment cost was 1.4 million yen and it was recovered in a short period.

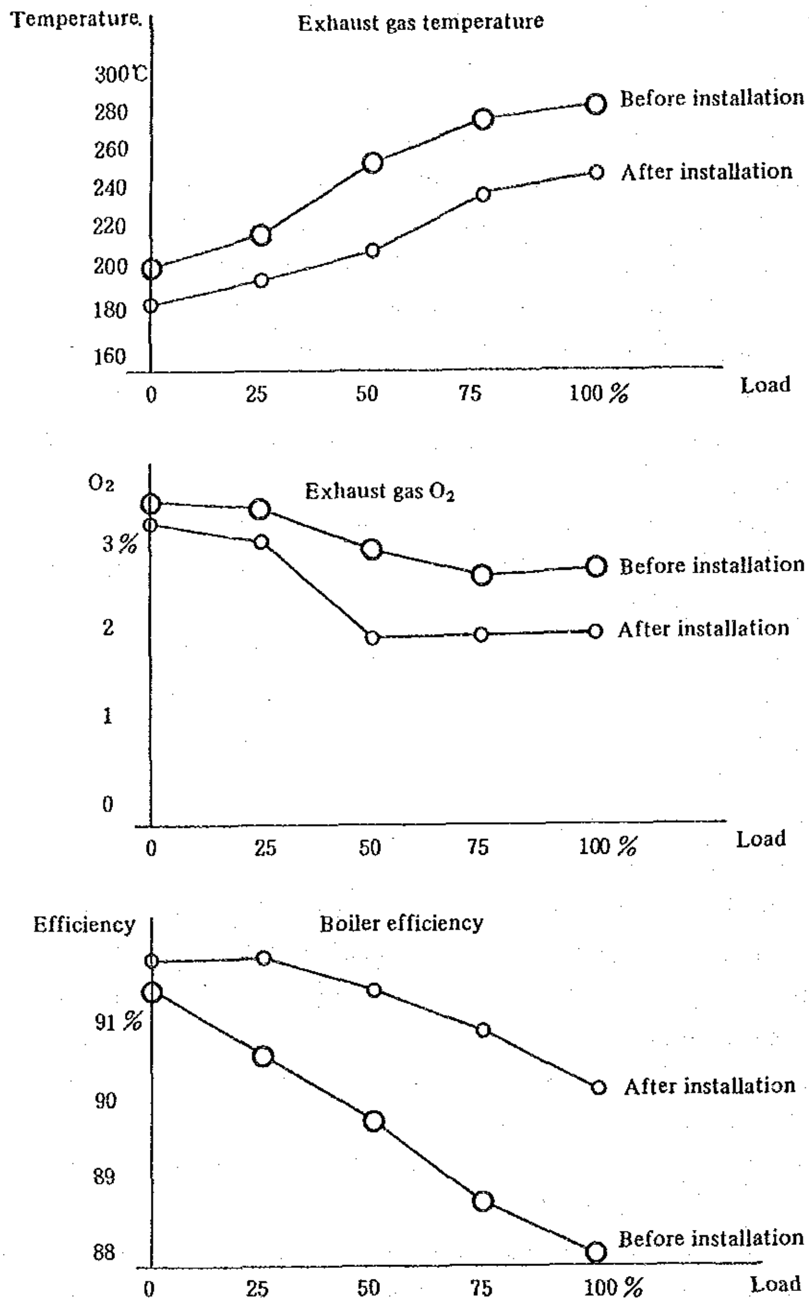


Figure 13–31 Comparison of before and after Improvement

13.2 Utilization of Steam

13.2.1 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 effecitve 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 Fig. 13–32)

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

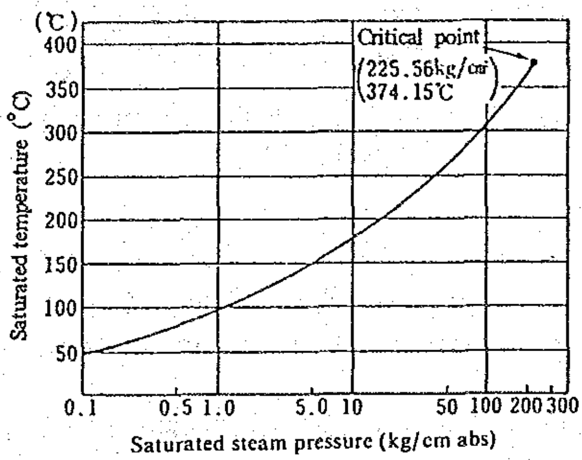


Figure 13–32
Relation between the Saturated Steam Pressure and the Saturated Temperature

(3) The latent heat of evaporation of steam is larger with lower pressure and it is reduced as the pressure rises. (See Fig. 13–33)

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

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

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

13.2.2 Effectiveness of Steam Setting Pressure

(1) Effectieness of boiler steam pressure

When steamis used as indirect heating, the lower the steam pressure, the heat quantity (latent heat of condensation) released when steam condensates is larger. Therefore, the use of lower pressure steam allows saving of the fuel. Accordingly, the setting pressure of the boiler is required to reduce to a pressure corresponding to the temperature necessary as a heating source.

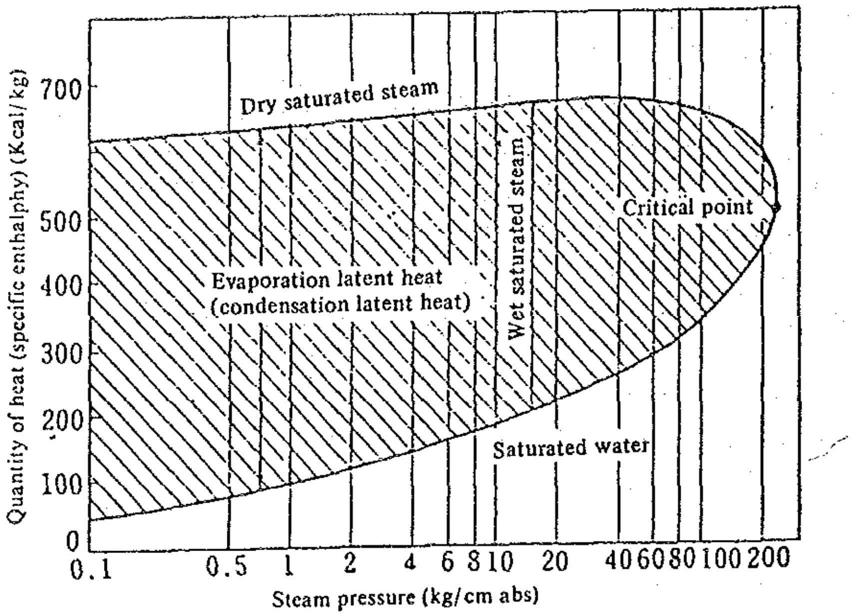


Figure 13–33 Relation between the Saturated Steam Pressure and the Quantity of Heat

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

Example of fuel saving through the reduction of boiler steam pressure is shown in Table 13–18.

Table 13–18

Steam pressure (kg/cm^2G)	Saturation temperature (°C)	Specific enthalpy of steam (kcal/kg)	Condensation latent heat (kcal/kg)
7	169.6	660.8	489.5
5	158.1	657.9	498.6

If the steam pressure is reduced from 7 kg/cm^2 G to 5 kg/cm^2 G, the latent heat of condensation rises to approximately 9 kcal/kg from Table 13–18. If an average steam consumption per month is taken as 5,400 metric tons, the steam consumption due to reduction of the steam pressure is

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

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:

$$\frac{5{,}400 \times 10^3 \times (660.8 - 20)}{10{,}000 \times 0.85} - \frac{5{,}300 \times 10^3 \times (657.9 - 20)}{10{,}000 \times 0.85} = 9{,}437 \text{ kg/month}$$

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

(2) Pressure reducing effect of steam

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

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

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

If a steam 9 kg/cm^2G of steam pressure and 0.95 of dryness is reduced to 2 kg/cm^2G, the latent heat of saturated steam before pressure reduction is

$481.65 \times 0.95 = 457.57$ kcal/kg

and the enthalpy of wet steam is

$181.25 + 457.57 = 638.82$ kcal/kg.

The latent heat after pressure reduction is

$638.82 - 133.41 = 505.41$ kcal/kg.

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

$505.41 - 457.7 = 47.84$ kcal/kg

In other words, the excessive heat quantity of $(47.84/457.57) \times 100 = 10.5\%$ is possible for utilization through pressure reduction. The dryness after pressure reduction results in the following:

$638.82 = 133.41 + X \times 517.9$

$X = 0.98$.

13.2.3 Steam Transport

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

(1) Piping plan

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

a. Servicing time and hours

b. Batch or continuance

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

With a plant plan of piping, the relation between the yard piping and the plant piping should be defined. The yard piping system diagram is shown in Fig. 13–34. 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.

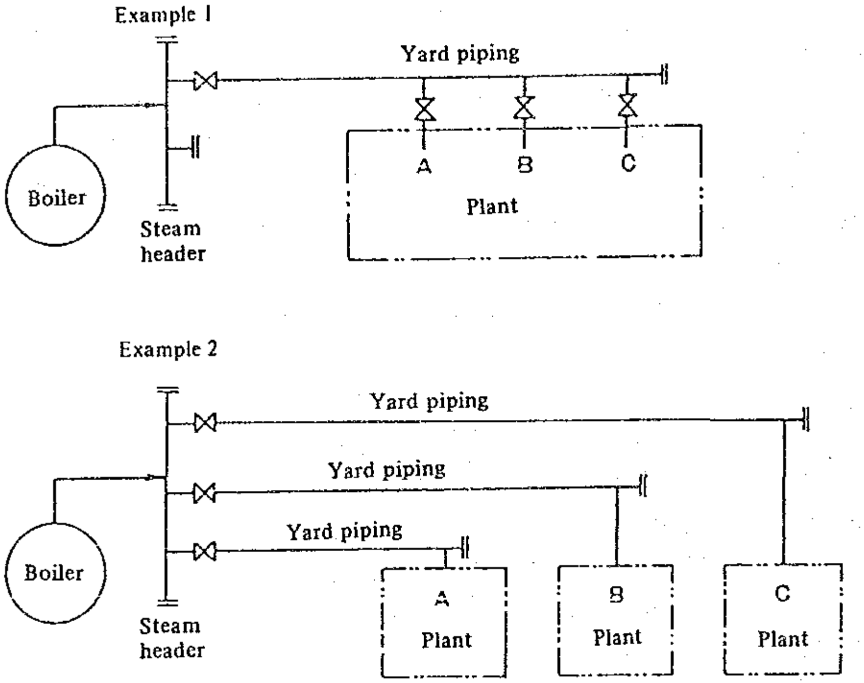


Figure 13–34 Yard Piping System Diagram

To take the piping from the yard piping into the plant, a main valve should be installed as shown in Fig. 13–35 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 header for future usage.

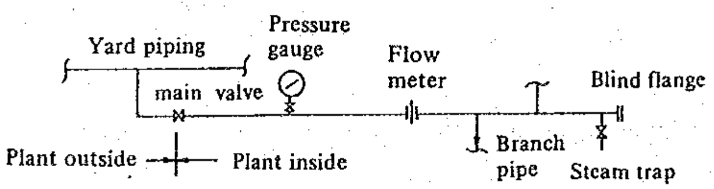


Figure 13–35 Plant Battery Limit Schematic Flow Diagram

(3) Heat Insulation of steam piping

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

A) Type and selection of heat insulating materials

a. Properties required of heat insulating materials

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

The thermal conductivity of insulating materials are:

(1) increases generally with the density;
(2) increases with absorption of moisture;
(3) increases with raising of the temperature.

b. Type of insulating materials

The insulating material used for steam piping is mostly an inorganic materials. Table 13–19 shows the kinds and features of inorganic insulating materials.

c. Selection of heat insulating materials

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

(1) Low thermal conductivity
(2) Small specific weight
(3) Low water absorption
(4) High strength and durability
(5) Withstands sufficiently against servicing temperatures
(but use below the safety servicing temperature.)
(6) Good workability

B) Heat insulation works

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

a. Works

(1) Use a molded product as far 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 sampe part, and the joint should be packed with a compressed asbestos fiber (Fig. 13–36).

Table 13–19 Heat Insulator Type and Its Feature

Heat insulator	Raw material and manufacturing process	Product	Property	Safety service temp.
Asbestos insulator	• Fiber shape formation of serpentinite or amphibole by subterranean heat and underground water. • Chrysotile asbestos of serpentinite is a thin white silklike and toughness fiber and is a good quality. • Amocite asbestos (brownish color) of amophibole is a longer, thick and brittle fiber and is unsuitable to yarn and fabric. There is blue asbestos in the same series.	• Long fiber is suitable to asbestos yarn and seat packing. Short fiber is for asbestos paper, asbestos plate and slate. • Asbestos insulation plate Asbestos insulation cylinder Asbestos insulation yarn Asbestos mat • Plate and ctlinder are molded by an inorganic adhesive.	Density: 0.23g/cm³ or less Thermal conductivity: 0.048~0.065 Kcal/m.h.°C	350~550 °C
Diatom earth insulator	• Aqueous rock formed by a heap of diatom remains. Recently not much use due to the development of an excellent insulator. • Diatom earth powder + reinforced binder (amocite asbestos fiber 3~5%)	• Water kneading insulator. Give a tackiness by addition of water in 160 to 200%. Coat it on reinforcement of a wire net. Slow drying.	Density (after drying): 0.45 to 0.55 g/cm³ Thermal conductivity (70°C): 0.08 to 0.09 Kcal/m.h.°C	Asbestos fiber: 500 °C or less Reinforcement of fibers for plastering: 250°C or less
Rock wool insulator	• Andesite, basalt, igneous rock, serpentinite, peridotite, chrolite-schist, slag of nikkel ore and manganese ore and limestone • Compound the above materials in a proper ratio, melt in a temperature of 1,500~1,600°C and form it to a thin fiber shape by blowing of compressed air/steam. SiO_2: 40~50%, Al_2O_3: 10~20%, CaO: 20~30% MgO: 3~7% Fe_2O_3: 2~5%	• Attacked by weak acid but not weathered. • Various shape products such as plate, cylinder, band and bracket. • Blacket is formed by set metal on both sides of the stratified rock wool and sew up with a wire. Good acoustic absorption effect.	Density: 0.10~0.38 g/cm³ Thermal conductivity (70°C): 0.039~0.048 Kcal/m.h.°C	Less 400~600°C
Glass wood insulator	• Manufactured by the similar manner to the rock wool.	• Plate, cylinder, bracket and band	Density: 0.008~0.096 g/cm³ Thermal conductivity (70°C): <0.042 Kcal/m.h.°C	Less 300~350°C
Calcium silicate insulator	• Add asbestos fiber into silicate power (mainly diatom earth) and slaked lime to reinforce, allow it to swell enough and mold in a metal moild to allow produce calcium silicate by steaming.	• Put on the market for a high temperature from 1952 and standardized in JIS in 1955. • Low price, good workability and durability. • Typical insulator used not only piping but a general machine.	Density: 1st class; less 0.22 g/cm³ 2nd class; less 0.35 g/cm³ Thermal conductivity (70°C): 1st class; <0.058 Kcal/m.h.°C 2nd class; <0.053 Kcal/m.h.°C	Ca. 650°C
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 verly light particle having fine bubble. Not change in quality and not fade the color. Not absorb moisture in atmospher.	• Less 1 mm for moulding insulator • Blend asbestos fiber and inorganic adhesive, mold by press and dry. • Classified to 1st class and 2nd class. One of many excellent insulators.	Density: 1st class; less 0.2 g/cm³ 2nd class; less 0.3 g/cm³ Thermal conductivity: 1st class; <0.053 Kcal/m.h.°C 2nd class; <0.065 Kcal/m.h.°C	Ca. 650°C
Basic magnesium carbonate insulator (magnesium carbonate insulator)	• The conventional basic magnesium carbonate insulator has been compounded with basic magnesium carbonate of 85% and asbestos of 15%. The thermal conductivity is influenced by this ratio. The present insulator is blended with asbestos of 8% or more.	• Classified to magnesium carbonate water kneading insulator, plate and cylinder. • Convert to magnesium oxide by heating in a temperature of 300°C or more and shrinke extremely • Almost same properties as it of calcium silicate except for heat resistance. As present not used too much.		Less 250°C

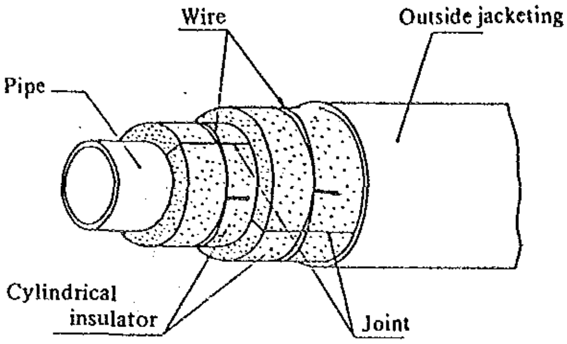


Figure 13–36 Case of Cylindrical Insulator

(3) The valves, the flanges, and the 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. Fig. 13–37 shows the works of heat insulation for valves, Fig. 13–38 shows the works of heat insulation for flange portions, and Fig. 13–39 shows the works of a heat insulation for hangers.

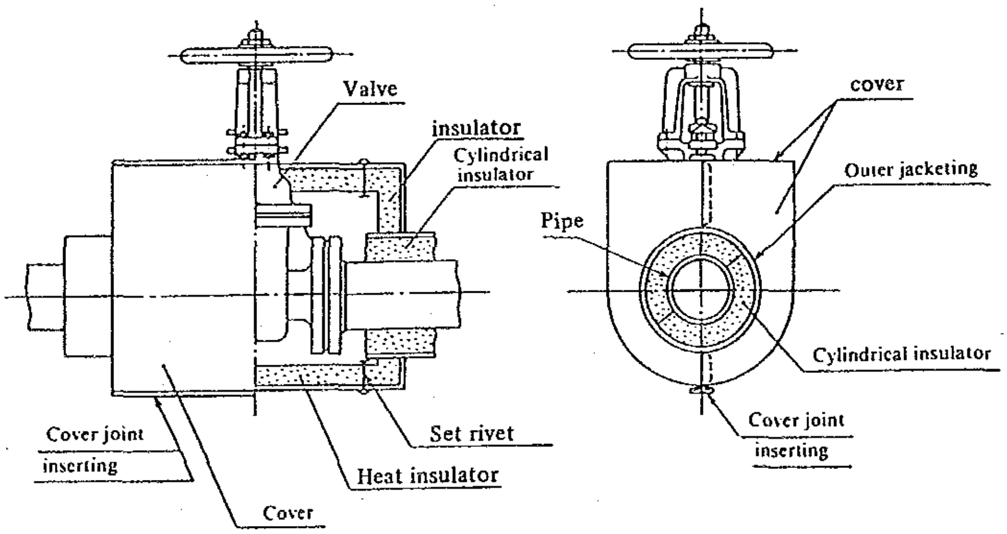


Figure 13–37 Insulation Work of Valve

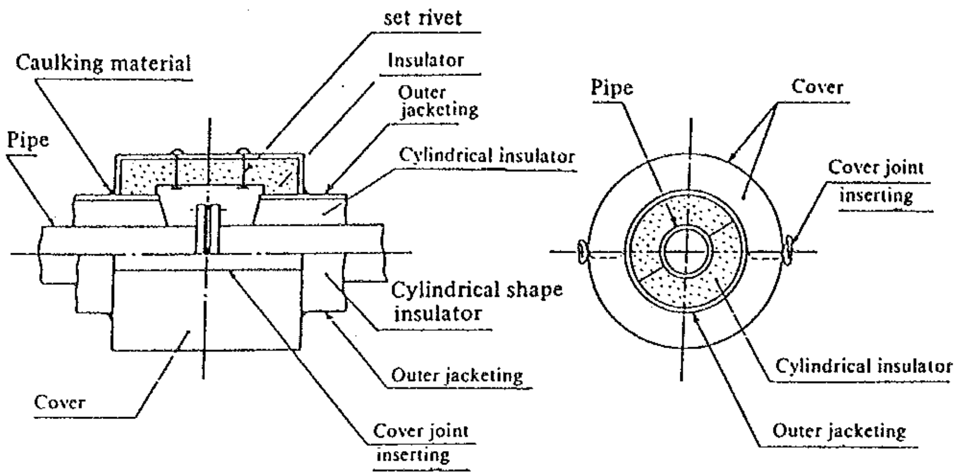


Figure 13–38 Insulation Work of Flange

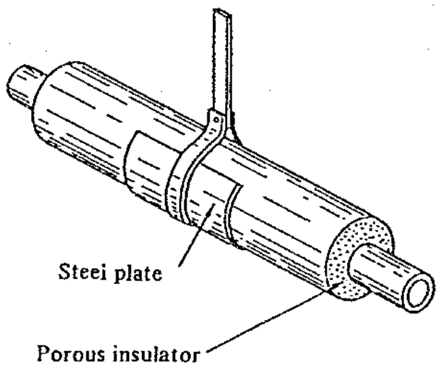


Figure 13–39 Installation Work of Hanger

(4) Consideration of vibration

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

(5) Consideration of rainwater resistance and chemical resistance

To prevent the heat insulation against rainwater or corrosive chemicals, the heat insulating material should be covered with steel sheet, aluminium sheet or mastic gum. When the heat insulating material absorbs moisture, because the thermal conductivity of water is approximately 0.5 kcal/mh°C which is larger by about 10 times than that of the insulating material, heat loss increases. Care must be taken against moisture.

The mastic gum is a liquid or a paste containing asphalt or plastics as the main component and is excellent for workability, antirainwater and chemical resistance.

b. Maintenance and inspection of heat insulation

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

Special attention is as follows:

(1) Deformation and damage of the outerjacketing

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

(3) Mark of steam leakage or falling of drops

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

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

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

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

c. Heat loss from the insulated pipe

A heat transfer in the pipe insulated as shown in Fig. 13–40 is shown in Table 13–20. The quantity of heat due to the heat transfer is expressed by the following equation.

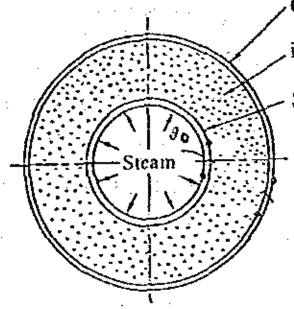


Figure 13–40 Insulated Pipe

Table 13–20 Heat Transfer from Steam in Tube

NO.	Place	Heat transfer way
1	From steam to steam tube	A part of steam heat transfers to steam tube by convection.
2	In steam tube	Transfer form tube inside to tube outside by thermal conduction.
3	From steam tube to insulator	The heat reached to the outside surface of steam tube transfers immediately to the inside surface of insulator because of absence of fluid (water or air etc.).
4	In insulator	Transfer from the inside surface of insulator to the outside by thermal conduction. The transfered heat is influenced substantially by the property and thickness of insulator.
5	From insulator to outerjacketing	Heat reached to the outside surface of insulator transfers immediately to the inside surface of outerjacket.
6	In outerjacket	Transfer the heat from the inside surface of outerjacket to the outside surface through thermal conduction.
7	From outerjacket to atmosphere	Transfer the heat by convection and radiation (convective heat transfer through updraft or wind and radiant heat transfer to wall or object around the steam tube)

$$Q = \frac{1}{R}(p_O - \theta_r)$$

$$R = \frac{1}{2\pi}\left(\frac{2}{d_1 \alpha} + \frac{1}{\lambda}\ln\frac{d_1}{d_0}\right)$$

Here, R: Thermal resistance (mh°C/kcal)

θ_O, θ_r: Steam temperature, atmospheric temperature (°C)

d_I, d_O: Inside diameter of heat insulation (Outside diameter of steam pipe), Outside diameter of heat insulation (m)

α: Heat transfer coefficient of surface (kcal/m^{2}h°C)

λ: Thermal conductivity of heat insulator (kcal/mh°C)

Q: Quantity of dissipating heat (kcal/mh)

d. Economical thickness of heat insulation

The heat insulation is the first step of energy conservation, but an economical optimization must be judged from the relation between the gain of energy recovered due to heat insulation and the cost spent for heat insulation.

An economical thickness of heat insulation is obtainable through the determination of a thickness that the sum (C) of the annual heat loss (A) due to the quantity of dissipating heat from the surface of heat insulation and the annual depreciation cost of the heat insulating construction (B) decreases to a minimum. This relation is shown in Fig. 13–41.

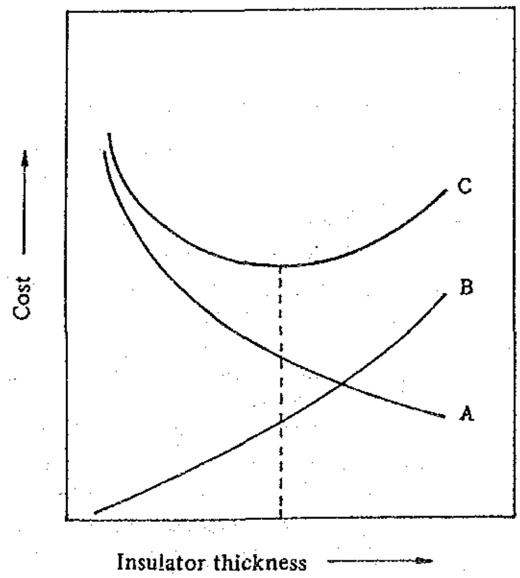


Figure 13–41

Relation between the Insulation Thickness and the Cost

The calculation equation of an economical thickness of heat insulators is as follows:

$$\frac{d_1}{2} \ln \frac{d_1}{d_0} + \frac{\lambda}{\alpha} = 10^{-3} \sqrt{\frac{b \cdot h \cdot \lambda (\theta_0 - \theta_r)}{aN}}$$

Here,

$$N = \frac{n (1 + n)^m}{(1 + n)^m - 1}$$

Here, d_1 : Outside diameter of heat insulation (m)

d_2 : Inside diameter of heat insulation (m)

λ: Thermal conductivity of heat insulating material (kcal/mh°C)

α: Heat transfer coefficient of surface (kcal/mh°C)

b: Cost of heat quantity ($/1,000kcal)

a: Works cost of heat insulation (1,000$/m^3)

h: Annual servicing hours (h)

n: Annual rate of interest

m: Servicing years (years)

In: Napierian logarithm

θ_0: Internal temperature (°C)

θ_r: Room temperature (°C)

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

The heat insulation efficiency – dissipated heat after heat insulation to dissipated heat of bare pipe – is shown in Fig. 13–42 and Fig. 13–47.

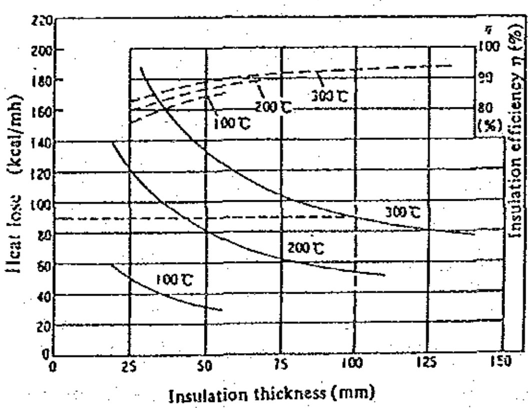


Figure 13–42 3" Piping

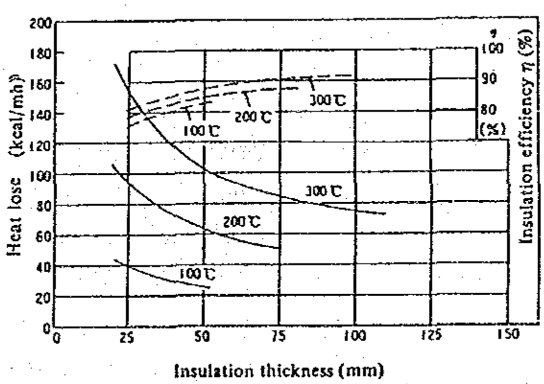


Figure 13–43 2" Piping

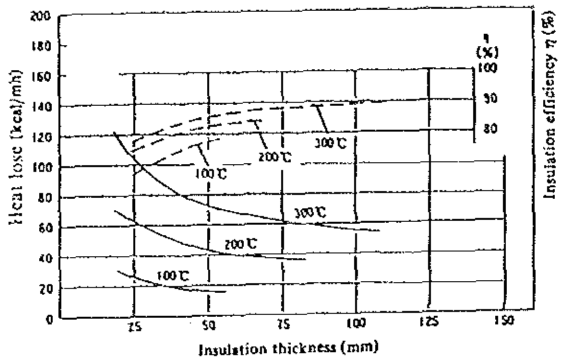


Figure 13–44 1" Piping

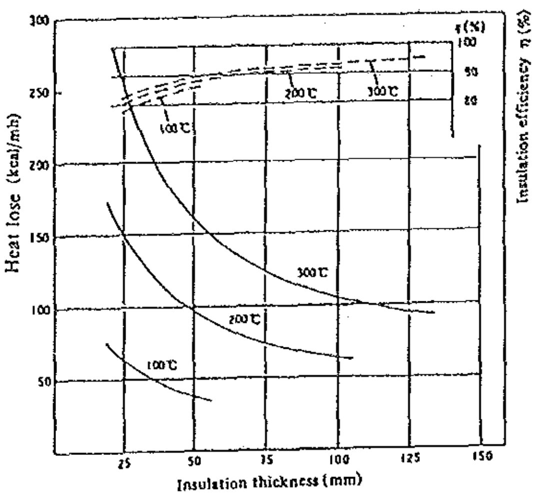


Figure 13–45 4" Piping

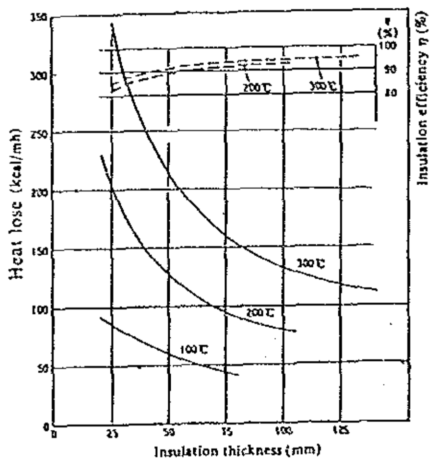


Figure 13–46 6" Piping

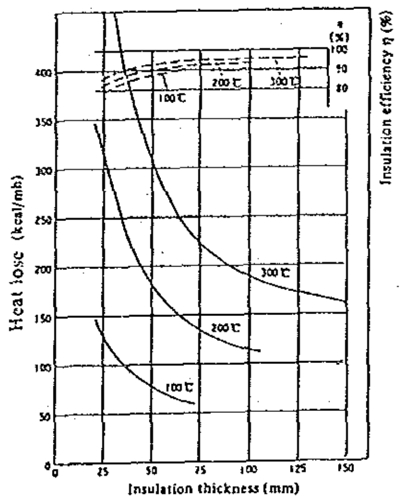


Figure 13–47 10" Piping

Heat insulation efficiency = $(Q_0 - Q)/Q_0$

Q_0: Dissipated heat of bare pipe

Q: dissipated heat after heat insulation

<Example of Fig. 13–42>

When a heat insulation thickness of 100mm is worked on 3" piping at a steam temperature of 300°C, obtain the dissipating heat quantity and the heat insulation efficiency. (Answer) Draw a horizontal line from the intersectional point of 300°C curve and obtain the dissipated heat quantity of the ordinate (90 kcal/mh). To obtabtain the heat insulation efficiency, draw a perpendicular line from the intersectional point of 300°C, draw a horizontal line in a right direction from the intersectional point of the dotted curve of 300°C and read the ordinate efficiency scale (93%).

13.2.4 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.

A steam trap is applied for this purpose.

(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 steam traps have been manufactured.

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

A) Mechanical steam traps

B) Thermostatic steam traps

C) Thermodynamic steam traps

Each type has various models and their classifications and characteristic are shown in Table 13–21.

Table 13–21 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 backet type Inverted backet type Free ball backet 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.
Thermostat 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 medium of temperature, response is slow. Accordingly the actuation cycle is longer. A large air exhaust capacity.
Thermo-dynamic	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.

A) 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 Fig. 13–48). 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 Fig. 13–49). This trap has a high reliability because there is little mechanical trouble. It has a continuous discharging characteristic of condensate.

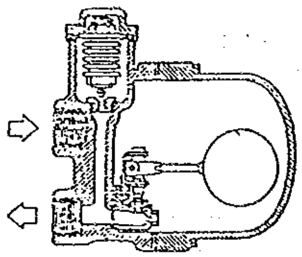


Figure 13–48
Float with Lever Type Trap

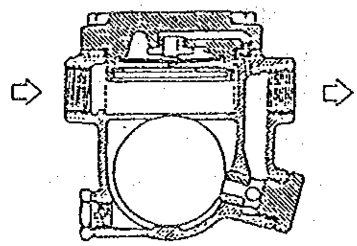


Figure 13–49
Free Float Type Trap

c. Open backet type trap

The trap is equipped with a valve on the valve stick which is fixed in the center of the upward opened backet (See Fig. 13–50).

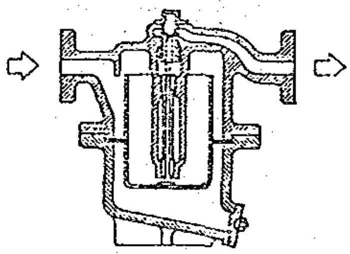


Figure 13–50 Open Backet Type Trap

d. Inverted backet type trap

The trap has a hanging mechanism of a downward opening backet by the lever and the valve mounted to the lever opens or closes the orifice located in the upper (See Fig. 13–51). Deformation or abrasion of the lever might cause trouble.

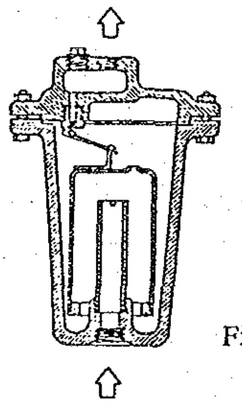


Figure 13–51 Inverted Backet Type Trap

e. Free ball backet type trap

The trap does not have the lever as in the inverted backet type trap and its actuating principle is the same as the inverted backet type trap (Fig. 13–52). The backet 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.

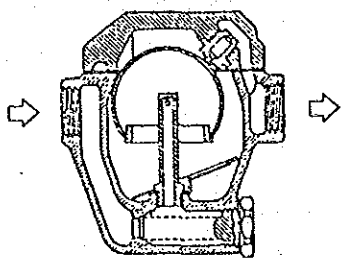


Figure 13–52 Free Ball Backet Type Trap

B) Thermostatic steam traps

The condensate is at a saturation temperature of steam just after the generation of condensate. After that, the temperature is reduced by dissipated heat to cause a temperature difference. This temperature difference is utilized for opening or closing of 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 Fig. 13–53).

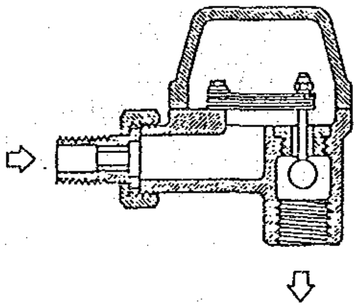


Figure 13–53 Bimetal Type Trap (Strip Type)

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 contraction of the enclosure due to the change of the liquid vapor pressure by temperature variation (See Fig. 13–54).

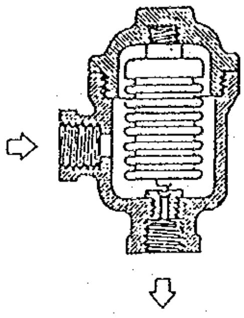


Figure 13–54 Bellows Type Trap

C) 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.

a. Impulse type trap

It is a trap utilized with fluid characteristics (when the condensate passes the orifice, some pressure drop is caused.) (Fig. 13–55). Although the trap has an advantage of smaller size compared to other types, it has disposition of easy trouble, because it has mechanism some steam leaks when valve shuts and precision fitting part.

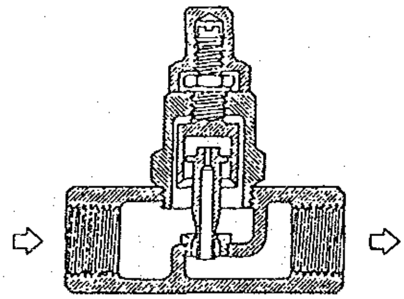


Figure 13–55 Impulse Type Trap

b. Disc 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 Fig. 13–56).

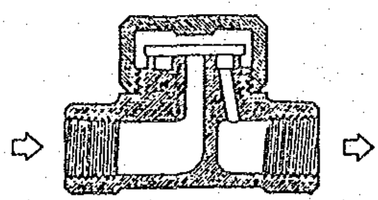


Figure 13–56 Disc Type Trap

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 is not based on an existence of condensate, the trap actuates in spite of condensate in case of rain and causes some heat loss.

(2) Selection of a stem trap

For selection of a steam trap, the following items should be investigated:

a. Condensate load of steam servicing equipment and load characteristics.

b. Steam condition: Pressure, temperature and saturated steam or superheated steam.

c. Back pressure condition: Discharge to atmospheric or recovery of condensate.

d. Maintenance condition: Long serviging life with little trouble. Easy disassembly and inspection.

e. Body material

Item "a" of the above items is especially important. When the equipment is in continuous operation, the load variation during operation is generally small. On the other hand, in a batch system, the operation starts and stops several times in a day and much air and condensate must be discharged at every starting-up. Besides, the starting hour is required to be shortened as much as possible from the viewpoint of productivity. While the steam pressure rises with the progress of the process, the quantity of condensate decreases.

Accordingly, although a load variation exists, the trap must discharge quickly the condensate and must have a sufficient discharge ability.

Next, an important issue is disorder of the trap. If the trap continues blow-off, it results in a larger quantity of steam loss than that in normal operation. If block trouble is caused, a huge steam loss may arise because of operation with unavoidable using of the bypass valve. A disorder of the trap lessens with the simpler structure of the trap. Therefore, a trap of a structure as simple as possible should be selected.

When condensate is recovered, since the trap is applied with back pressure, a mechanical trap-whose actuation is not affected by the back pressure-should be used.

(3) Installation procedure of steam traps

For installation of traps, the following points should be considered.

a. The steam trap does not have the power to push out condensate as in a pump. Condensate is pushed out by steam pressure.

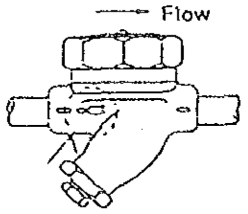
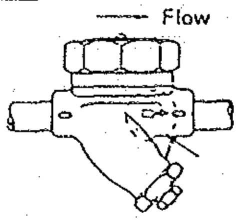
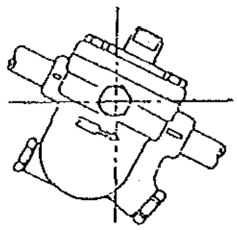
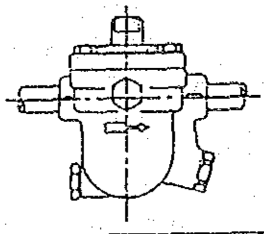
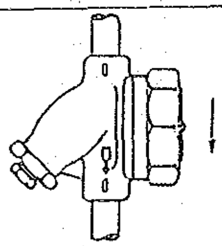
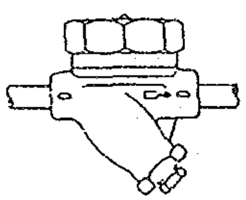
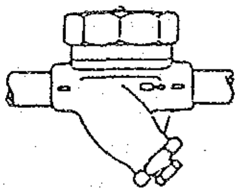
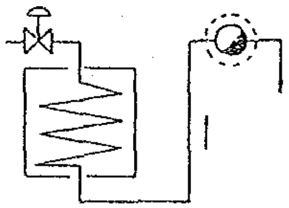
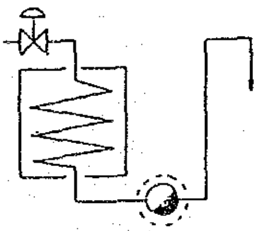
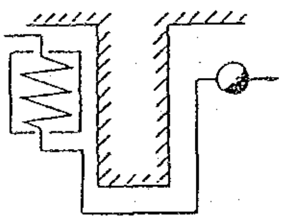
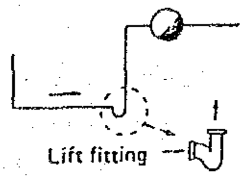
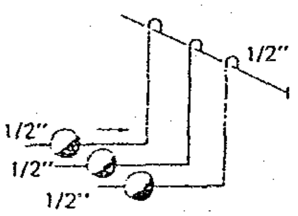
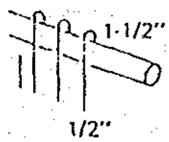
b. If condensate does not enter into a steam trap, it can not work; consequently, the piping from the condensate exhausting point in the equipment to the steam trap should be installed in a gravity flow.

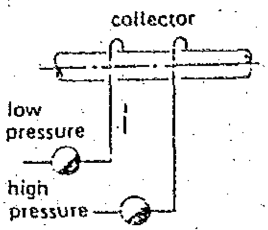
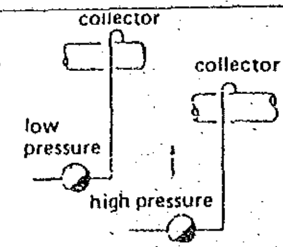
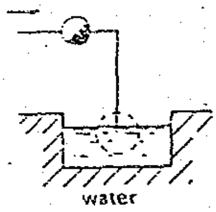
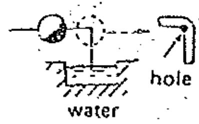
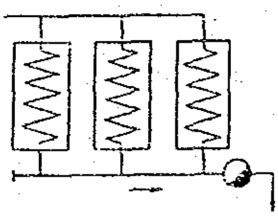
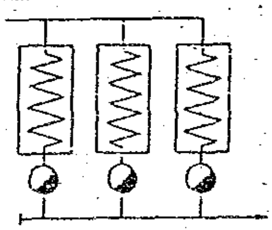
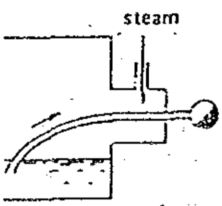
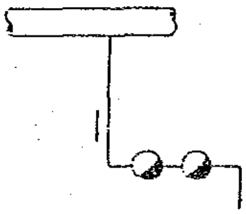
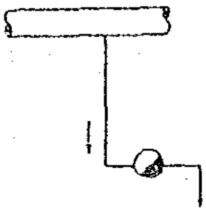
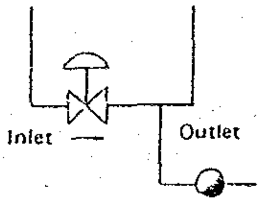
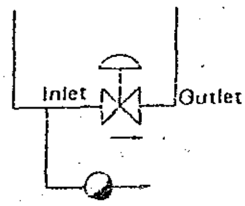
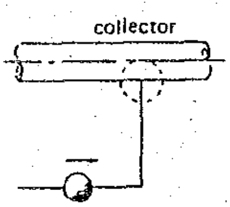
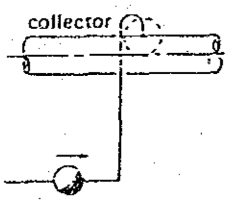
These are important rules for installation of steam traps. On the basis of these rules, some good and worse examples are shown in Fig. 13–57.

(4) Maintenance of steam traps

A) Inspection

Steam traps are consumables and their function declines after a period of use to be scarcely fit for use. The life of steam traps is uncertain. Steam traps should always be checked carefully and if any trouble is found, they must be replaced with good one, or put in good condition by repairing.

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 binding 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.	

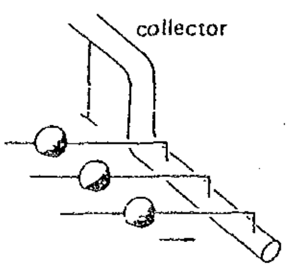
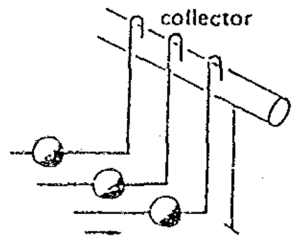
WRONG INSTALLATION	DESCRIPTION	CORRECT INSTALLATION
	Collector should not have a riser. The head of condensate in the collector exerts on the traps as a back pressure.	

Figure 13–57 Good Example and Worse Example of Installation .

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 (See Table 13–22)

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 to not worsen the steam consumption rate.

B) 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 can be simply checked without experience.

D) Disorder of steam traps

The disorder of steam traps are classified into the following four groups. With this due to go upon, a trouble spot can be found.

a. Blockage

Blocakge means that opening the valve of the steam trap is impossible. Such steam

Table 13–22. List of Check Results of Steam Traps

Plant:

	Block	
	Trap No.	
	Main	Applications
	Boiler	Applications
	Heater	Applications
	Dryer	Applications
	General heating	Applications
	Tracing	Applications
	Heating	Applications
	Others	Applications
	Pressure	
	Recovery	
	Indoor	
	Manufacturer	
	Model	
	Size	
	Installation Date	
	Working hrs/day	
	Good 0	Conditions
	Blowing 1	Conditions
	Leaky Valve 2	Conditions
	Leakage thru packing 3	Conditions
	Leakage thru body 4	Conditions
	Capacity shortage 5	Conditions
	Blockage 6	Conditions
	Shut-down 7	Conditions
	Worn valve	Causes
	Defective body	Causes
	Foreign material caught	Causes
	Incorrect selection	Causes
	Wrong Installation	Causes
	Air binding	Causes
	Steam locking	Causes
	Incorrect adjustment	Causes
	Others	Causes
	Remedy	
	Last Inspection	Former Conditions
	Before-last Inspection	Former Conditions
	Violation	
	Replaced trap	

Date

traps do not discharge condensate and air, and are also cold. When the outlet of the discharge pipe is open to atmosphere, blockage can be easily confirmed.

b. Continuing blow-off

Continuing blow-off means that it is impossible to close the valve of the steam traps. Such traps continue to discharge a large quantity of steam with condensate. In this case, since the steam servicing equipment is operated and its production is not obstructed, this disorder is apt to be left as it is. But, because a large quantity of steam is wasted, the daily inspection should lay emphasis on detection of this trouble.

c. Steam leakage

Although the trap works, steam leakage is too much compared to normal actuation. From the viewpoint of energy conservation, this is a problem similar to the continuing blow-off.

d. Insufficient discharge

Although the trap works, condensate stays in the equipment due to the poor discharging ability.

13.2.5 Condensate Recovery

(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 Fig. 13-58. If this heat content of condensate is recovered 100% and utilized effectively, the fuel consumption can be saved by approximately 20 to 30%. This will result in large energy conservation.

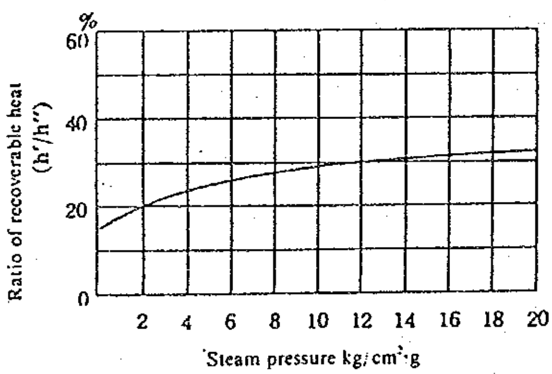


Figure 13–58
Ratio of Recoverable Heat (Enthalpy of Condensate/Enthalpy of Saturated Steam)

(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.

A) 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 Fig. 13-59).

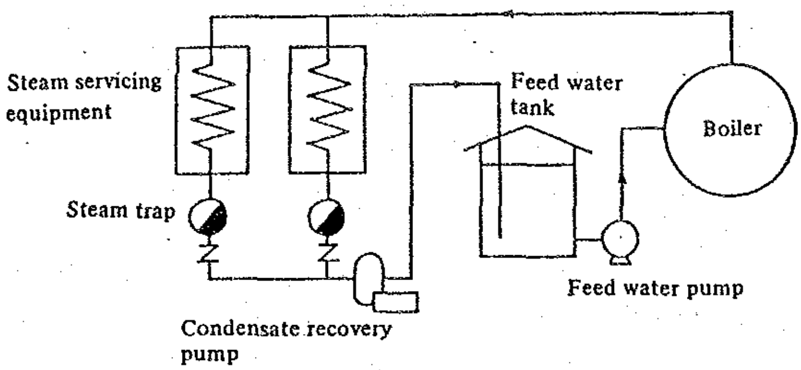


Figure 13–59 Direct Utilization to Feed Water Tank

B) 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 (Fig. 13-60).

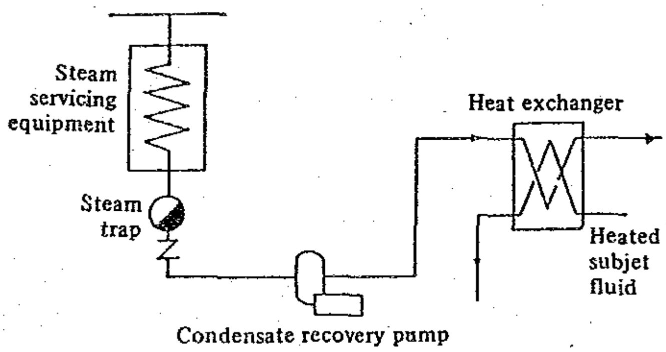


Figure 13–60 Indirect Utilization through Heat Exchanger

C) 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 Fig. 13-61). Fig. 13–61

(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.

A) Method by only steam trap

Condensate can be recovered to a flash tank or a condensate tank by the steam

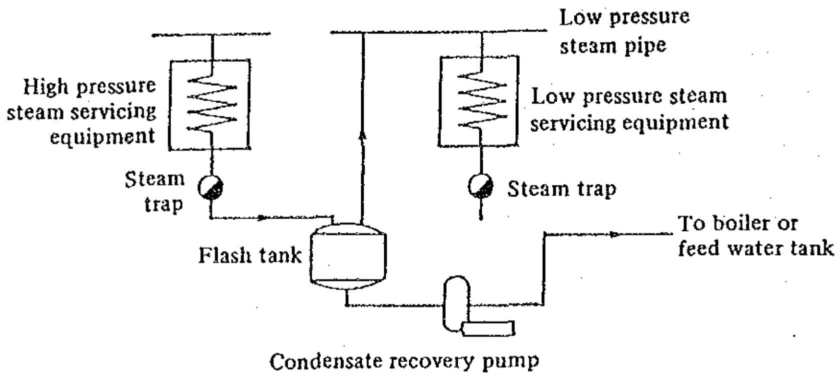


Figure 13–61 Flash Steam Utilization

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 Fig. 13-62).

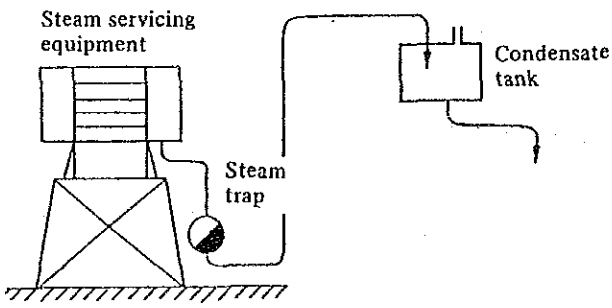


Figure 13–62 Recovery by Steam Trap Only

B) 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 Fig. 13-63).

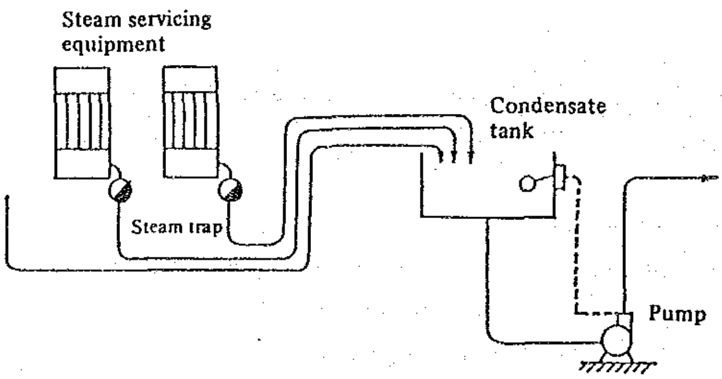


Figure 13–63 Recovery by Centrifugal Pump

In this case, care must be used for ensuring the water head of the pump, a level control of condensate, 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.

C) 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 (Fig. 13-64).

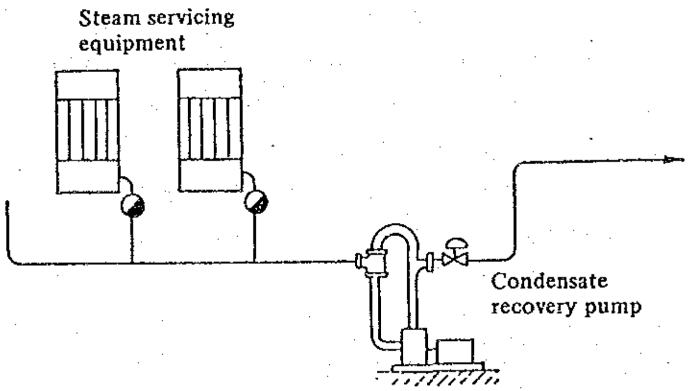


Figure 13–64 Recovery by Condensate Recovery Pump

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

(4) Consideration for condensate recovery

A) Selection of steam traps

In a condition of application of back pressure to the steam trap and pressure fluctuation, a mechanical steam trap having little trouble should be selected.

B) 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.

C) Condensate recovery piping

If piping systems for different steam pressures are installed, the condensate recovery pipings must be installed by a steam pressure system.

Since the recovery piping accompanied with flash steam is a two-phase flow of steam and condensate, it should be designed for the maximum flow rate within 15 m/s and a large pressure loss and water hammer should be prevented.

D) 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.

(5) Utilization of flash steam

In the paragraph about utilization of recovery condensate, 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.

a. 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 condensate result in a fair amount. But it is necessary to manage to gather these small quantity condensates with a cost as small as possible.

b. 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.

Fig. 13-65 shows the example using flash steam. The example is used with a flash steam in the front stage of air heater.

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 13-23 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 involved 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.

Fig. 13-66 shows a chart to decide the inside diameter of the flash tank.

Obtain the inside diameter of the tank through the example shown in Fig. 13-65.

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

Table 13–23 Flash Steam Generating Rate (wt. %)

Pressure in high pressure side (kg/cm²G)	Low pressure side (kg/cm²G)															
	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

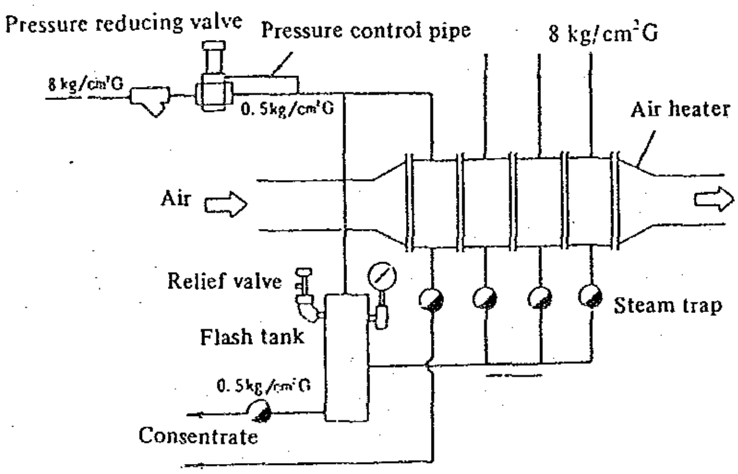


Figure 13–65 Example of Flash Steam Use in Air Heater

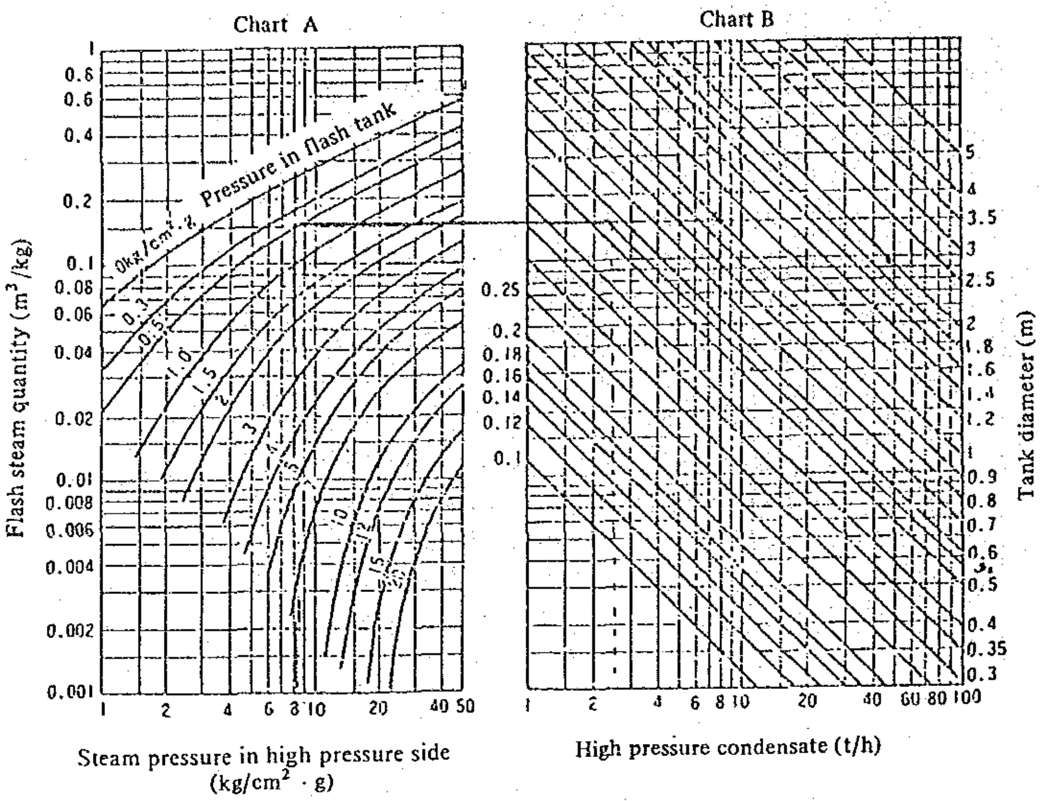


Figure 13–66 Chart of Flash Tank Diameter

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.

(6) Utilization of thermocompressors

The structure of thermocompressors is composed of three basic parts, body, a steam nozzle and diffuser as shown in Fig. 13-67. 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. Fig. 13-68 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.

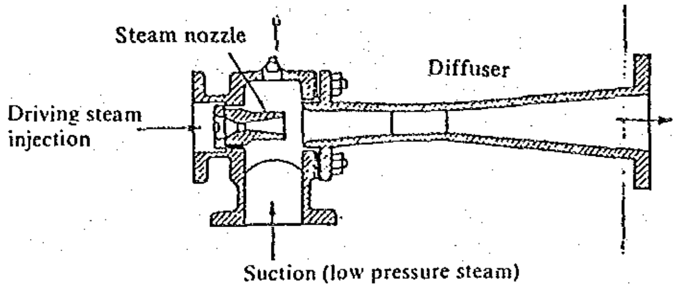


Figure 13−67 Thermocompressor

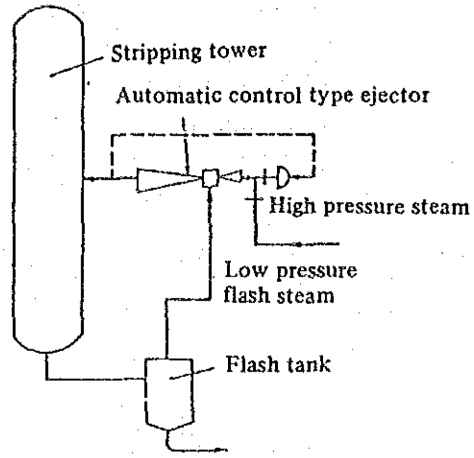


Figure 13−68 Example of Thermocompressor. Use for Stripping Tower

13.2.6 Utilization of Direct Heating by Steam

Direct heating by steam has the following two methods:

(1) Direct heating in a closed vessel.

(2) Heat by direct blowing steam to liquid.

The direct heating method has advantages such as simple and low cost equipment, quick work, and a constant temperature.

(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 low 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 13-24.

(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 of 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 Fig. 13-69 and Fig. 13-70).

Table 13–24 Relation between the Air Mixing Ratio and Steam Temperature

Air mixing ratio % \ Steam Pressure kg/cm²	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

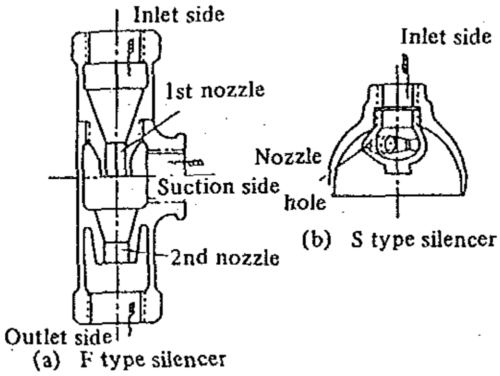


Figure 13–69 Silencer

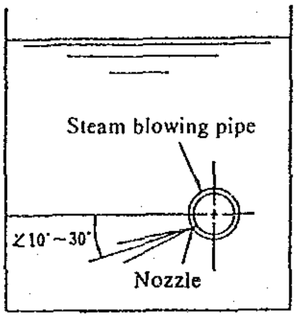


Figure 13–70

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 atomosphere, and great consideration is necessary.

a. Reduce the velocity of steam bubbles blowed into liquid.

b. 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 Fig. 13-70).

c. Install the blow nozzle under a large water head.

d. 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.

e. 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 Fig. 13-71. When the steam side comes in a vacuum, the valve opens by a pressure difference to atmospheric pressure, the vacuum is destroyed and the backflow of liquid can be prevented.

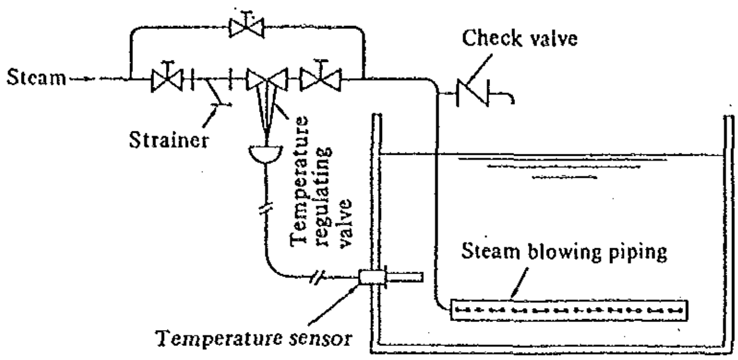


Figure 13–71 Steam Direct Blow-In Heater

14. Electricity

14. Electricity

14.1 Electric Power Management

For electric power conservation, it is necessary to manage the electric power from both electric energy and maximum electric power aspects.

It is important to manage the electric energy from the following two aspects:

(1) Improvement of the electric power consumption rate

(2) Improvement of the power factor

and for the maximum electric power, it is important to manage from the stand point of improvement of the load factor.

14.1.1 Improvement of the Electric Power Consumption Rate

To generally improve the electric power consumption rate, it is important to get a reasonably clear picture of the transition in this consumption rate, classify each production process and each raw material and associate them with changes in the processing method and for technical improvement. It is also essential to determine the target value for the electric power consumption rate in each production process, work out a plan starting from a portion which can be improved and carry it out.

Important items to improve the electric power consumption rate are concretely described as follows:

(1) Placement of measuring instruments

Provide with measuring instruments at important points so that the electric power consumption for each hour may be measured and checked periodically. It is necessary to grasp the load condition, maximum electric power and electric power consumption rate from the results of measurement. If there is any problem, it must be solved quickly.

(2) Electric power management

Optimize voltage and capacity in each distribution line and endeavour to introduce high-efficiency electric equipment, operate them efficiently and reduce troubles.

(3) Equipment management

Optimize capacity for the production equipment, intend to introduce and operate high-efficiency production equipment, and endeavour to prevent troubles by completing maintenance and control. Special attention should be paid to troubles with the electric equipment since they are liable to cause the suspension of operation, equipment damage and accident resulting in injury or death.

(4) Process control

Rationalize the operation processes and improve the layout.

(5) Quality control

Establish an overall company cooperative system for quality control and endeavour to reduce defective ratio.

(6) Participation by all employees

Enhance consciousness for increased productivity and cost, and positively promote for the establishment of a work improvement suggestion system and for thoroughness of QC circle activities.

14.1.2 Improvement of the Power Factor

When AC electric power is provided to a load, the electric power at this point is generally less than the product of the voltage and current. In this case, the ratio of the two is called "Power factor", and is expressed by the following equation:

$$\text{Power factor} = \frac{P}{E \cdot I} \times 100\% \quad \cdots\cdots (1)$$

Where P: Electric power (W)
E: Voltage (V)
I: Current (A)

$$P = E\, I \cos\phi \quad \cdots\cdots (2)$$

ϕ: Phase difference between voltage and current

$$I = \frac{P}{E \cos\phi} \quad \cdots\cdots (3)$$

Then, the current to get a specified output should be increased as being inverse proportion to the power factor. A phase-advancing capacitor is generally provided to improve this power factor. The energy conservation effect due to this is obtained by reducing all of the surplus current and resistance loss of the distribution line or the transformer.

Effects obtained by improvement of the power factor are described below:

(1) Reduction effect of Distribution Line Loss

Since power loss in the distribution line is given by (Line current)^2 x (Line resistance), reduced distribution line loss (P_L) to be obtained by providing with a phase-advancing capacitor to improve the power factor in Fig. 14-1 is determined by the following equations:

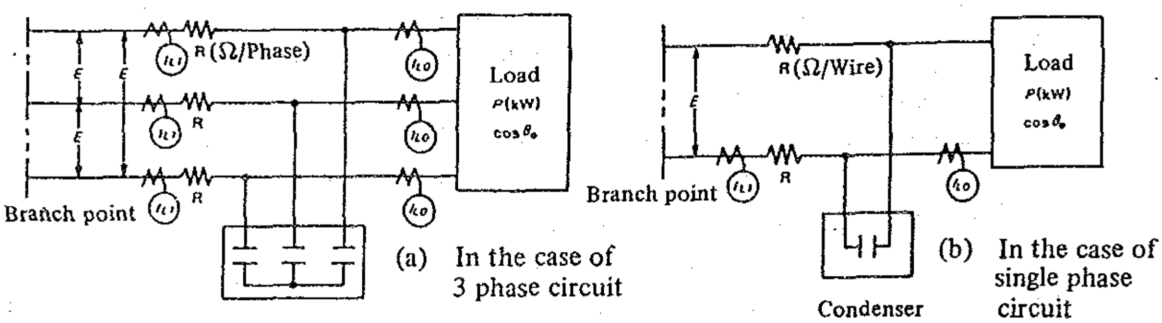


Figure 14–1 Reduction Effect of Distribution Loss

A) Equation for three phase circuit

$$P_L = 3 \times (I_{LO}^2 - I_{LI}^2) \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (4)$$

Where

Before improvement

$$I_{LO}^2 = \left(\frac{P}{\sqrt{3} \times E \times \cos\theta_0}\right)^2 = \frac{P^2}{3E^2} \cdot \frac{1}{\cos^2\theta_0}$$

After improvement

$$I_{LI}^2 = \left(\frac{P}{\sqrt{3} \times E \times \cos\theta_0}\right)^2 = \frac{P^2}{3E^2} \cdot \frac{1}{\cos\theta_1}$$

$$I_{LO}^2 - I_{LI}^2 = \frac{P^2}{3E^2}\left(\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1}\right)$$

Hence,

$$P_L = \frac{P^2}{E^2} \times \left(\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1}\right) \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (5)$$

In equation (5), substituting

$$\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1} = k_1$$

$$P_L = \frac{P^2}{E^2} \times k_1 \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (6)$$

Where,

$$\frac{P^2}{E^2} = 3\cos^2\theta_0 \cdot I_{LO}^2$$

Hence,

$$P_L = 3 \times (I_{LO} \times \cos\theta_0)^2 \times k_1 \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (7)$$

B) Equation for single phase circuit

$$P_L = 2 \times (I_{LO}^2 - I_{LI}^2) \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (8)$$

Where

Before improvement

$$I_{LO}^2 = \left(\frac{P}{E\cos\theta_0}\right)^2$$

After improvement

$$I_{LI}^2 = \left(\frac{P}{E\cos\theta_1}\right)^2$$

$$I_{LO}^2 - I_{LI}^2 = \frac{P^2}{E^2}\left(\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1}\right)$$

Hence,

$$P_L = 2 \times \frac{P^2}{E^2} \times \left(\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1}\right) \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (9)$$

$$= 2 \times \frac{P^2}{E^2} \times k_1 \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (10)$$

$$= 2 \times (I_{LO} \times \cos\theta_0)^2 \times k_1 \times R \times 10^{-3} \text{ (kW)} \quad \cdots\cdots (11)$$

Where

P (kW) : Load power

I_{LO} (A) : Present load current

I_{LI} (A) : Line current after improvement

E (kV) : Line voltage

$\cos\theta_0$: Present power factor

$\cos\theta_1$: Power factor after improvement

C) Calculation example

Reduced loss in the model system of three phase distribution line is calculated by using the preceding equation (7), as is shown in Table 14- 1.

Table 14—1 Calculation Example of Reduction Effect of Loss in 3 Phase Distribution Line Due to Power Factor Improvement

Resistance value of distribution line and cable R: (Size of electric wire)	Length of wiring ℓ	Present power factor ($\cos\theta_0$)	Present load current	Load current after improvement		Reduction of loss in wiring	
				$\cos\theta_1=0.90$	$\cos\theta_1=0.95$	$\cos\theta_1=0.90$	$\cos\theta_1=0.95$
Ω/km	m		A	A	A	kW	kW
0.20(100sq or equivalent)	500	0.60	131	87.3	82.7	2.87	3.10
		0.70	131	102	96.5	2.04	2.30
0.13(150sq) or equivalent	500	0.60	219	146	138	5.18	5.61
		0.70	219	170	161	3.68	4.26
0.10(200sq) or equivalent	500	0.60	262	175	165	5.74	6.21
		0.70	262	104	193	4.08	4.72
0.08(250sq) or equivalent	500	0.60	306	204	193	6.25	6.76
		0.70	306	238	225	4.44	5.14
0.06(325sq) or equivalent	500	0.60	350	233	221	6.12	6.62
		0.70	350	272	258	4.35	5.04

(2) Reduction effect of transformer loss

Generally speaking power loss in transformers consists of "Iron loss" which occurs in iron core, and "Copper loss" which occurs in coil, of which "Copper loss" is greatly affected by the power factor.

A) Equation

Reduced transformer loss (P_t) when the power factor is improved by a phase-advancing capacitor on the secondary side of the transformer as shown in Fig. 14-2 is determined by the following equations:

However, it is assumed that Total load loss of transformers: Copper loss = 1:0.8. The equations are the same for both single and three phase.

$$P_t = (\frac{100}{\eta} - 1) \times \frac{4}{5} \times (\frac{P}{L_0})^2 \times (\frac{1}{\cos^2\theta_0} - \frac{1}{\cos^2\theta_1}) \text{ (kW)} \quad \cdots\cdots (12)$$

$$= (\frac{100}{\eta} - 1) \times \frac{4}{5} \times (\frac{P}{L_0})^2 \times k_1 \times L_0 \text{ (kW)} \quad \cdots\cdots (13)$$

$$= k_2 \times k_1 \times L_0 \text{ (kW)} \quad \cdots\cdots (14)$$

Where,

$$k_2 = (\frac{100}{\eta} - 1) \times \frac{4}{5} \times (\frac{P}{L_0})^2$$

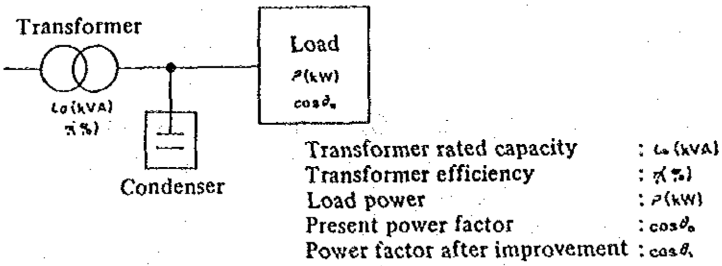


Figure 14–2 Reduction Effect of Transformer Loss

The calculation example of reduced transformer loss using preceding equation (14) is shown in Table 14-2.

Table 14–2 Calculation Example of Reduction Effect of Transformer Loss

Transformer specification	L_0=300kVA η=98%			L_0=500kVA η=98.5%			L_0=1,000kVA η=99%		
P/L_0	0.5	0.6	0.7	0.5	0.6	0.7	0.5	0.6	0.7
$\cos\theta_0 \rightarrow \cos\theta_1$	kW	kW	kW	kW	kW	kW	kW	kW	kW
0.60 → 0.90	1.89	2.72	3.70	2.35	3.39	4.61	3.12	4.49	6.11
0.60 → 0.95	2.04	2.95	4.01	2.55	3.67	4.99	3.37	4.86	6.61
0.70 → 0.90	0.99	1.42	1.93	1.23	1.77	2.41	1.63	2.35	3.19
0.70 → 0.95	1.14	1.65	2.24	1.42	2.05	2.79	1.88	2.72	3.69

Note: 1. P : Load power (kW)
L_0: Transformer rated capacity (kVA)
2. Loss reduction (Pt) is determined from equation (14)

(3) Effect by reducing bus voltage drop

A) Decreasing bus voltage drop and energy conservation

Since improving the power factor reduces the line current, voltage drop in the distribution line can be reduced, which is, to a large extent, energy conservation. That is,, it is because the following various problems which occur, because of the voltage drop, can be settled by improvement of the power factor.

a. Life of fluorescent and mercury lamps, etc. becomes short and the brightness lowers.

b. In electric heaters utilizing Joule heat, the operating efficiency lowers because heating capacity decreases in proportion to the square of the voltage.

c. In a constant load state, load current of induction motors increases, efficiency lowers and distribution line loss increases because motor torque decreases in proportion to the square of the voltage.

It should be noted that when more phase-advancing capacitors than required are operated in a light-load time zone such as on holidays, at night, etc., the bus voltage to the contrary rises excessively, thus resulting in shortened life of all electric equipments such as motors, lighting appliances as well as the capacitors themselves. Therefore, unnecessary capacitors must be released by means of an automatic control system, etc. as described later.

B) Equation

Voltage drop reduction value (namely, voltage buildup value) ΔV due to phase-advancing capacitors can be generally determined by the following equation:

$$\Delta V = \frac{Qc}{R.C.} \times 100(\%) \quad \cdots\cdots (15)$$

Where R.C.: Short-circuit capacity of capacitor-connecting bus (kVA)

Q_c : Capacity of capacitor (kVA)

C) Example of calculation

Let us determine bus voltage buildup value ΔV, when 500 kVA phase-advancing capacitor is connected to a bus with short-circuit capacity of 125 MVA.

$$\Delta V = \frac{500\ (kVA)}{125 \times 10^3\ (kVA)} \times 100 = 0.4\ (\%)$$

(4) Increased surplus capacity for distribution equipment

Load on transformer and distribution equipment in distribution line will be less when the line current reduces due to the improved power factor. Namely, the equipment will have a margin in capacity. Therefore,

a. In the existing equipment, it is possible to increase the load without involving equipment expansion such as re-installation of the distribution line and increased transformer capacity,

b. For new equipment, cost can be saved because equipment with a smaller capacity is purchased.

How much load can be increased by improvement of the power factor in the existing distribution equipment varies with the power factor of the extension load in addition to the power factor before improvement ($\cos\theta_0$), and the power factor after improvement ($\cos\theta_1$).

For one thing, the ratio of extensible load capacity P_1 (kW), when the extension load power factor is identical with the load power factor after installation of the capacitor, to the existing load capacity P_0 (kW) (K_3) is determined.

$$k_3 = \frac{P_1}{P_0}$$

Then

$$\frac{P_0}{\cos\theta_0} = \frac{P_0 + P_1}{\cos\theta_1} = \frac{P_0 + k_3 \cdot P_0}{\cos\theta_1}$$

Hence

$$P_0\ (1 + k_3) = P_0 \cdot \frac{\cos\theta_1}{\cos\theta_0}$$

$$\therefore k_3 = \frac{\cos\theta_1}{\cos\theta_0} - 1 \quad \cdots\cdots (16)$$

Example:

When a 100 kW load at a power factor of 70% is improved to 95% of the power factor, k = 0.36. That is, a load of 100 kW x 0.36 = 36 kW (power factor 95%) can be increased with the present equipment as it is.

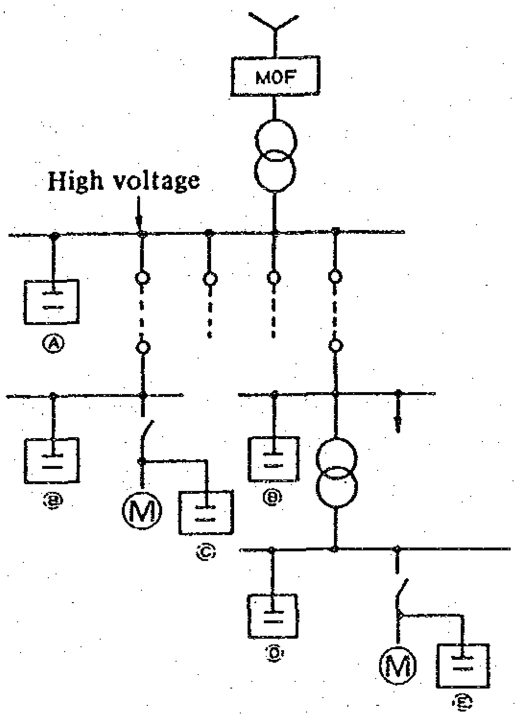
(5) Reduced electric charge

Accordingly, improving the power factor in low power factor factories reduces the electric charge. We have described effects due to installation of capacitors in above items (1) to (5) and will describe problems on selection of capacitor connection and automatic switching control below.

(6) Selection of capacitor connection

A) Connection and effect

There are many points to be considered when connecting a phase-advancing capacitor as shown in Fig. 14.3.



(A) Incoming high voltage bus
(B) Sub s/s high voltage bus
(C) High voltage load direct
(D) Low voltage bus lump
(E) Low voltage load direct

Figure 14–3 Connection Points of Condenser

a. Receiving power factor improvement effects

The has almost nothing to do with the connecting point of phase-advancing capacitor.

b. Required capacitor capacity

Generally, since more phase-advancing capacitors are dispersed, the smaller their use ration (operating time) will be, the total capacity of required capacitors will be the larger. In Fig. 14-3, when capacitors are centralized to (A), a required capacitor capacity may be calculated for all the leveled load in the compound, while when dispersed to (B) to (E), a capacitor capacity to meet load for a restricted area must be calculated.

c. Reduction effect of power loss

It is needless to say that the closer a capacitor is installed to the end of the distribution line, the greater the effect will be and, the longer the line length is, the greater the effect will be.

d. Increased equipment surplus capacity

Increased equipment surplus capacity due to installation of a phase-advancing capacitor takes place in the distribution line, cable and transformer inserted in a series between the capacitor connection and the receiving end. Therefore, the closer the capacitor is connected to the end, the greater the effect will be. However, even if the surplus capacity is increased, for example, it is no worse if there is no space to expand or no planning to increase load in the future.

It is necessary to widely consider this.

e. Reduction effect of voltage drop

Since reduction effect of voltage drop due to a phase-advancing capacitor is determined by power source impedance viewed from the connecting point, the effect will be larger when it is connected at the end.

The foregoing items are summarized in Table 14-3.

B) Determination of capacitor connection

To obtain the maximum energy conservation effect, phase-advancing capacitors should be connected to the end of all of them. However, taking into consideration other conditions such as investment effect, etc., the practical way to determine is as follows.

a. Directly connect to a load with comparatively large capacity (See Fig. 14-3, (C), (E)).

b. Collectively install at concurrence load
(See Fig. 14-3, (B), (D)).

c. Connect the capacitor for improving receiving power factor to the receiving high voltage bus (Fig. 14-3, (A)).

The above methods are considered and should be determined according to each user's conditions on a basis of this information.

(7) Automatic switching control of capacitors

Operating unnecessary capacitors causes the distribution line and transformer losses due to capacitor current in addition to the difficulty due to rises in the bus voltage, thus nullifying the energy conservation effect. Therefore, a switching control will be required. Especially since capacitors installed at the end of the factory are considered difficult to control manually, it is recommended to use an automatic switching control. The automatic switching control mainly has the following four systems:

a. System to switch synchronizing to load on-off signal

b. System to switch according to increase or decrease in load current (Current control)

c. System to switch according to increase or decrease in line reactive power (Reactive power control)

d. System to switch by means of a time switch (Programmed control)

It is necessary to select a suitable system according to the load fluctuation pattern. One example of selection is shown in Fig. 14-4.

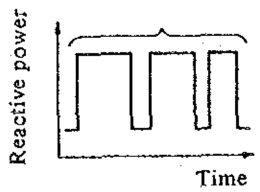
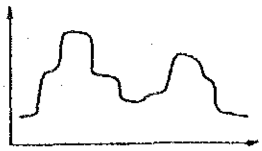
	(Same every day)	(Changes every day)
Load fluctuation pattern		
Applied control system	Reactive power control Current control Program control	Reactive power control

Figure 14–4 Condenser Control System

14.1.3 Improved Load Factor

Since the load factor is defined as shown in equation (17), it is important for improving load factor to restrain the maximum power in such a manner not to concentrate production in a specified time zone through appropriate factory management or through operation control.

$$\text{Load factor} = \frac{\text{Mean power (kW)}}{\text{Maximum power (kW)}} \times 100\ (\%) \quad \cdots\cdots (17)$$

Improving the load factor provides the following advantages:

(1) Since capacity for the receiving and distribution equipments, etc. can be effectively utilized, the equipment investment can be saved.

(2) It is possible to know operating conditions of the factory and machine equipments and to eliminate waste by checking the load curve and load factor.

(3) It is possible to reduce the demand charge by lowering the maximum power.

When the maximum power is likely to exceed the contract demand after lowering it, a demand controller may be required. The demand controller usually consists of a monitor portion and a control portion; the monitor portion receives metering pulse from a watt hour meter and performs operations and judgements required for demand control, it also displays the present demand value and predicted demand value, and it performs alarm, control instructions and recording, etc. The control portionreceives instruction from the monitor portion and stops and returns the predetermined load.

14.2 Transformers

For transformer energy conservation, it is necessary to pay attention to the following:

(1) Transformer efficiency

(2) When there are two or more transformers, operation with an efficient number of transformers.