THE STUDY (AFTER-CARE)
ON THE ENERGY CONSERVATION PROJECT
IN THE KINGDOM OF THAILAND

TEXTBOOK FOR THE ENERGY AUDIT TECHNIQUES WORKSHOP

8. Energy Conservation in the Utilization of Steam

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1. ENERGY CONSERVATION IN THE UTILIZATION OF STEAM

1. UTILIZATION OF STEAM

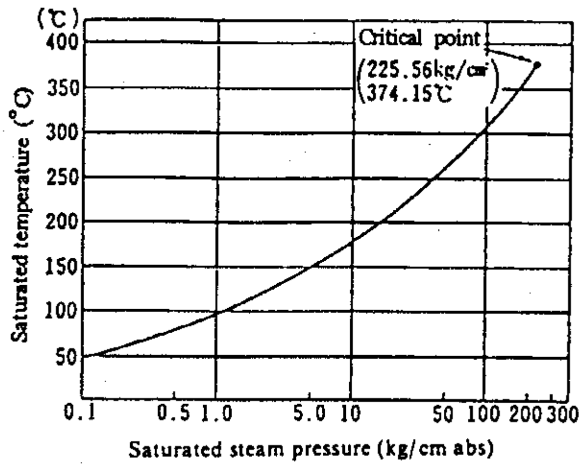
Steam is widely used in factories, buildings and so on as an energy source because of its excellent physical and chemical properties. Available utilization of steam with a thorough comprehension of its properties is related to an effective energy conservation.

The general characteristics of steam are as follows:

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

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

Figure 1 Relation between the Saturated Steam Pressure and the Saturated Temperature



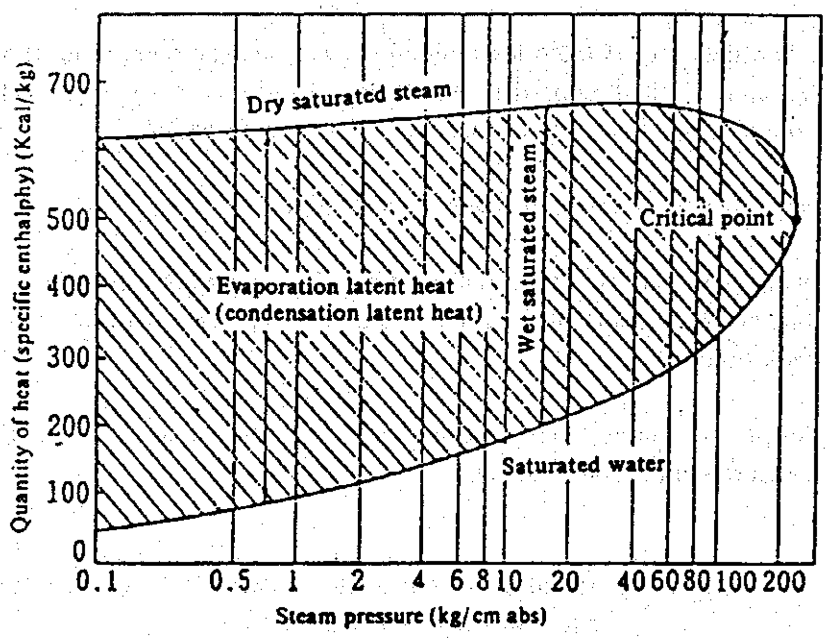
(3) The latent heat of evaporation of steam is larger with lower pressure and it is reduced as the pressure rises. (See Figure 2)

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

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

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

Figure 2 Relation between the Saturated Steam Pressure and the Quantity of Heat



2. EFFECTIVENESS OF STEAM SETTING PRESSURE

(1) Effectiveness of boiler steam pressure

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

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

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

Table 1 Difference of Steam Effective Heat by Pressure

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

If the steam pressure is reduced from 7 bar (G) to 5 bar (G), the latent heat of condensation rises to approximately 9 kcal/kg from Table 1. If an average steam consumption per month is taken as 5,400 metric tons, the steam consumption due to reduction of the steam pressure is

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

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

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

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

(2) Pressure reducing effect of steam

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

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

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

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

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

and the enthalpy of wet steam is

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

The latent heat after pressure reduction is

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

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

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

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

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

3. STEAM TRANSPORT

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

(1) Piping plan

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

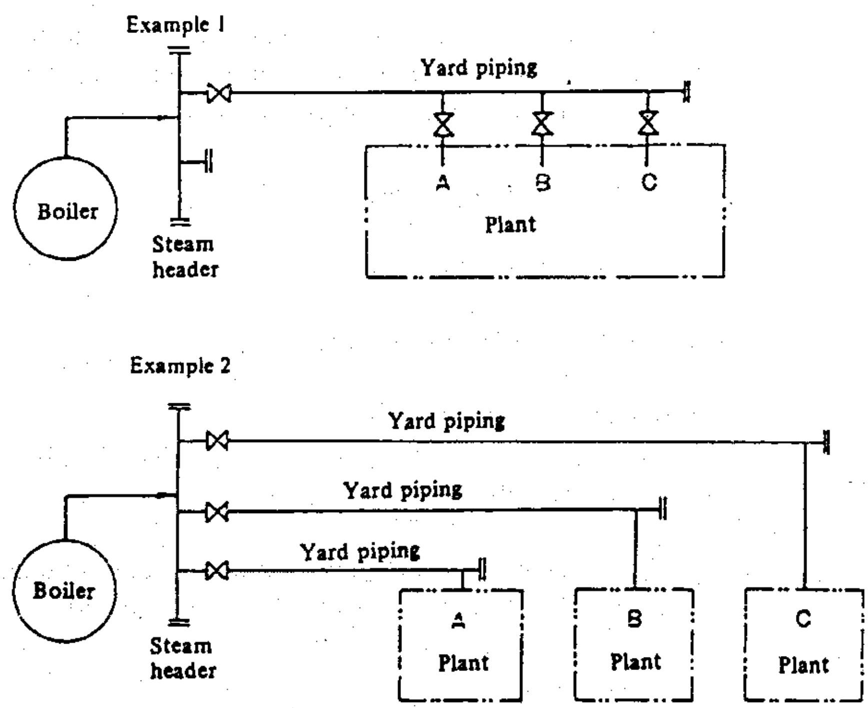
a. Servicing time and hours

b. Batch or continuance

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

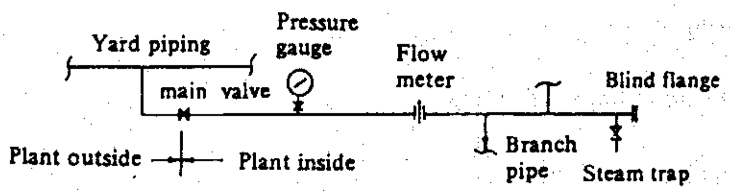
With a plant plan of piping, the relation between the yard piping and the plant piping should be defined. The yard piping system diagram is shown in Figure 3. Decision of either the example 1 or 2 should be taken into consideration for various factors such as the area of factory, the length of yard piping, the time of expansion plant, the operating process of each plant, the initial cost and the heat loss. It is also required to investigate for an exclusive piping for the daytime and the night time, and a separation of the high pressure line and the low pressure line.

Figure 3 Yard Piping System Diagram



To take the piping from the yard piping into the plant, a main valve should be installed as shown in Figure 4 to lessen the influence on the work for the plant extension or to avoid heat loss by closing the main valve at a dead time. A pressure gauge and a flow meter must be installed. Also it is a method that a blind flange is mounted to some terminals of the heater for future usage.

Figure 4 Plant Battery Limit Schematic Flow Diagram



(2) Heat insulation of steam piping

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

A) Type and selection of heat insulating materials

a. Properties required of heat insulating materials

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

The thermal conductivity of insulating materials is:

(1) increases generally with the density;

(2) increases with absorption of moisture;

(3) increases with raising of the temperature.

b. Type of insulating materials

The insulating material used for steam piping is mostly an inorganic materials. Table 2 shows the kinds and features of inorganic insulating materials.

Table 2 Heat Insulator Type and Its Feature

Heat insulator	Raw material and manufacturing process	Product	Property	Safety service temp.
Rock wool insulator	• Andesite, basalt, igneous rock, serpentinite, peridotite, chlorite-schist, slag of nickel ore and manganese ore and limestone • Compound the above materials in a proper ratio, melt in a temperature of 1,500 ~ 1,600 °C and form it to a thin fiber shape by blowing of compressed air/steam. SiO_2 : 40~50 % Al_2O_3: 10~20 % CaO : 20~30 % MgO : 3~7 % Fe_2O_3: 2~5 %	• Attacked by weak acid but not weathered. • Various shape products such as plate, cylinder, band and bracket. • Blacket is formed by set metal on both sides of the stratified rock wool and sew up with a wire. Good acoustic absorption effect.	Density: < 0,3 g/cm³ Thermal conductivity (70 °C): < 0.042 kcal/m. h. °C	600 °C or less
Glass wool insulator	• Manufactured by the similar manner to the rock wool.	• Plate, cylinder, bracket and band	Density: < 0.1 g/cm³ Thermal conductivity (70 °C): < 0.042 kcal/m. h. °C	400 °C or less
Calcium silicate insulator	• Add asbestos fiber into silicate power (mainly diatom earth) and slaked lime to reinforce, allow it to swell enough and mold in a metal mold to allow produce calcium silicate by steaming.	• Put on the market for a high temperature from 1952 and standardized in JIS in 1955. • Low price, good workability and durability. • Typical insulator used not only piping but a general machine.	Density: less 0.22 g/cm³ Thermal conductivity (70 °C): < 0.053 kcal/m. h. °C	1000 °C or less
Perlite insulator	• Calcinate ignition rock such as pearlite or obsidian at 800 ~ 1,200 °C in kiln. • White or gray white color fine particle and very light particle having fine bubble. Not change in quality and not fade in the color. Not absorb moisture in atmosphere.	• Less 1 mm for moulding insulator • Blend asbestos fiber and inorganic adhesive, mold by press and dry. • Classified to 1st class and 2nd class. One of many excellent insulators.	Density: less 0.2 g/cm³ Thermal conductivity: < 0.065 kcal/m. h. °C	900 °C or less
Basic magnesium carbonate insulator (magnesium carbonate insulator)	• The conventional basic magnesium carbonate insulator has been compounded with basic magnesium carbonate of 85 % and asbestos of 15 %. The thermal conductivity is influenced by this ratio. The present insulator is blended with asbestos of 8 % or more.	• Classified to magnesium carbonate water kneading insulator, plate and cylinder. • Convert to magnesium oxide by heating in a temperature of 300 °C or more and shrink extremely • Almost same properties as those of calcium silicate except for heat resistance. As present not used too much.	Density: less 0.3 g/cm³ Thermal conductivity: < 0.065 kcal/m. h. °C	250 °C or less

c. Selection of heat insulating materials

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

(1) Low thermal conductivity

(2) Small specific weight

(3) Low water absorption

(4) High strength and durability

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

(6) Good workability

B) Heat insulation works

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

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

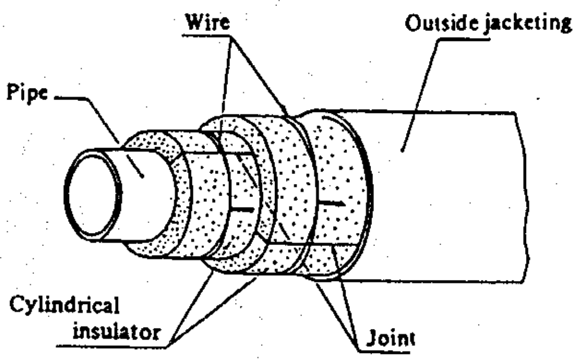
a. Works

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

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

The thermal expansion of piping and the shrinkage of the insulator cause some gasp. In case of two layers or more (if a required thickness is more than 75 mm, the works should be two layers as much as possible), the longitudinal and the lateral joints in each layer should be installed, in shifting, not to be put at the sample part, and the joint should be packed with a compressed fiber (Figure 5).

Figure 5 Case of Cylindrical Insulator



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

The valve portions and the flange parts may sometimes not be insulated by reason of maintenance or inspection and complexity of the works, but these also should be insulated. Figure 6 shows the works of heat insulation for valves, Figure 7 shows the works of heat insulation for flange portions, and Figure 8 shows the works of a heat insulation for hangers.

Figure 6 Insulation Work of Valve

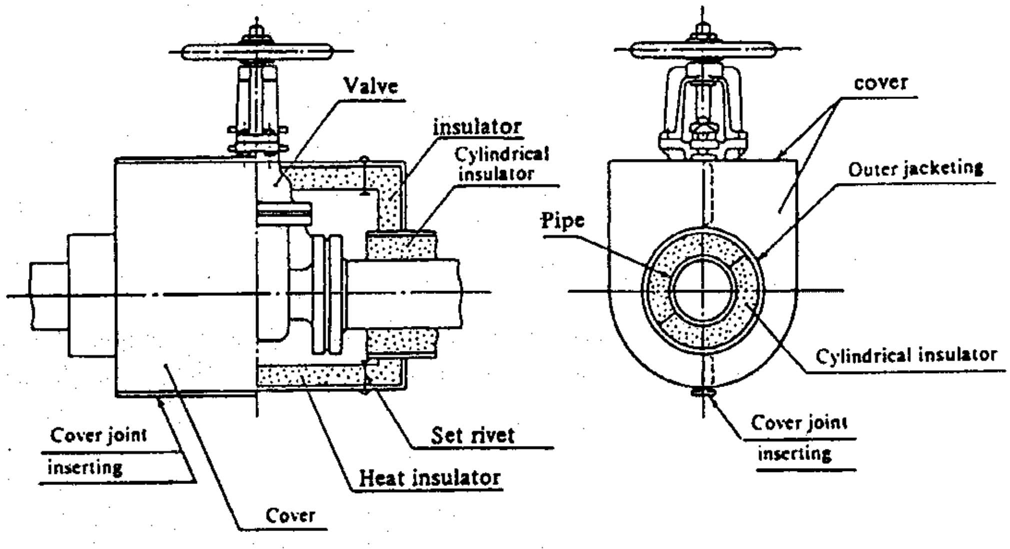


Figure 7 Insulation Work of Flange

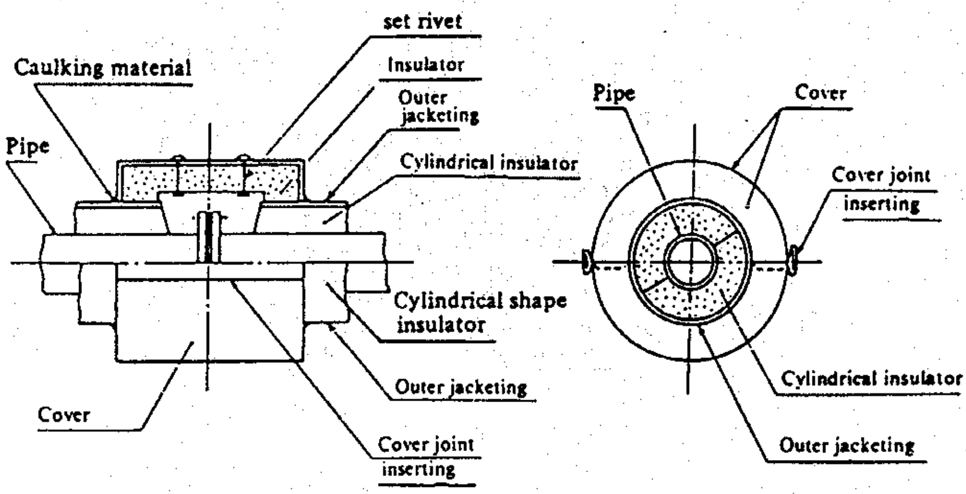
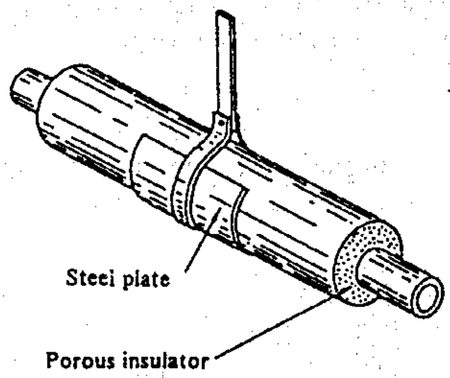


Figure 8 Installation Work of Hanger



(4) Consideration of vibration

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

(5) Consideration of rainwater resistance and chemical resistance

To prevent the heat insulation against rainwater or corrosive chemicals, the heat insulating material should be covered with steel sheet, aluminium sheet or mastic gum. When the heat insulating material absorbs moisture, because the thermal conductivity of water is approximately 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 should be paid to the following points:

(1) Deformation and damage of the outer jacketing

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

(3) Mark of steam leakage or falling of drops

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

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

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

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

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

The heat insulation efficiency and heat loss after heat insulation are shown in Figure 9 to 14.

Figure 9 3" Piping

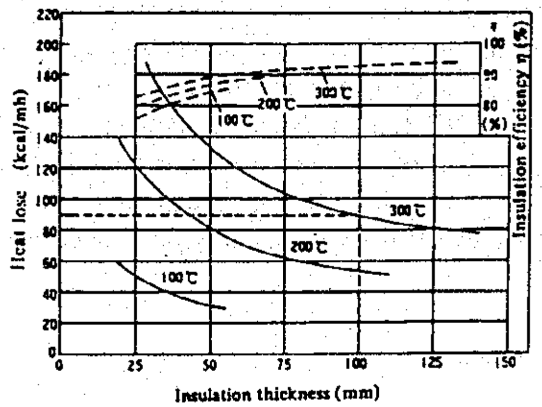


Figure 10 2" Piping

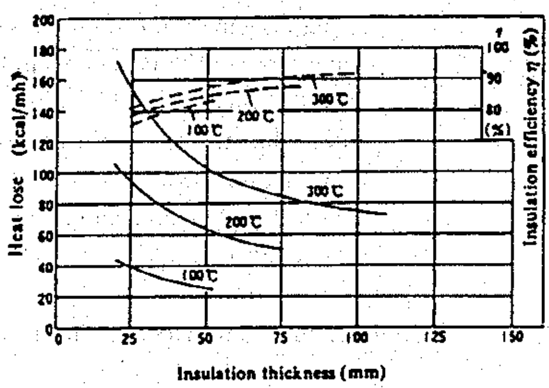


Figure 11 1" Piping

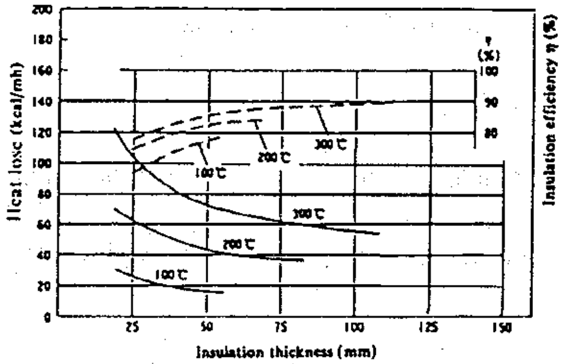


Figure 12 4" Piping

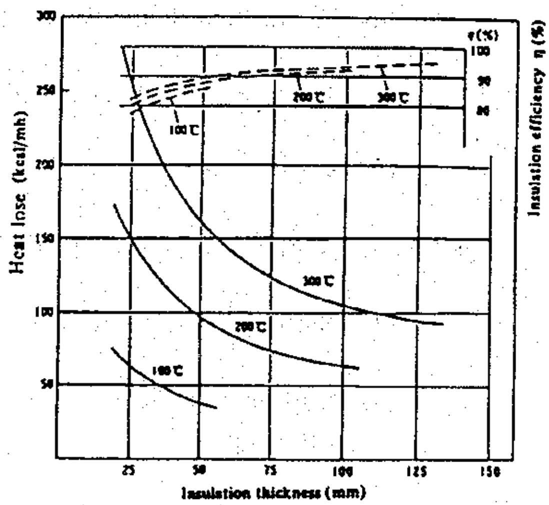


Figure 13 6" Piping

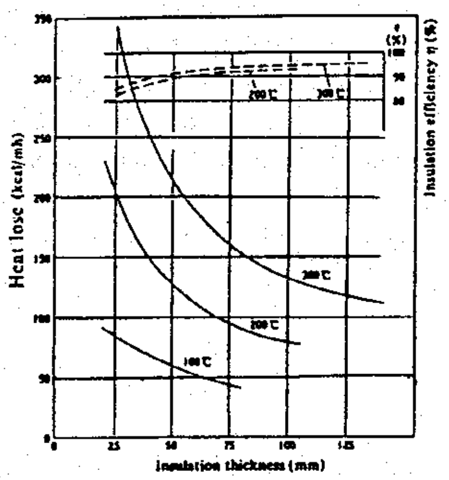
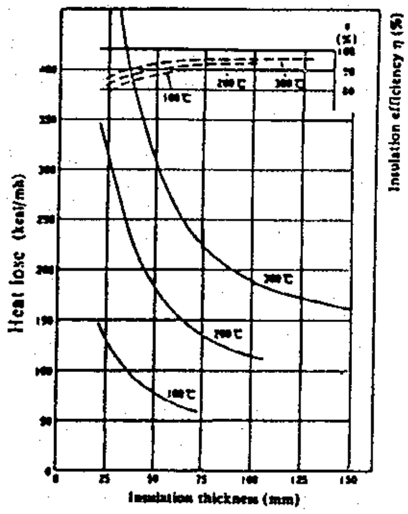


Figure 14 10" Piping



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

Q_0: Dissipated heat of bare pipe

Q: Dissipated heat after heat insulation

<Example of Figure 9>

When a heat insulation thickness of 100 mm 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 obtain 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 30 0 °C and read the ordinate efficiency scale (93 %).

4. STEAM TRAPS

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

A steam trap is applied for this purpose.

(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 3.

Table 3 Classification and Characteristic of Steam Trap

Large classification	Operation principle	Middle classification	Characteristic
Mechanical	Utilize the density difference between the steam and the condensate.	Lever float type Free float type Open bucket type Inverted bucket type Free ball bucket type	The presence of condensate drives directly a trap valve. It is not necessary to wait a temperature drop of the condensate for actuation. The actuation is quick and secure and has a high reliability.
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 Figure 15). Deformation due to abrasion or shock of the lever mechanism might cause warpage or incompetency of the valve seat.

b. Free float type trap

The float itself serves as valve to open or close the valve port (See Figure 16). This trap has a high reliability because there is little mechanical trouble. It has a continuous discharging characteristic of condensate.

Figure 10.15 Float with Lever Type Trap

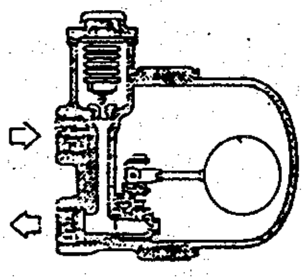
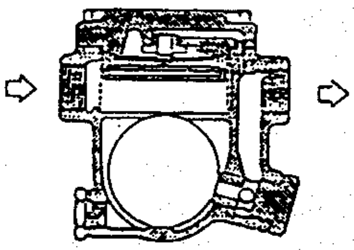


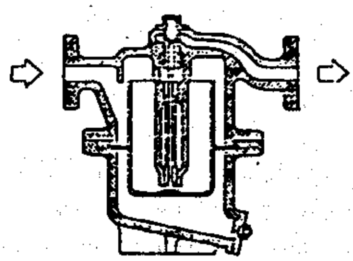
Figure 16 Free Float Type Trap



c. Open bucket type trap

The trap is equipped with a valve on the valve stick which is fixed in the center of the upward opened bucket (See Figure 17).

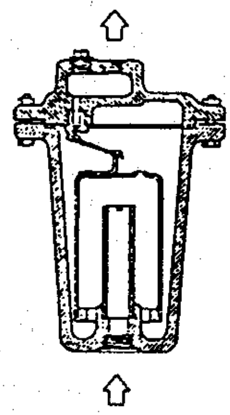
Figure 17 Open Bucket Type Trap



d. Inverted bucket type trap

The trap has a hanging mechanism of a downward opening bucket by the lever and the valve mounted to the lever opens or closes the orifice located in the upper (See Figure 18). Deformation or abrasion of the lever might cause trouble.

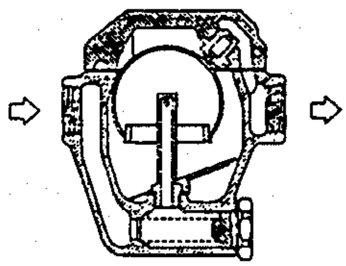
Figure 18 Inverted Bucket Type Trap



e. Free ball bucket type trap

The trap does not have the lever as in the inverted bucket type trap and its actuating principle is the same as the inverted bucket type trap (Figure 19). The bucket is a globe and its outer surface actuates as a valve. The trap actuates intermittently for a small quantity of condensate and discharges continually condensate for a large quantity.

Figure 19 Free Ball Bucket Type Trap



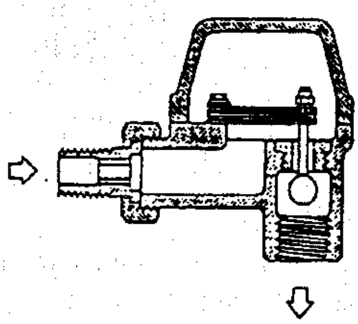
B) Thermostatic steam traps

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 Figure 20).

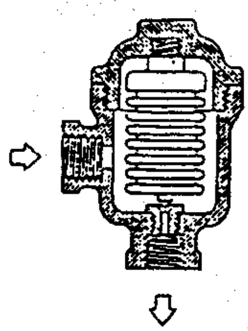
Figure 20 Bimetal Type Trap (Strip Type)



b. Bellows type trap

A low boiling point liquid is sealed in an expandible hermetically sealed enclosure and the valve can be opened or closed through utilization of expansion and contractions of the enclosure due to the change of the liquid vapor pressure by temperature variation (See Figure 21).

Figure 21 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.

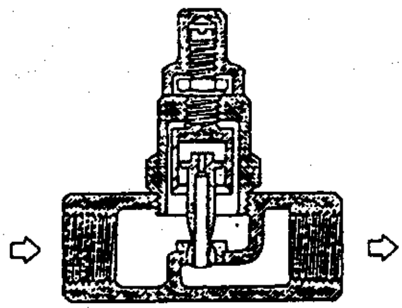
The trap performance is restricted by the pressure such that the trap's back pressure is less than 50 % of the inlet pressure. If the pressure goes to 50 % or more, the trap results in a blow-off condition and is impossible to actuate normally.

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

a. Impulse type trap

It is a trap utilized with fluid characteristics (when the condensate passes the orifice, some pressure drop is caused.) (Figure 22). Although the trap has an advantage of smaller size compared to other types, it has disposition of easy trouble, because it has mechanism that some steam leaks when valve shuts and precision fitting part.

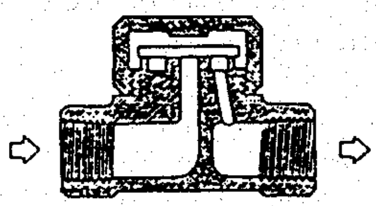
Figure 22 Impulse Type Trap



b. Disk type trap

The trap is equipped with a variable pressure chamber having a disc valve between the inlet and the outlet port and the disc valve opens or closes through the pressure change in the variable pressure chamber (See Figure 23).

Figure 23 Disc Type Trap



The trap has a simple structure of only a disc valve in the moving part and can actuate in a wide pressure range without adjustment. But since its actuation depends on the ambient temperature and 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) Steam trap selection

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

a. Condensate load of the steam use equipment and load characteristics

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

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

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

where

Wp	: Condensate generation quantity	kg/h
C	: Specific heat of the heated fluid	kcal/(kg.°C)
G	: Weight of the heated fluid	kg/h
(T2 - T1)	: Temperature rise	°C
r	: Latent heat of the steam	kcal/kg

In addition, the amount carried in from the piping line, the radiation amount from the equipment, and condensate quantities generated otherwise are taken into consideration, and the generated condensate amount is made 1.5 to 2 times of the calculated value.

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

b. Steam conditions (pressure, temperature, dryness)

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

- Mechanical or thermostatic trap: 0.1 bar (G) or more
- Thermodynamic trap: 0.3 bar (G) or more

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

c. Back pressure conditions

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

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

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

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

d. Maintenance conditions: Is there little trouble and is the life long? Are disassembly and inspection easy?

The following troubles can be considered for steam traps.

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

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

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

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

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

e. Body material

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

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

Table 4 shows the general caution items for steam trap selection.

Table 4 Steam Trap Selection

○ Appropriate △ Some problems × Problematic

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

(3) Steam trap installatin method

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

As the steam flow velocity in a steam transport pipe may be 20 to 30 m/s, a short pipe is connected to the lower part of the piping for removal so that the condensate can be separated easily. The basic rules for steam trap installation are that the condensate from the steam heating equipment shall flow smoothly by gravity flow to the trap, and that the condensate leaving the trap shall be sent by the steam pressure to the collection place. Figure 24 shows good and bad installation examples.

(4) Steam trap maintenance

A) Inspections

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

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

Figure 24 Good Example and Worse Example of Installation (1/4)

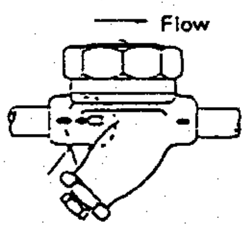
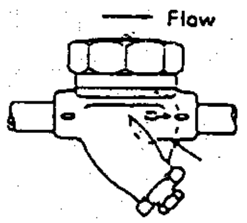
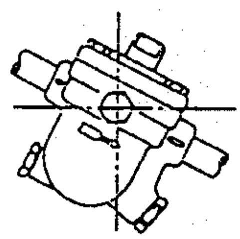
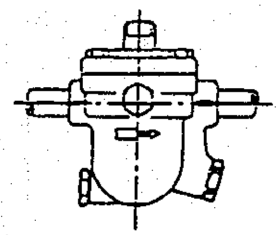
Wrong installation	Description	Correct installation
	Steam trap should be fitted in the direction of flow. All steam traps bear on the body stamp or mark showing flow direction.	
	Free float type steam trap should be fitted horizontally.	

Figure 24 Good Example and Worse Example of Installation (2/4)

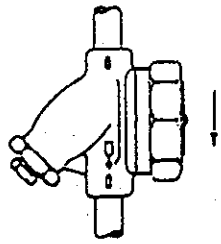
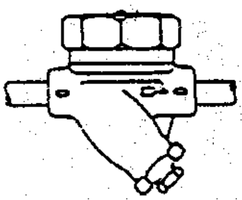
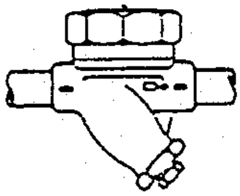
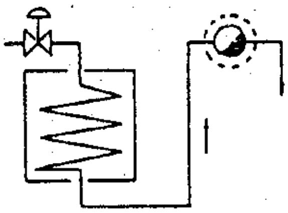
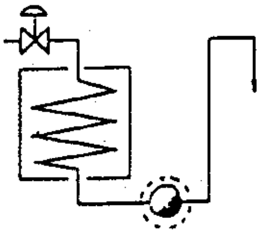
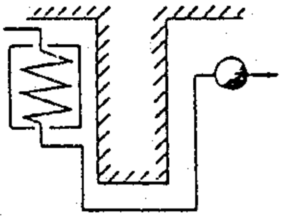
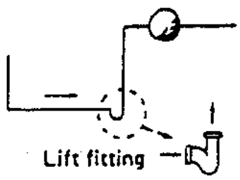
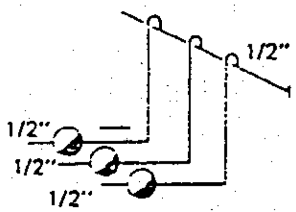
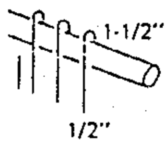
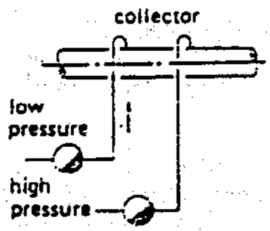
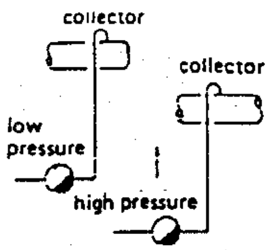
Wrong installation	Description	Correct installation
	Thermodynamic steam traps have no limitation as to position. It can be fitted vertically.	
	Never use an inlet pipe smaller than trap size. Steam locking and air binding are apt to occur when inlet pipe is too small.	
	Never install steam trap at a 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.	
	Condensate discharged through two traps which operate at different pressures should not be collected to a common collector.	

Figure 24 Good Example and Worse Example of Installation (3/4)

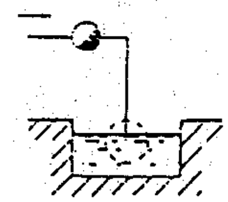
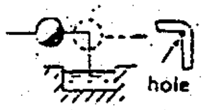
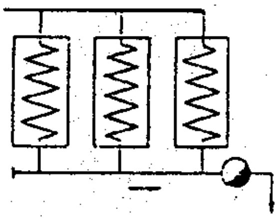
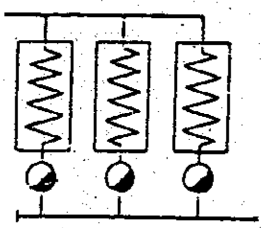
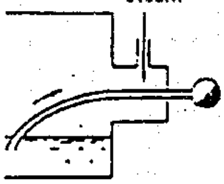
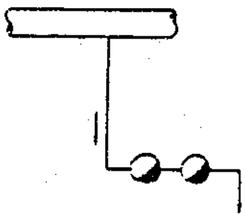
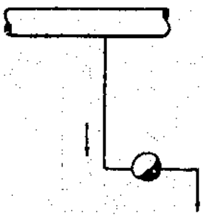
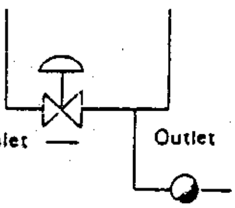
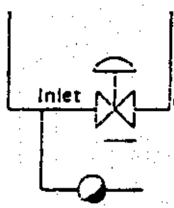
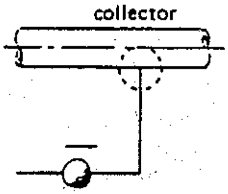
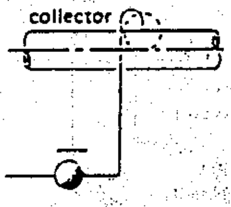
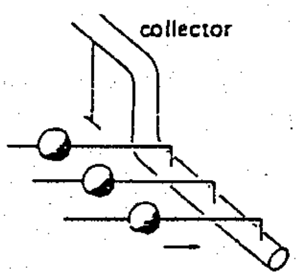
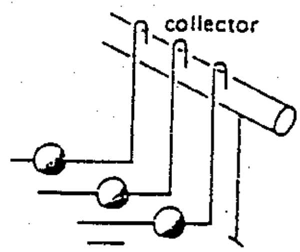
Wrong installation	Description	Correct installation
	Outlet pipe should not be submerged into trenches. Provide small hole to break vacuum.	
	Each steam unit should always have individual steam trap. (Individual trapping) To fit one trap to several steam equipment is a bad practice. (Group trapping)	
	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.	

Figure 24 Good Example and Worse Example of Installation (4/4)

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.	

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

a. Steam trap plot plan

b. Steam trap register book

c. Steam trap check list

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

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

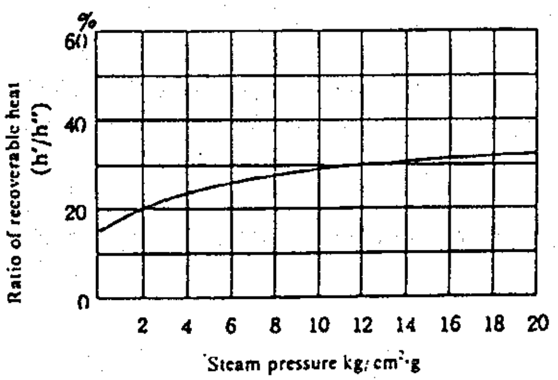
This inspection is a method to measure the actuating sound by an ultrasonic measuring instrument and can be simply checked without experience.

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 Figure 25. If this heat contents of condensate is recovered 100 % and utilized effectively, the fuel consumption can be saved by approximately 10 to 13 %. This will result in large energy conservation.

Figure 25 Ratio of Recoverable Heat (Enthalpy of Condensate/Enthalpy of Saturated Steam)



(2) Utilization of recovered condensate

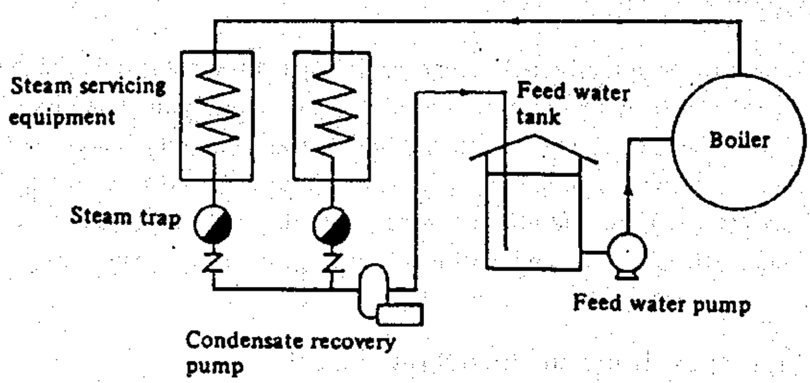
The recovered condensate is generally utilized as feed water of the boiler. Consideration of the pressure and the quantity of condensate and the layout of the steam equipment is necessary to more effectively recover the condensate. The utilization of condensate is classified into the following three 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 Figure 26).

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

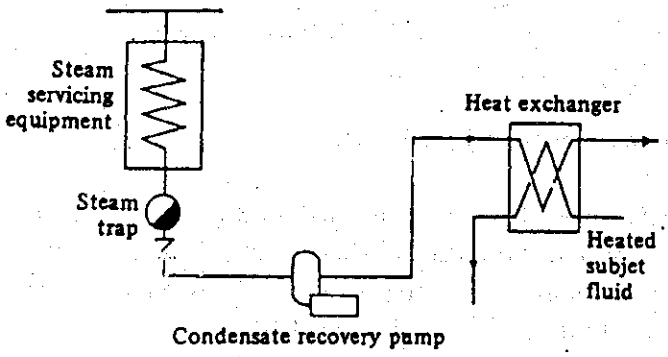
Figure 26 Direct Utilization to Feed Water



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 (Figure 27).

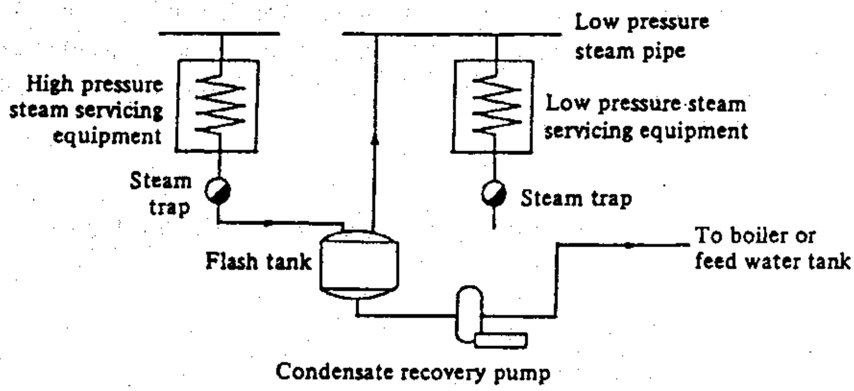
Figure 27 Indirect Utilization through Heat Exchanger



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 Figure 28).

Figure 28 Flash Steam Utilization



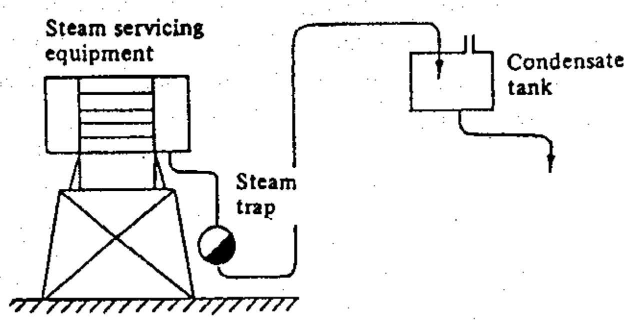
(3) Condensate recovery method

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 pressure acting on the steam trap. This can be applied to the case of a short distance between the condensate generating place and the utilizing place (See Figure 29).

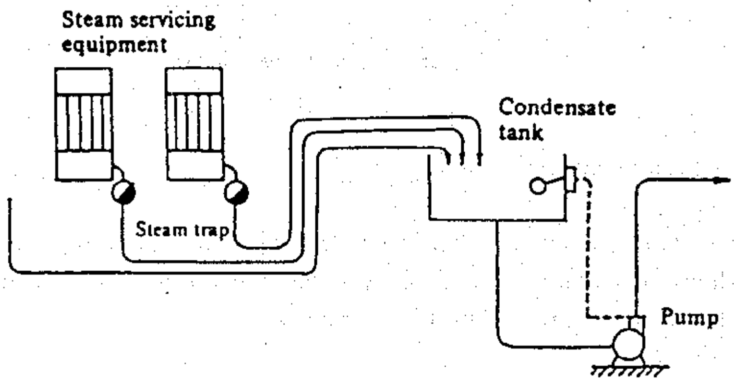
Figure 29 Recovery by Steam Trap Only



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 Figure 30).

Figure 30 Recovery by Centrifugal Pump

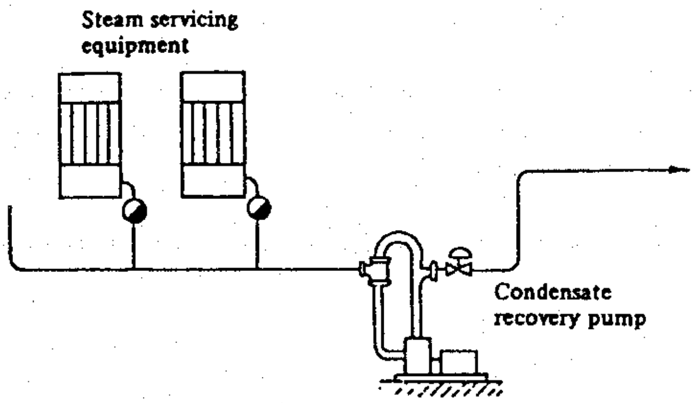


In this case, care must be used for ensuring the water head of the pump, a level control of condensate tank, and a pump capacity as well as a back pressure limit of the steam trap. Especially when the temperature in the tank is 80 °C or more, a positive water head of 4 to 5 m is required to prevent a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

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 (Figure 31).

Figure 31 Recovery by Condensate Recovery Pump



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

(4) Caution items for condensate recovery

A) Steam trap back pressure limit

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

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) Appropriate selection of the condensate recovery pipe

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

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

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

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

where

d : Piping inside diameter, cm

W : Condensate quantity, kg/h

V : Flow velocity in the pipe, m/s

Open recovery : 10 to 15 m/s,

closed recovery: 5 to 10 m/s

ve : Equivalent specific volume

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

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

v" : Specific volume of saturated steam at the pressure inside the recovery pipe, m^3/kg

f : Reevaporation ratio

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

h_1 : Condensate enthalpy at the trap inlet side, kcal/kg

h_2 : Condensate enthalpy at the pressure inside the recovery pipe, kcal/kg

r : Evaporation latent heat at the pressure inside the recovery pipe, kcal/kg

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

Example for calculation of the pipe diameter:

$W = 300$ kg/h

$V = 10$ m/s

$h_1 = 160.2$ kcal/kg (6 bar)

$h_2 = 111.1$ kcal/kg (1.5 bar)

$r = 531.8$ kcal/kg (1.5 bar)

$v' = 0.00105$ m³/kg

$v'' = 1.159$ m³/kg

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

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

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

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

D) Insulation

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

E) Flash loss prevention

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

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

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

F) Sight glass installation

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

G) 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 (2) C), 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 condensates result in a fair amount. But it is necessary to manage to gather these small quantity condensates with a cost as small as possible.

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.

Figure 32 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 bar(G) is used by 2,500 kg/h and condensate is discharged into a flash tank of 0.5 bar(G) of internal pressure, the quantity of flash steam is generated with 12.3 % (wt.) by Table 5 and a steam quantity of 307.5 kg/h is obtained.

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

Figure 33 shows a chart to decide the inside diameter of the flash tank.

Obtain the inside diameter of the tank through the example shown in Figure 32.

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

Table 5 Flash Steam Generating Rate (wt.%)

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

Figure 32 Example of Flash Steam Use in Air Heater

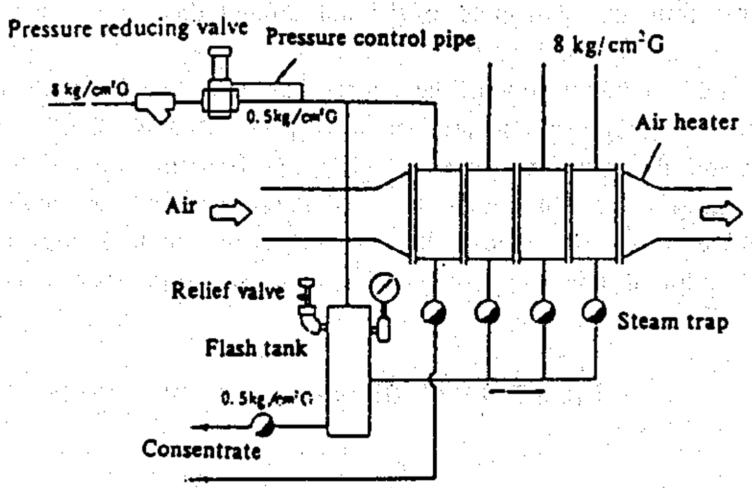
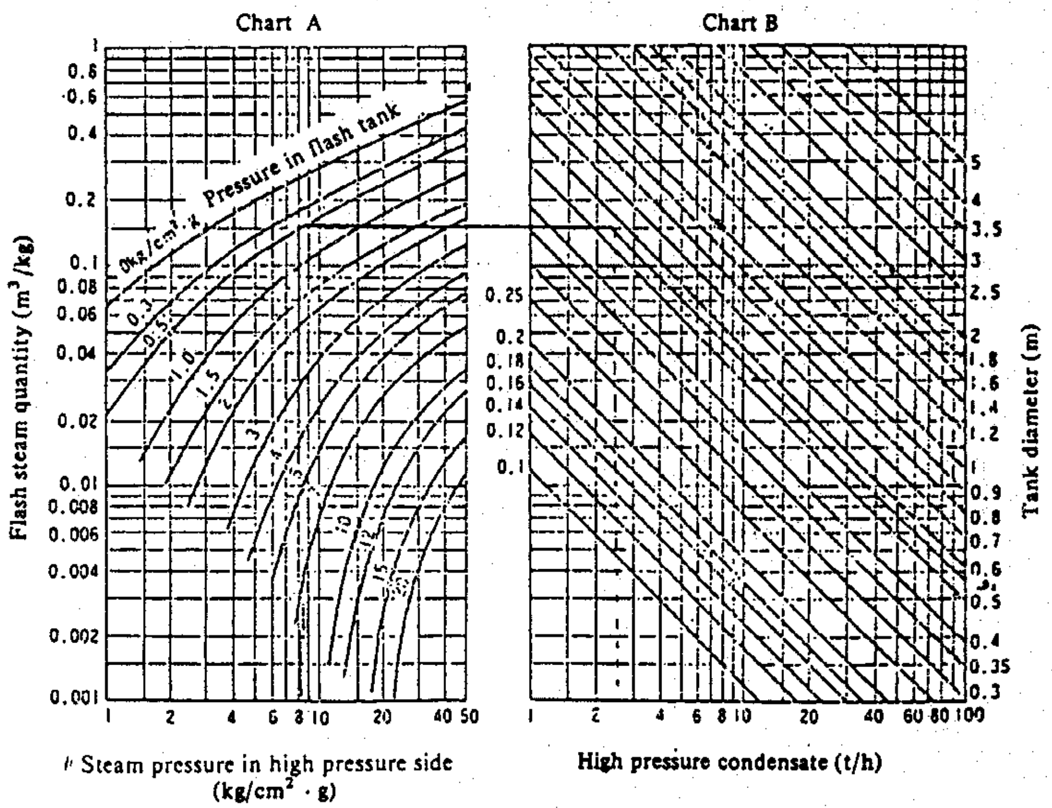


Figure 33 Chart of Flash Tank Diameter



(6) Utilization of thermocompressors

The structure of thermocompressors is composed of three basic parts, body, a steam nozzle and diffuser as shown in Figure 34. When a driving steam is expanded through the steam nozzle, a supersonic jet having an extremely low static pressure is generated. When its speed is reduced by the diffuser, the pressure is recovered. That is, when a low pressure steam is sucked into the Venturi throat section, it becomes high pressure steam.

Figure 35 shows an example of a chemical plant. The bottom liquid in a stripping tower is introduced to a flash tank and the low pressure of a generated flash steam is raised to a proper pressure by the thermocompressor to save additional steam.

Figure 34 Thermocompressor

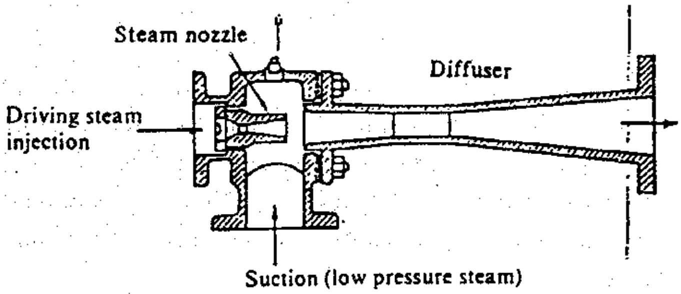
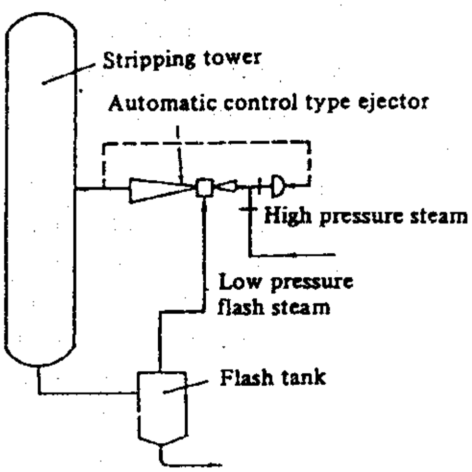


Figure 35 Example of Thermocompressor Use for Stripping Tower



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 lower than the saturation temperature of steam alone. Therefore, sufficient air elimination is required at the start up. For reference, the relation between the air mixing ratio and the steam temperature is shown in Table 6.

Table 6 Relation between the Air Mixing Ratio and Steam Temperature

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

(2) Direct steam blow heating method

A direct steam blowing operation is often carried out in some processes such as when hot water is required or when heating a raw material solution. For steam blowing, there are various methods, such as installation of a silencer to the tip of steam pipe, or a steam blowing pipe with a number of small holes (See Figure 36 and Figure 37).

Figure 36 Silencer

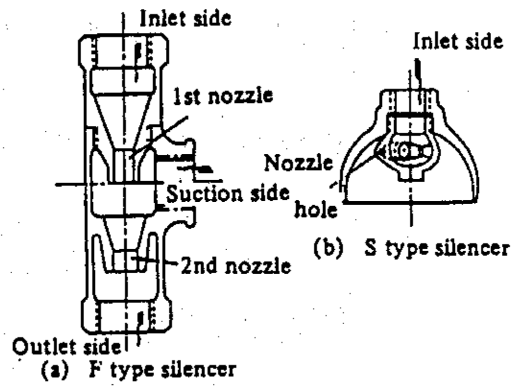
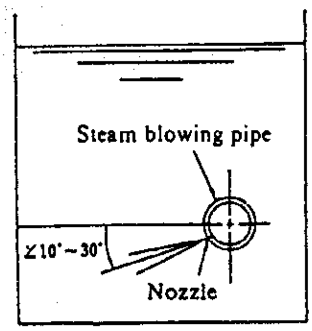


Figure 37 Steam Blowing Angle from Nozzle



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

a. Reduce the velocity of steam bubbles blown 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 Figure 37).

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 Figure 38. When the steam side comes in a vacuum, the valve opens by a pressure difference to atmospheric pressure, the vacuum is destroyed and the back flow of liquid can be prevented.

Figure 38 Steam Direct Blowing Heater