Text No.22

ENERGY CONSERVATION TECHNOLOGIES FOR STEAM USING FACILITIES

蒸気使用設備の省エネルギー技術

June 23, 2003

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1. Rationalization of Energy Use

1-1 How to implement energy conservation measures

(1) Three steps of energy conservation

The best way of tackling energy conservation is to take the following three steps:

Step 1: Improve the condition of facilities and their operating conditions without major capital investment.

Step 2: Add facilities and undertake facility improvements requiring some capital investment.

Step 3: Undertake manufacturing facility modifications and process modifications requiring major capital investment and introduce new facilities.

When proceeding with step-by-step energy conservation, it is necessary to ascertain the current state of energy use involving the existing facilities based on actual data and accurately determine whether the design performance has been achieved. Performance degradation due to aging does occur, and an increase in energy consumption is often encountered in unexpected places.

It is recommended that energy be managed based on the concept of energy intensity, i.e. energy consumption per unit output. This will involve the recording of the energy intensity of each facility, each process and the factory as a whole, and a cross-comparison of yearly and monthly figures to identify any problems. If the energy intensity increases despite the introduction of energy conservation measures, it is likely that the facility availability rate has worsened or excessive energy consumption is occurring in unexpected places.

(2) Payback period of energy conservation capital investment

When undertaking energy conservation capital investment, the payback period should be calculated to ensure high investment efficiency. In Japan, capital investment payback periods are generally set in the 3–5 year range. An effective way of going about energy conservation capital investment is to start with projects with short payback periods and gradually move on to those with longer payback periods.

However, the standard payback period inevitably varies from country to country due to differences in energy prices, government assistance, interest rates and other circumstances.

At step 1 or 2, a payback period is often obtained by simply dividing the amount invested by the annual cash inflow. At step 3, where capital investment is substantial, however, equation (1) below is used.

$X = A/B$ ....(1)

where X: Payback period year

A: Net investment ....yen

A = Amount invested – Net proceeds on sale of old facilities

B: Net income increase ....yen

B = Income increase + (New facility depreciation – Old facility depreciation)

1-2 Details of Energy Conservation Measures

With step 1 or 2 of energy conservation, there are four perspectives from which the energy conservation potential of various measures should be investigated: loss, waste, recovery and efficient facility operation.

(1) Eliminating energy loss

a. Prevention of heat dissipation (heat insulation)

Heat dissipation from tank, pipe and wall surfaces should not be ignored. Although the amount of heat dissipated varies depending on the nature of air/liquid flow over the convective heat transfer surface and its temperature, heat insulation generally proves effective for surfaces that are at least 50–60 °C in temperature and directly or indirectly in contact with flowing water, such as those found on washing machines. Traditionally, dyeing machines and washing machines were not heat-insulated due to the susceptibility of heat insulators to water intrusion and high cost of making them watertight. Recently, however, heat insulators made of closed-cell water-repellent plastic foam have been developed, and the glue installation of such a heat insulator is now fairly common. The limit on the working temperature of heat insulators has also risen to about 100 °C, and this has made their high-temperature applications possible, examples including the heat insulation of hot water tanks and covering of liquid surfaces as floating lids to prevent heat dissipation from them. Table 1 shows experimental results.

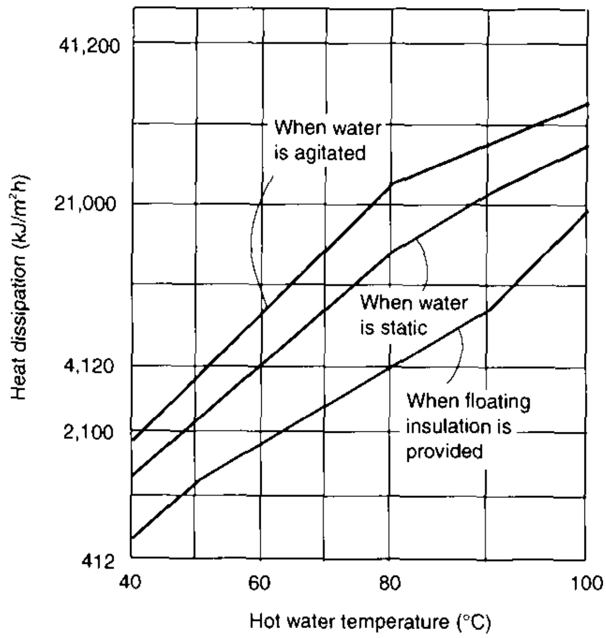
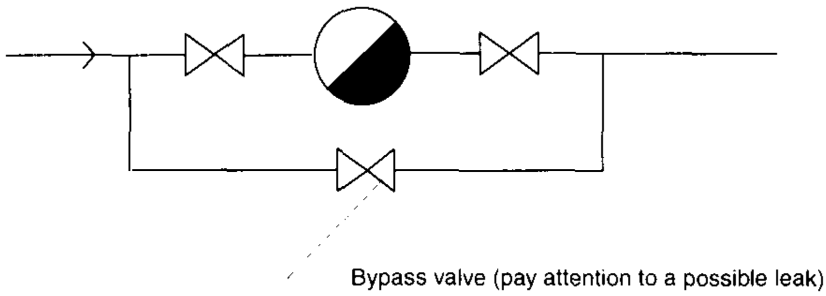


Table 1 Heat Dissipation from Hot Water Surface

b. Preventing heat leakage

The valve seats of steam supply valves, water supply valves, etc. get scratched through prolonged use, and this causes leakage and heat loss. Steam traps and automatic valves are provided with a bypass line, and leaks sometimes occur from bypass lines due to a slight opening of the bypass valve.



c. Heat loss due to poor steam trap management

The operating condition of steam traps should be inspected regularly (once or twice yearly) to check whether condensate discharge is normal.

In cases where condensate is being recovered, an abnormally high temperature of the condensate collection tank or a leak from the top of the tank is likely to have been caused by malfunction of a steam trap.

(2) Eliminating waste

a. Reduction of washing water quantities

For normal cloth washing purposes, an amount of water that is about 4-5 times the weight of the cloth is adequate. If that amount of water is insufficient to achieve the required results, it will be necessary to use a washing machine with a greater washing efficiency. There are three ways of improving washing effectiveness as follows:

1) Increasing the frequency of the contact between the cloth and water
2) Making the cloth and water flow in opposite directions .... parallel flow → counter flow
3) Shaking the cloth and water

To save water and energy, the use of water for washing tanks should be managed by clearly distinguishing recycled hot water and fresh cooling water, with the effluent of one stage led to the next stage for counter-flow washing in the case of a multistage washing process. When employing counter-flow washing, particular attention should be paid to the optimization of the water flow rate in each tank.

In concrete terms, the following methods are available:

1) Installation of constant flow valves
2) Maintenance of constant water supply pressure -------- installation of a pressure relief valve
3) Maintenance of constant water level and temperature - installation of sensors

These methods lead to improved washing effectiveness and better water quantity and temperature management. The amount of water can be reduced to less than 3 times the weight of the cloth as compared to conventional methods' 4–5 times, while steam consumption can be cut by more than half.

b. Reduction of liquor ratio

In addition to consuming large quantities of water, the dyeing process often employs heating (70–105 °C) to increase the degree of exhaustion. For this reason, saving water tends to save heat energy as well.

The volume of water (in liters) required to dye 1 kg of goods is called the "liquor ratio", which varies widely depending on the dyeing equipment and dyeing method.

A variety of low-liquor-ratio dyeing machines have been developed.

These machines reduce the liquor ratio from the conventional 1:20–30 to less than 1:10 by spinning the cloth at high speeds of more than 200 m/min or shaking it, thus improving its contact with the dye liquor. Notably, batch dyeing has been undergoing a shift from stationary-liquor dyeing to circulating-liquor dyeing, and this has already resulted in substantial energy conservation through a dramatic reduction in liquor ratio. All in all, these measures have cut energy consumption by more than 50%. Circulating-liquor dyeing also cuts dyeing time by allowing the cloth forwarding speed to be raised, thus increasing the number of cycles for an eight-hour working day from one to four or more. As well as dramatically improving productivity, circulating-liquor dyeing also saves space.

Liquor ratio

1:20 → 1:15 → 1:10 → 1:5

c. Reduction of dyeing time

A shift to circulating-liquor dyeing has led to an increase in cloth forwarding speed and a reduction in dyeing time. In addition, a dyeing method capable of raising temperature quickly by increasing the capacity of the tank heater and incorporating a program that speeds up temperature rise over the temperature range unrelated to dyeing, while eliminating the need for dip dyeing, has also been developed. Unlike the Smith

Drum dyeing machine, which uses a chain or belt to transmit power from the driving motor, a geared motor has been used to directly drive the drum. The VVVF control of a motor has also been introduced to control the rotating speed of the drum and change the direction of its rotation as a means of improving the degree of exhaustion.

d. Reduction of processing temperature

To reduce the processing temperature for bleaching, dyeing and other processes, methods such as changing chemical agents are used. The possibility of further reducing the washing temperature should be investigated. There is an instance of the dyeing temperature for a nylon product being reduced from 98 °C to 70 °C.

Lowering processing temperature leads not only to a reduction in the quantity of heating steam but also a reduction in heat dissipation and condensate waste heat.

e. Improvement of drying efficiency

1) Raising cylinder dryer efficiency

Cylinder dryers are widely used because of their superiority to hot air dryers in terms of heat transfer efficiency. However, poor maintenance leads to insufficient drying due to a reduction in the cylinder surface temperature, and this sometimes forces a reduction in the cloth forwarding speed, for example from the design value of 60 m/min to 40 m/min.

With a cylinder dryer, steam must be handled in the following manner:

- Keep condensate out of the cylinder by increasing the dryness of the steam.
- Keep the steam pressure constant. → Install a pressure control valve capable of maintaining constant cylinder supply steam pressure.
- Remove any condensate that forms inside the cylinder as thoroughly and quickly as possible. → Install a steam trap for each cylinder.

2) Controlling dryer drying power

With a hot air dryer, incorporate an inverter into the hot air fan and exhaust fan motors to prevent overdrying and save heat and electric energy through VVVF control.

- Measure the dryness of cloth at the dryer outlet using a moisture sensor to control the moisture content of hot air jets or provide the hot air circulation fan with VVVF control.
- Measure the exhaust temperature at the suction side of the exhaust fan to automatically control the opening of the exhaust damper.
- Air shrinker dryer → designed to dry cloth by blowing hot air at a high speed (35 m/s) using slit nozzles.

These measures have achieved heat and electric energy savings of more than 20% and a productivity improvement of 20%.

f. Thorough dewatering using mangle

Prior to drying, cloth must be thoroughly dewatered using a mangle to reduce the amount of energy needed for drying. To increase the dewatering rate, rollers that are provided with suitable hard rubber coating are used, with adjustments made to ensure a uniform distribution of roller pressure. Some more effective systems use nonwoven fabric rollers, while others are of a vacuum type designed to suck moisture via slits. As they are capable of reducing water content to 25–50%, they can double the drying speed, while achieving a substantial reduction in drying costs - up to 17% in one instance.

Alongside the elimination of loss and waste, recovery/reuse is another important approach.

(3) Recovery/reuse of waste energy

a. Recovery of waste heat

A dyeing plant releases large amounts of heat, and substantial portions are wasted through, for example, dryer exhaust and hot effluent from washing and dying facilities.

Table 2 Breakdown of Energy Consumption at Dyeing Plant

Item	Share (%)	
Heat treatment	16.6	
Heating for drying	17.2	
Effluent heat loss	24.9	○
Heat dissipation	12.3	
Exhaust heat loss	9.3	○
Adjustment/warm-up operation	3	
Evaporation heat loss	4.7	
Condensate heat loss	4.7	○
Other	0.6	
Total	100.0	

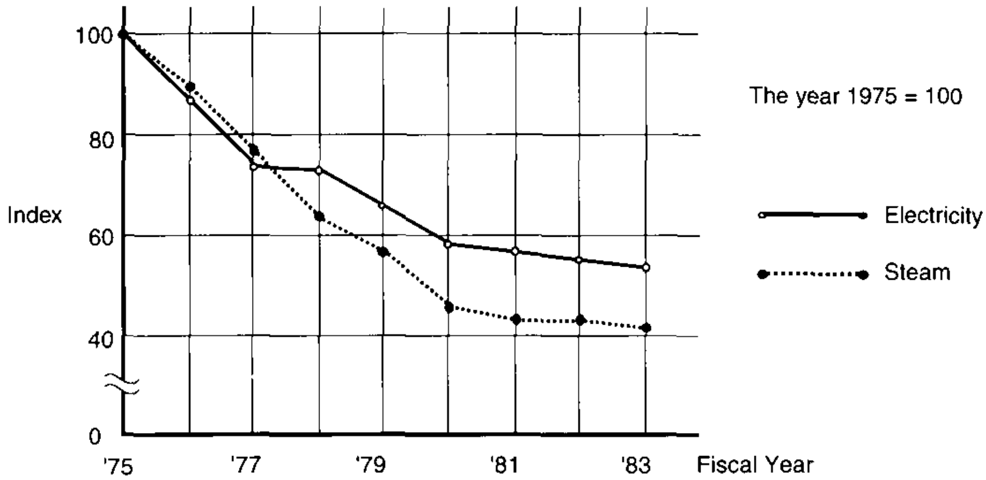
Combined total of items marked "○" about 40%

Table 2 is an example of the analysis of heat energy use at a textile factory. From the table, it can be seen that the bulk of waste heat occurs in the form of hot effluent. For this reason, attempts are often made to recover waste heat from dyeing and washing process effluents through heat exchange, with the cooling water used as feedwater.

However, as dyeing process effluent, combustion gas, etc. contain dirt, fat/oil, dust and other foreign matter, plate heat exchangers require regular cleaning. Otherwise, a deterioration in the heat transmission coefficient will occur.

* Of the total energy consumed, only about 30% is used for processing, with the remaining 70% thrown away.

The diagram below shows how energy intensity reductions have been achieved over time at a dyeing plant through effluent recovery. With the energy intensity for the fiscal year when the measure was introduced (1975) set to 100, the index fell to less than 50 eight years later (1983).



b. Recovery and use of condensate

The recovery of condensate is a highly effective energy conservation measure. Although cylinder dryers, water heaters, etc. effectively utilize the latent heat of steam, they waste its sensible heat.

Generally speaking, 20–30% of all heat energy consumed as steam can be recovered as condensate (ratio of condensate enthalpy to steam enthalpy), and this translates into a 10–13% saving of net boiler energy input.

There are two ways of recovering condensate as follows:

- Via steam trap discharge pressure
- Via pump pressure

In condensate recovery via pump pressure, a jet pump is used to return condensate directly to the boiler. Closed recovery, which is more effective than open recovery, has been widely used.

Figures 1 and 2 show condensate recovery flowcharts.

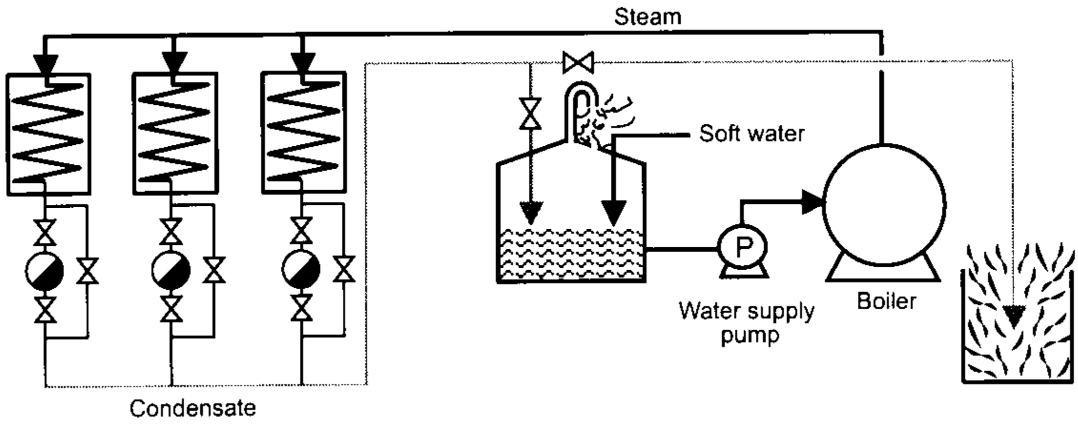


Figure 1 Process Flow of Open Condensate Recovery

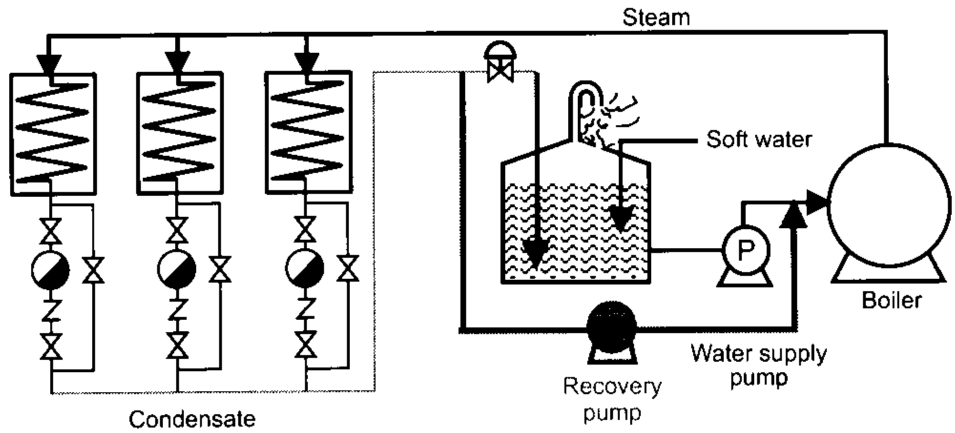


Figure 2 Process Flow of Closed Condensate Recovery

Note: Choose mechanical steam traps as they have the following advantages:

1) Relatively immunity to the effect of back pressure and its fluctuation

2) Simple construction and high reliability

When introducing condensate recovery, the following should be taken into consideration:

- The back pressure of the recovery piping should not be more than 40–50% of the minimum working steam pressure.
- The recovery piping should be heat-insulated.
- As vibration and noise is generated when the interior temperature of the recovery tank exceeds 80 °C (in the case of flash steam being present), a large number of small holes should be provided to widely disperse condensate.
- Cooling piping should be provided to prevent the interior temperature of the recovery tank from rising above 90 °C.
- The recovery piping should be provided with glass windows so that the condi-

tion of the condensate can be monitored.

The size of the recovery piping can be calculated using equation (2).

$$d = \sqrt{\frac{3.53 \times W \times Ve}{V}} \quad \text{..........(2)}$$

where d : Inside diameter of piping .... cm

W : Condensate buildup .... kg/h

V : Condensate flow speed .... m/s

Open recovery 10-15 m/s

Closed recovery 5-10 m/s

Ve: Equivalent specific volume

$$Ve = V'(1 - f) + V'' \cdot f$$

V' : Specific volume of saturated water at the internal pressure of the recovery piping .... m^3/kg

V'': Specific volume of saturated steam at the internal pressure of the recovery piping .... m^3/kg

f : Re-evaporation rate

$$f = \frac{h_1 - h_2}{\gamma_2}$$

h_1 : Condensate enthalpy on the inlet side of the steam trap .... kJ/kg

h_2 : Condensate enthalpy at the internal pressure of the recovery piping .... kJ/kg

γ_2 : Latent heat of evaporation at the internal pressure of the recovery piping .... kJ/kg

c. Generation and utilization of waste heat

As waste heat media contain dirt, fat/oil, dust and other foreign matter, effective waste heat recovery requires careful selection of a heat exchanger according to the recovery method (air to air, air to water, water to water, flash steam, etc.), heat exchanger characteristics (susceptibility to staining, corrosion resistance, susceptibility to leaking, ease of cleaning, etc.), and past performance records.

The table below summarizes common waste heat sources found at a dyeing plant along with recovery methods. Please take time to study it.

Source	Form of waste heat	Waste heat recovery method
I. Dyeing and bleaching facilities	Hot water effluent (50 80°C)	Recovered via a plate heat exchanger for reuse as dyeing and bleaching water
II. High-temperature high-pressure dyeing machines	a) Hot water effluent (80 95 °C)	Recovered via a plate heat exchanger for reuse as dyeing process water
	b) Hot water effluent (100 - 120 °C)	Recovered via a plate heat exchanger after the suppression of flash steam with water spray for reuse as dyeing water
	c) Heated cooling water (50 - 70 °C) (cooling water for a coil heater)	Collected in a pit for reuse as dyeing water
III. Air compressors	Fresh cooling water (30 40 °C)	To be reused as washing water, shower water, bath water, etc.
IV. Steam heat-setting machines	Exhaust steam from setting process (100 120 °C) (contains condensate, oil/fat, dust, etc.)	Collected in a pit and recovered via a plate heat exchanger after condensation in a cooling coil for reuse as dyeing/bleaching water and boiler feedwater
V. Dryers	a) Exhaust air (70 80 °C) (contains cotton dust, etc.)	Recovered via a rotating disk sensible heat exchanger and reused to preheat heating air
	b) Exhaust air that has gone through heat exchanger (40 50 °C)	To be recovered using a cooling coil for reuse as boiler feedwater
VI. Tenters	LPG (LNG) Combustion gas exhaust (220 °C)	Recovered via a rotating disk sensible heat exchanger and reused to preheat combustion air
VII. Air conditioners	Air conditioner waste heat	Recovered for reuse as the heat source of an absorption heat pump along with the recovered hot water in item 1. above, with the generated hot water used as dyeing and bleaching water
VIII. Washing machines	Hot water (70 80 °C)	(1) Used for counter-flow washing (2) Collected in a pit and recovered via a plate heat exchanger after screen-filtering for reuse as washing water

Apart from loss/waste and recovery/reuse, facility maintenance is also an important factor.

(4) Getting 100% performance from facilities

Facilities experience performance degradation due to aging, whereby they progressively fall short of their initial performance.

As the operation method can change from one operator to another, attention should be paid to the following matters:

- Carry out regular facility maintenance to improve the facility availability rate.

- Draw up an operation manual to ensure uniform handling even if operators change.
- Depending on the product number, perform operation control based on optimum values (temperature, pressure, flow rate, etc.) using measuring instruments.
- When one facility is connected to another via a roll of cloth, make their cloth forwarding speeds identical.
- Improve the quality of steam (dryness) used for cylinder dryers.
- Clean filters regularly to prevent poor drying due to reduced air flow.
- Provide motor-driven facilities with VVVF control as much as possible.
- With steaming equipment, take care not to let condensate touch the cloth.

These constitute facility-oriented energy conservation measures.

Example: Standardization of washing water quantities

• Facility improvement

a. Change the shape of the valve handle from circular to lever.

.... to make the degree of opening easier to see

b. Keep the amount of water supplied to the mangle constant by installing an orifice plate.

.... 300 - 500 L/h

c. Install a pressure relief valve on the main water supply pipe to keep the pressure constant.

.... 0.2 0.22 MPa

Install a float-type instantaneous flowmeter and pressure gauge on the main water supply pipe as well.

• Standardization of washing water quantities

a. The required amount of water has been set for each product number.

It is five times the weight of the cloth to be washed.

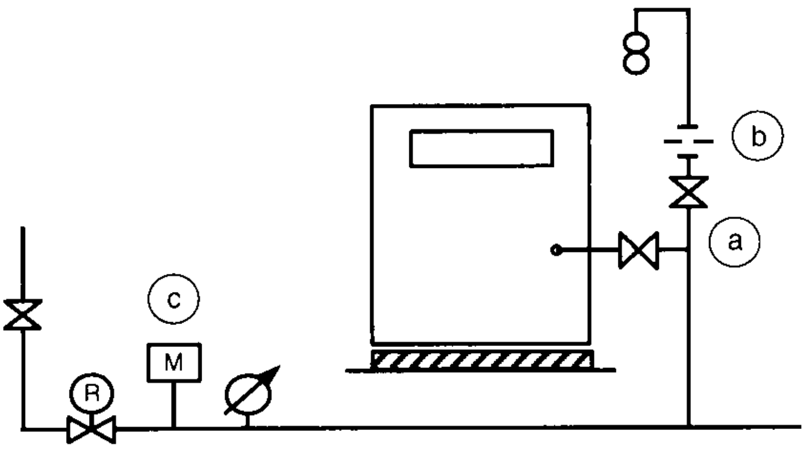


Figure 3 Standardization of Washing Water

2. Facilities suitable for Energy Conservation and Methods

2-1 Heat exchangers

(1) Waste heat recovery from hot effluent via plate heat exchanger (effluents from dyeing machines, washing machines, etc.)

• Basic construction

A plate heat exchanger features heat transfer plates produced by press-molding sheets of a corrosion-resistant metal (0.5–1.2 mm), such as stainless steel or titanium, which are sealed with gaskets and propped up with frames, pipes and other metal pieces, including nuts and bolts.

Heat transfer plates incorporate various projections and grooves for greater mechanical strength and surface area. The four corners of a plate are provided with wave and ball-shaped projections to increase heat transfer efficiency by generating a vortex in the liquid. There are two types of plates, A and B, and they are sandwiched to create a flow path between them. Hot and cold liquids flow alternately along the main flow route, and heat exchange occurs via a heat transfer plate, either type A or B.

- Application range

  Processing capacity : 100–2500 m^3/h

  Working pressure : Max. 25 bar

  Working temperature : Max. 180 °C

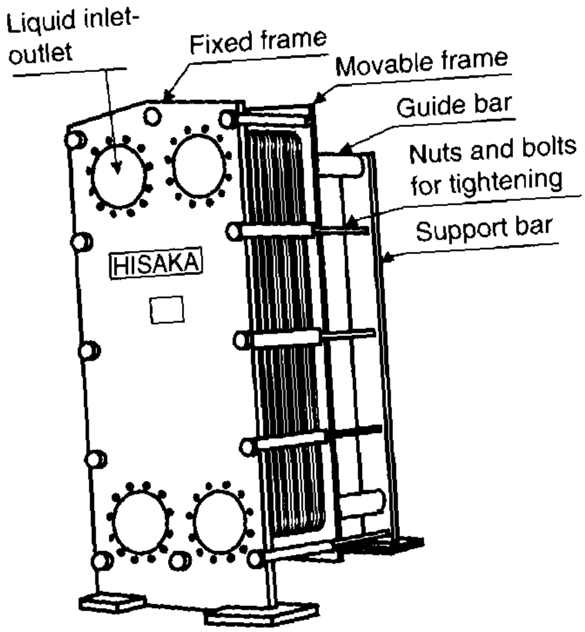
  Heat transfer surface area : 0.087–1500 m^2 per unit

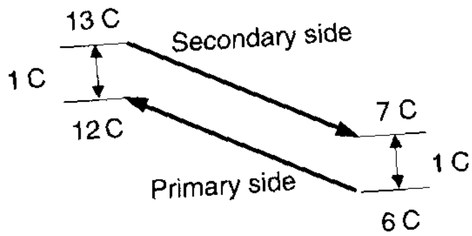
  Gasket material: Acrylonitrile-butadiene rubber (NBR)
  Isobutylene-isoprene rubber (IIR)
  Ethylene-propylene rubber (EPR)
  Other

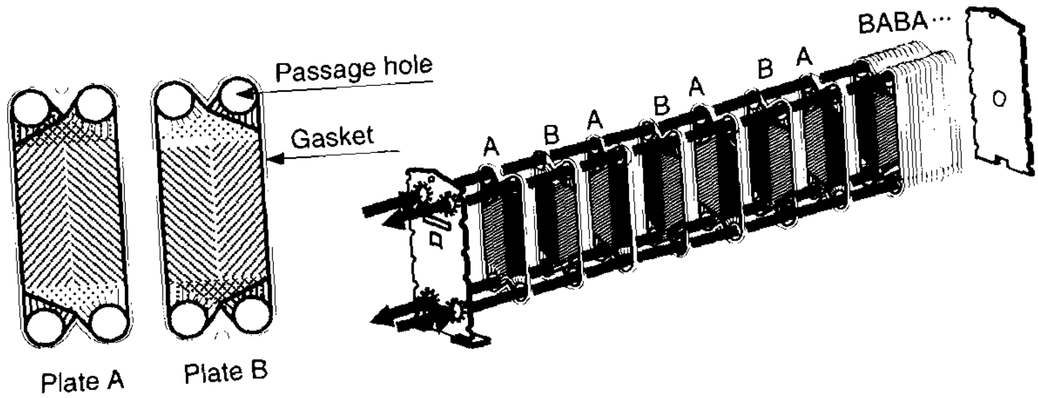
- Overall heat transfer coefficient

  16,800–29,400 $kJ/m^2h°C$

- End temperature differences (counter-flow configuration)


Liquid inlet-
outlet
Fixed frame
Movable frame
Guide bar
Nuts and bolts
for tightening
Support bar
HISAKA

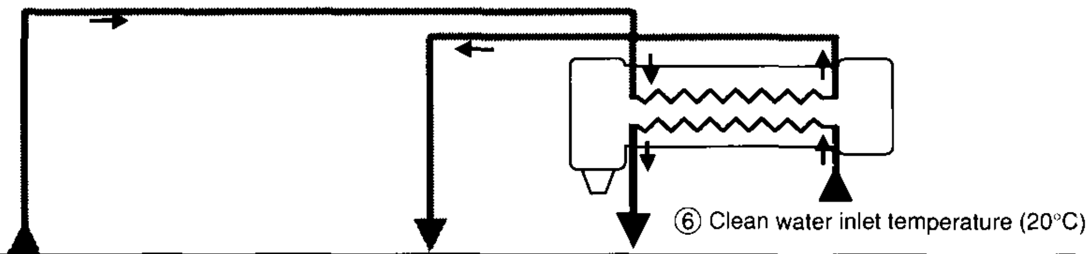

13 C
Secondary side
1 C
12 C
7 C
1 C
Primary side
6 C


Passage hole
Gasket
Plate A
Plate B
BABA···
A
B
A
B
A
B
A

The diagram below shows equivalent fuel oil recovery rates obtained under various water temperature and flow rate conditions. (Source: Hisaka Works, Ltd. data)

Table of Equivalent Fuel Oil Recovery Rates under Various Water Temperature and Flow Rate Conditions

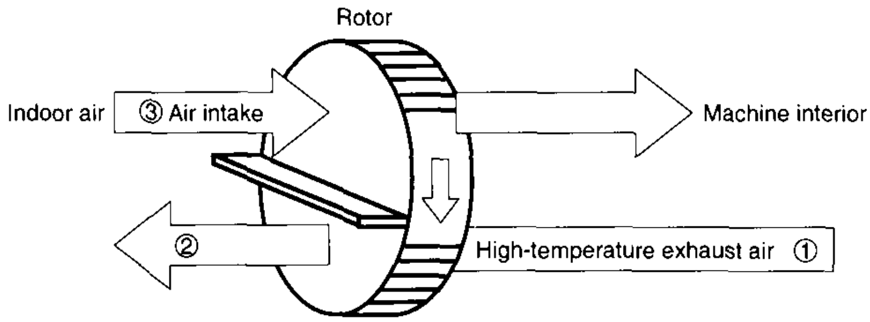
Refer to the table below for ① hot water effluent inlet temperature, ②-③ effluent outlet temperature and ④-⑤ hot clean water outlet temperature. It is assumed that ⑥ clean water inlet temperature is 20 °C.



① Hot water effluent inlet temperature °C	Hot water effluent flow rate m³/h	② ③ Hot water effluent outlet temperature °C	④ ⑤ Clean water outlet temperature °C	Clean water flow rate m³/h	Equivalent fuel oil recovery rate kg/h
90	5	35	75	5	34.3
		30	80		37.5
	10	35	75	10	68.6
		30	80		75.0
	20	35	75	20	137.2
		30	80		140.0
	30	35	75	30	205.8
		30	80		225.0
80	5	35	65	5	28.1
		30	70		31.2
	10	35	65	10	56.2
		30	70		62.4
	20	35	65	20	112.4
		30	70		124.8
	30	35	65	30	168.6
		30	70		187.2
70	5	35	65	5	21.8
		30	60		25.0
	10	35	55	10	43.6
		30	60		50.0
	20	35	55	20	87.2
		30	60		100.0
	30	35	55	30	130.8
		30	60		150.0
60	5	35	45	5	15.1
		30	50		18.8
	10	35	45	10	30.2
		30	50		39.6
	20	35	45	20	60.4
		30	50		79.2
	30	35	45	30	90.6
		30	50		118.3

(2) Recovery of waste heat from exhaust air via rotating disk sensible heat exchanger (dryer exhaust)

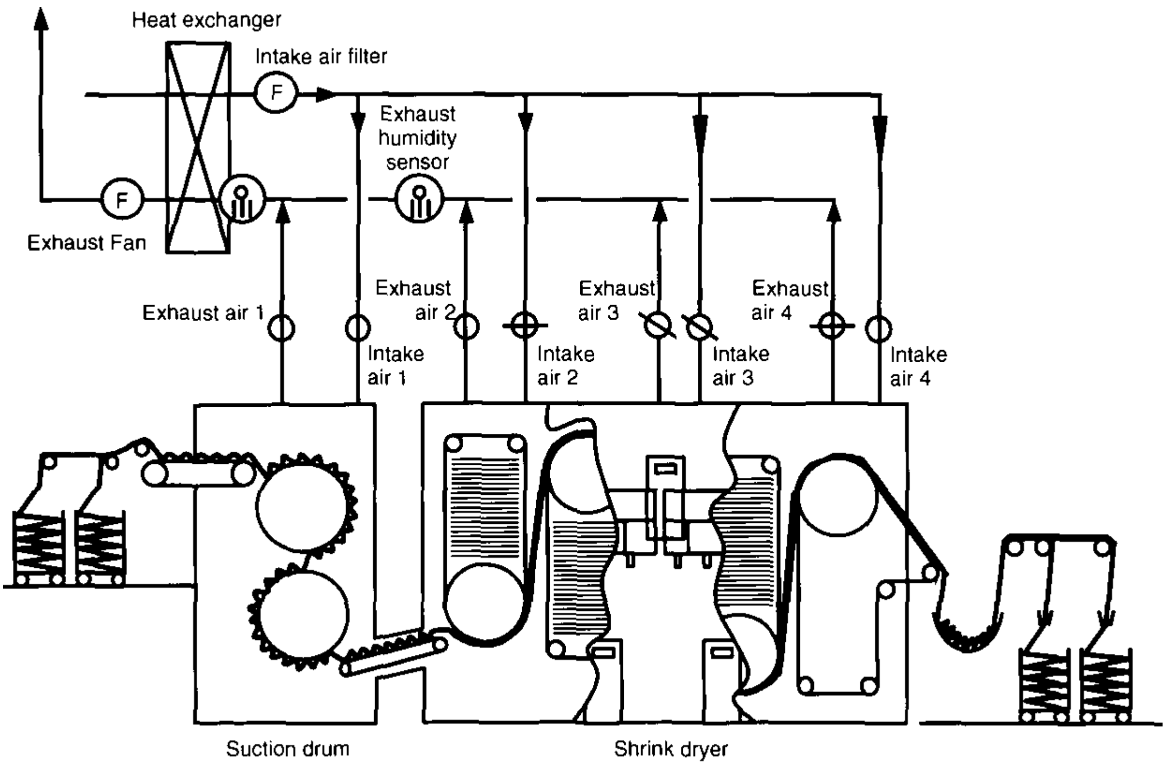
Install a rotating disk sensible heat exchanger on the dryer exhaust duct. Made of a metal honeycomb, the rotor rotates at 6–10 rpm.



Due to leaks from sealed parts and the intermixing of intake and exhaust air, the actual heat recovery rate of the heat exchanger is around 50%. An example of its installation on a shrink dryer follows.

• Improvement example 1: Installation of rotating disk sensible heat exchanger

As exhaust air from a dryer is very humid (DB 88 °C, WB 49 °C), a rotating disk sensible heat exchanger, instead of a static heat exchanger, has been installed. The diagram below shows the flow paths of intake air and exhaust air.



Shrink Dryer

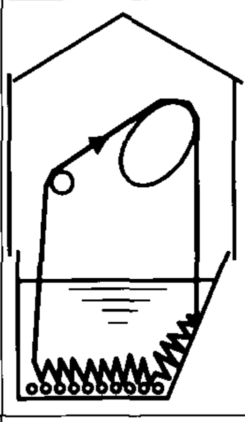
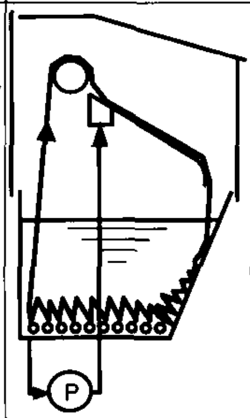
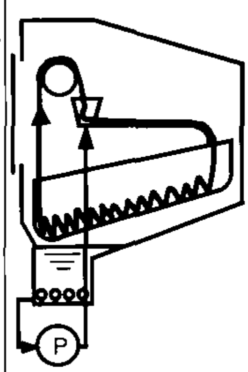
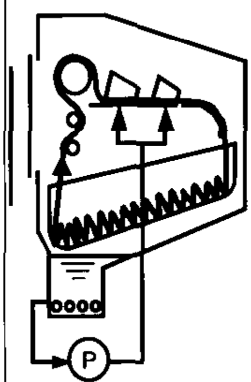
There is also a recent example in which the heat exchanger is supplemented with a cooling coil to recover the latent heat of dryer exhaust air by heating clean water to be used as boiler feedwater.

In this case, the combined heat recovery rate is around 70%.

2-2 Low-liquor-ratio dyeing machines

Various low-liquor-ratio dyeing machines have been developed. These machines have reduced the liquor ratio from a conventional 1:20–30 to less than 1:10 by, for example, spinning the cloth at high speeds of more than 200 m/min or shaking it, thus improving its contact with the dye liquor. Notably, batch dyeing has been undergoing a shift from stationary-liquor dyeing to circulating-liquor dyeing, and this has already resulted in substantial energy conservation through a dramatic reduction in liquor ratio. All in all, these measures have cut energy consumption by more than 50%.

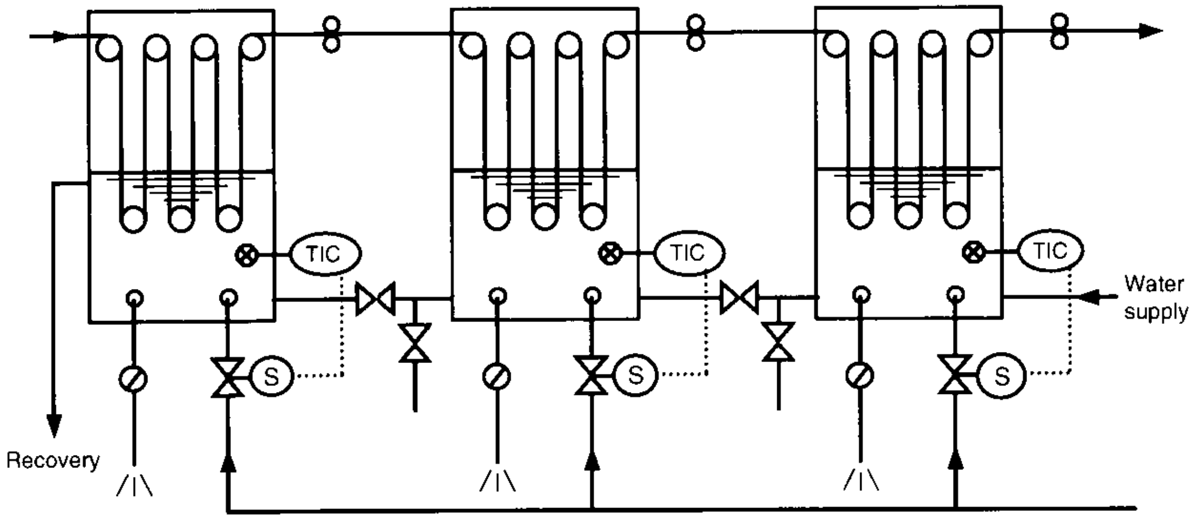
The table below compares conventional and low-liquor-ratio dyeing machines.

Machine type	Winch	Circulating liquor winch (Wimpact)	Circulating liquor winch (Dash Line)	Circulating liquor winch (Super Flow)
Conceptual diagram				
Fabric forwarding speed	60 m/min	80 m/min	80 m/min	210 m/min
Circulation cycle	–	60 sec	30 sec	20 sec
Bath ratio	1 : 20	1 :15	1 : 10	1 : 5
Productivity	1 cycles/D	2 cycles/D	3 cycles/D	4 – 5 cycles/D

2-3 Counter-flow washing and effluent recovery for washing machines

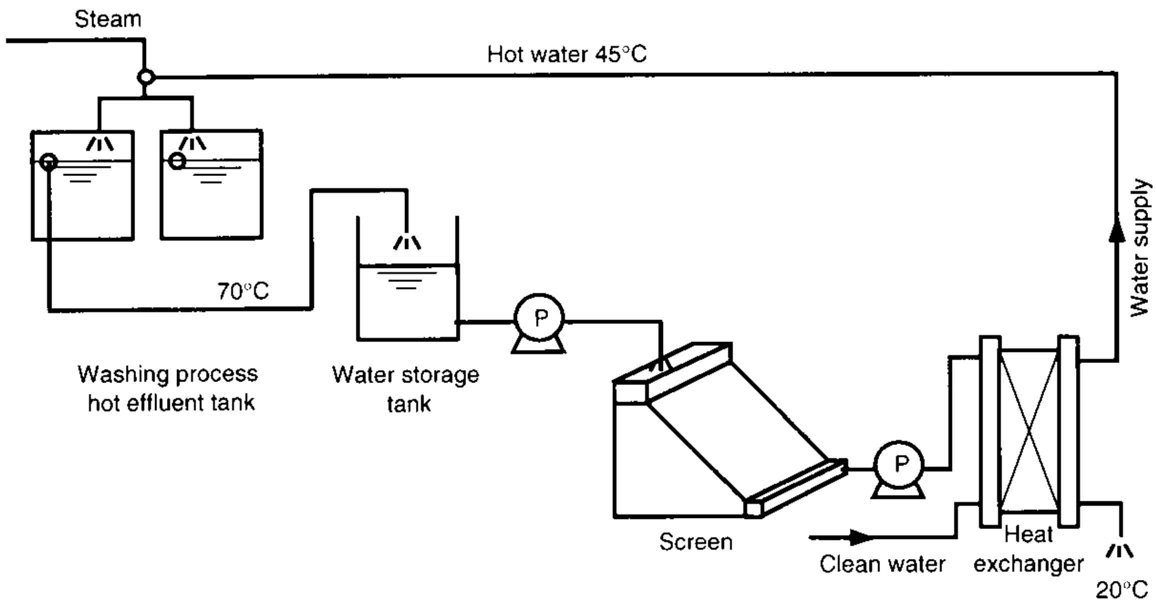
Water consumption and temperature are 3000 L/h and 80°C, respectively. Water and cloth are made to flow in opposite directions to improve washing effectiveness.

A temperature sensor is mounted on each water tank to enable washing water temperature to be controlled through indirect steam heating via a high heat exchanger.



Both washing process effluent and steam condensate are recovered.

As washing process effluent contains fibers and other contaminants, it is passed through an approx. 30-mesh gravity-filter screen to remove them.



Hot Effluent Recovery and Heat Exchanger

2-4 Heat recovery via absorption heat pump

Heat can recovered from low-temperature effluent (45°C) through the use of an absorption heat pump.

• Improvement example 2: Utilization of absorption heat pump

While improvement example 1 involved the recovery of heat from hot effluent via a heat exchanger for use in the heating of dyeing water, it has been learnt that heat can even be recovered from low-temperature effluent through the use of an absorption heat pump.

In addition, heat carried by air conditioner exhaust, which used to be released into the atmosphere via refrigerator radiators and cooling towers, is also now recovered to heat water.

Figure 4 shows a flowchart.

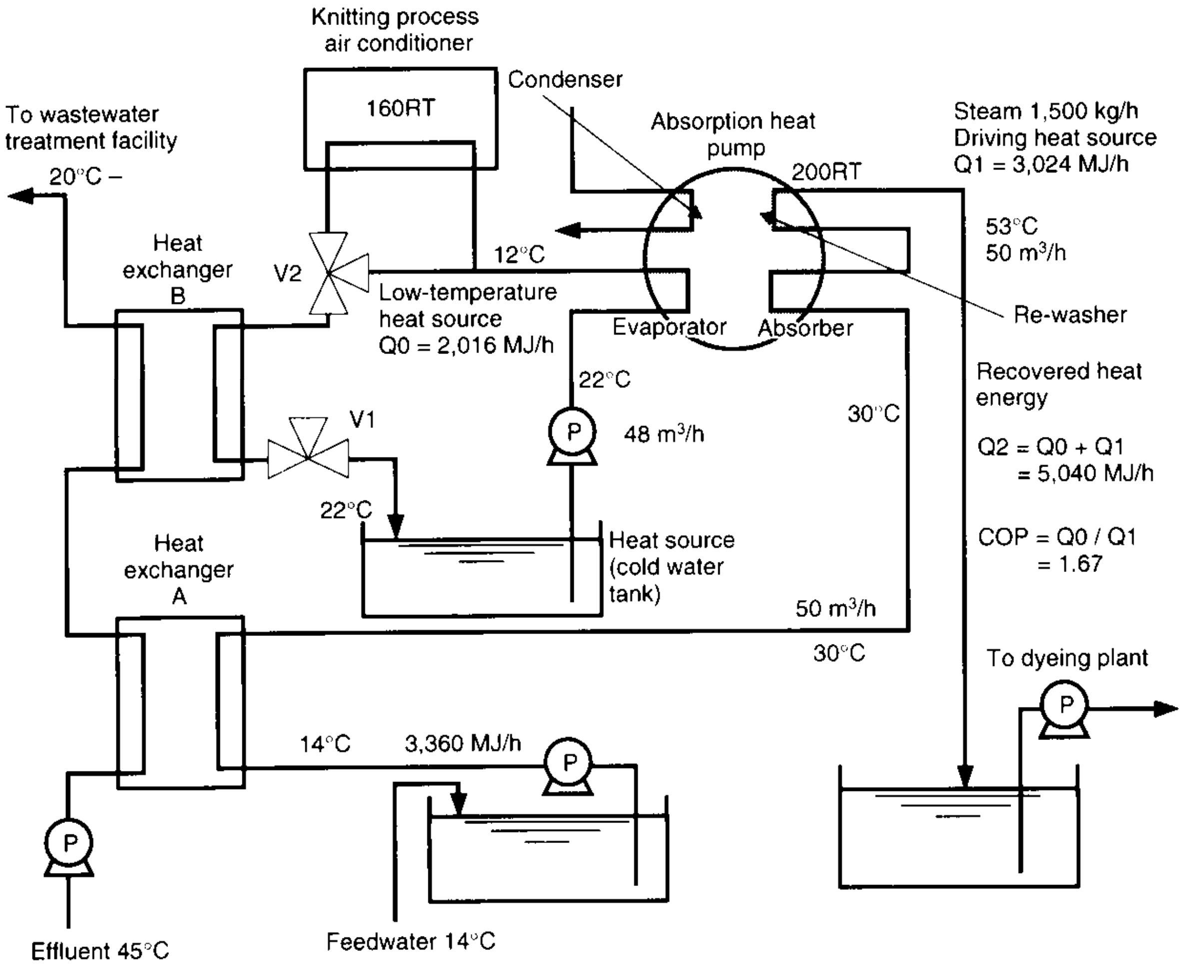


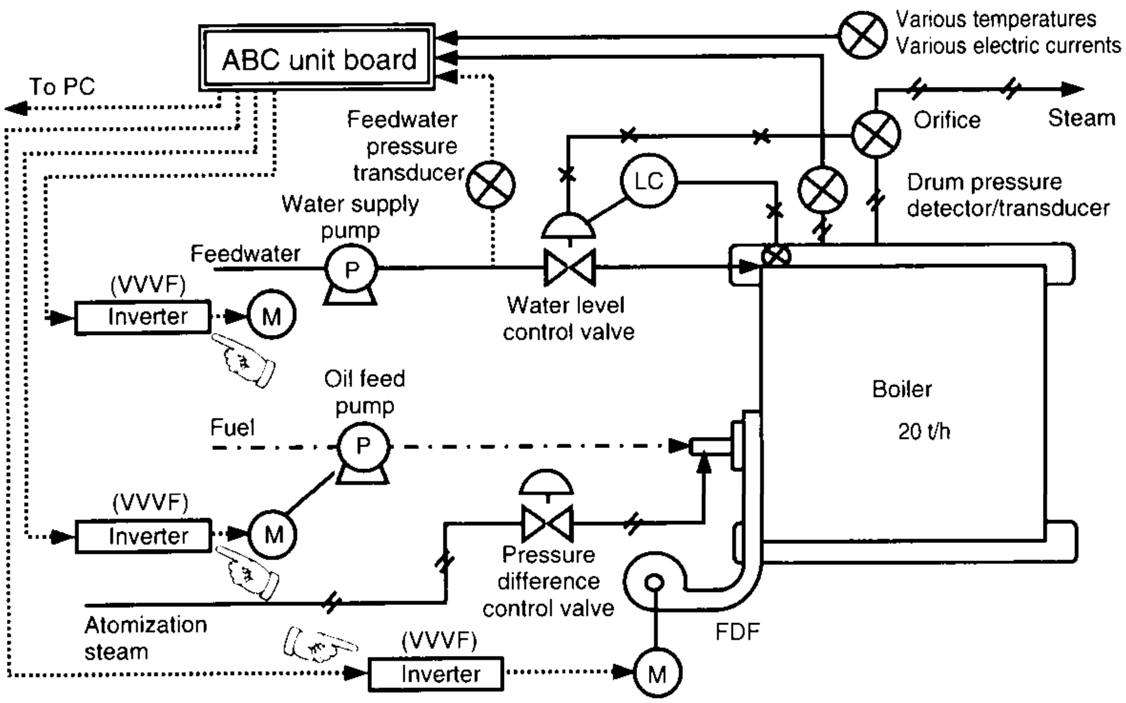
Figure 4 System Flowchart of Absorption Heat Pump

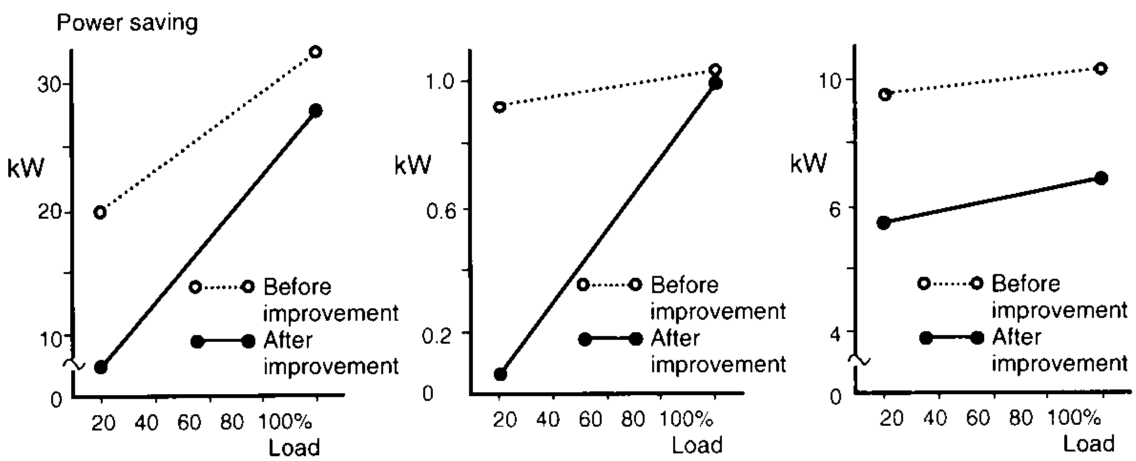
Oil saving from hot effluent utilization	170 kL/year	5,100	1000 yen/year
Reduction in contract demand	170 kL/year	3,400	1000 yen/year
Reduction in electric energy consumption	360 × 10 kL/year	7,200	1000 yen/year
Total		15,700	1000 yen/year

2-5 Energy conservation via variable voltage variable frequency (VVVF) control

With water supply pumps, blowers and other motor-driven machines, the motor rotational speed should be controlled to control flow rate according to load conditions. Although flow rate can also be controlled via a throttle device, it accompanies energy loss.

The diagram below shows an example in which VVVF control (computerized rotational speed setting) has been incorporated into a water supply pump, oil feed pump and forced draft fan associated with a 20 t/h water tube boiler.





FDF Motor Power Input

Oil Feed Pump Power Input

Water Supply Pump Power Input

2-6 Types of steam traps and operating principles

(1) Roughly speaking, steam traps are classified into three types as shown in Table 3. The most suitable steam trap needs to be selected according to the equipment it is used for, the condensate recovery method and other conditions.

Table 3 Steam Trap Types and Condensate Discharge Methods

	Mechanical		Thermodynamic	Thermostatic
Type	Float	Bucket	Disk	Bilateral
Condensate dis-charge	Continuous	Intermittent	Intermittent	Intermittent

a. Mechanical trap (small discharge capacity 100 kg/h)

Condensate and steam have different specific weights, and a mechanical steam trap uses this difference to push a bucket or float discharge up and down, thus operating a valve and discharging condensate. There are continuous and intermittent discharge types. Although back pressure often poses a problem for condensate recovery, mechanical steam traps are relatively immune to its effects, and tolerate a back pressure of up to about 90% of the inlet pressure.

b. Thermodynamic trap (large discharge capacity 400 kg/h)

Thermodynamic steam traps use the differences in thermodynamic characteristics between condensate and steam to push a disk up and down, thus operating a valve and discharging condensate. They are purely of the intermittent discharge type, and are relatively susceptible to back pressure (up to 30–60%). Attention should be paid to the presence of air or steam at the trap inlet, as it would facilitate the occurrence of air or steam locking, which interferes with condensate discharge.

c. Thermostatic trap (medium discharge capacity 300 kg/h)

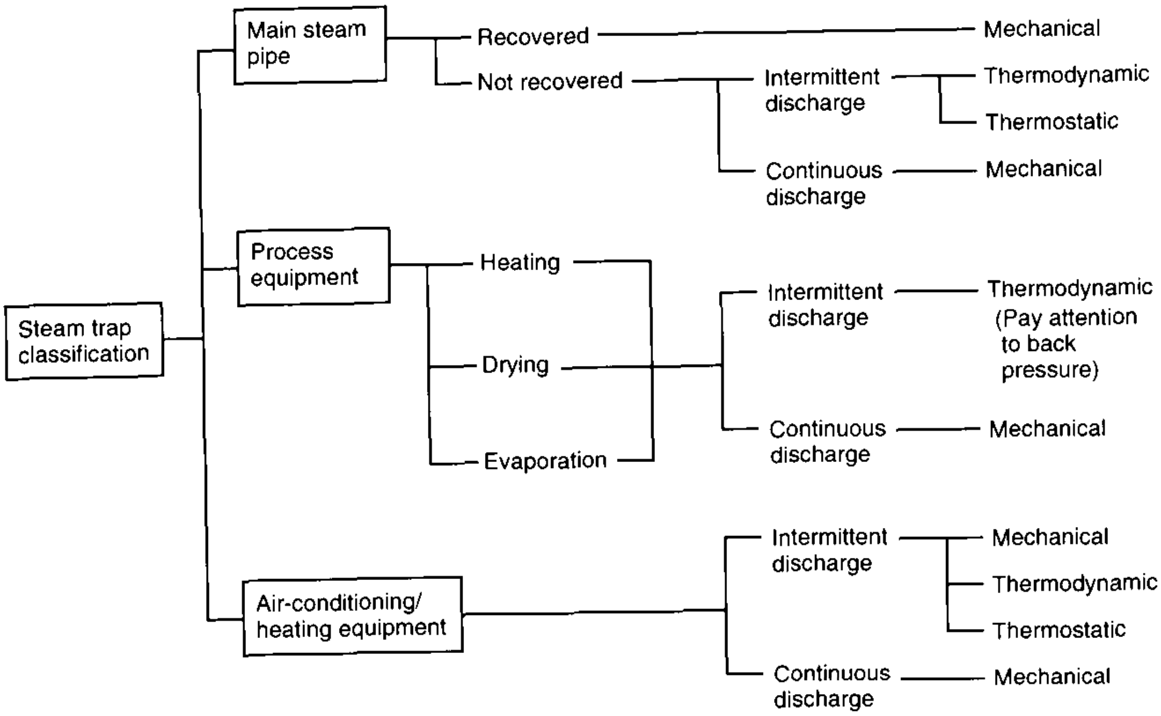
Thermostatic steam traps use the differences in thermostatic characteristics between condensate and steam to operate a valve. Although steam always maintains a constant saturation temperature according to its pressure, the temperature falls below that mark as it turns into condensate. This temperature change is picked up by a bellows or bi-metal to operate the valve.

As they offer excellent exhaust outlet performance, they are used for steam tracing lines and air conditioners.

(2) Selection of steam trap

a. Selection by application

As there are a diverse range of steam traps, it is necessary to select the best possible product for the intended application according to the procedure shown below.



b. Investigation into condensate buildup and selection of appropriate steam trap

Before determining the steam trap size, it is necessary to determine the trap pipe size by investigating condensate buildup. Condensate buildup can be obtained either from a manufacturer's data or a calculation. Equation (3) below is a simplified calculation formula.

$$w\rho = \frac{C.G.(T_1 - T_2)}{\gamma} \quad \cdots\cdots (3)$$

where wp : Steam demand or condensate buildup .... kg or kg/h

C : Specific heat of liquid to be heated .... kJ/kg・K

G : Amount of liquid to be heated - kg or kg/h .... kg

T_2–T_1 : Temperature rise to be achieved .... deg・K

γ : Latent heat of steam........ kJ/kg

In the case of a batch process, hourly condensate buildup (kg/h) depends on the duration of heating, and it can be obtained from equation (4) below.

$$Qt = w\rho \times \frac{60}{h} \quad \text{...}(4)$$

where Qt : Condensate buildup .... kg/h

h : Heating time .... min

The wp and Qt obtained from equations (3) and (4) represent theoretical values, and real condensate buildup should be calculated by taking into consideration the amount of condensate carried over from the piping and that attributable to heat dissipation from the equipment. Once condensate buildup is determined, a suitable steam trap can be selected.

The steam trap should have a discharge capacity that is 1.5–2 times the condensate buildup, except for a cylinder dryer steam trap, in which case the discharge capacity should be around 4–5 times the condensate buildup.

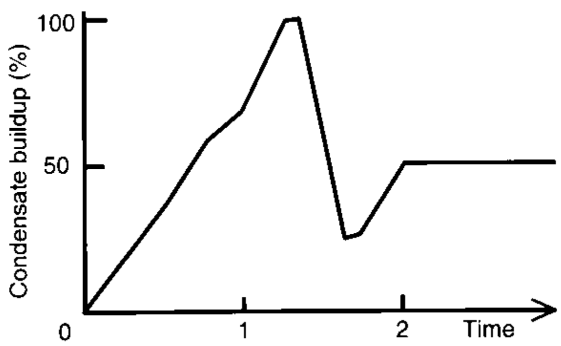
Condensate discharge capacities are shown below (Figures 5 and 6).

c. Factors to be considered in making selection

1) Condensate buildup and load characteristics

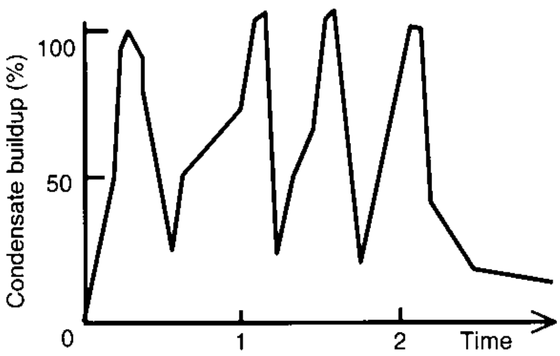
The amount of condensate generated differs between continuous and batch processes.

In a continuous process, load fluctuations are small, so that condensate buildup is steady. In a batch process, however, load fluctuations are large, so that condensate buildup also fluctuates widely, giving rise to a need for careful consideration with regard to steam trap selection. The diagrams below show the condensate buildup patterns of continuous and batch processes.



Characteristics of condensate buildup in cylinder dryer (continuous process)

Figure 5 Small Capacity Steam Trap



Characteristics of condensate buildup in pressurizer (batch process)

Figure 6 Large Capacity Steam Trap

2) Working pressure and trap material

The material of the steam trap should be selected according to steam pressure.

- Up to 1.6 MPa/220°C ....cast iron (FC)
- Up to 2.0 MPa/350°C ....black heart malleable cast iron (FCMB)
- Up to 4.5 MPa/425°C ....cast iron (SCPH)

3) Maximum working pressure

Each steam trap has its maximum working pressure specified, and the following condition will lead to blockage.

Steam pressure > Maximum steam trap working pressure

4) Minimum steam pressure

In cases where a temperature and pressure control valve (TIC, PIC) has been installed, condensate discharge capacity decreases as the valve is throttled due to a reduction in steam pressure. For this reason, there must be a pressure differential between the inlet and outlet of a steam trap.

- Mechanical trap or thermostatic trap ....0.01 MPa or more
- Thermodynamic trap ....0.03 MPa or more

5) Back pressure condition

In cases where condensate is being recovered, its re-evaporation will generate a back pressure for the steam trap, and each steam trap has a specific back pressure tolerance as calculated below.

$$\text{Back pressure tolerance} = \frac{\text{Steam trap outlet pressure}}{\text{Steam trap inlet steam pressure}} \times 100 \quad \text{.................. (\%)}$$

- Mechanical trap: ....90% or less
- Thermostatic or thermodynamic trap: ....30–50% or less

(3) Inspection and maintenance of steam traps

Through prolonged use, steam traps experience wear and tear on the valve seat and other mechanical parts and sustain even greater damage due to steam leakage. They should therefore be inspected regularly and maintained in good condition, thus ensuring efficient operation of steam-consuming equipment.

a. Malfunctions of steam traps include:

1) Failure to terminate discharge: nonexistent or improper pressure differential or mechanical failure

2) Blockage: plugging of strainer (due to corrosion or scaling)

3) Steam leakage: scratches on the valve seat or float

In cases where condensate is being recovered, the detection of a failure to terminate discharge or steam leakage may be delayed, giving rise to energy loss. This could even adversely affect the temperature control of other equipment due to a high back pressure in the recovery line.

b. Methods of inspecting steam trap operation include, among other things, 1) observation through side windows, 2) a stethoscope, 3) a test valve, 4) a pressure gauge and 5) a thermometer. Regular inspection is essential for traps for production facilities that are important in maintaining product quality, etc.

2-7 Heat insulation

Although the installation of a heat insulator tends to be regarded as minor work, it is important to treat it as an essential part of the plant, particularly in an era of energy conservation, with an economical heat insulation design suitable for the intended operating conditions incorporated into the plan right from the design stage. This will ensure best possible heat insulation.

Objectives of heat insulation

1) Energy conservation + Stable facility operation

2) Maintenance of a pleasant environment

3) Improvement of safety and efficiency

The key to heat insulation is the use of a heat insulator best suited to the equipment to be heat-insulated in achieving the above objectives.

There are three criteria to consider in determining the thickness of the heat insulator in heat insulation design.

1) Keeping heat loss at or below a specified value

2) Keeping the surface temperature at or below a specified value

3) Ensuring an economic balance between the cost of installing a heat insulator and the financial loss arising from heat loss.

In terms of criteria 1) and 2), it is easy to determine the thickness of the heat insulator once standard conditions are set.

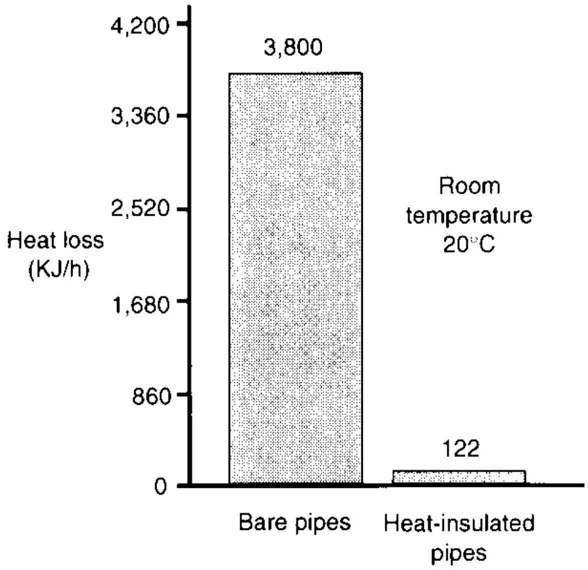
However, criterion 3) involves variable factors, such as heat energy prices and labor costs.

(1) Heat loss and heat insulation effects

a. Difference in heat loss from steam piping

The heat loss generated by 4B piping (114.3 mm in diameter) delivering saturated steam at 1.0 MPa (179 °C) is 3800 kJ/h for each meter of piping in the case of bare pipes (no heat insulation) being used.

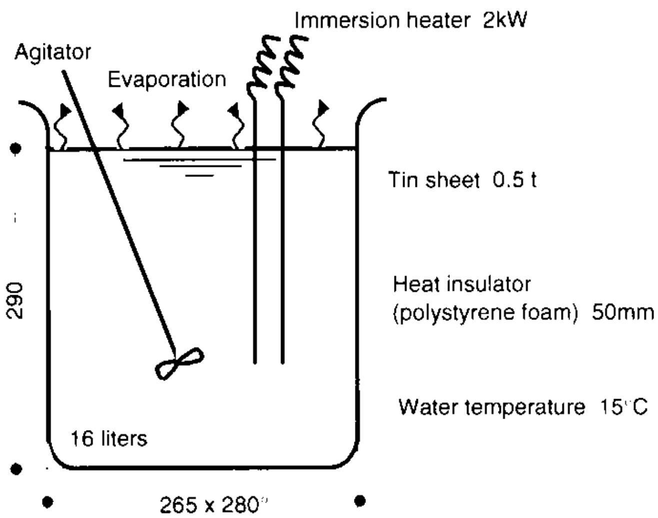
A 75-mm thick calcium silicate heat insulator would cut heat loss to 122 kJ/h, or 1/30 of the initial figure, for each meter of piping (See Figure 7.).



b. Heat loss from equipment walls and free surfaces

An experiment has been conducted to ascertain the effect of heat insulation using a tin container. Although the completeness of heat insulator installation differs between large equipment and small experimental apparatus, the energy conservation rate obtained from this experiment can be applied to large equipment.

• Experimental apparatus



• Experimental results

Experiment No.	Heat insulation			Time taken to raise temperature to 96 °C (min)	Heat inflow rate required to keep temperature at 96 °C (kJ/h)	Total heat energy required to raise temperature to 96 °C and keep it there for 1 hour (kJ)	Energy conservation effect (%)
	Free surface	Side surface	Bottom surface				
1	None	None	None	100	6,150	9,240	0
2	Floating lid ○	○	○	58	2,900	9,240	47
3	Floating lid ○	None	○	65	3,570	10,710	39
4	Floating lid ○	○	None	60	2,940	9,450	46
5	None	○	○	92	6,300	16,380	6
6	Polystyrene chips ○	○	○	56	2,100	7,980	54

Floating lid : A polystyrene plate covering 57% of the free surface
Polystyrene chips : Entire free surface covered
Character "○" : Means "heat insulation provided"

As can be seen from these results, a floating lid placed over a free surface has a dramatic effect, cutting fuel consumption by about half. (Source: Osaka Prefectural Textile Technology Research Institute)

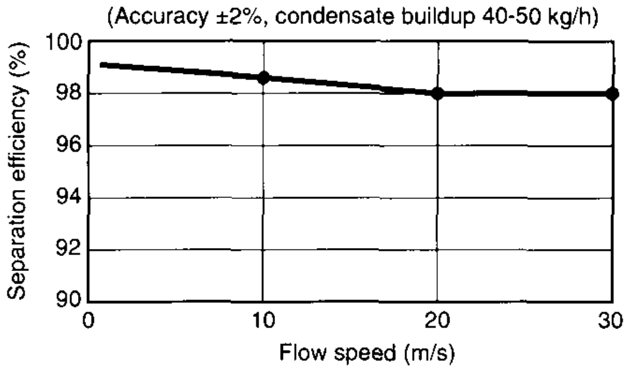
2-8 Drain separator utilization methods

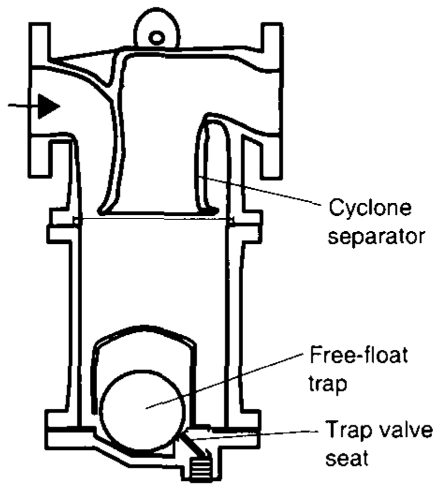
In principle, condensate generated in piping should be removed at the inlet of steam-consuming equipment. In the case of a cylinder dryer, condensate could reduce the cylinder surface temperature by forming a liquid film over the heating surface. The diagrams below show the configuration of a drain separator and its separation efficiency.

• Best application areas of separator-trap

Application	Purpose
Main pipe	Prevention of water hammer
Equipment inlet	Supply of dry steam/air
Equipment using live steam (steamer, steam-based process equipment, steam kneader, atomizer, etc.)	Improvement of product quality and productivity through supply of high-quality dry steam

• Separation effectiveness

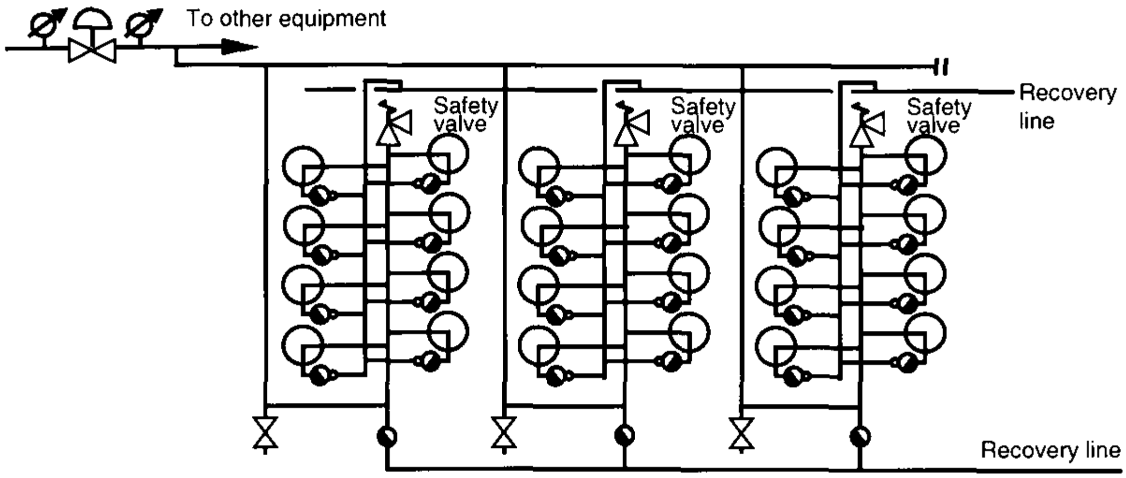




$$\text{Separation efficiency (\%)} = \frac{\text{Amount of condensate discharged from trap}}{\text{Condensate inflow}}$$

(1) Improvement of cylinder dryer efficiency and energy conservation

Poor drying in cylinder dryers has been occurring. Although this is being dealt with by reducing the cloth forwarding speed, daily production capacity has fallen considerably. The diagram below shows the configuration of the piping that supplies steam to cylinders.



The current state of the facility is as follows:

a. Cloth forwarding speed .... 45 m/min

b. Steam supply pressure .... 0.13 – 0.16 Mpa

c. The surface temperatures of some cylinders are low .... Steam trap malfunction

Improvement measures

a. Installation of drain separator

......Prevents condensate buildup inside the cylinder by increasing the dryness of steam

b. Installation of a pressure reducing valve exclusive to cylinders

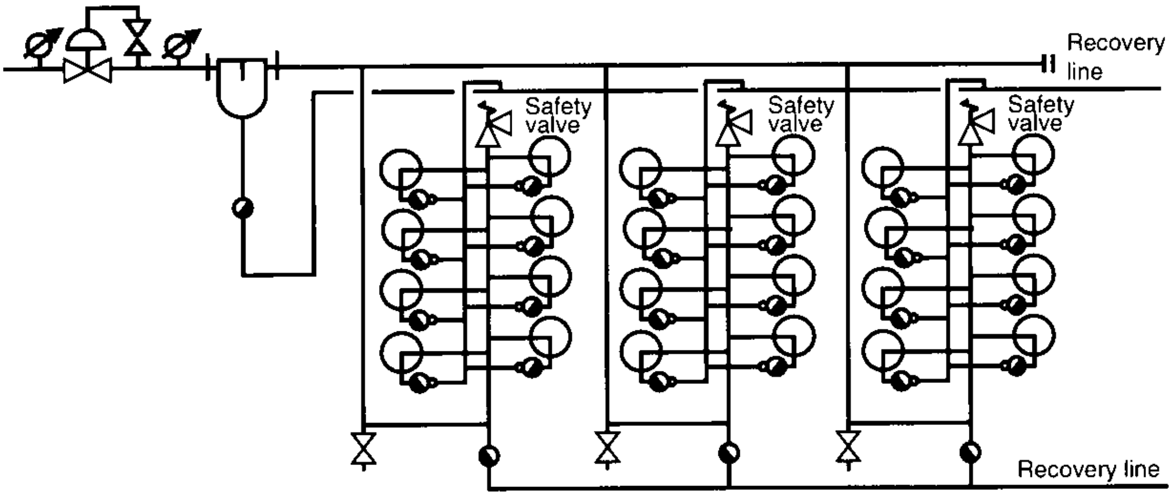
.... To keep the steam supply pressure constant (0.15 MPa)

c. Change of steam traps

.... A back pressure of 0.1 MPa present due to condensate recovery

Thermodynamic trap → Mechanical trap

The implementation of a., b. and c. has raised the cloth forwarding speed to 65 m/min, an increase of about 30%. In addition, it has stabilized product quality and reduced steam intensity (steam consumption per unit output) by ensuring constant steam supply pressure and uniform drying.

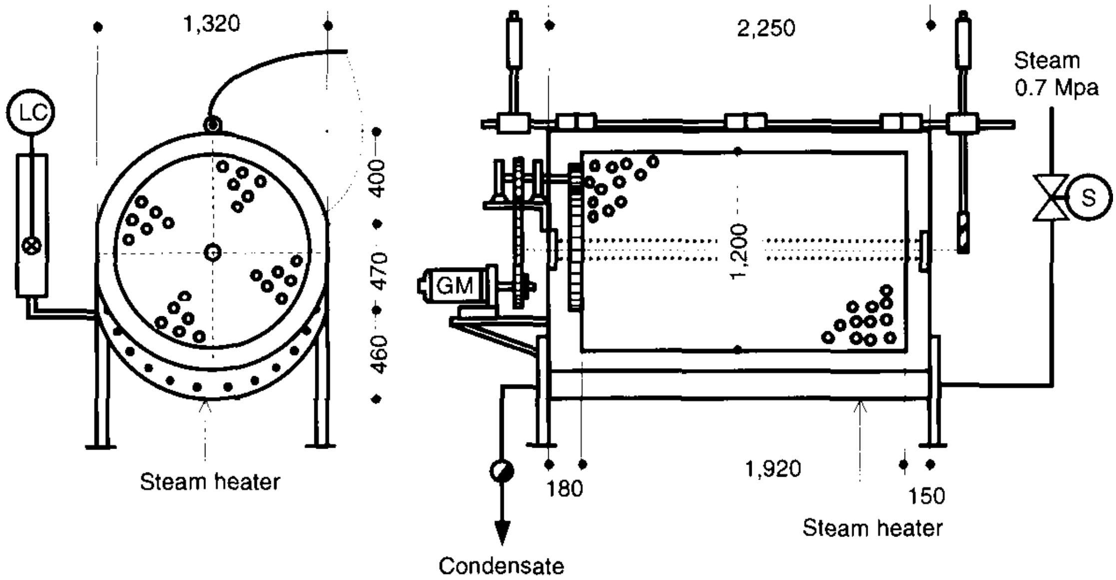


3. Energy Conservation Measures in the Factory

3-1 Energy conservation measures for dyeing machines

(1) Present state

a. Type: drum dyeing machine



b. Metal sheet material: SUS 304, 2.3 mm thick, and emissivity ε = 0.35

c. Surface temperature: dyeing process = 90°C, fixing process = 75°C and softening process = 45°C

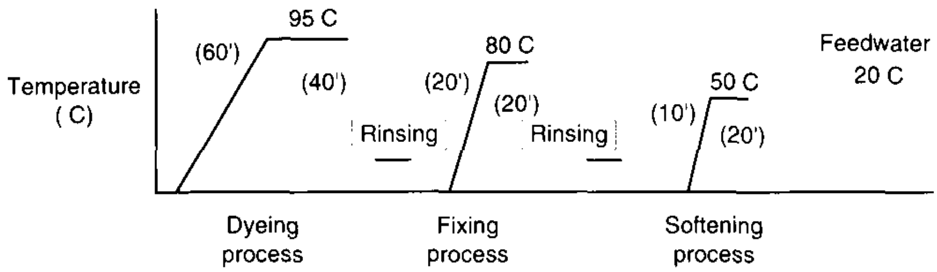
d. Heat insulation: none

e. Water supply quantities: 1300 L/round

Heating 1300 L × 3 rounds per cycle
Washing 1300 L × 2 rounds per cycle — Total 6500 L/cycle

f. Product weight: 85kg, specific heat = 1.80 kJ/kg・K
Material: nylon 100%

g. Dyeing recipe



h. Heating method: indirect heating via steam heater, condensate released into atmosphere

(2) Steam use data

a. Steam conditions

Steam consumption 536 kg/cycle·unit

$536 \times (2{,}721.1 - 83.7)$ kJ/kg = 1,413,646 kJ/unit

Steam pressure (gauge)................................ P = 0.7 MPa

Enthalpy of dry saturated steam .... h" = 2,762.1 kJ/kg

Enthalpy of saturated water........................ h' = 1,716.0 kJ/kg

Dryness of steam .... X = 0.98

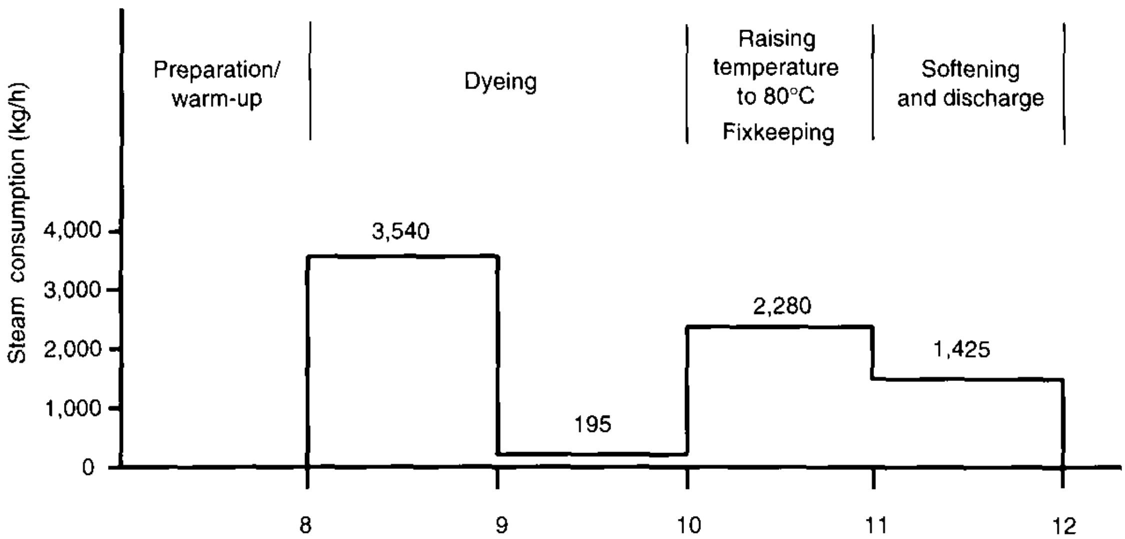
Enthalpy of wet saturated steam................ h = 2,721.1 kJ/kg

Latent heat .... γ = 2,005.1 kJ/kg

b. Heat input and output

Heat input	kJ/cycle	%	Heat output	kJ/cycle	%
Steam consumption	1,413,646	100.0		1,413,646	100.0
			Heat taken by effluent	897,897	63.4
			Heat taken by goods	3,060	0.2
			Dissipated heat	34,295	2.4
			Heat taken by condensate	338,912	24.0
			Other	139,482	10.0

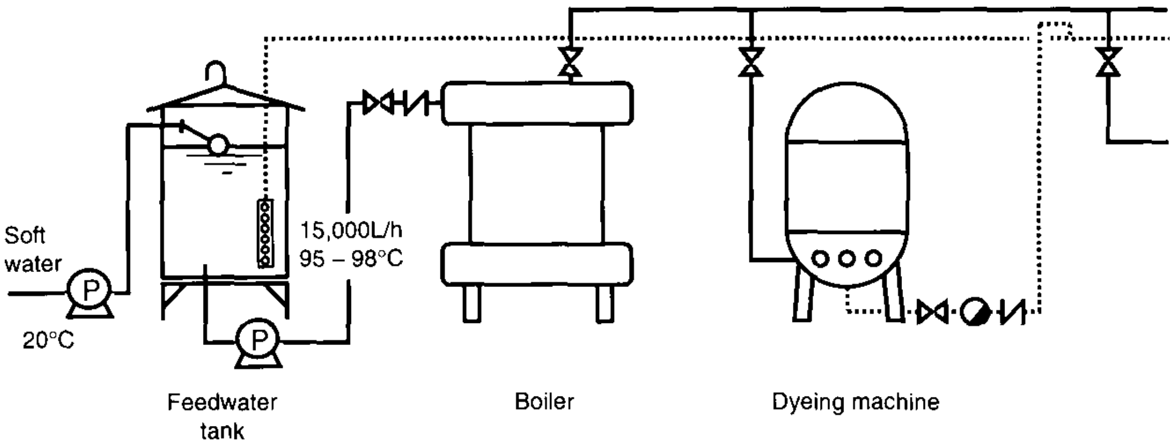
c. Load curve (15 units)



(3) Energy conservation measures

a. Condensate recovery

1) Flowchart (open recovery)



2) Points to note

- Selection of steam trap: a type resistant to back pressure recommended (mechanical type)
- Determination of recovery piping size
- Individual traps: installation of a check valve on the secondary side

3) Collection of condensate into the boiler feed tank and its use as boiler feedwater

Amount of heat recovered: q kJ/cycle · unit

$$q = 536 \text{ kg/cycle} \times (716.0 - 83.7) \text{ kJ/kg} = 338{,}912 \text{ kJ/cycle}$$

Amount of energy saved (fuel oil): G kg · oil/year

Lower heating value of fuel: 42,111 kJ/kg

Boiler efficiency: 80%

$$G = \frac{388{,}912}{42{,}111 \times 0.80} \times 300 \text{ days} = 3{,}018 \text{ kg} \cdot \text{oil/year}$$

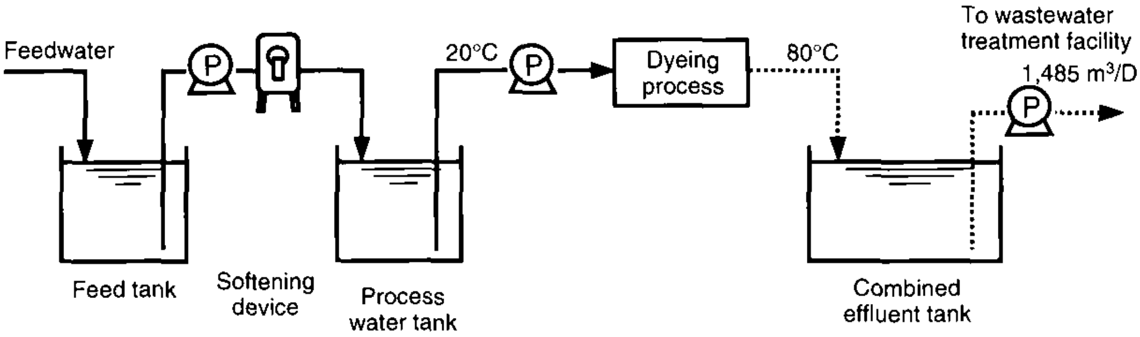
4) Capital investment

Piping work US$80/m

b. Dyeing process - energy conservation through effluent heat recovery

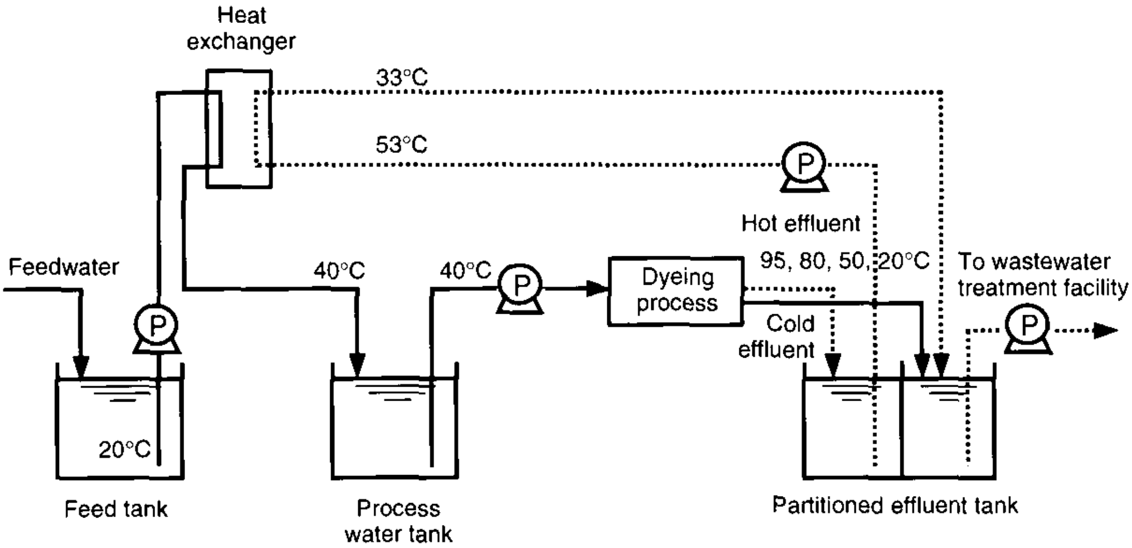
Effluents from the dyeing plant are released into a river after wastewater treatment covering BOC, COD, SS, chromaticity, etc. at the wastewater treatment facility (activated sludge process + coagulation and sedimentation). Before the improvement, all the effluents were directed to a combined effluent tank.

1) Effluent treatment flowchart before improvement



2) Improvement measure: waste heat recovery via counter-flow plate heat exchanger

Hot and cold effluents were separated, and the hot effluent was subjected to heat recovery via a plate heat exchanger with a view to utilizing the recovered heat for the heating of dyeing water. The cold effluent, on the other hand, was directed straight to the wastewater treatment facility.



3) Amount of heat recovered: 897,897 kJ/cycle·units

Equivalent fuel recovery: G = kg·oil/year

$$G = \frac{897,897}{42,111 \times 0.8} \times 300 \text{ days} \times 0.85 = 6,796 \text{ kg·oil/year}$$

4) Capital investment

Heat exchanger	¥4,000,000	US$40,000
Piping work	¥1,000,000	US$10,000
Effluent tank partitioning	¥2,400,000	US$24,000
Total	¥7,400,000	US$74,000

c. Energy conservation through heat insulator installation

1) Dyeing machine specifications

Surface temperature: 90°C

Heat insulation: polyethylene heat insulator (surface sheeting finish), 15 mm thick

Thermal conductivity $\lambda = 0.146$ kJ/m・K

Emissivity $\varepsilon = 0.23$

Area to be heat-insulated: 12.1 m^2 Cylindrical surface 9.33 m^2

Vertical surface 2.74 m^2

2) Heat dissipation after heat insulator installation (per unit per cycle)

(Unit: kJ/unit-cycle)

	Without heat insulation	With heat insulation	Effect of heat insulation
Dyeing process	25,506	5,625	19,881
Fixing prices	7,608	1,716	5,892
Softening process	1,181	288	893
Total	34,295	7,629	26,666

3) Equivalent fuel recovery: G = kg·oil/year

$$G = \frac{26,666}{42,111 \times 0.8} \times 300 \text{ days} = 237 \text{ kg·oil/year}$$

4) Capital investment: US\$60/m^2 × 12.1m^2 = US\$726/unit

d. Energy conservation via reduction of liquor ratio

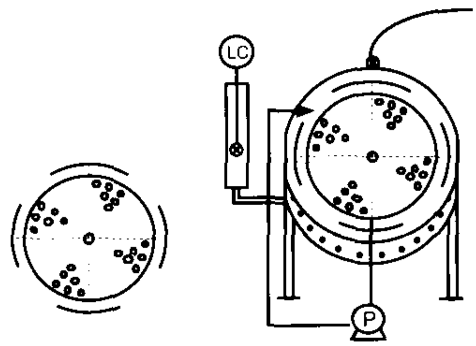
The liquor ratio can be reduced by drawing dye liquor from the bottom of the dyeing machine and showering it over the goods using a circulation pump.

1) Present state

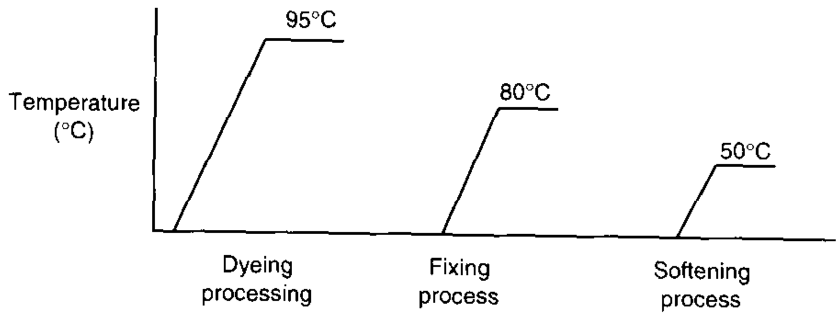
- Amount of liquor: 1300 L

2) Improvement measure

- Installation of a circulation pump
- Installation of rotating drum
- Amount of liquor: 900 L



3) Dyeing recipe



4) Energy conservation effect

Heat input before improvement:

$$1{,}300\text{L}\ \{(95-20)+(80-20)+(50-20)\}\times 4.186 = 897{,}897\ \text{kJ/cycle}$$

Heat input after improvement:

$$900\text{L}\ \{(95-20)+(80-20)+(50-20)\}\times 4.186 = 621{,}621\ \text{kJ/cycle}$$

Heat input reduction rate: $\dfrac{897{,}897 - 621{,}621}{897{,}897}\times 100 = 30.8\%$

5) Change in liquor ratio (weight of cloth dyed 85 kg)

1:15 → 1:10

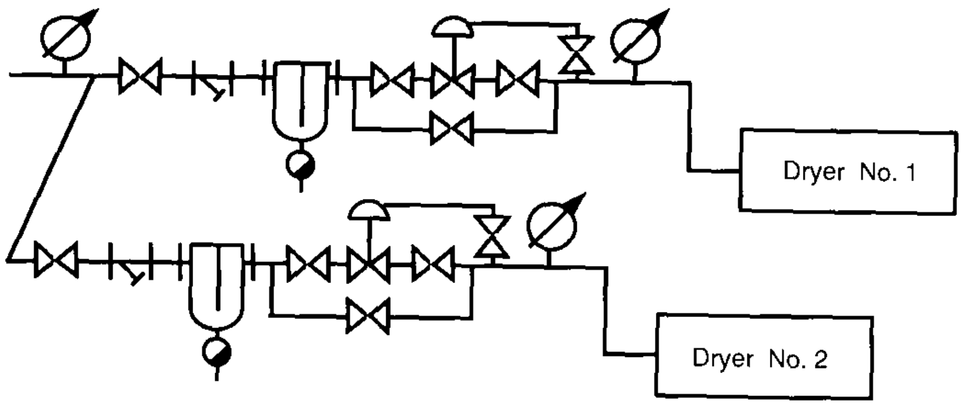
6) Capital investment

• Pump facility	US$2000/unit		
•Impurovement of rotating dorum	US$1500/unit	Total	US$3500/unit

3-2 Energy conservation involving dryers

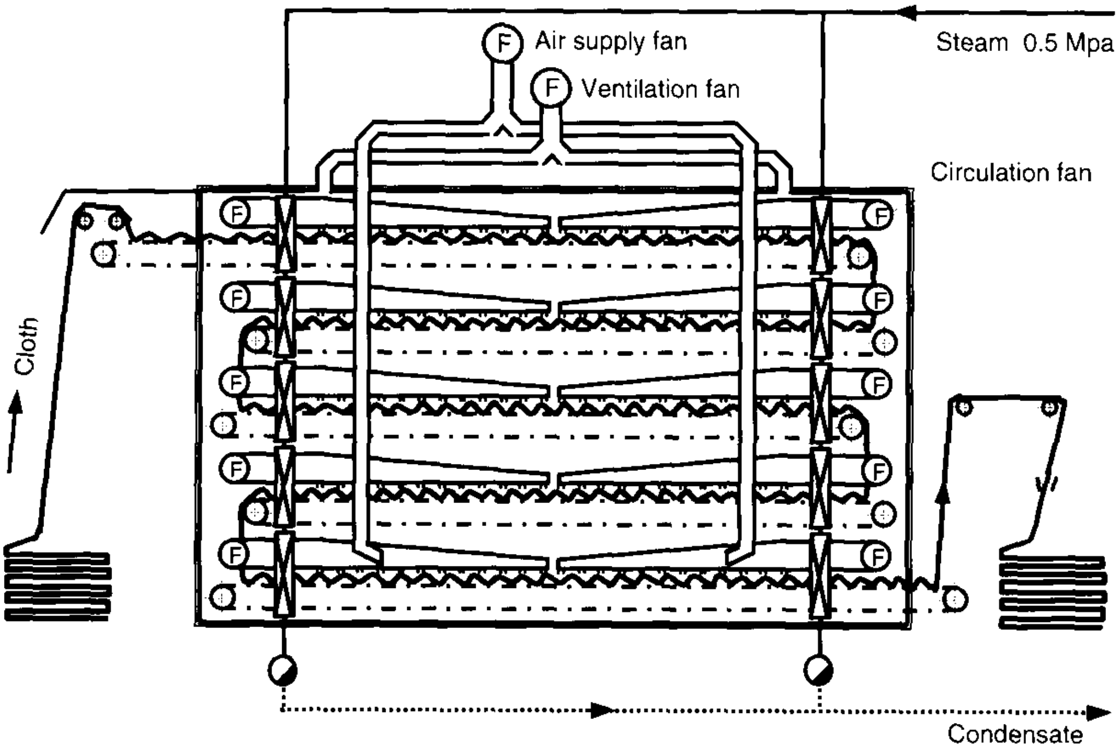
(1) Present state

a. Piping diagram



b. Specifications

1) Type: continuous tray dryer



2) Metal sheet: steel

3) Heat insulation: glass wool 20 mm

Thermal conductivity: $\lambda = 0.188$ kJ/m・K

Emissivity: $\varepsilon = 0.23$

4) Product : cotton 100%

5) Surface area: 434 m^2

6) Temperatures during operation

Room temperature: 85°C average Surface temperature: 82°C

7) State of energy use

• Drying data

Steam intensity:	1.80 kg/kg· fabric	
Electric energy intensity:	0.23 kWh/kg· fabric	
Amount of fabric:	570 kg/h	
Moisture content:	101.9% at inlet	4.5% at outlet

Intake air condition: DB33°C WB23°C h = 68.2 kJ/kg

Exhaust air condition: DB70°C WB42°C h = 184.1 kJ/kg

Exhaust air generation: 238 Nm^3/min· unit

Steam pressure: 0.5 MPa

Wet saturated steam enthalpy: h = 2,712.2 kJ/kg

Saturated water enthalpy: h' = 666.8 kJ/kg

• Heat input and output (0°C standard, 1 hour)

(Heat input)

Item	Calculation	kJ	%
Steam heat energy	1.8 kg/kg × 570 kg/h × 2.712.2 kJ/kg	2,782,717	60.2
Electric heat energy	0.22 kWh × 570 × 3,600 kJ/kWh	471,960	10.2
Intake air heat energy	238 Nm^3/min × 1.3 kg/Nm^3 × 60 min × 68.2 kJ/kg	1,266,065	27.4
Cloth heat energy	570 kg/h × 1.3 kJ/kg・K × 33°C	24,453	0.5
Cloth moisture heat energy	570 kg/h × 1.019 × 4.186 kJ/kg・K × 33°C	80,235	1.7
Total		4,625,430	100.0

(Heat output)

Item	Calculation	kJ	%
Exhaust heat energy	238 Nm^3/min × 1.3 kg/Nm^3 × 80 min × 184.1 kJ/kg	3,417,632	73.9
Cloth heat energy	570 kg/h × 1.3 kJ/kg・K × 70°C	51,870	1.1
Cloth moisture heat energy	570 kg/h × 0.045 × 4.186 kJ/kg・K × 70°C	7,516	0.2
Condensate heat energy	1.8 kg/kg × 570 kg/h × 666.8 kJ/kg	684.137	14.8
Dissipated heat energy	(102 m^2 × 343 kJ/m^2) + (230 m^2 × 330 kJ/m^2) + (102 m^2 × 305 kJ/m^2)	141,996	3.1
Other		322,279	6.9
Total		4,625,430	100.0

(2) Drying efficiency

$$\eta = \frac{\text{Energy used for evaporation of water}}{\text{Overall energy input}} \times 100$$

$$= \frac{[570 \times \{(1.019 \times (70 - 33)\} + \{555.7 \times (1.019 - 0.045)\}] \times 4.19 \text{ kJ}}{2,782,717 + 471,960} \times 100$$

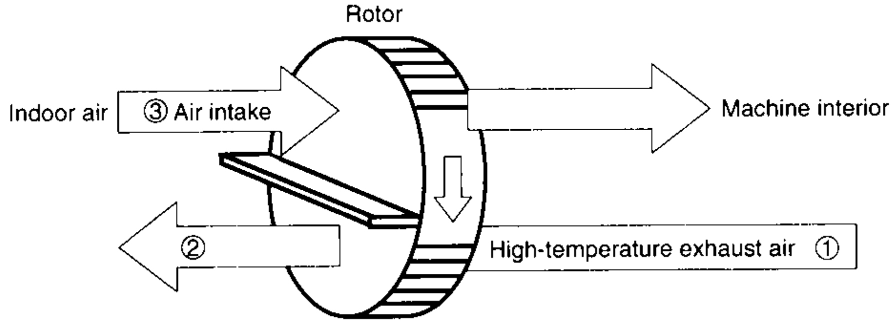
$$= \frac{1,382,718}{3,254,677} \times 100 = 42.5\%$$

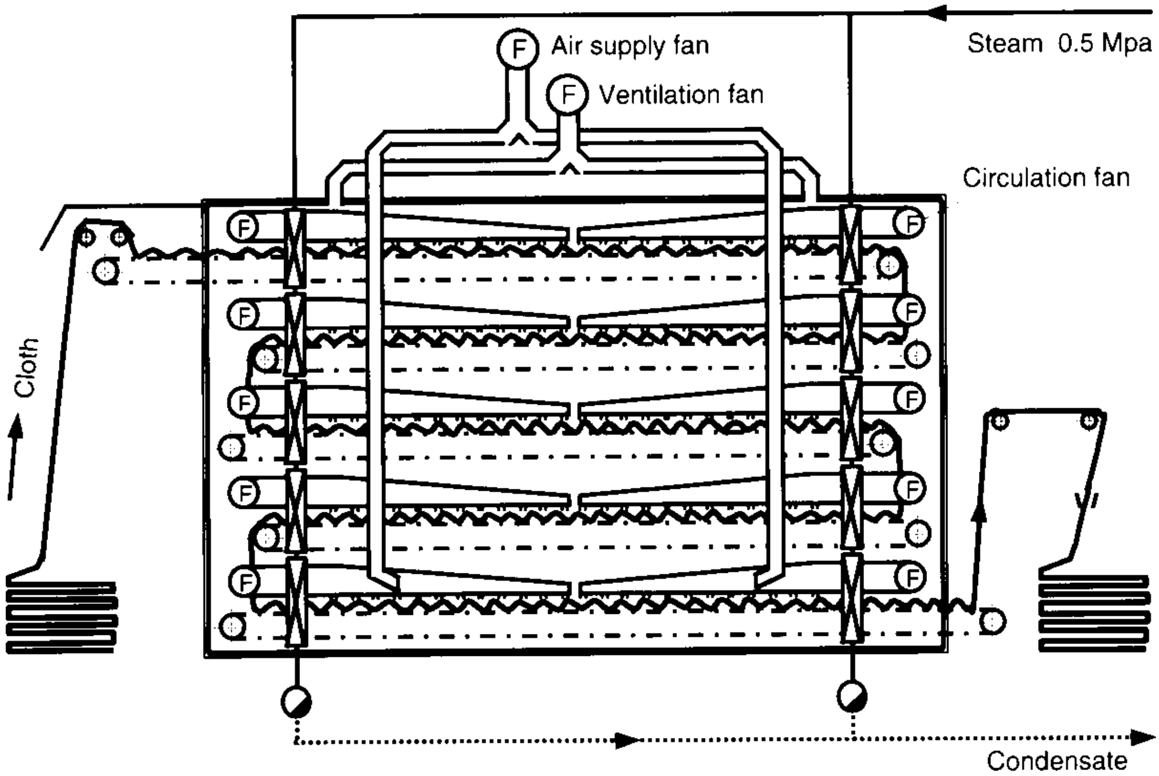
(3) Energy conservation measures

a. Heat recovery from drying process exhaust air via rotating disk sensible heat exchanger

Exhaust air heat recovery via a rotating disk sensible heat exchanger

A rotating disk sensible heat exchanger is installed on the dryer exhaust duct. Made of a metal honeycomb, the rotor rotates at 6–10 rpm.





1) Dryer data

Steam intensity: 1.43 kg/kg· fabric

Electric energy intensity: 0.23 kWh/kg· fabric

Moisture content: 101.9% at inlet 4.5% at outlet

Intake air condition: DB33°C WB23°C h = 68.2 kJ/kg

Exhaust air condition: DB50°C WB40°C h = 167.4 kJ/kg

2) Equipment investment US$30,000/unit

3) Amount of heat recovered q kJ/h

Difference in steam intensity (steam consumption per unit output) as measure of energy conservation: q kJ/h

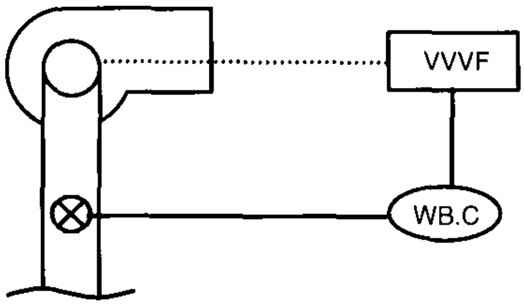
$$q = (1.8 - 1.43)\ \text{kg/kg} \times 570\ \text{kg/h} \times 2{,}712.2\ \text{kJ/kg} = 572{,}003\ \text{kJ/h}$$

Equivalent fuel recovery G = kg·oil/year

$$G = \frac{572{,}003}{42{,}111 \times 0.80} \times 12\ \text{h/day} \times 300\ \text{days} = 61{,}124\ \text{kg oil/year}$$

b. Constant exhaust air moisture control

The exhaust fan motor is provided with a VVVF control modification to control the moisture content of exhaust air.



Exhaust fan control

1) Dryer data

Steam intensity: 1.33 kg/kg·cloth

Electric energy intensity: 0.23 kWh/kg·cloth

Moisture content: 102% at inlet 4.5% at outlet

Intake air condition: DB33°C WB23°C h = 68.2 kJ/kg

Exhaust air condition: DB50°C WB40°C h = 167.4 kJ/kg

Exhaust air flow rate: 157 N^3m/min

2) Capital investment US$2500/unit

3) Amount of heat recovered q kJ/h

Difference in steam intensity (steam consumption per unit output) as measure of energy conservation: q kJ/h

$$q = (1.43 - 1.33)\ \text{kg/kg} \times 570\ \text{kg/h} \times 2{,}712.2\ \text{kJ/kg} = 154{,}595\ \text{kJ/h}$$

Equivalent fuel recovery G = kg·oil/year

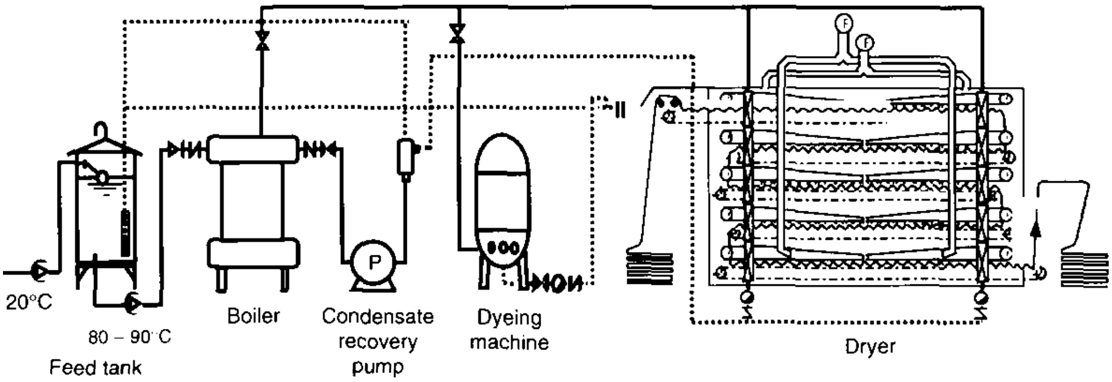
$$G = \frac{154,595}{42,111 \times 0.80} \times 12 \text{ h/day} \times 300 \text{ days} = 16,520 \text{ kg oil/year}$$

c. Condensate recovery

Condensate from the dyeing machines is being recovered, and the temperature of the boiler feed tank is already 80–90°C. Directing any more condensate to the feed tank would generate slash steam, and would thus reduce the effectiveness of condensate recovery.

For this reason, condensate from the dryers is recovered via a separate line and fed directly to the boiler.

1) Flowchart (including dyeing machine)



2) Point to note

Install piping to divert part of the condensate to the feed tank.

3) Amount of heat recovered q kJ/h·unit

$$q = 1.8 \text{ kg/kg} \times 570 \text{ kg/h} \times (666.8 - 83.7) \text{ kJ/kg} = 598,260 \text{ kJ/h}$$

Equivalent fuel recovery G = kg·oil/year

$$G = \frac{598,260}{42,111 \times 0.80} \times 12 \text{ h/day} \times 300 \text{ days} = 63,717 \text{ kg oil/year}$$

4) Capital investment

Recovery pump facility	¥2,000,000	US$20,000
Boiler feed system modification	¥500,000	US$5,000
Piping work	¥1,200,000	US$12,000
Total	¥3,700,000	US$37,000

3-3 Heat insulation of pipe

(1) Details of improvement

1) Renewal of heat insulation

・Of the 500m steam pipe (80A), 60% is not heat-insulated.

(2) Calculation of effects

- Renewed length of pipe = 300m, heat-insulated with 50mm glass wool
- Steam pipe ....0.7MPa, 169℃
- Heat release conditions..........60% of the total length is not heat-insulated.

	Not insulated	Insulated	Effect of insulation
Heat release (kj/mh)	2,721	293	2,428

・Newly heat-insulated length .... 500m × 0.6 = 300m

1) Effect of insulation renewal 2,428 kj/mh

- Heat release (kj/day)

  = 2,428 × 500m × 0.6 = 728,400 kj/h

- Steam recovery rate (kg・unit/h)

  = 728,400/(2712.2-83.7) = 277.1 kg/h

- Energy and cost saved (G: kg・oil/year, X: $/year)

  HL: 42,111 kJ/kg, boiler efficiency: 80.0% (No.1 unit), oil@: $0.2/kg

  G = 728,400/(42,111 × 0.8) × 13h = 281.1 kg・oil/day

  - Energy saved per year = 281.1 × 300 = 84,330 kg・oil/year
  - Cost saved per year

    X 1 = 84,330 × 0.2 = $16,866/year

- Payback period (n years)

  - Investment

    Piping works: $30/m × 300m = $9,000

  ・n

$$n = \frac{\mathrm{Log}\left(\dfrac{P}{P\text{-}L^{*} \quad 1}\right)}{\mathrm{Log} \quad (1 \quad + \quad I)}$$

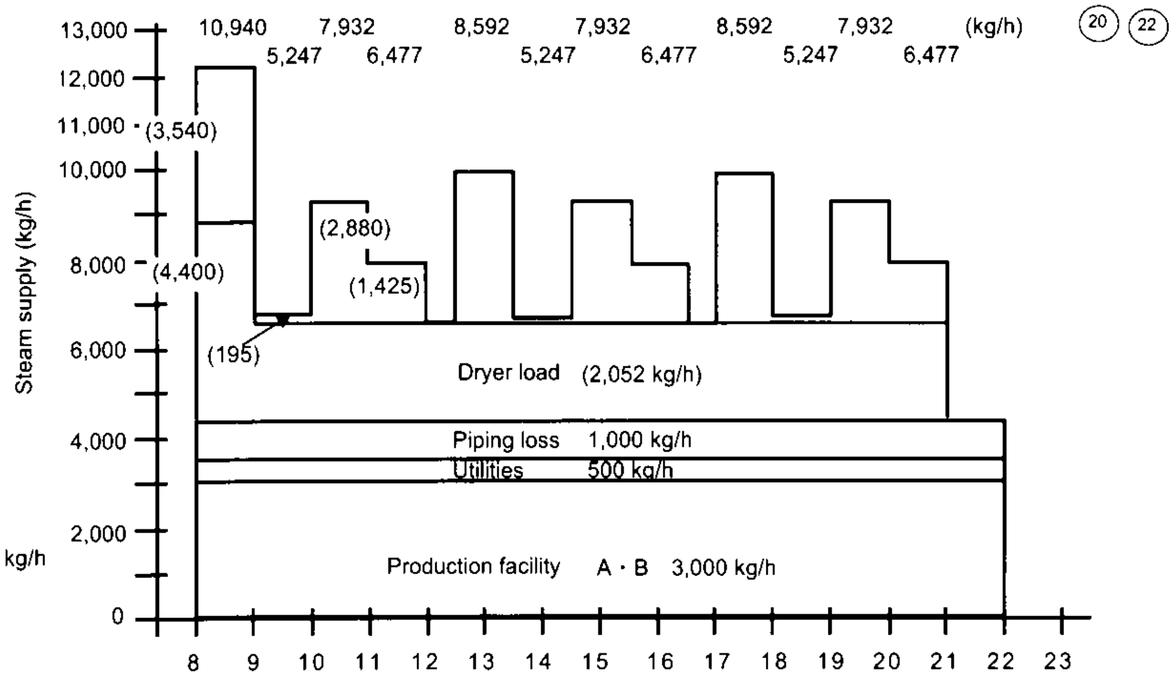
n = log(16,866/(16,866-9,000 × 0.1))/log(1+0.1)

n = log1.0563/log(1+0.2) = 0.6 year

3-4 Steam load curve in the factory

(1) Existing load curve

Factory-wide steam load curve



Problems

- Large load fluctuations
- Operation of two boilers necessary

(2) Improvement measures

a. Shift of start-up time of dyeing machine

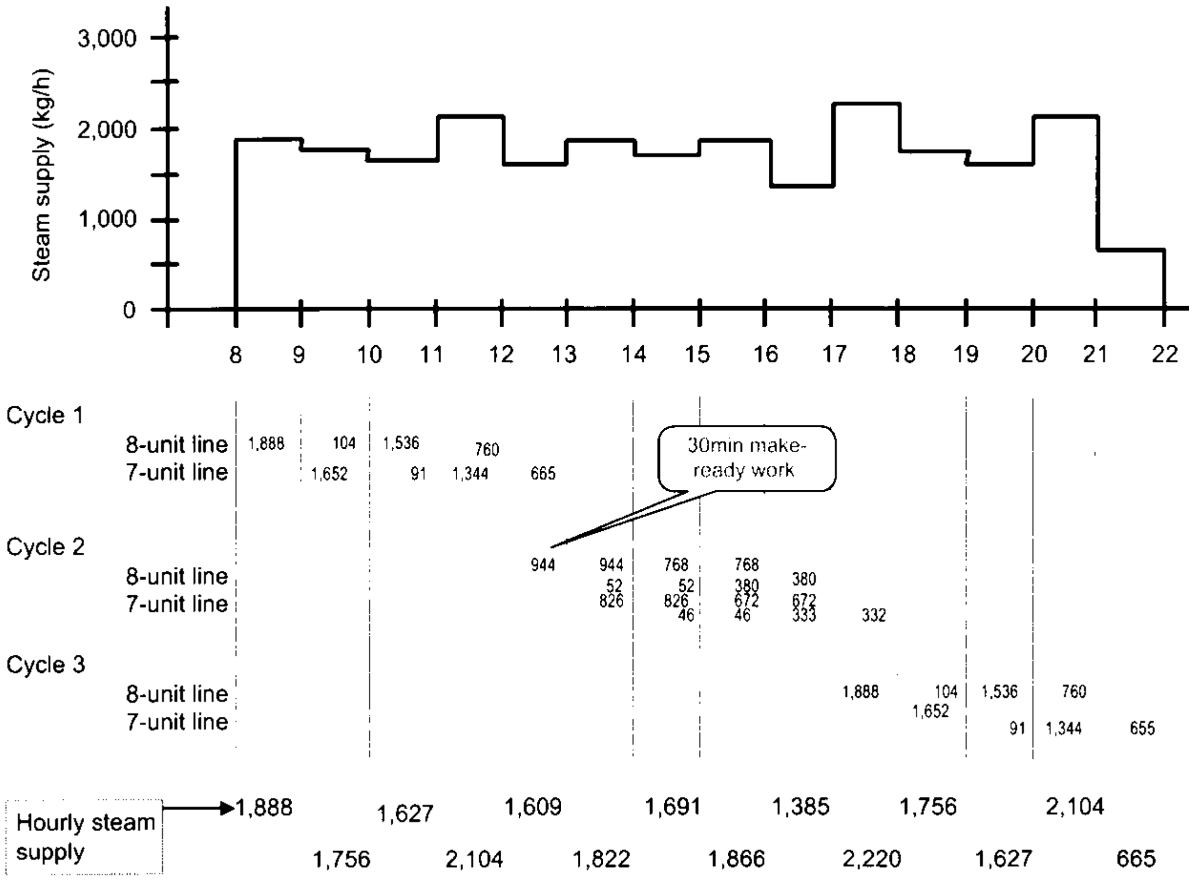
		Heating	Dyeing	Fixing	Softening	Make-ready	Total
Time (min)		60	60	60	60	30	240
Steam consumption (kg/h)	1 unit	236	13	192	95	0	536
	7 units	1,652	91	1,344	665	0	3,752
	8 units	1,888	104	1,536	760	0	4,288
	15 units	3,540	195	2,880	1,425	0	8,040

b. Shift of start-up time of dryer

		Warm-up	Dyeing
Steam consumption (kg/h)	1 unit	2,200	1,026
	2 units	4,400	2,052

c. Of the 15 dyeing machines, eight and seven are started at 8:00 and 9:00, respectively.

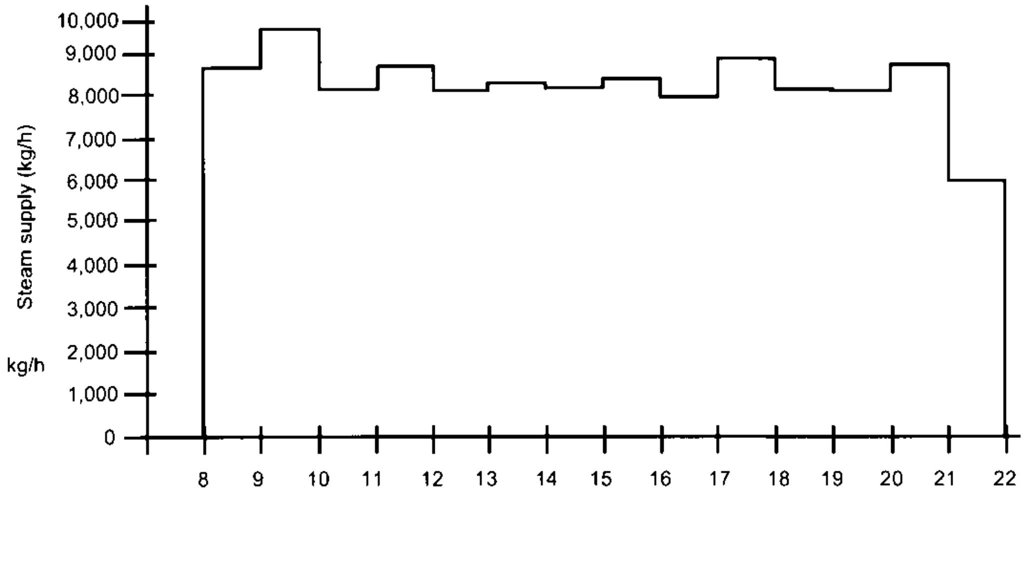
The revised load curve is shown below.



Dryer Nos. 1 and 2 are started at 8.00 am and 9.00 am, respectively.

8:00 – 9:00 = 2,200 kg 9:00 – 10:00 = 3,226 kg 10:00 – = 2,052 kg

d. Load curve after improvement



Steam supply flowchart