## 4.2 Silica Block

4.2.1 Preface

Building materials can generally be divided into metals and non-metals, while non-metals can be further categorized into inorganic (mineral matters) and organic materials. The former is called ceramics. This section deals with construction materials, mainly ceramic construction materials (Calcium silicate products), manufactured by autoclave curing, using silica sand, cement, and lime as the principal raw materials.

Of these calcium silicate products, silicate lime block, cement block (Trade name: Color bestos, etc.), and autoclave light weight concrete (Trade name: Ytong, Syporex, etc.), etc., were subject to the recent Poland Study.

Next, a systematic classification of building materials is shown in Figure 4.2.1.

Figure 4.2.1 Systematic Classification of Building Materials
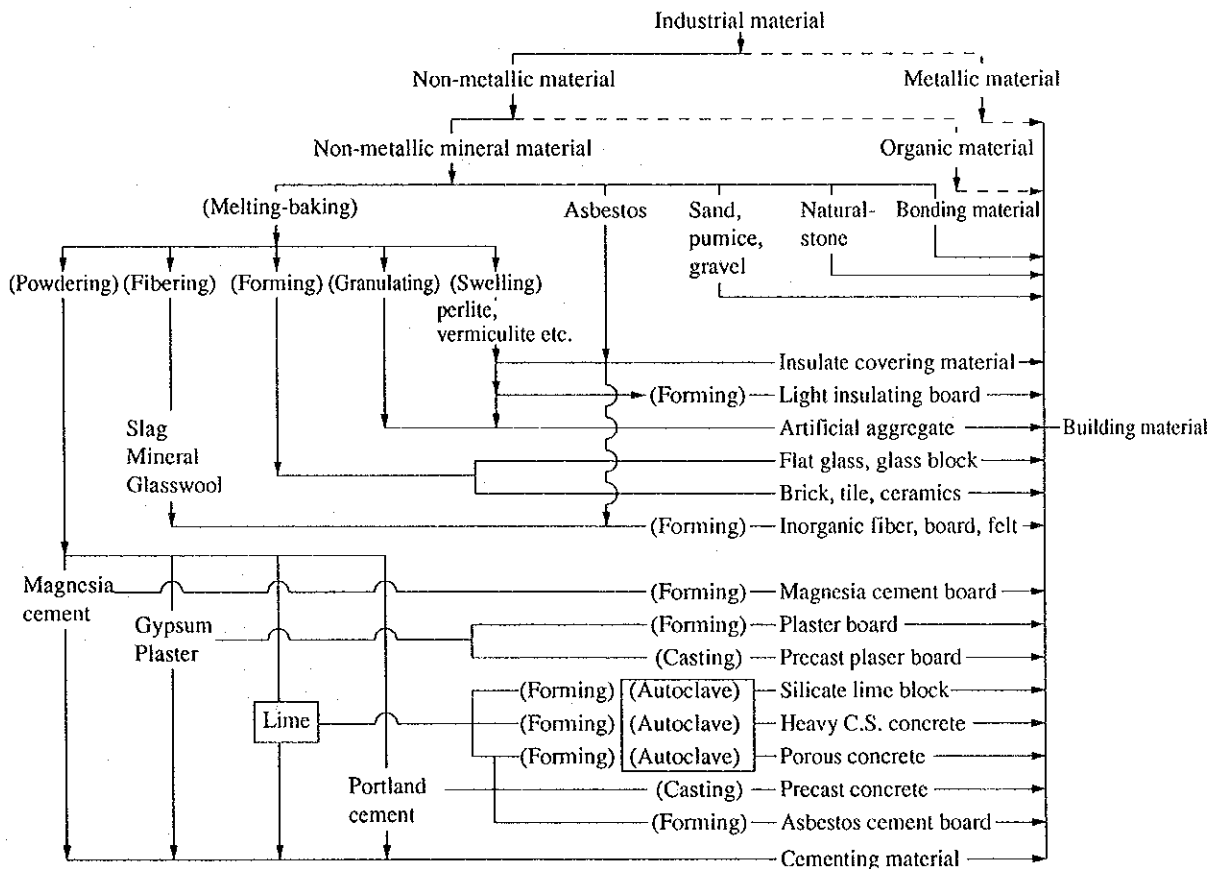
4.2.2 Calcium Silicate Products

When raw materials are mixed so that an appropriate SiO_2 and CaO mole ratio is achieved, and they are made to react under a few atmospheric pressures to a several scores of atmospheric pressure, by means of autoclave with an excessive presence of water, CSH which has a small crystallinity, Tobermorite (C_5S_6H) which has a somewhat higher crystallinity, and Xonotlite (C_6S_6H) with an even higher value, etc., are made, and used as light weight, heat insulation, and fire resistant materials. While the crystals mentioned above are currently used industrially, there is great hope that if crystal forming can be further controlled, even Foshagite (C_4S_3H) and Hiltebrandite (C_2SH) can be developed for industrial use.

Formed compounds are influenced by the type, grain size, CaO/SiO_2 ratio, time and temperature of hydrothermal reaction, etc., of the starting raw material.

(1) Silicate Lime Block

Silica sand is the main component, and its lime content is small. It is used as white bricks in construction, in a manner similar to red bricks. Whereas red bricks are manufactured by baking at 900 to 1,000 °C, these products are made by autoclave hardening, and therefore they are energy-saving type, and are environmentally friendly. Figure 4.2.2 shows an example of a manufacturing process.

Figure 4.2.2 Production Process of Silicate Lime Block
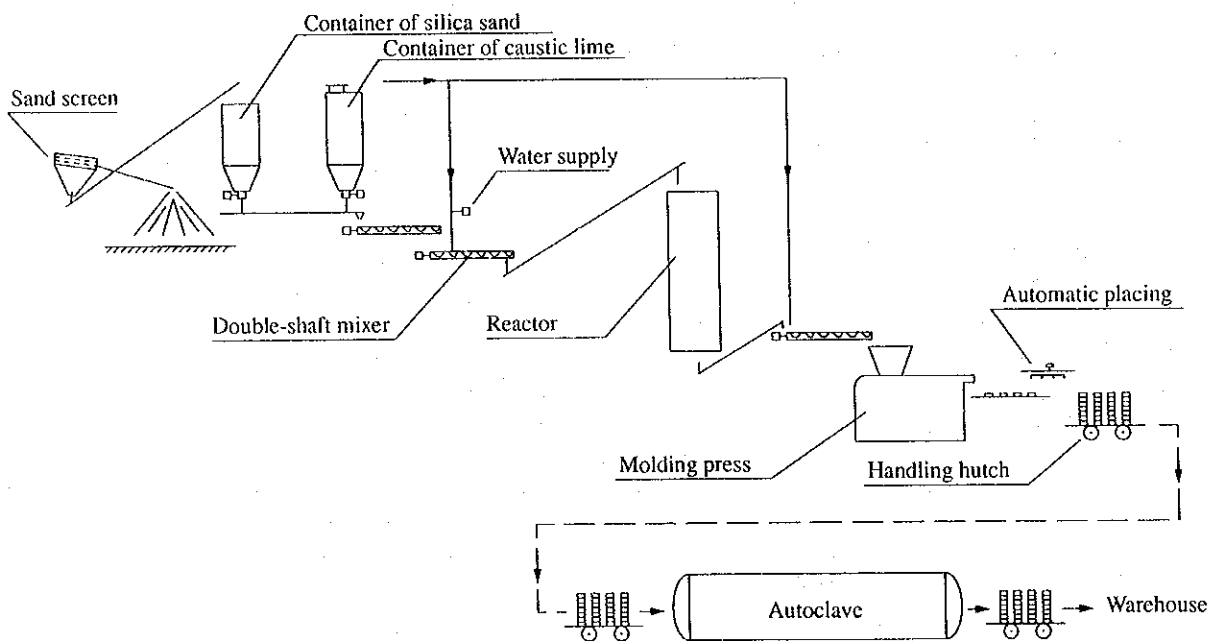
(2) Cement Roof Tile

Cement roof tiles are completely nonflammable construction materials made by forming special cement admixture and reinforcing fiber as the principal raw materials, to be then hardened in autoclave. Figure 4.2.3 shows an example of a manufacturing process.

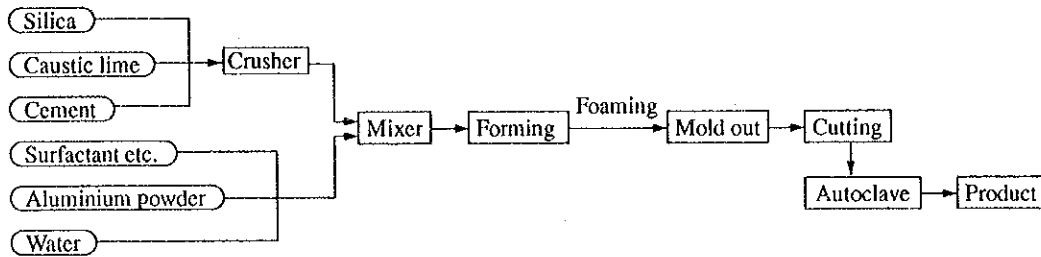**Figure 4.2.3 Production Process of Cement Roof Tile**
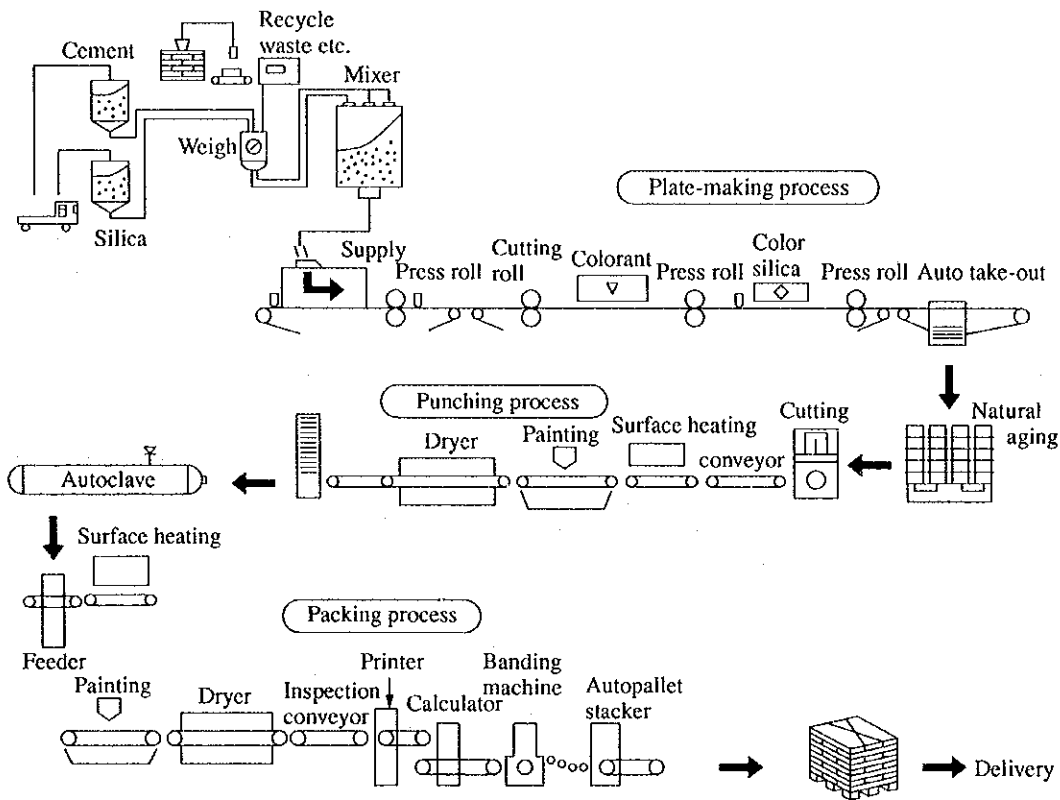
(3) Autoclave Lightweight Concrete

In order to improve the shortcoming of concrete, i.e., its heavy weight, various methods have been studied to develop lightweight concrete, which has come into use for structural and insulating purposes, and their uses are increasing as steel skeleton constructions using precast panels are becoming widespread. One such lightweight concrete is the autoclave lightweight concrete. This material was originally developed as a heat insulating material in the cold regions of Northern Europe.

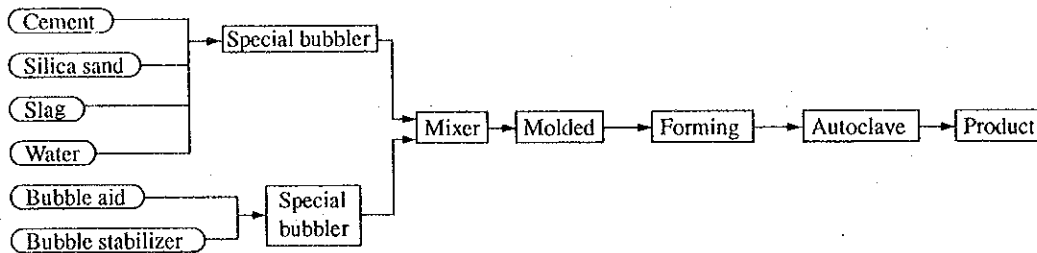While an example of a manufacturing process is shown in Figure 4.2.4, it should be noted that there are 2 types of such lightweight concrete: one is ALC (Autoclaved lightweight concrete) which is foam material first formed by generating gas through a chemical reaction using aluminum powder, and then hardened in autoclave; and the other type that is formed into foam material by foaming slurry by means of a foaming machine.

Figure 4.2.4 Production Process of ALC Products

Foaming method (ALC)

```
( Silica )
( Caustic lime )──►[ Crusher ]
( Cement )                      ┌─[ Mixer ]─►[ Forming ]──Foaming──►[ Mold out ]─►[ Cutting ]
( Surfactant etc. )                                                                    │
( Aluminium powder )                                                          [ Autoclave ]─►[ Product ]
( Water )
```

Preforming method

```
( Cement )
( Silica sand )──►[ Special bubbler ]
( Slag )                              ┌─[ Mixer ]─►[ Molded ]─►[ Forming ]─►[ Autoclave ]─►[ Product ]
( Water )
( Bubble aid )────┐   ┌─ Special
( Bubble stabilizer )─┘   │   bubbler
```

Next, the strength and heat-insulating performance of light weight concrete are shown in Figure 4.2.5 and Figure 4.2.6.

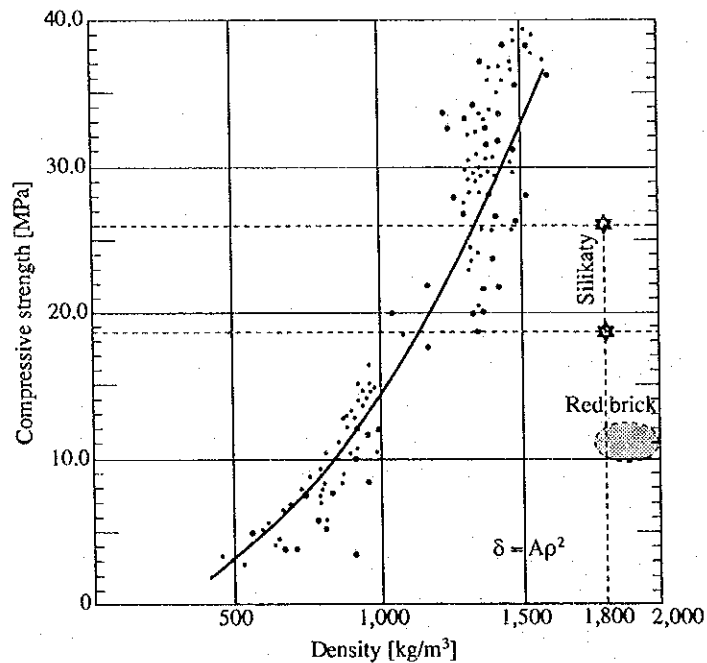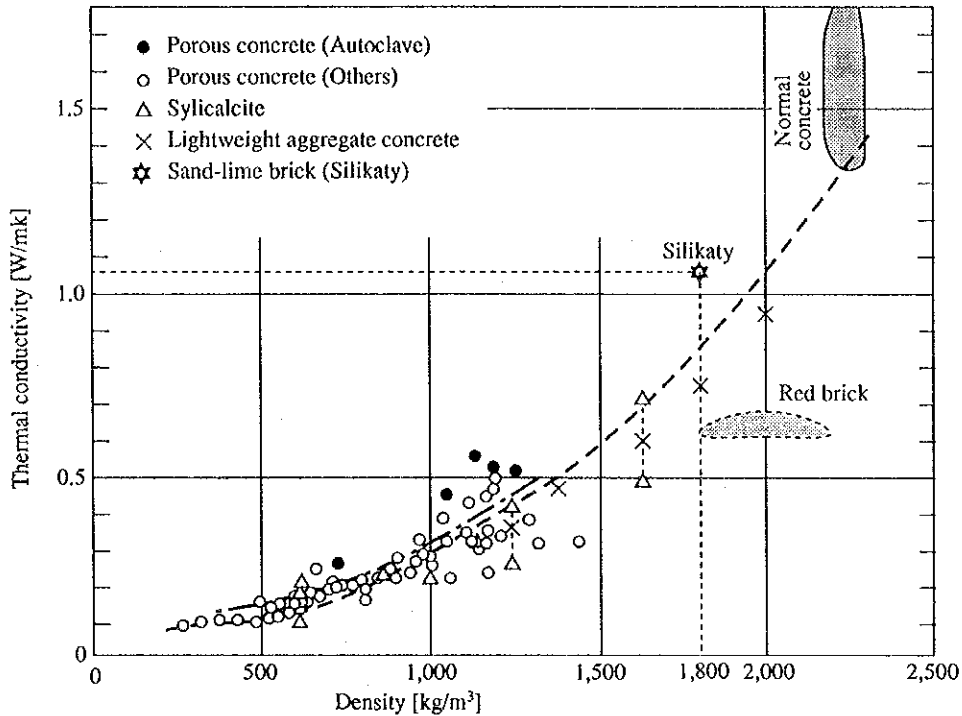## Figure 4.2.5 Compressive Strength vs. Density of Porous Concrete

Figure 4.2.6 Thermal Conductivity vs. Density of Lightweight Concrete

4.2.3 Energy Conservation of Autoclave

(1) Structure of Autoclave

While autoclave comes in several types of methods and configurations, depending on the purpose and characteristics of the material, this section deals with the lateral type, and static type, steam-process autoclave used for curing (hardening) calcium silicate products.

As shown in Figure 4.2.7, the structure of autoclave consists of a cylindrical body and an end plate door (entrance and exit) for inserting materials and carrying in/out products.

The body of the autoclave proper, and the external surface of the door, are generally heat-insulated by 65 to 100 mm of calcium silicate.

There are various dimensions such as D × L of 1.8 mϕ × 20 m, 2.5 m × 40 m, 3.0 m × 50 m.

Generally, about 3 m at both ends go indoor, and the middle outdoors.

Figure 4.2.7 Outline of Autoclave
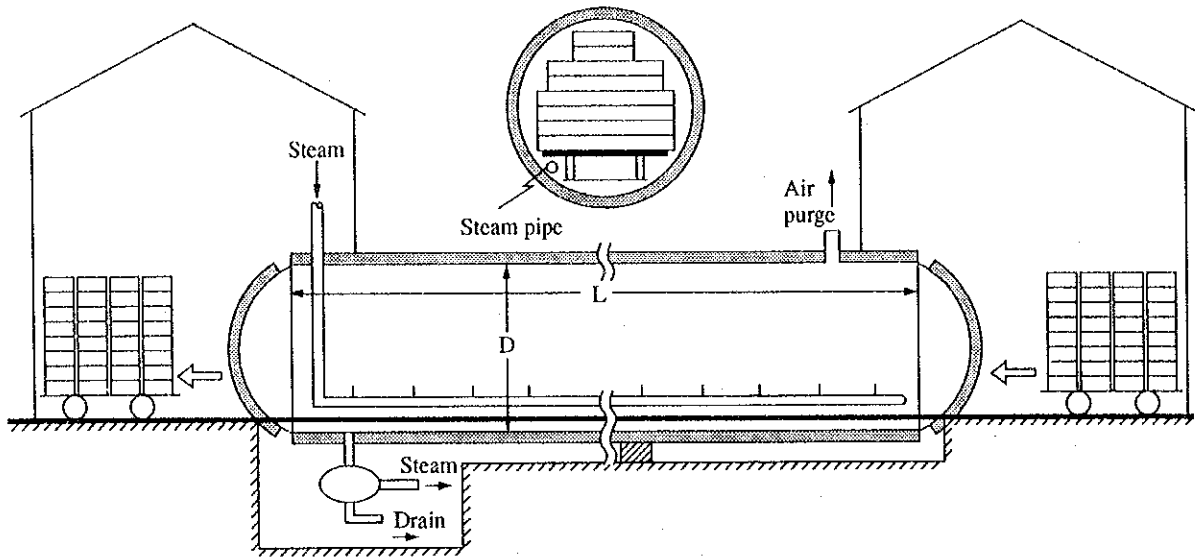
(2) Concept of Energy Conservation of Autoclave

A general concept of energy conservation for autoclave is shown in Figure 4.2.8.

Figure 4.2.8 General Items of Energy Conservation of Autoclave

① Improvement of operation standard

⑥ Automatic control of system by CPU

② Reduction of radiation heat loss

Energy conservation of autoclave

⑤ Heat recovery and effective use

③ Improvement of filling ratio

④ Prevention of steam leakage by close maintenance
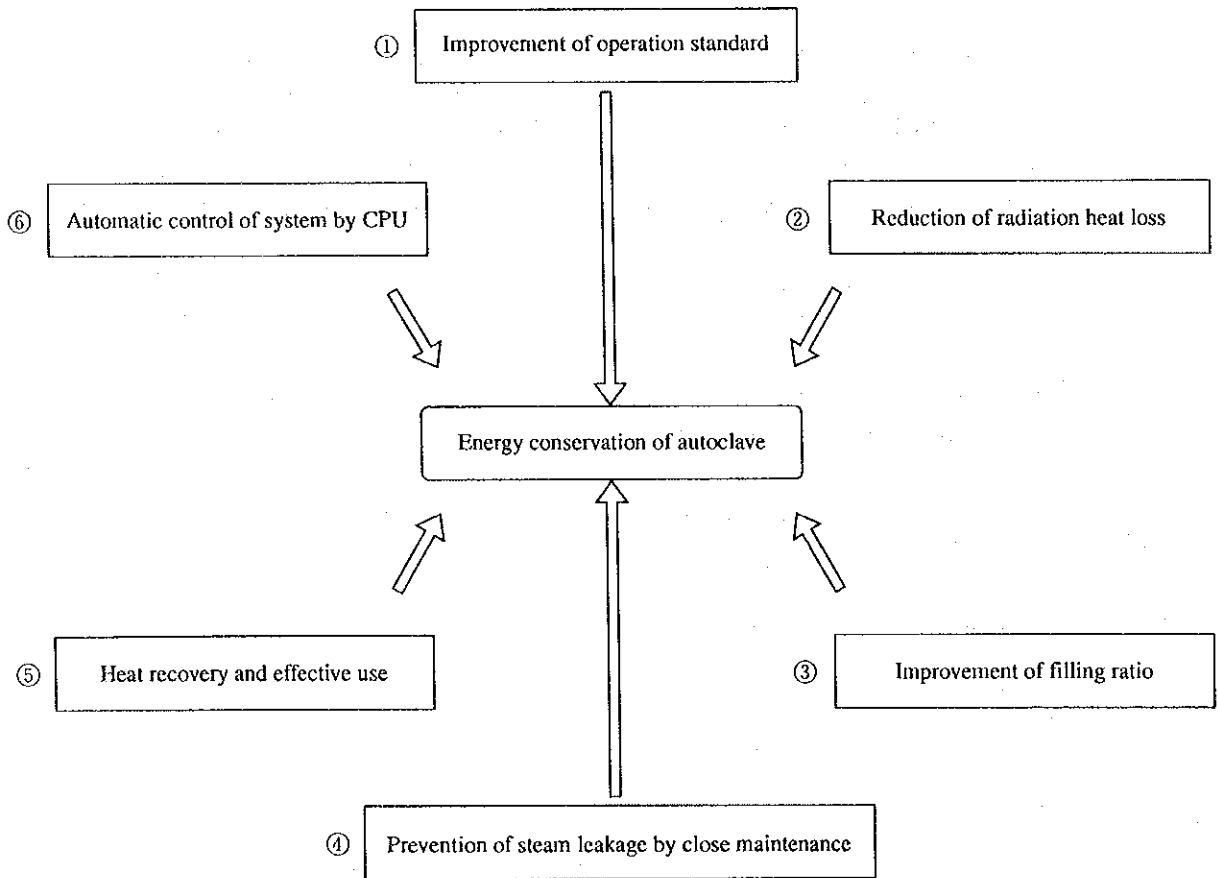
(3) Reviewing Operating Criteria

Various long-standing criteria used for operations should be reviewed from an energy conservation standpoint, and the best operating criteria should be established based on various tests and data collected.

a. Setting Product Quality Criteria

b. Reviewing selection of raw material type, grain size, and mixing proportions

c. Work process

Insert material — Shut door — Draw out air* — Insert steam —Raise temperature — Hardening — Transfer steam to another drum — Release steam — Retrieve product
* Drawing out air: Obtain vacuum of 150 mmHg using a vacuum pump.

(Reason) When air and other inert gas are contained in the super heated steam, gas will accumulate in the heating chamber, hampering heat transfer, reducing partial pressure of steam, and thus reducing heating temperature.

d. Measuring and collecting basic data of autoclave operations (Refer to Figure 4.2.9)

1) Relationship between holding pressure and holding time
2) Relationship between saturated steam pressure and enthalpy
3) Pressure rise time and steam quantity
4) Temperature descent, and its time, after stopping steam

e Reviewing temperature and time of autoclave reaction

Although reducing steam pressure will lead to energy conservation since the latent heat of steam is being used, the relationship between holding pressure and holding time, mentioned in the previous section, and the pressure's relationship to facility capacity, should be studied, and the optimal criteria that accommodate fluctuations in production quantity should be devised.

If ample allowance exists in the facility's capacity, reducing steam pressure, and lengthening the holding time (hardening time) would be effective in terms of energy conservation.

Figure 4.2.9 Basic Data of Autocalve Operation (Example)
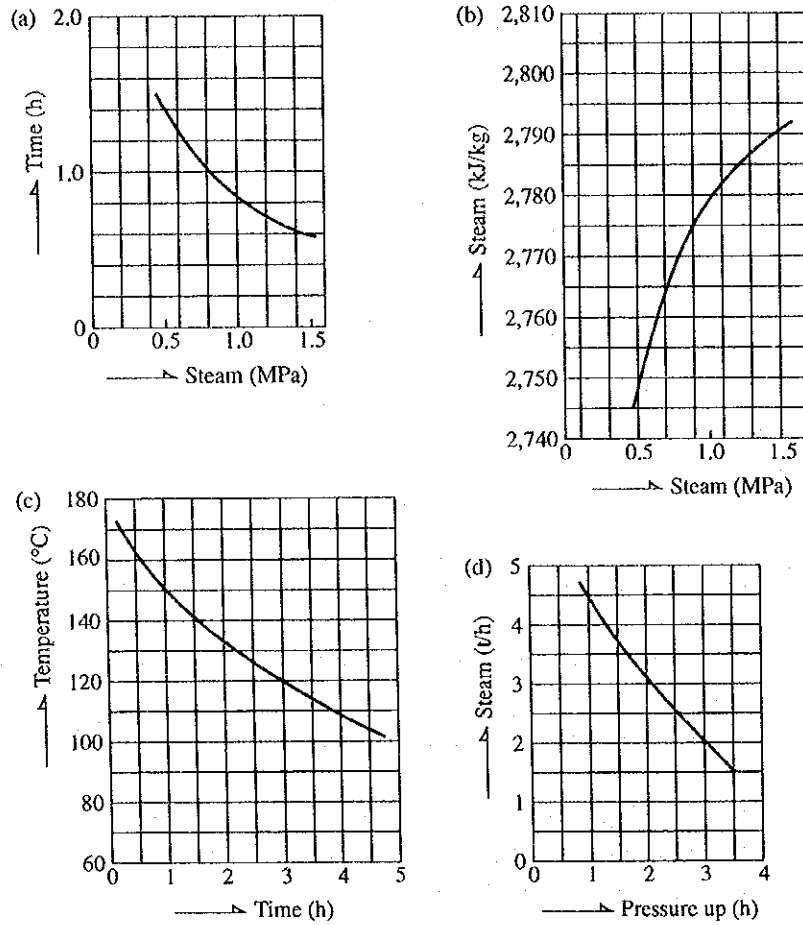
(4) Reducing Radiation Heat

Heat radiation should be restrained by insulating the autoclave proper, waterproofing the outdoors segment, insulating the door, the steam pipes, and the valves, etc.

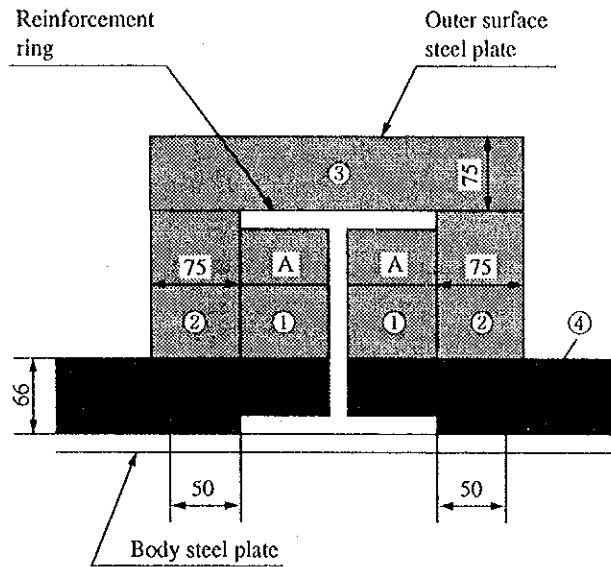An example of heat insulation for the main body of the autoclave proper and reinforcing ring is shown in Table 4.2.1 and Figure 4.2.10.

Table 4.2.1 Specification of Insulation

	Materials	Thickness
①	Glass wool 24 kg/m³	A
②	Glass wool 24 kg/m³	75 mm
③	Glass wool 24 kg/m³	75 mm
④	Calcium silicate 150 kg/m³	65 mm

Outer surface steel plate thickness: 0.4 mm

Figure 4.2.10 Section of Insulation

Next, an example of calculations for insulating the autoclave main body is shown.

When autoclave outside diameter: $d_2 = 3.0$ m, Temperature inside drum: $t_1 = 180$ °C, Outside air temperature: $t_2 = 15$ °C.

(Example-1)

Heat insulating material: 100 mm of glass wool. Assuming that heat radiation from the body of the autoclave proper is Q_1,

$$Q_1 = \frac{2\pi\left(t_1 - t_2\right)}{\dfrac{2}{d_1 h} + \dfrac{1}{\lambda}\,Ln\,\dfrac{d_1}{d_2}}$$

$$= \frac{2\pi\left(180 - 15\right)}{\dfrac{2}{3.2 \times 10} + \dfrac{1}{0.042}\,Ln\,\dfrac{3.2}{3.0}} = \frac{1,036.7}{1.6} = \underline{648 \text{ kcal/m}\cdot\text{h}}$$

Where, $\begin{cases} d_1 : & \text{Outside diameter of drum (m)} \\ h : & \text{Thermal conductivity from the heat-insulated surface} = 10 \text{ kcal/m}^2\cdot\text{h}\cdot\text{°C} \\ \lambda : & \text{Thermal conductivity of heat-insulating material} = 0.042 \text{ kcal/m}\cdot\text{h}\cdot\text{°C} \end{cases}$

(Example-2)

Heat-insulation material: 65 mm of calcium silicate heat insulating material. Assuming that the amount of radiation heat from the main shell is Q_2,

$$Q2 = \frac{2\pi(180-15)}{\dfrac{2}{3.13\times10}+\dfrac{1}{0.042}Ln\dfrac{3.13}{3.0}} = \frac{1,036.7}{1.074} = \underline{965\ kcal/m\cdot h}$$

where, {Calcium silicate heat insulation material λ: 0.042 kcal/m·h·°C}

(5) Improvemet of Filling Factor

Improve the autoclave's filling factor by modifying the transfer cart.

(6) Check and repair any leakage of steam from the autoclave main body and steam header, steam piping joints, and valves through careful maintenance work.

(7) Recovery and Effective Use of Heat

a. Recovery of excess steam in the autoclave holding process. (See Figure 4.2.11)

b. Recovery of exhaust steam in the autoclave pressure reduction process. (See Figure 4.2.11)

c. Recovery of autoclave drain. (See Figure 4.2.11)

Figure 4.2.11 Flow Chart of Heat Recovery (Example)
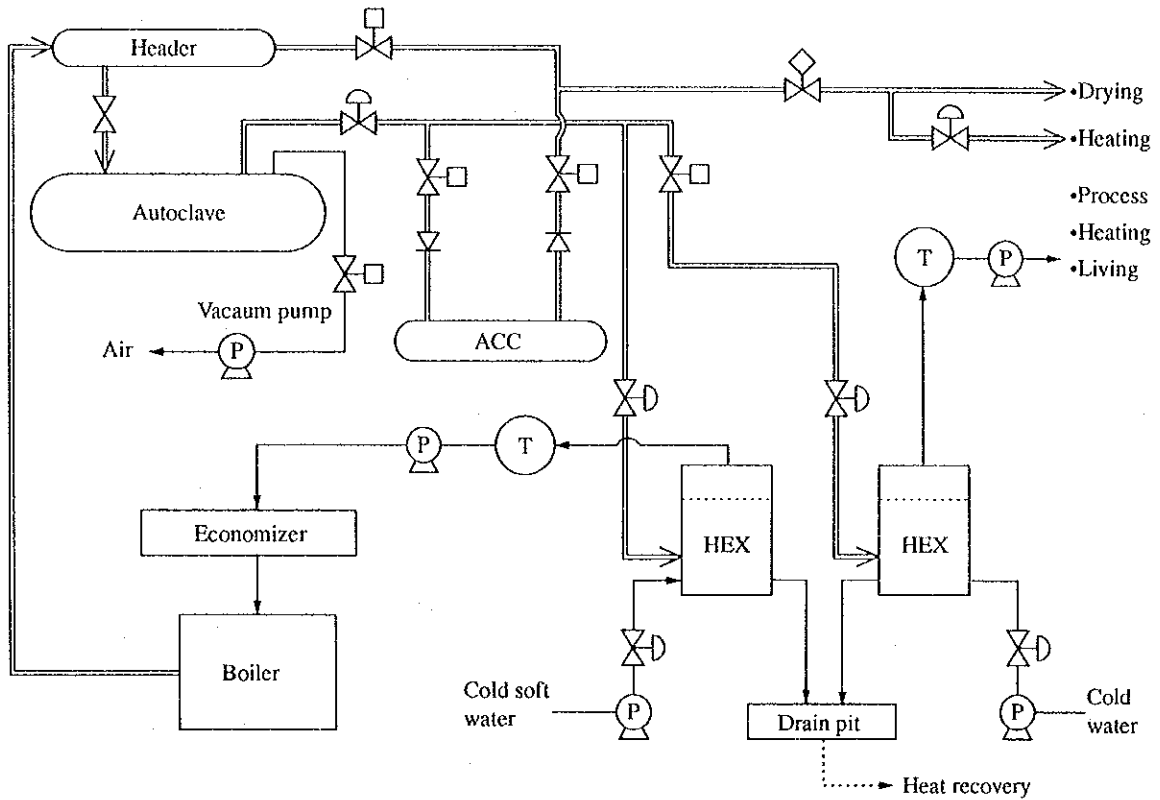
d.   Use of exhaust steam from the reduction process for preheating the next autoclave.

Next, the arrangement of the selector valves for the 6 autoclave units is shown in Figure 4.2.12.

Figure 4.2.12 Steam Valve Station of Autoclave

(8) Maintenance and Computer-Aided Automatic Control of Measurement Devices

    a. Scientifically grasp the operating state of the autoclave by installing temperature and pressure recorders.

    b. Simulate autoclave operating conditions that are best suited for fluctuations in demand.

    c. Reduce the amount of wasted steam by means of programmable control of autoclave steam pressure.

    d. By automating and speeding up of control and switching of the operation of each autoclave, the amount of steam loss can be reduced.
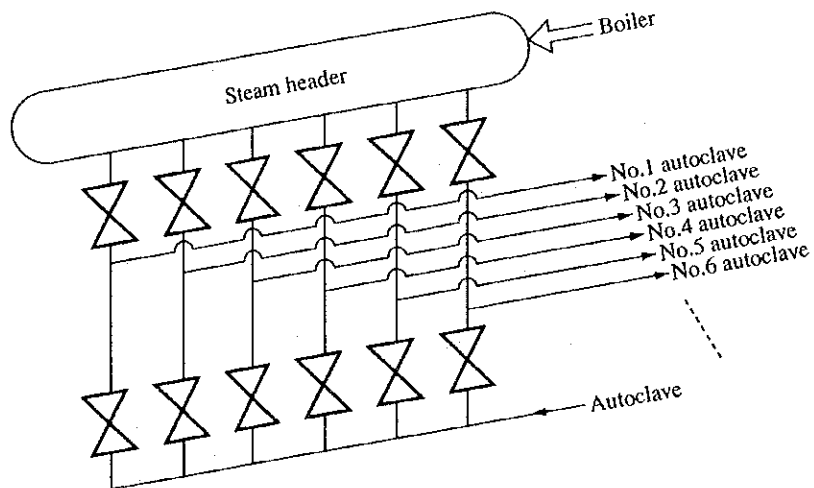
    e. Forecast fluctuations in the amount of steam that accompany operation control of each autoclave, and obtain balance for the steam generated by the boiler.

    f. Efficient operation can be achieved by automating the distribution of boiler water for preheating, hot water, and steam for miscellaneous purposes.

(9) Raise the level of efficiency in energy use for the entire factory by introducing a cogeneration system.

    See Chapter 5 for examples.

4.2.4. Example of Energy Conservation through Improvement of Autoclave Hardening Process

(1) Preface

    a. Item produced: Autoclave lightweight concrete product (ALC)

    Representative products: General panels, water-proof panels, mould panels, modified cross-section panels, customized panels, L-shape and R-shape panels

    b. Number of employees: 210

    c. Annual energy consumption: Kerosene 3,131 kL, Electricity 5,780 MWh

    d. Manufacturing process: shown in Figure 4.2.13.

    This factory manufactures autoclave lightweight concrete (ALC).

Figure 4.2.13 Outline of Production Process
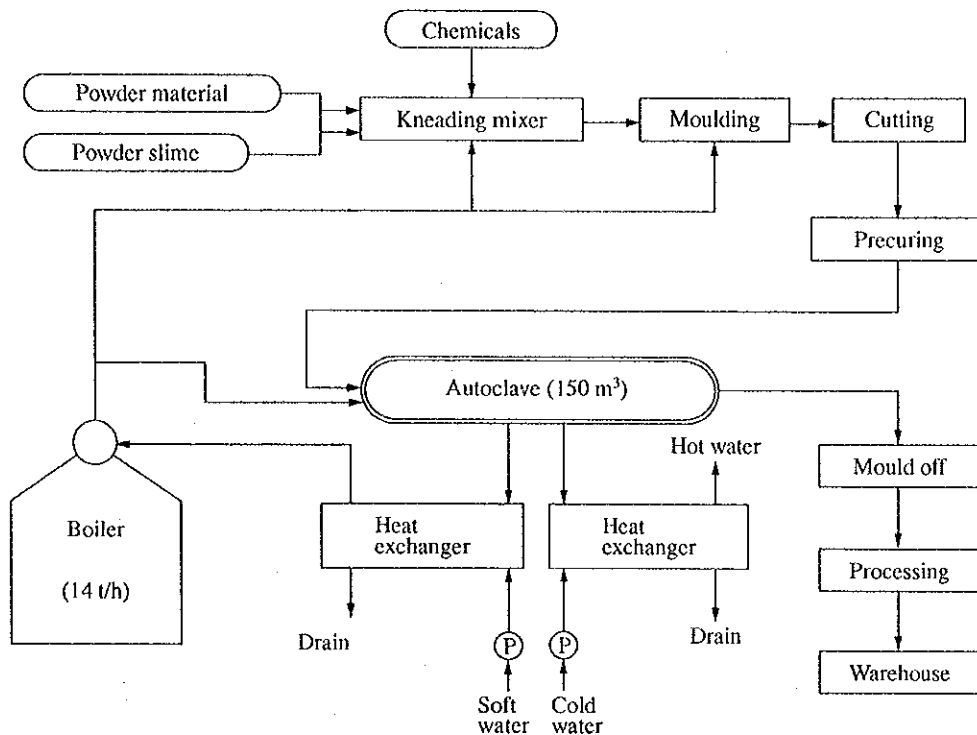
(2) Grasping and Analyzing Current State

a. Autoclave hardening process

Autoclave is used for hardening raw ACL, using high temperature, high pressure steam, and the pressure is controlled by a specified program.

Approximately 11.3 t of high pressure steam from the boiler is consumed per autoclave cycle (1 batch), and the process is as shown in Figure 4.2.14.

b. State of Steam Use in the Hardening Process

Most of the steam used in the hardening process shown in Figure 4.2.14 is for the pressure raising process, and some of it is used in the later half of the retaining process. The first half of the holding process in Figure 4.2.14 is for generating the chemical reaction for the ALC in the autoclave to become a product, and generates heat. Because the pressure inside the autoclave rises due to this heat generation, the steam that corresponds to the rise is released in order to maintain the program curve in Figure 4.2.14. Eventually, in the latter half of the holding process, the heat generation subdues and disappears, and as the pressure falls, steam will need to be supplemented.

Automatic control of such rise and fall in the pressure level is carried out in order to maintain the program curve shown in Figure 4.2.14.

Figure 4.2.14 Discharge Steam and Charge Steam in Hardening Process of Autoclave

Pressure up process

Pressure holding process

Pressure down process

Program curve

Pressure

Steam discharge

Steam charge

Time
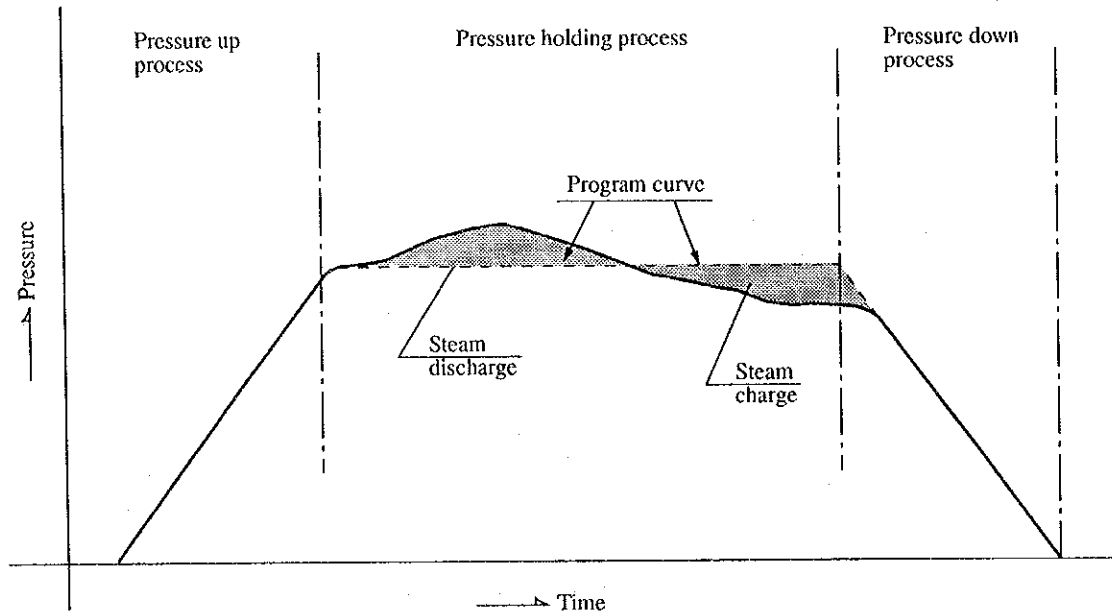
c. Exhaust steam and heat recovery

The steam released during the holding process raises the temperature of the boiler's feedwater through a heat exchanger to recover the heat. (Figure 4.2.15)

Additionally, the exhaust steam in the pressure reduction process is also turned into hot water by another heat exchanger, to recover the heat.

Figure 4.2.15 Heat Recovery of Exhaust Steam

```
                    ┌─────────────────────────────┐
                    (          Autoclave           )
                    └─────────────────────────────┘
                     Steam              Pressure
                     discharge          down
                        │                  │
                        ▼                  ▼
              ┌──────────────┐   ┌──────────────┐
      ┌───────│     Heat      │   │     Heat     │────────┐
      │       │   exchanger   │   │   exchanger  │        │
      │       └──────────────┘   └──────────────┘        │
      ▼            ▲       │        │      ▲              ▼
┌──────────┐      │       │        │      │      ┌──────────────┐
│ Hot soft │      │       │        │      │      │ Hot water tank│
│water tank│      │       ▼        ▼      │      └──────────────┘
└──────────┘      │    ┌─────────────┐    │              │
      │           │    │  Drain pit  │    │              │
      │           │    └─────────────┘    │              │
     (P)         (P)                     (P)            (P)
      │           │                       │              │
      ▼           │                       │              ▼
┌──────────┐  ┌──────────┐         ┌──────────────┐
│Economizer│  │Cold soft │         │Cold water tank│
└──────────┘  │water tank│         └──────────────┘
      │       └──────────┘
      ▼
┌──────────┐
│  Boiler  │
└──────────┘
```
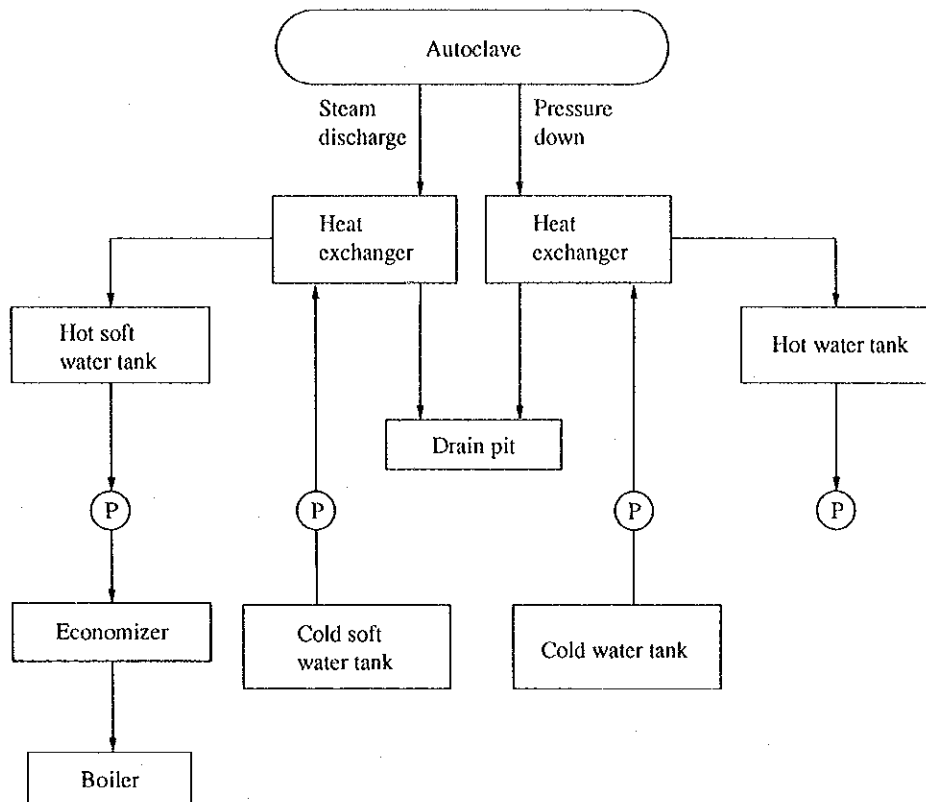
(3)   Details of the Activity

a.   Setting targets

Reduction of steam to be supplemented in the latter half of the holding process

b.   Problems and countermeasures

1)   How should the fall in pressure be covered without supplementing the necessary amount of steam in the latter half of the holding process?
2)   To what level should the fall in pressure be limited?
3)   What kind of influence does the fluctuation in pressure during the retaining process have on the quality of the product?

The 3 points mentioned above were raised as major problems, and tests were conducted to come up with countermeasures.

As for 1), the steam that was being released in the first half of the holding process was sealed in, and by keeping the steam locked in even when the pressure went up, the drop in pressure during the latter half was limited.

The point raised in 2) was solved, as test results showed that the pressure hardly dropped below the reference pressure even during the latter half.

As for 3), quality control data was obtained, with the help of the Manufacturing Section and the Technical Section, and a total absence of any influence was verified.

Along with the above test, the amount of steam supplemented during the latter half of the holding process was measured (Figure 4.2.16).

At the same time, even though the steam that was released in the first half of the holding process was no longer available to raise the temperature of the boiler's water supply, this was solved by using the exhaust steam available during pressure reduction.

Figure 4.2.16 Measuring Data of Charged Steam Consumption
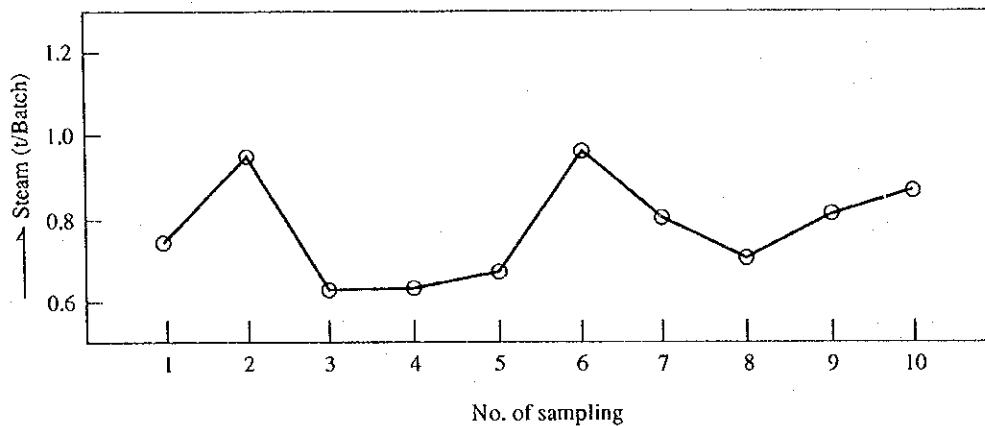
(4) Effects found after the countermeasures were implemented

As a result of various tests, it was judged that there is no undesirable effect, and the measures are fully effective, and thus they were applied to actual operations. There was almost no cost as it did not involve modifications to the facilities, and the amount of steam was reduced by an average of 900 kg per unit of autoclave as shown in Figure 4.2.17. A reduction of about 7.9 % in ratio, or 250 kL of kerosene annually, when converted to fuel, was achieved.

Figure 4.2.17   Comparison between before and after Improvement of Hardening Process in Autoclave

Before improvement

After improvement

Steam (t/Batch)

No. of sampling   No. of sampling
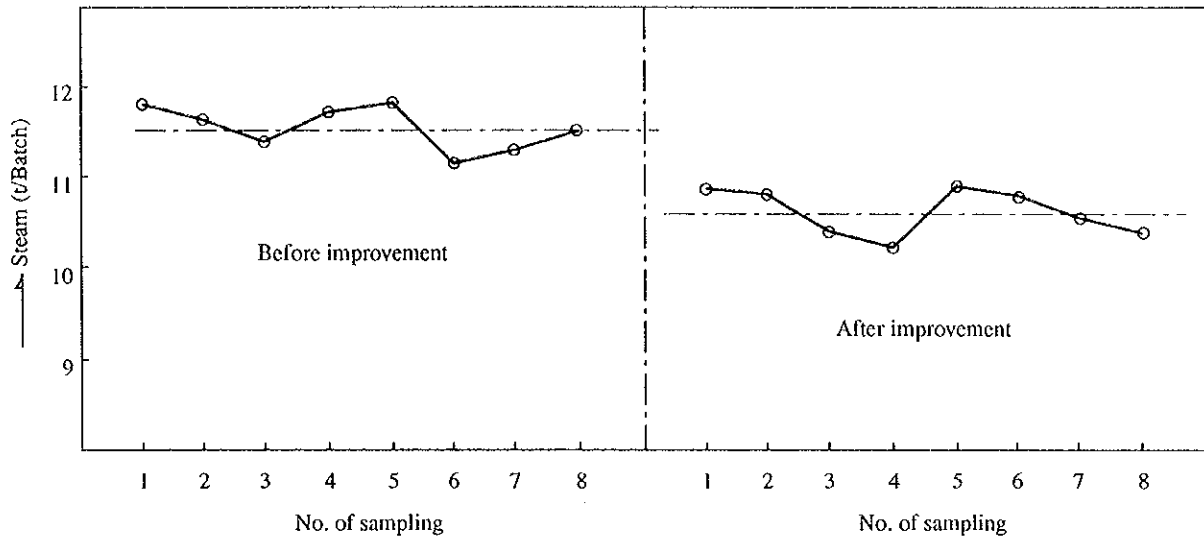
4.2.5   Example of Energy Conservation by Introducing an Exhaust Re-combusting Type Co-Generation System

(1)   Preface

a.   Items produced: Outer wall building material (cement, calcium silicate products)

b.   Production facility: New plant in that has an integrated line, concentrated in 2 factories in the plant, that performs the manufacture, fabrication, coating, packing, and shipping of raw cement plate.

c.   Facility's energy capacity: Steam 15 t/h, Electricity 4,300 kW

d.   Area: 480 m²

(2)   Forecast for Amounts of Electricity and Steam at New Plant

In response to the substantial increase in the plant's overall use of electricity and steam, an exhaust re-combusting type co-generation system was introduced.

Forecasts for the consumption pattern of electricity and steam are shown in Figure 4.2.18.

Figure 4.2.18 Prediction of Power and Steam Demand
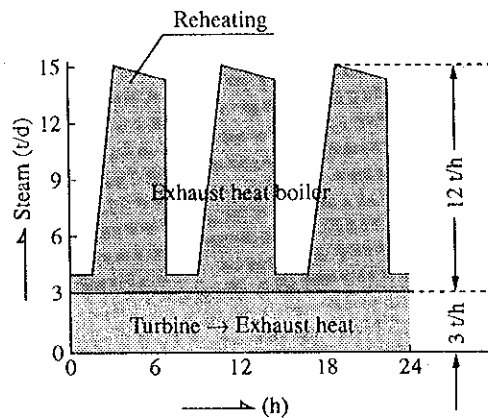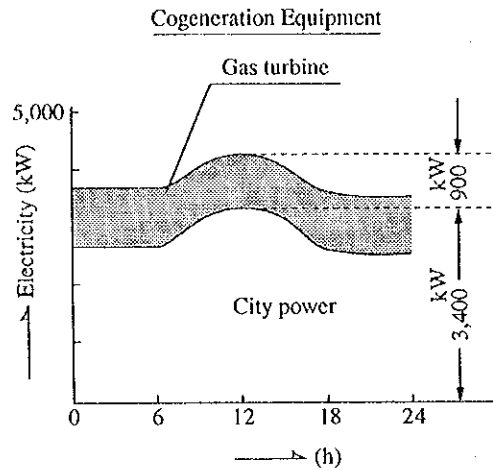
(3) Overview of the Co-Generation System

While co-generation systems using gas turbines can be divided into the 4 methods of simple cycle, combined cycle, exhaust re-combusting cycle, and chain cycle, depending on the form of exhaust heat use, the method adopted in this example is the exhaust re-combusting method. This method enables a large amount of steam to be recoverd from the exhaust heat boiler by after-burning the exhaust gas of gas turbines. Additionally, a substantial increase in the amount of steam that can be used by the co-generation system, and an improvement in overall efficiency, were achieved for the exhaust heat boiler, by adopting an exhaust re-combusting burner that is capable of both individual operation and after-burning operation.

The flow of the co-generation system is shown in Figure 4.2.19.

Specifications for principal equipment are shown in Table 4.2.2.

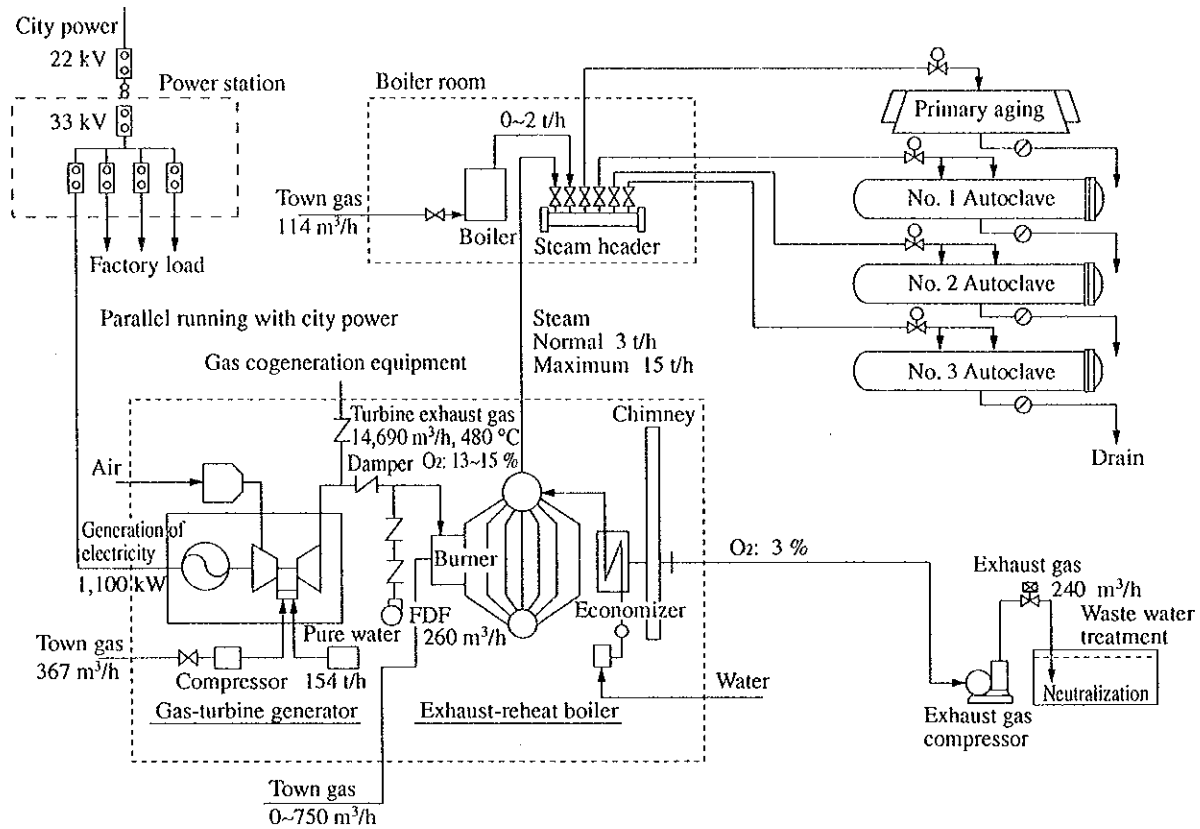## Figure 4.2.19 Gas Cogeneration System for Building Material Production

City power
22 kV

Power station

33 kV

Factory load

Parallel running with city power

Gas cogeneration equipment

Boiler room

Town gas
114 m³/h

0~2 t/h

Boiler

Steam header

Steam
Normal 3 t/h
Maximum 15 t/h

Primary aging

No. 1 Autoclave

No. 2 Autoclave

No. 3 Autoclave

Drain

Air

Generation of
electricity
1,100 kW

Town gas
367 m³/h

Turbine exhaust gas
14,690 m³/h, 480 °C
Damper O₂: 13~15 %

Burner

FDF
260 m³/h

Pure water

Compressor 154 t/h

Gas-turbine generator

Chimney

Economizer

Water

Exhaust-reheat boiler

O₂: 3 %

Exhaust gas
240 m³/h
Waste water
treatment

Neutralization

Exhaust gas
compressor

Town gas
0~750 m³/h

Table 4.2.2 Specification of Principal Machines

Name	Piece	Specification
Gas turbine	1	Simple open cycle 2-axis type
		Compressor section: Axial flow part: 3-stage, centrifugal part: 1-stage
		Combustor: Annular type
		Turbine main shaft: 22,850 r.p.m.
Generator	1	3-phase AC synchronous power generator
		Capacity: 1,389 kVA
		Rated power: 3,300 V, 1,100 kW, 1,800 r.p.m.
Gas compressor	1	Motor drive: Screw type
		Capacity: 400 m³$_N$/h, 75 kW
		Pressure: Suction: 1.3 kg/cm²·G, Delivery: 15.0 kg/cm²·G
Exhaust-reheat boiler	1	Natural-circulation water-tube type Exhaust-reheat boiler
		Capacity: 150 t/h, Pressure: 9 kg/cm²·G
		Temperature (saturated): 179 °C
		Exhaust gas flow volume: 14,690 m³$_N$/h

The following is an overview of this system.

a. The generator which is driven by gas turbine generates 3,300 V, 1,100 kW of power, and is constantly in parallel operation in conjunction with the commercial system (receiving).

b. The power generated is used as power for the plant, and is prevented from reverse flowing into the commercial system.

c. While the exhaust gas from the gas turbine is guided to the exhaust re-combusting boiler, and constantly generating 3 t/h or steam, by after-burning it, it is possible to generate 15 t/h of steam.
(It can accommodate sudden load fluctuations.)

d. Even when the gas turbine is stopped, 15 t/h of steam can be generated by the exhaust gas re-combusting boiler individually, using gas as fuel (switches to FDF forced draft fan).

e. The steam generated is used for the next hardening and autoclave hardening, via a steam header.

f. Water is sprayed onto the turbine combustor in order to reduce the NO_x content of the gas turbine exhaust gas.

g. Through a pipeline, the CO_2 that comes out of the chimney is guided to a waste water processing facility, and utilized for the removal of Ca (calcium) in the waste water of the manufacturing process.

(4) Total Energy Efficiency

The energy efficiency of this system is shown in Figure 4.2.20.

Figure 4.2.20 Energy Efficiency of This System
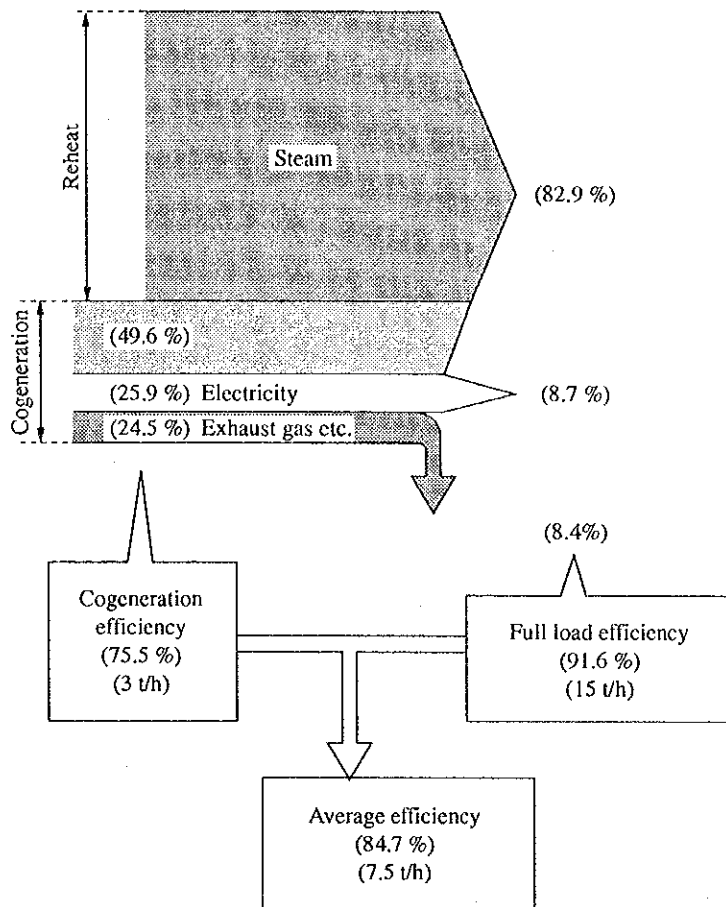
As evident from the figure above, an extremely high efficiency is obtained with even the average efficiency at 84.7 %. Devising a system that utilizes heat energy efficiently is an important aspect of improving the economy of gas co-generation systems, because their ratio of thermal energy is great compared to the amount of power generated.

While the amount of heat loss for this system is 24.5 % without after-burning, and 8.4 % when after-burning is in full load, efficiency can be raised even further if this heat is used for baths, hot water supplies, air conditioning and heating, and heating related to manufacturing processes, etc.

5. ENERGY CONSERVATION IN THE FOOD PROCESSING INDUSTRY

5. ENERGY CONSERVATION IN THE FOOD INDUSTRY

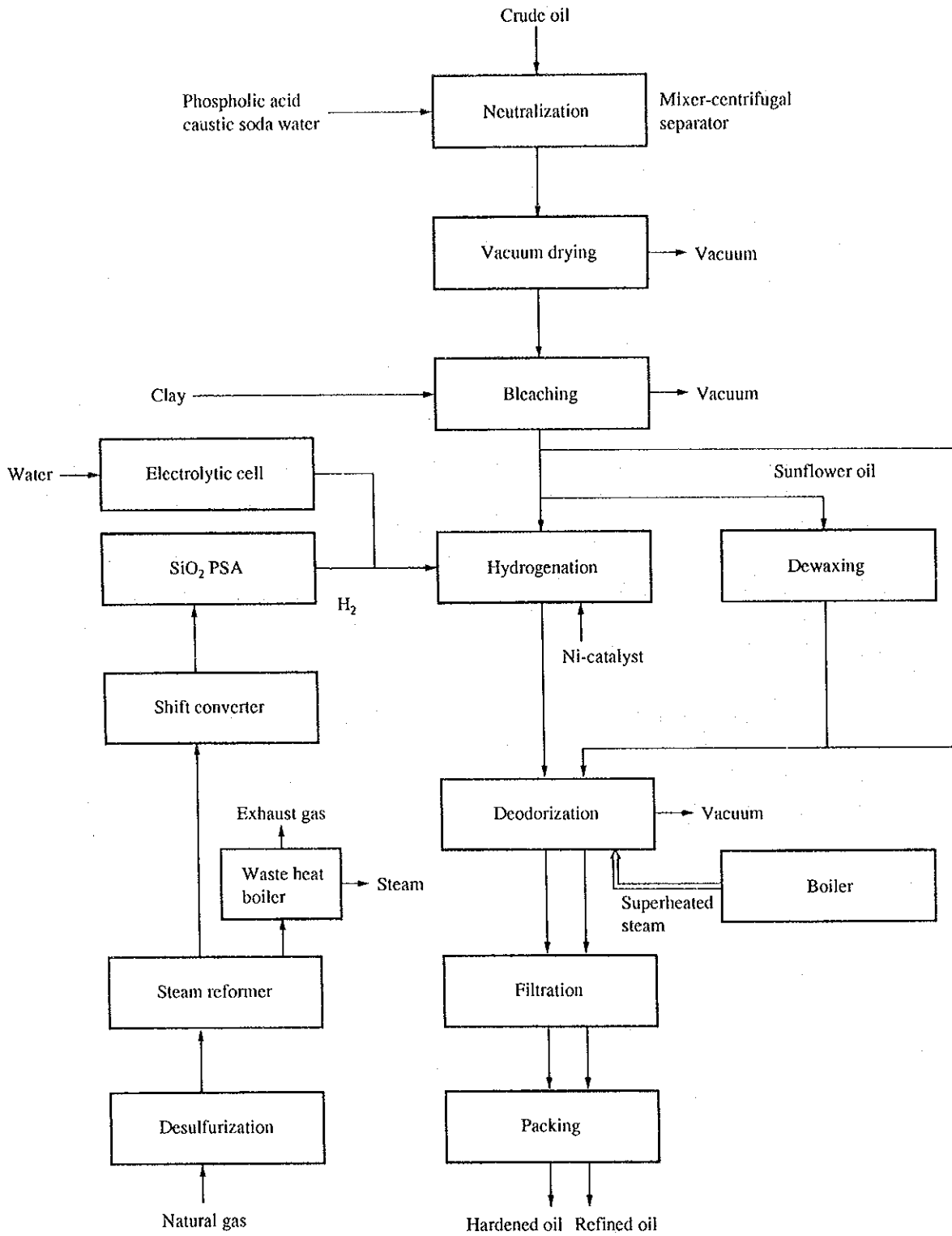## 5.1 Energy Conservation at the Vegetable Oil Industry

5.1.1 Production Process

Edible oils can be broadly classified into two types; vegetable oils and animal fats. The plant covered by our study project is a vegetable oil manufacturing plant. The seeds of soybean, rape, sunflower and palm are often used as materials of the edible oils throughout the world. The sunflower seeds contain 40 to 45 % oil; they contain much linoleic acid and oleic acid in particular. The sunflower is grown in the former Soviet Union, Australia, East Europe and the United States. Except that the vegetable oils are partly taken by the expression process, they are extracted from the seeds containing oil of 20 % or less directly by hexane (extraction method). When more oil is contained in the seeds, generally, the expression process is used first; then extraction method is used after oil has been reduced (prepress and solvent expression).

Oils taken by these methods contain a great deal of impurities, and cannot be used as edible oils as it is, and a variety of impurities such as free fatty acid, coloring matter, wax, odorant components must be removed in the refining process. Figure 5.1.1 shows the sunflower seed oil manufacturing process. Defatted meal is generated as by-products in the vegetable oil manufacturing plant, and the generated amount is generally greater than that of the oil. Defatted meal is often used as feeds containing much protein; therefore factories are required to produce high-quality defatted meal.

The production process differs slightly according to the quality of materials or oil and meal required, technical levels and method, but it roughly consists of the oil extraction process to extract oil from the material seeds and the refining process to make the extracted raw oil suitable for food.

Figure 5.1.1 Process Flow for Oil Refining

Crude oil

Phospholic acid
caustic soda water → **Neutralization** — Mixer-centrifugal separator

Vacuum drying → Vacuum

Clay → **Bleaching** → Vacuum

Water → **Electrolytic cell**

SiO₂ PSA

H₂

Sunflower oil

Hydrogenation

Dewaxing

Ni-catalyst

Shift converter

Exhaust gas

Waste heat boiler → Steam

Deodorization → Vacuum

Superheated steam

Boiler

Steam reformer

Filtration

Desulfurization

Packing

Natural gas

Hardened oil   Refined oil

(1) Oil extraction process

a. Pre-processing

The raw material, from which foreign matters have been removed, is heated. This heating process which consolidates protein of cellular walls is important to obtain the high-quality raw oil through improving operability and enhancing the oil extraction rate by making the extraction solvent flow smoother and making the raw material composition strong and hard enough not to be destroyed.

b. Expression (Squeezing)

Expression is a method that has been used long and applies a high pressure physically to raw materials such as rape seed, safflower, and sesame containing much oil. Generally, a continuous squeezing machine, called the expeller, is used to squeeze 1/3 to 1/4 of oil contained in the raw material.

c. Extraction

For a raw material such as soy bean containing relatively less oil, oil can not be obtained as desired by squeezing it alone. Therefore, the material is crushed flat to increase the surface area and oil is efficiently eluted with a solvent, hexane. In the extraction machine (using countercurrent extraction) that moves hexane against the transfer direction of the flat crushed material, the raw material is dipped into hexane and the residual oil is reduced to approximately 1 % or less within a few hours. For a large machine, its standard capability is 1,500 to 2,000 tons/day. The hexane solution that has extracted oil is called the micella, whose oil content is 25 to 30 %. The micella is first condensed in a distiller and then a stripper (blows in vapour under vacuum) almost completely removes hexane to produce the raw oil. Hexane is recovered and reused.

d. Expression/extraction method

After expression described above, the residual oil content is 10 to 20 %, which is recovered by extraction. These expression and extraction are called the expression/extraction method.

(2) Refining process

Since the raw oil contains phospholipid, free fatty acid, trace metal, and pigments as well as its unique odorant matter, it is not suitable for food. Refining removes these unnecessary matters while retaining useful contents such as tocopherol, etc. as much as possible.

a. Degumming

Among the matters contained in the raw oil, phospholipid is useful for several purposes and the residual phospholipid in the oil results in coloring or bubbling when oil is heated. Therefore, phospholipid should first be removed. Then, lecithin is recovered separately from this phospholipid.

The process that removes mainly this phospholipid is called degumming, which gives warm water or water vapour to the raw oil to hydrate phospholipid, and then separates the gum content from the oil with a centrifugal separator. The content of phospholipid (such as lecithin) in soy bean oil is 2 to 3 %, but after the degumming process, it will be approximately 0.5 % or less.

b. Neutralization (Alkali Refining)

The neutralization (alkali refining) process is intended mainly to eliminate free fatty acid (FFA) from the oil. The amount of FFA is represented as acid value (AV). The value provides a guideline to check the quality of the raw material seed or the adequacy of oil expression process. This process removes the oil soluble phospholipid, protein, coloring matter, and water content which could not be removed in the degumming process. FFA can be also removed by the deodorization process. The amount of FFA can be expressed in the following equation:

FFA (%) = AV/2

The representative process is the neutralization process where alkali aqueous solution is mixed with oil sufficiently to be made into contact with each other and FFA is separated from the oil in the form of alkali foots. Alkali refining generally uses caustic soda aqueous solution of 10 to 24 °Be (6.55 to 17.7 %).

The following shows an example of the batch type neutralization process for cotton seed meal: Degummed oil is heated to 50 °C, and caustic soda aqueous solution of 18 °Be (12%) is added 100 % of the neutralization equivalent in excess. Then it is stirred for 20 to 30 minutes. Stop stirring when flaking has occurred, and add 10 % water preheated to 50 °C against the oil amount. Settle it for about one hour. After removing the alkali foots from the lower layer, add 10 % alkali aqueous solution of 0.4 % concentration to oil; then wash it at 100 °C. After removing the lower layer, wash it again with alkali water of 95 °C, and wash it finally with 8 to 10 % boiling water against the oil amount two or three times. The entire process requires 10 to 12 hours.

According to the batch type neutralization, the contact time for alkali aqueous solution and oil is 10 to 60 minutes, and 1 to 10 hours are required for separation of alkali foots. Furthermore, sedimentated alkali foots contain much neutral oil, indicating a great loss of oil. The continuous alkali refining process provides a method of preventing the loss of neutral oil by reduction of treatment time and separation of the alkali foots by centrifugal separator.

The following describes an example of short mix process of Alfa-Laval Inc. as a representative case of the continuous neutralization process. Caustic soda aqueous solution is used as alkali aqueous solution. Figure 5.1.2 illustrates the flow sheet of the Continuous Neutralization Process.

Figure 5.1.2 Continuous Neutralization Process
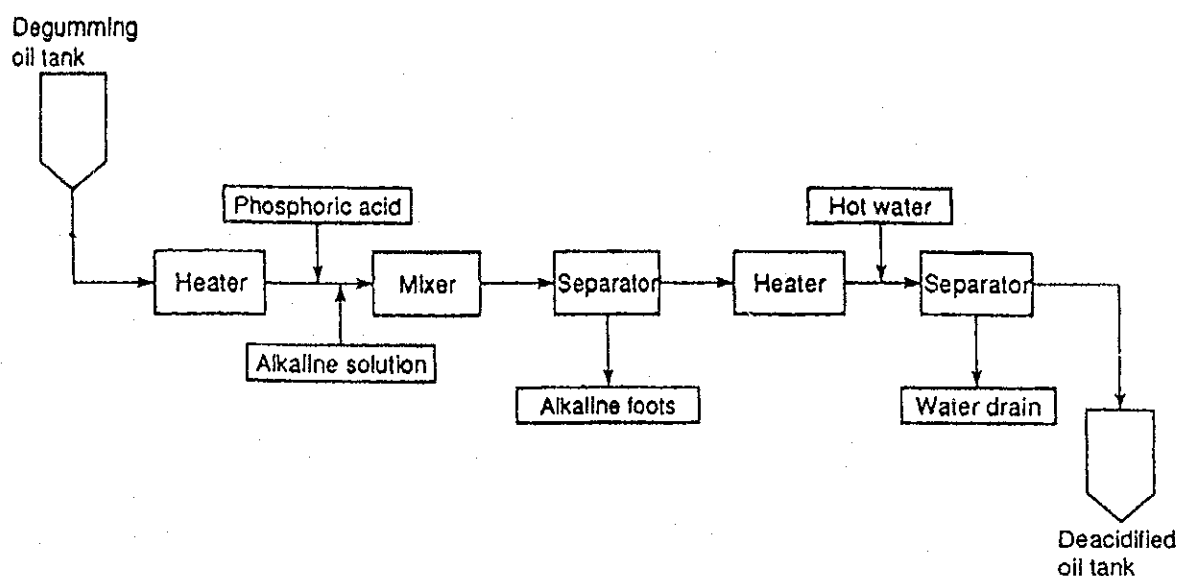
The amount of alkali aqueous solution to be used in this process can be expressed in the following equation:

Amount of alkali aqueous solution to be used (%) =

$$\frac{FFA\ (\%) \times Factor \times Excess}{Concentration\ of\ alkali\ aqueous\ solution\ (\%)} \times 100$$

The factor can be calculated in the following equation:

Factor = Caustic soda molecular weight/oleic acid molecular weight
= 40/282
= 0.142

Excess is normally 0.1 to 0.13 % in the case of soybeans. Add about 0.1 % phosphate to the degummed oil pre-heated to 75 to 82 °C, and add a specified volume of alkali aqueous solution to the mixture oil; then make them contact with each other after mixing carefully with the line mixer or paddle mixer. During the short-term contact (2 to 3 hours), hydration of oil soluble phospholipid, neutralization of FFA and reaction with coloring component take place. Alkali foots generated by using the enclosed type rotary disk centrifugal separator (6,000 rpm) is separated from the neutral oil. The back pressure at the outlet of the oil from the centrifugal separator is adjusted to shift the separation zone for heavy liquid and light liquid inside the centrifugal separator. Increase of the back pressure that means the reduction of pressure difference will reduce the amount of soap remaining in oil, and will increase the amount of the neutral oil enclosed in the alkali foots, resulting in greater alkali refining loss. On the contrary, reduction of the back pressure will reduce the alkali refining loss, but will increase the amount of soap content in oil. Normally, adjustment is made so that the soap content in the neutralized oil will be below 300 ppm. Of the refining loss (total 1 to 2 %), the neutralization loss accounts for the greatest percentage, 65 %. Neutralized oil is fed to the washing process. After the oil is heated up to about 90 °C by the heat exchanger, it is mixed with 10 to 20 % hot water of 95 °C and is made to contact; then it is separated by the centrifugal separator. Figure 9.1.3 illustrates the centrifugal separator. About 90 % of soap remaining in the neutralized oil shifts to the washing water side.

Theoretical loss in the alkali refining process is called "Wesson loss", and can be calculated in the following equation:

Wesson loss (%) = AV/2 + phospholipid (%) + water content (%)

If FFA, phospholipid and water content can be removed completely in the alkali refining process, the alkali refining loss will become equal to Wesson loss.

c. Decolorization

Decolorization under the normal pressure accelerates oil oxidation and deteriorates the decolorization effect of the activated clay; therefore decolorization is performed under the reduced pressure in recent years. To minimize contact with air and to ensure effective operation, continuous vacuum decolorization process is often adopted.

The following describes an example of the continuous vacuum decolorization process, and Figure 5.1.3 illustrates the flowchart.

Figure 5.1.3 Continuous Vacuum Decolorization Process
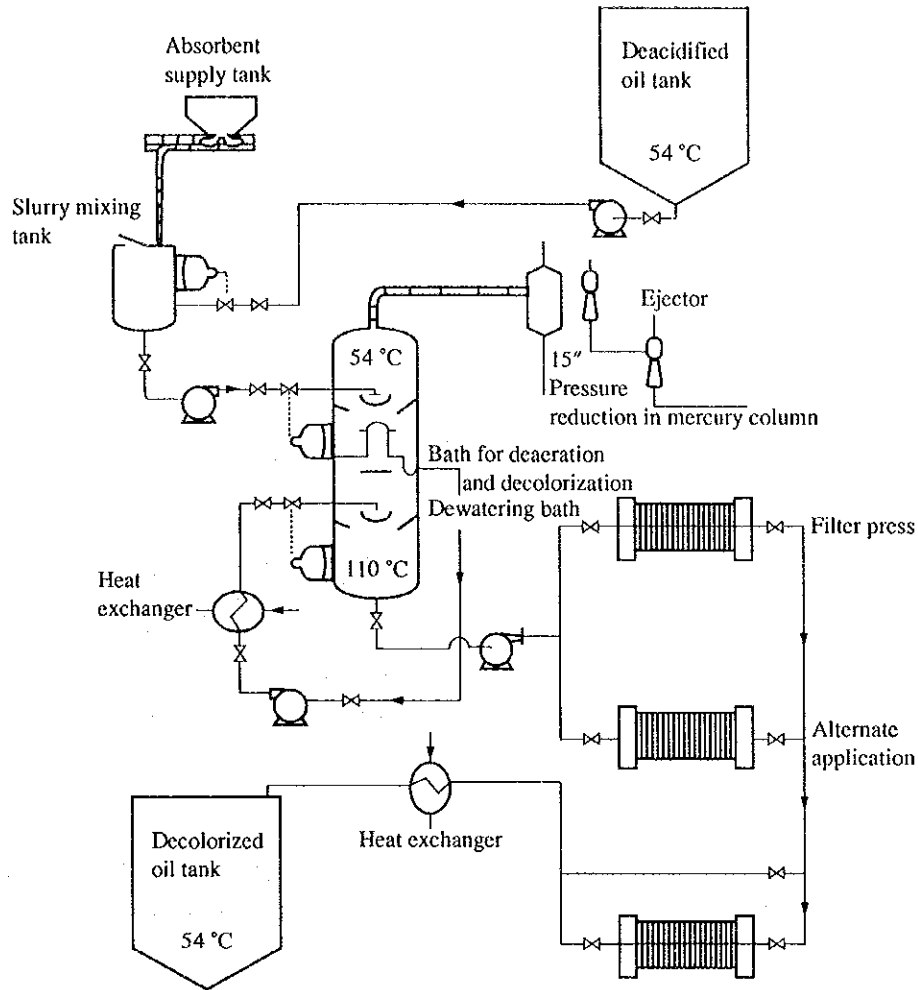
0.3 to 2.0 % activated clay is added to neutralized oil which has been pre-heated to 54 °C, to be made into slurry. It is then led to the deaeration tank on the upper stage of the decolorization tower whose pressure is reduced to 380 Torr, and is dehydrated and deaerated. Then it is heated by the heat exchanger and is maintained at 110 °C under the reduced pressure for seven minutes. After that, it is separated from the clay. The horizontal or vertical pressure type leaf filter accommodated in the enclosed vessel is generally used as the filter, in addition to the filter press.

The waste clay separated from the oil and fat is discarded or is washed by elution by such solvent as hexane, in order to recover the oil adsorbed by the waste clay.

About 10 to 100 ppm of soap content is normally in the oil after neutralization, and promotes deterioration of oil during heating. Chlorophyll and pheophytin much contained in rape seeds and immature seeds promote oxidation of oil, and their elimination will contribute to stabilization of the oil quality. Tocopherol, carotene and phospholipid working as natural antioxidant, however, are also removed by adsorption.

Clay is a mineral mainly comprising montomorillonite ($Al_4Si_8O_2O(OH)_4 \cdot nH_2O$) which is formed of volcanic ashes exposed to efflorescence for a long time and is produced by thermochemical reaction through geothermal energy. Adsorption is increased as more aluminum ion is replaced by hydrogen. Adsorption will be deteriorated when water content is excessive or insufficient; water content of 8 to 16% is said to be appropriate.

The amount of the activated clay to be used should be 0.3 to 2.0 %. A greater amount of clay is required as more coloring matter and products decomposed by oxidation are contained.

d. Dewaxing

This process is generally performed after decoloring and before deodorizing. If oil contains solid-state grease when mayonnaise is made and stored by freezing, mayonnaise emulsion is broken (i.e. freeze breaking). Therefore, the original purpose of this process was to eliminate the low-temperature hardened grease. This process is also performed to prevent oil from becoming cloudy with wax at a low temperature.

In any case, oil is gradually cooled down and the contents that harden at a low temperature are fully precipitated and then removed by filtering.

e. Hydrogenation (hardening)

To manufacture solid-state grease such as margarine and shortening, solid-state grease should be used or liquid-state oil should be consolidated. This method is used to consolidate oil.

Since fatty acid composing liquid-state oil such as vegetable oil or fish oil is non-saturated (i.e. partially lacks hydrogen), inserting hydrogen into this part through chemical reaction is referred to as hydrogenation. As a catalyst, Ni is mainly used and reaction is promoted by adding hydrogen, applying a pressure and a temperature, and stirring. Controlling the degree of reaction properly allows you to obtain the hydrogenated oil with the desired hardness. Since the oil becomes hardened and at the same time comes closer to saturation, it becomes more resistant to oxidization, which might be one of the purposes.

f. Deodorization

After decolorization and hydrogenation, oil still contains various odorant components and other volatile matters. Therefore, the decolored oil is maintained at a temperature of 240 °C or higher and steam is blown into it under vacuum to evaporate odorant content along with water vapour. This process is referred to as deodorization.

To increase oil stability against oxidization, tocopherol as a natural anti-oxidization contained in oil is left as much as possible and a small amount of citric acid that works with tocopherol is added for finishing. In addition, silicon resin is normally added to give stability against heating and the debubbling property.

To heat to a high temperature of 240 °C or higher, a heat medium (particularly Dowtherm) was previously used. However, even a very small amount of the heat medium contained in the product affects health of human body seriously; therefore superheated steam is used presently.

The steam jetting device such as ejector and booster is used for vacuum generation. A high degree of vacuum below 6 Torr is normally used.

Deodorization uses the principle of steam distillation method where steam is blown into the oil heated to a high temperature under a high degree of vacuum to distill the volatile matters. The lower the absolute pressure of the system, the lower will be the heating temperature, though the situation may depend on the amount of the steam to be blown inside. Table 5.1.1 shows the vapor pressure of the palmitin acid and oleic acid which are representative free fat acids contained in the oil.

Figure 5.1.4 and Figure 5.1.5 show vapor pressure for esters and that for hydrocarbon, chlorinated hydrocarbon and organic silicon compounds respectively.

Table 5.1.1 Vapor Pressure of Fatty Acid

mmHg	Palmitin acid (°C)	Oleic acid (°C)
1	153.6	176.5
5	188.1	208.5
10	205.8	223.0
20	223.8	240.0
40	244.4	257.2

Figure 5.1.4 Vapor Pressure Curve of Organic Compounds (Esters)
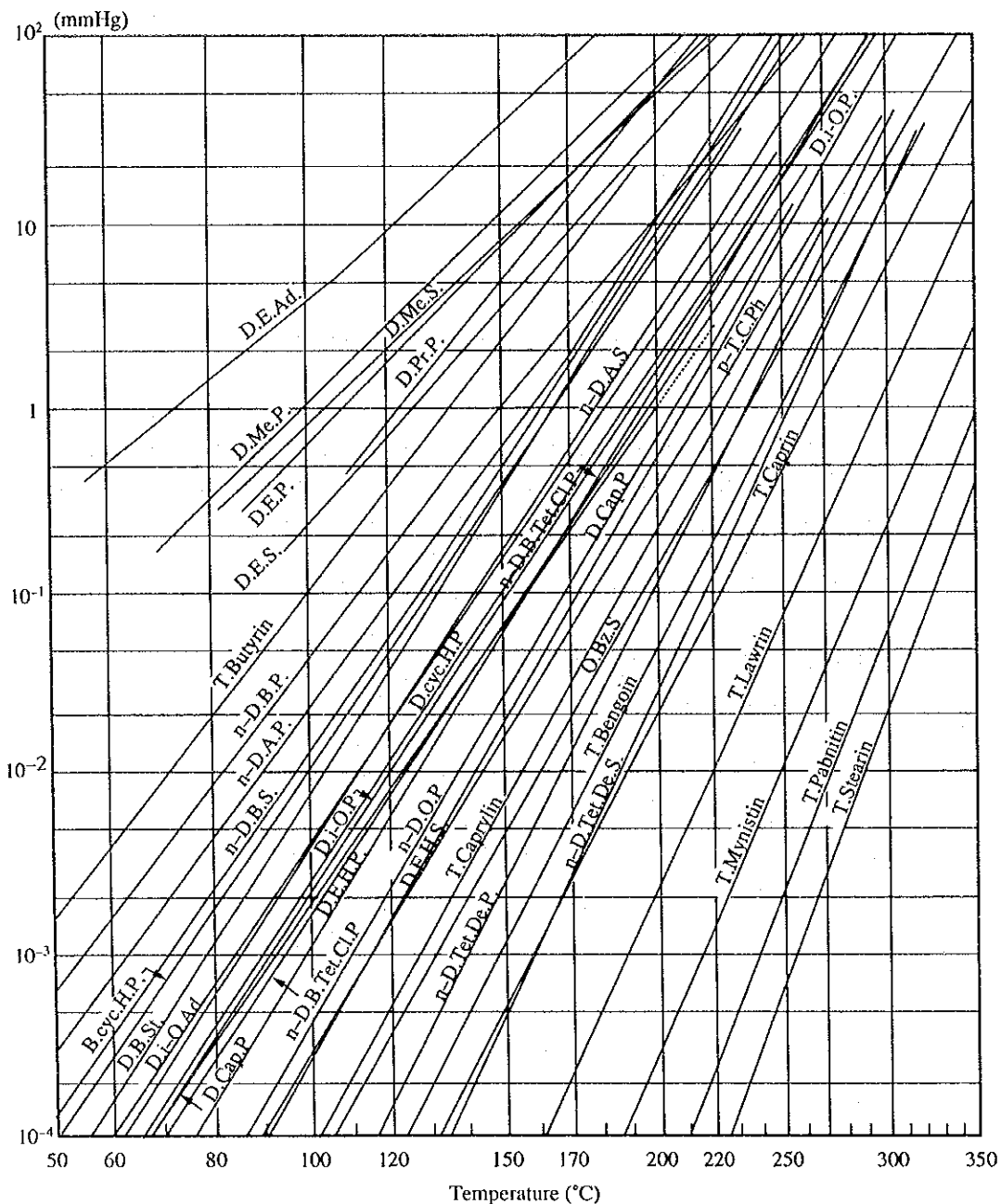
Symbols:

A.	Amyl	D.	Di	P.	Phthalate
Ad.	Adipate	E.	Ethyl	Ph.	Phosphate
B.	Butyl	H.	Hexyl	S.	Sebacate
Bg.	Benzyl	i–	iso-	St.	Stearate
C.	Cresyl	Me.	Methyl	T.	Tri
Cap.	Capryl	n–	normal	Tet.	Tetra
cyc.	cyclo	O.	Octyl		

Figure 5.1.5 Vapor Pressure Curve of Organic Compounds
(Hydrocarbon, chlorinated hydrocarbon and organic silicon compounds)
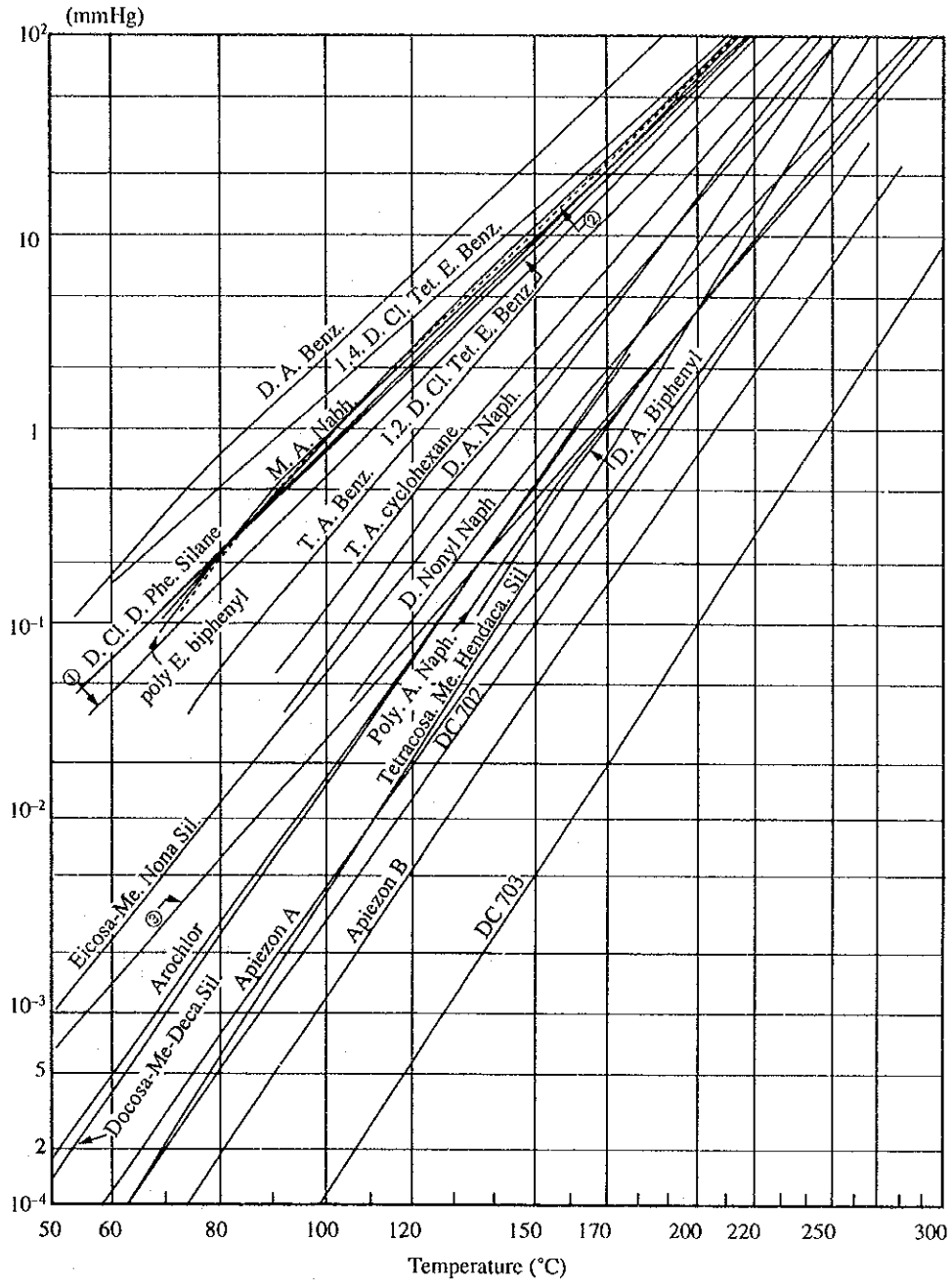
A.	Amyl	E.	Ethyl
Benz.	Benzene	Naph.	Naphthalene
Cl.	Chloro	Sil.	Siloxane
D.	Di	T	Tri
M.	Mono	Phe	Phenyl

② Chlor. Me. D. phe. Silane   Broken line: Dodecyl Benz.

③ D. Phe. Silicon D. isothio cyanate

The blown-in steam serves to stir the oil during deodorization to facilitate evaporation of volatile matters. The amount of the steam to be used is 1 to 4 % in the case of the continuous and semi-continuous processes, and is 20 to 30 % in the case of the batch process.

Deodorization temperature is usually 230 to 250 °C and the degree of vacuum is 3 to 6 Torr for the continuous and semi-continuous processes. In the batch process, both the temperature and degree of vacuum are higher (lower absolute pressure) than those in the case of the continuous and semi-continuous processes, though they may depend on the type of the oil.

Figure 5.1.6 illustrates the flowchart of the continuous process according to the Gardner method.

Figure 5.1.6 Continuous Deodorization Process

Refined oil   Edible oil
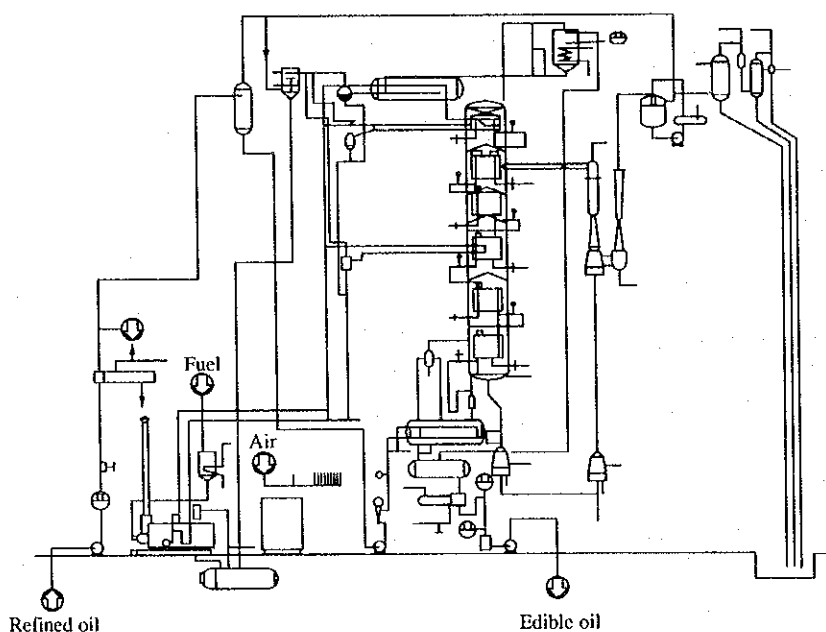
In the process of Gardner method, 5 to 6 trays are suspended in one vertical cylindrical vacuum tower (shell). Inside the shell, almost constant vacuum is maintained by the operating of the ejector and booster, and the dewaxed oil is fed inside, passing from the first tray to the next one downward sequentially. In the 5-stage tray structure, each tray is assigned with different functions; deaeration for the first tray, heating for the second tray, deodorization for the third and fourth trays and cooling for the fifth tray.

In the case of the continuous process, oil is fed continuously to the first tray and is fed to the next lower tray after it has overfilled the first one; therefore the inter-stage valve is not provided. Energy intensity differs according to the water content of the material, ambient temperature, required product quality as well as according to the process.

The following shows the energy intensity of continuous and semicontinuous deodorizers in Japan:

Energy intensity in Japanese deodorization process

Steam   : 80 to 120 kg/t (product oil, in tons)
Electricity: 30 to 50 kWh/t (product oil, in tons)

5.1.2   Rationalization in Energy Use

Before taking rationalization measures for energy use, it is necessary to check the amount of energy currently used. In the case of steam, it is possible to get steam consumption by the orifice, vortex flowmeter, etc. for direct steam, and by measuring the amount of drain generated for indirect steam. It is possible to get it by calculating the heat balance.

After that, in the case of direct steam, try to reduce the amount of steam to be used, with consideration given to the position of steam blowing, nozzle shape, steam pressure, material contact time and use of exhaust gas. In the case of indirect steam, study the steam pressure, reuse of the condensate and replacement of steam by alternative heat sources and such related matters. In the continuous process, the temperature is raised or lowered in order to ensure treatment under the optimum conditions; therefore it is needed to study the possibility of mutual heat exchange.

(1)   Heat recovery in the deodorizer

The amount of heat recovered by the deodorizer is the largest in the refining process. However, attention much be directed to quality, safety, operation, and maintenance because this heat recovery system deals with the final product.

Heat recovery by the deodorizer means basically heat exchange between the feed oil at the inlet and the high-temperature product oil at the outlet. However, how waste heat (if present) should be utilized must be considered. Therefore, heat recovery in the deodorizer should be considered as a part of the entire factory's heat recovery system as with other heat recoveries.

For the heat recovery method, the method employed by each manufacturer or working examples announced are described. These methods can be used in a combination.

Generally, heat recovery methods are divided into 1. Oil-to-oil direct heat exchange and 2. Indirect heat exchange using an intermediate medium.

The simplified flow, method, and the recovered heat amount of these heat exchanges are described below.

a.   Oil-to-oil direct heat exchange

1)   Heat recovery using the coil in the tray (Figure 5.1.7)

Figure 5.1.7 Heat Recovery by Coil in the Tray
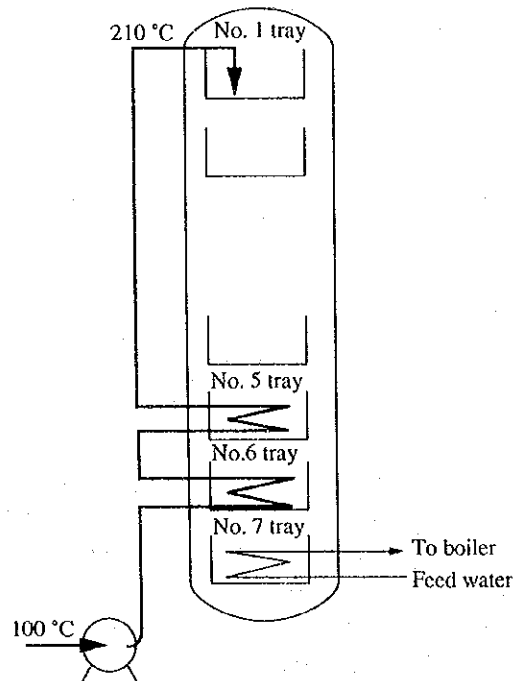
Two oil-to-oil heat exchange trays are installed in the deodorizing tower for heat recovery. For the cooling tray, heat recovery is performed by using water supplied to the boiler as the cooling water.

The feed oil at 100 °C flows through the coil in the No. 6 tray, so oil heat in the No. 6 tray is transferred to the feed oil, which is preheated to 140 °C. This preheated oil flows through the coil in the No. 5 tray and heated in the same way. As a result, the feed oil is heated up to 210 °C and fed to the No. 1 tray.

On the other hand, the deodorized oil is pre-cooled by the No. 5 and 6 trays and comes down to the No. 7 cooling tray.

The No. 7 cooling tray uses the water supplied to the boiler for cooling and then the heated water is used.

What must be taken into account with this heat recovery system is that the cleansing method should be examined carefully because the coil inner surface may generate dirt on a long-term basis.

Also, it is necessary to degas the feed oil before it comes to the heat exchange trays.

Exchanged heat amount:

Feed oil : 100 °C → 210 °C — 272,000 kJ/t-oil
Hot water: 30 °C → 60 °C   — 151,000 kJ/t-oil

Steam saved:

Feed oil heating : (medium-pressure steam 10 kg/cm² (G))— 66 kg/t-oil
                 : (high-pressure steam 66 kg/cm² (G))   — 87 kg/t-oil
Feedwater heating: — 73 kg/t-oil

2)   Heat recovery by external heat exchangers (Figure 5.1.8)

Figure 5.1.8 Heat Recovery by External Heat Exchangers (1)
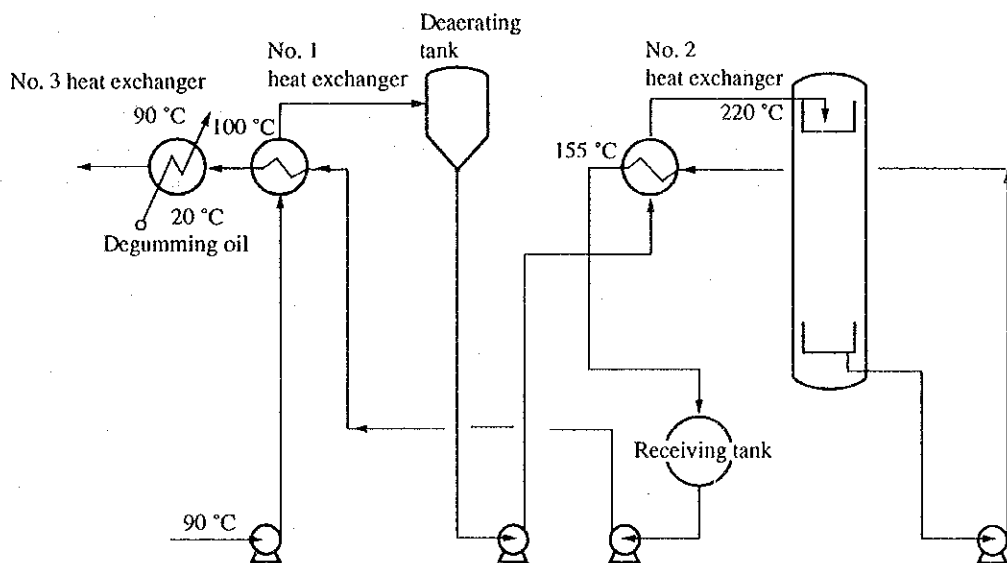
This system performs heat recovery by using three heat exchangers.

The feed oil at 90 °C enters the No. 1 heat exchanger, where heat exchange with the product oil is performed. The feed oil is heated up to 130 °C and then goes in the degassing tank.

This degassed oil goes in the No. 2 heat exchanger, where heat exchange with the product oil is performed again. Then, the feed oil is heated up to 220 °C.

On the other hand, the deodorized high-temperature oil enters the No. 2 heat exchanger while being extracted continuously from the bottom tray. Then the oil is cooled down to approximately 155 °C, entering the receiving tank.

Then, the oil, which goes in the No. 1 heat exchanger, is cooled down to 110 °C, enters the No. 3 heat exchanger, and then cooled down to 30 to 50 °C which is the desired final product temperature.

What must be taken into account with this heat recovery system is the quality aspect and how to remove dirt from the heat transfer surface on the heat exchanger.

Calories exchanged:

    Feed oil   : 90 °C → 220 °C — 301,000 kJ/t-oil
    Degummed oil: 20 °C → 90 °C — 138,000 kJ/t-oil

Steam saved:

    Feed oil heating: (medium-pressure steam 10 kg/cm² (G))— 75 kg/t-oil
                    : (high-pressure steam 60 kg/cm² (G))   — 95 kg/t-oil
    Degummed oil heating:
                    (medium-pressure steam 10 kg/cm² (G))— 69 kg/t-oil

The method described below is considered as a variant of the system described above. (See Figure 5.1.9.) This method performs extraction from the deodorizing tower with the No. 6 tray, and then returns the oil from the No. 2 heat exchanger to the tray in the deodorizing tower.

What must be taken into account and the heat recovery volume are same as those of the method described above.

Figure 5.1.9 Heat Recovery by External Heat Exchangers (2)

Deaerating tank

No. 1
heat exchanger

No. 3 heat exchanger

Receiving
tank

Degumming oil

No .6

No. 7

No. 2
heat exchanger
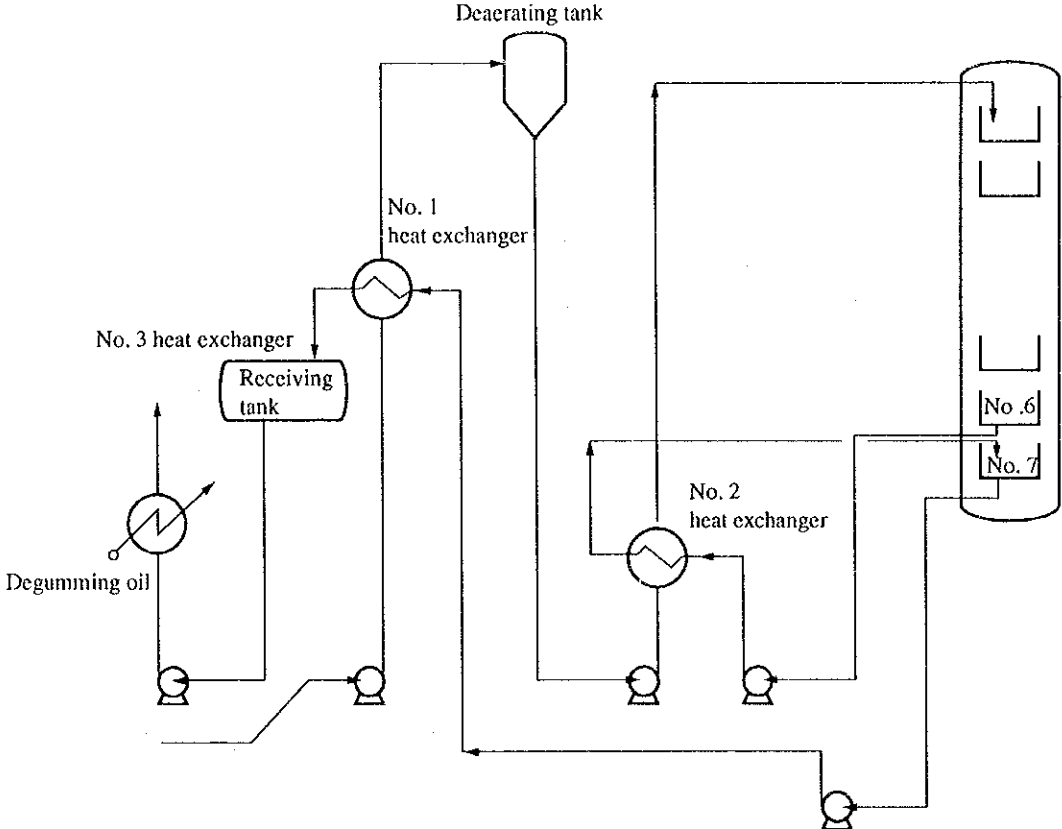
3) Heat recovery by Desmet method (Figure 5.1.10)

Figure 5.1.10 Heat Recovery by Desmet Method (Continuous Type)
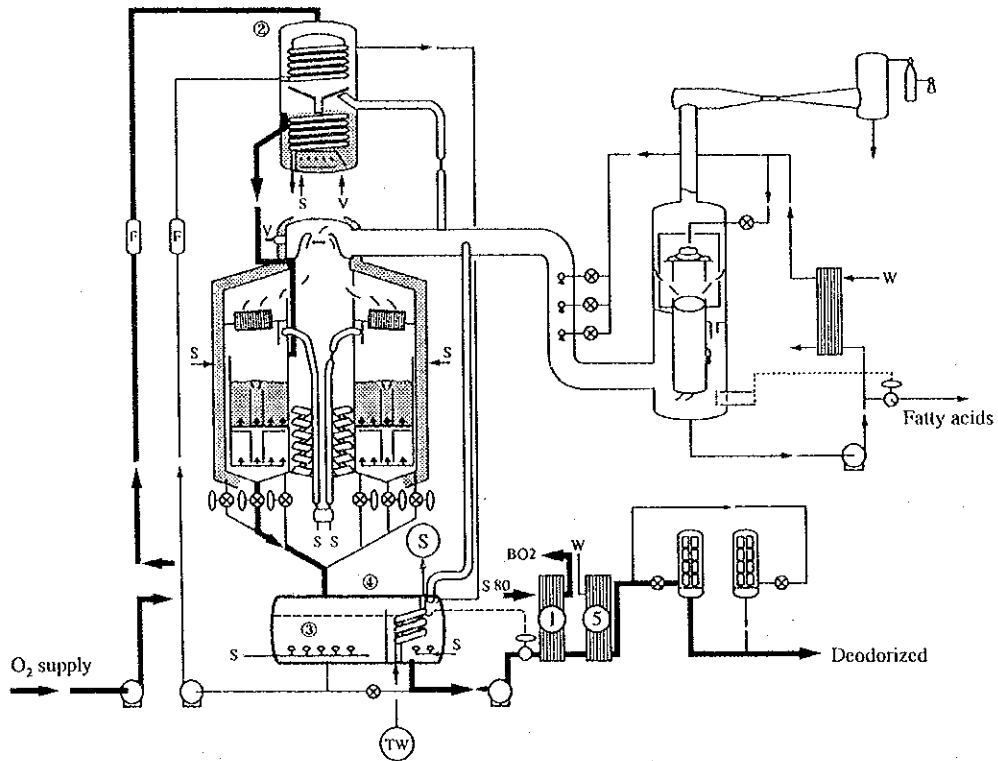
This system performs heat recovery by using two heat exchangers, one of which is also used as a degassing tank.

The feed oil at 50 °C goes in the heat exchanger ①, where heat-exchange with the deodorized product oil is performed. Then, the feed oil is preheated and enters the degassing tank ②. In this degassing tank, the oil in a film state drops onto the heat exchange oil. During this period, heat exchange and degassing are performed and the oil is heated up to 210 °C.

On the other hand, the product deodorized in ③ drops to the left of the receiving tank ④. This oil flows through the coil in the degassing tank, is heat-exchanged with the feed oil, cooled, and then fed to the right of the receiving tank ④. This tank contains the coil used to cool down the oil.

Water contained in this coil is heat-exchanged with the oil and evaporated. This results in generating steam of 1.5 kg/cm² (G), which can be used as the steam to be blown into the deodorizing tower. To supply this water, the steam drain in the process is used.

As described above, the pre-cooled product oil is heat-exchanged with the feed oil and cooled in the heat exchanger ① to obtain the desired temperature in the final cooler.

The degassing/heating tank ② and the receiving tank ④ blow in live steam under the same vacuum as in the deodorizing tower.

Energy conservation effects achieved by this system are as follows:

	Heat recovery facility	
	Provided	Not provided
Calories required for heating	150,000 kJ/t-oil	500,000 kJ/t-oil
	(Steam 52.6 kg/t-oil)	(Steam 175.3 kg/t-oil)
Live steam	–	17 kg/t-oil

Deodorizing temperature: 255 °C
Amount of energy saved: Steam 139.7 kg/t-oil

4) Heat recovery by the heat exchanging tank (Figure 5.1.11)

Figure 5.1.11 Heat Recovery by Heat Exchanging Tank
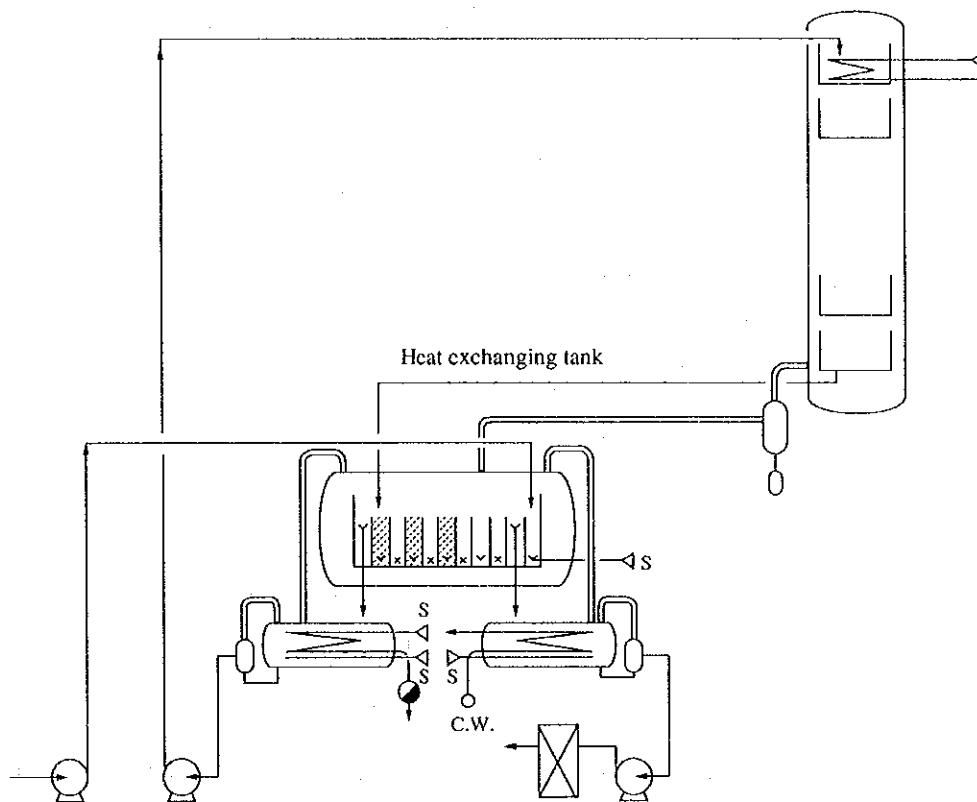
This system is so configured as to make the deodorized oil and feed oil flow as the counter current to each other via the heat exchanging wall and blow steam to each other. It is of such shape that the heat exchanging tray is contained in the shell.

The feed oil at 70 °C is heated up to 225 °C by heat exchange and the product oil at 250 °C is cooled down to 100 °C.

One of the advantages of this system is that calories exchanged are large. Care should be taken so that the feed oil and product will never be mixed in the heat exchange tank.

Calories exchanged:

Feed oil: 70 °C → 225 °C — 360,000 kJ/t-oil

Steam saved:

Feed oil heating: (medium-pressure steam 10 kg/cm² (G))— 87 kg/t-oil
Feed oil heating: (high-pressure steam 60 kg/cm² (G))   — 116 kg/t-oil

b.   Indirect heat exchange

1)   Heat recovery by hot water circulation (Figure 5.1.12)

Figure 5.1.12 Heat Recovery by Hot Water Circulation
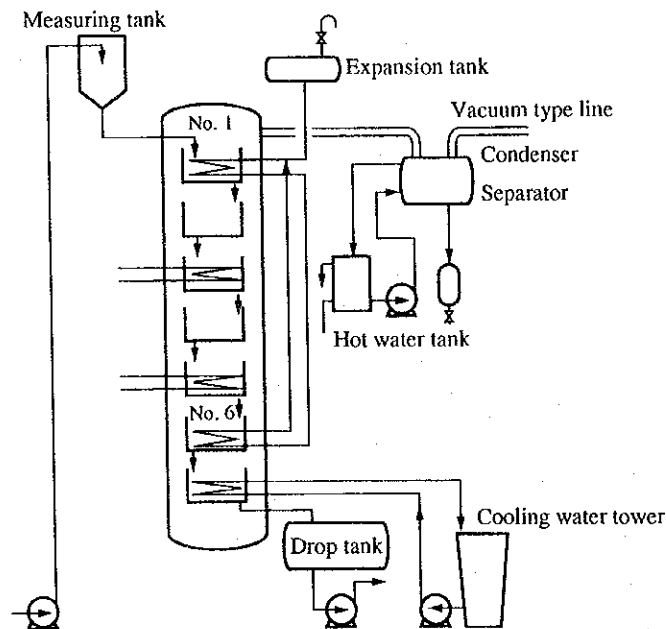
Coils of the No. 1 tray and No. 6 tray are connected via piping and closed.

Since hot oil (normally at 250 °C) that completed deodorizing at the trays up to No. 5 tray drops onto the No. 6 tray, the heat is transferred to water in the coil. When hot water flows through the coil in the No. 1 tray, heat is transferred from the hot water to the cold oil (at approximately 90 °C) dropping from the measuring tank. Oil in the No. 1 tray is thus preheated.

Water cooled down as a result of giving heat to oil returns to the No. 6 tray, receives heat from the hot oil, and then returns it to the No. 1 tray to preheat oil.

As described above, hot water in the coil is naturally circulated between the No. 1 tray and No. 6 tray. Therefore, the preheating steam is not required.

Since this method uses water as a medium and the operating method is unchanged, it does not affect the quality.

Calories exchanged:

Feed oil: 90 °C → 170 °C — 176,000 kJ/t-oil

Steam saved:

(Medium-pressure steam 10 kg/cm² (G)) — 85 kg/t-oil

2) Heat recovery by steam/hot water circulation

This concept is same as that of hot water circulation in 1) described above. Steam is generated in the coils of the No. 6 and No. 7 trays. Heat of this steam is transferred in the coils of the No. 1 and No. 2 trays. After condensation, drain water flows into the coils of the No. 6 and No. 7 trays.

In these processes, oil in the No. 1 and No. 2 trays is heated, while oil in the No. 6 and No. 7 trays is cooled.

This system eliminates the expansion tank only in the flow sheet shown above and there is no other change. The feed oil at 70 °C is preheated up to approximately 200 °C.

Figure 5.1.13 shows the heat recovery equipment.

Figure 5.1.13 Heat Recovery Equipment
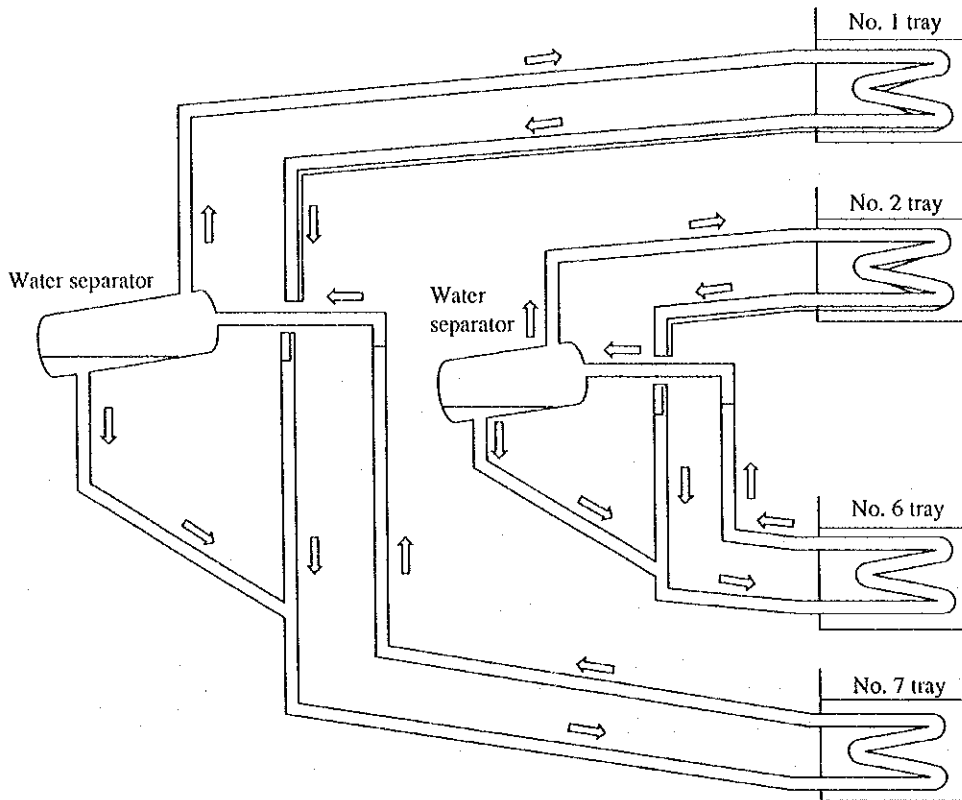
Amount of heat exchanged: 70 °C → 200 °C 245 MJ/t-oil
Amount of steam saved   : (Medium-pressure steam 10 kg/cm² (G)) 86 kg/t-oil

(2)   Vacuum retaining measure

What occupies the largest percentage in steam intensity in the refining process is the steam used for the vacuum generating equipment in the deodorizing tower.

To maintain the proper quality, it is necessary to set and keep a proper vacuum degree in the deodorizing tower. Doing this greatly contributes to energy conservation.

For operation of the vacuum equipment, care must be taken to the following:

•   Air leakage around the deodorizing tower should be reduced.

Vacuum degree reduction and time should be measured each time operation is stopped. Leak and the leak amount should be checked. If any leak is found, repair should be made immediately.

•   Load applied to the booster should be reduced.

Heating and degassing should be performed before feeding to the deodorizing tower.

This load is applied not to the booster but to the barometric condenser onward.

The suitable steam volume should be obtained.

- Load to the booster should be continuous.

Feeding to the deodorizing tower should be continuous.

- The driving steam pressure should be kept constant.

Fluctuation in the steam pressure greatly affects the performance of the booster that runs in the low vacuum area, thus making the vacuum degree unstable.

- The cooling water volume and temperature for the barometric condenser should be kept constant.

To reduce the driving steam volume while attaining a stable vacuum degree, the water temperature in the barometric condenser should be as low as possible. The steam volume can further be reduced by selecting nozzles for the summer and winter seasons.

Table 5.1.2 shows the relationship between the ejector steam volume and water temperature.

Table 5.1.2 Relationship between Barometric Condenser Cooling Water Temperature and Ejector Steam Amount

Temperature	°C	10	15	20	25	30	34
Steam amount for drive	kg/h	200	250	330	425	585	720

a. Optimization of driving steam pressure

The big difference between the boosters manufactured before energy conservation was introduced and the present energy conservation type boosters is the allowance considered when manufacturers design boosters even though the specification (i.e. extraction amount) is identical.

As shown in Table 5.1.3, the traditional design values have a large allowance for the suction and delivery sides, and overlapping between the No. 1 and No. 2 boosters is large.

Table 5.1.3 Difference in Booster Setting Values

	Calculated Value		Conventional Value Used		Energy Conservation Type Value to be Used	
	Suction Pressure	Discharge Pressure	Suction Pressure	Discharge Pressure	Suction Pressure	Discharge Pressure
Booster No. 1	3	12.2	2.8	15	3	13
Booster No. 2	12.2	49.7	11	60	12	55

(The above values are assumed ones, not actual ones)

To retain 3 Torr with this booster, there is no problem even though the designed driving pressure is slightly reduced because the steam extraction specification has an allowance against the actual volume and overlapping is large.

To control the pressure to 4-5 Torr with this 3-Torr type booster, the No. 1 booster driving pressure is reduced and the booster is run in the low vacuum operation area. There is no theoretical support for the operation in this low vacuum operation area; therefore trials and errors may be necessary to obtain data.

In a certain actual example, the driving steam pressure difference between 10 kg/cm^2 (G) and 7 kg/cm^2 (G) resulted in a 30 % reduction of the steam volume used.

b. Review of deodorizing booster capacity (improvement case)

Traditionally, a large steam ejector (i.e. booster) is used to generate vacuum required in the oil deodorizing process. Boosters manufactured before energy conservation was highly evaluated may have a too large allowance and exceed the design value. By replacing the booster with the one matching the current operating condition, energy conservation may be achieved.

We checked the booster of the deodorizing equipment constructed in 1971, to find that the booster was run with the value before improvement as shown in Figure 5.1.14 (average capability 180 t/d).

Figure 5.1.14 Operating Condition for Vacuum Device

	Steam pressure	Consumption
Before improvement	15 kg/cm²(G)	386 kg/h
After improvement	10 kg/cm²(G)	272 kg/h

	Suction pressure	Suction aomunt
Before improvement	2.8 Torr	250 kg/h
After improvement	3.0 Torr	199 kg/h

		Discharge pressure
Before improvement		15 Torr
After improvement		13 Torr

	Water temperature	Discharge pressure
Before improvement	32 °C	60 Torr
After improvement	27 °C	50 Torr

	Steam pressure	Consumption
Before improvement	15 kg/cm²(G)	1,316 kg/h
After improvement	10 kg/cm²(G)	738 kg/h

	Suction pressure	Suction aomunt
Before improvement	11 Torr	636 kg/h
After improvement	12 Torr	471 kg/h

Steam — From the deodorizer — No. 1 booster — No. 2 booster — Barometric condenser — To vacuum pump — Cooling water — Steam

Note: The above-mentioned steam quantities indicate the annual mean values.

The suction volume was calculated based on the required deodorizing condition, leak air measurement, and volatile matters in the raw material oil.

The maximum water temperature was determined from the annual cooling water temperature (seawater). For the suction pressures of the No. 1 booster and No. 2 booster, the minimum overlapping was selected after discussion with the manufacturer. In this case, to prevent fluctuation in the booster's driving steam pressure, a pressure lower than that in the main steam pipe was selected as the design value. (The main pipe pressure (15 kg/cm² (G) is reduced and 10 kg/cm² (G) is supplied.)

As a result, the value after improvement in Figure 5.1.14 was obtained.

Effects of energy conservation are as follows:

Annual steam saving: $\{(386 + 1,316) - (272 + 738)\} \times 7,200H = 4,982$ t/y

c. Forced cooling of the barometric condenser cooling water (improvement case)

As shown in Figure 5.1.15, there is a method that forcibly cools the barometric condenser cooling water to reduce the steam consumed by the booster. In this case, steam saving can be accomplished by performing forced cooling of the cooling water with a freezer. (See Table 5.1.4.)

Energy saved: $\left\{\begin{array}{l}\text{Steam} \quad 147 \text{ kg/y} = 419 \text{ MJ/y} \\ \text{Electricity} \ ▲14.9 \text{ kWh/y} = ▲152 \text{ MJ/y}\end{array}\right\}$ 267 MJ/y

Figure 5.1.15 Forced Cooling of Barometric Condenser Cooling Water
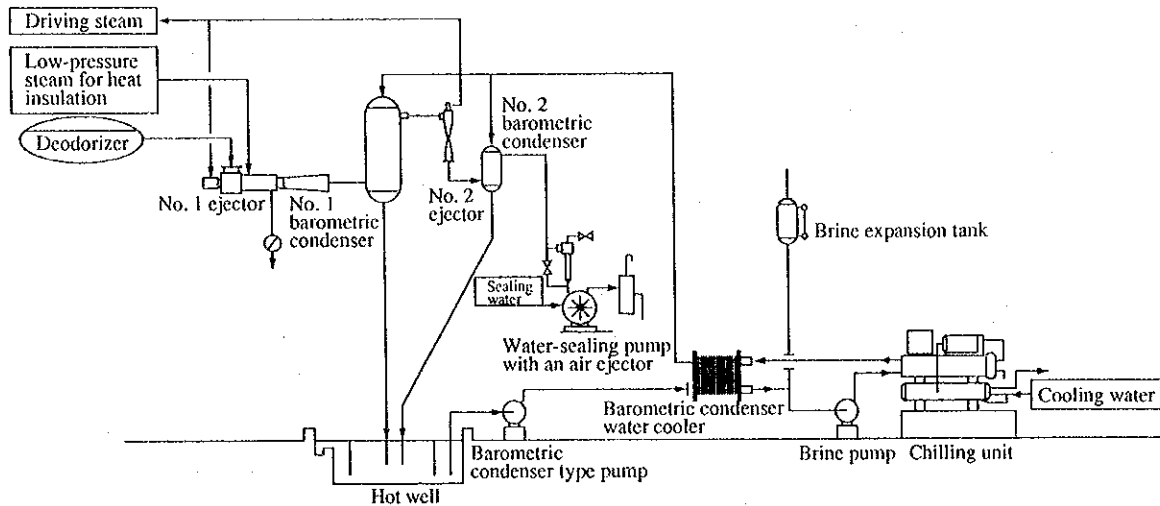
Table 5.1.4 Forced Cooling of Barometric Condenser Cooling Water

	Conventional method	After Improvement	Difference in Energy Used
Steam	197 kg	50 kg	147 kg
Electricity			
Vacuum pump	0.9 kWh	0.9 kWh	
Barometric condenser pump	4.4 kWH	1.5 kWh	
Brine cooling equipment	–	17.8 kWh	
Total	5.3 kWh	20.2 kWh	Δ14.9 kWh

(3) Deodorizing tower tray improvement

On the tray in the deodorizing tower, deodorizing is performed while blown steam ascends in the tube along with oil. After special processing, the system that allows film-type ascension has reduced the blown steam by 30 %.

(4) Energy conservation in the hydrogenation process

In the hydrogenation process, the reaction time can be shortened by effectively promoting the contact time between the oil and hydrogen and by selecting a proper catalyst. The hydrogenation equipment includes the conventional type (agitating type) and the oil circulating type (manufactured by BUSS Co. in Switzerland, Miura Office in Japan, Lurugi Co. in Germany, etc).

a. Conventional type (Agitating type)

As shown in Figure 5.1.16, the improved agitating type hydrogenation system feeds raw oil of 55 % of the tank capacity, and is operated under the following conditions:

Oil feeding temperature   : 60 °C (Time required for oil feeding: 20 minutes)

Oil temperature at hydrogenation:
    135 °C To be made vacuum before hydrogenation

Steam heating temperature: 150 °C

Temperature at which hardening reaction is completed:
    210 to 220 °C (20 minutes from the starting of hydrogenation)

        To be cooled when the temperature is 210 °C or higher

        Whether reaction is completed or not can be determined based on the amount of hydrogen added and sampling analysis (iodine value)

Temperature at which cooling is completed:
    90 °C (Time required for cooling: 30 minutes)

Total time required   : 70 minutes

One thermometer is installed at the bottom of the hydrogenation tank.
The hydrogen intensity required for lowering the iodine value by 1 is 0.8 kg-H_2/ton-oil.
Therefore, 4 kg/t of hydrogen is required for reducing the iodine value by 50.

Figure 5.1.16 Agitating Type Hydrogenation Tank
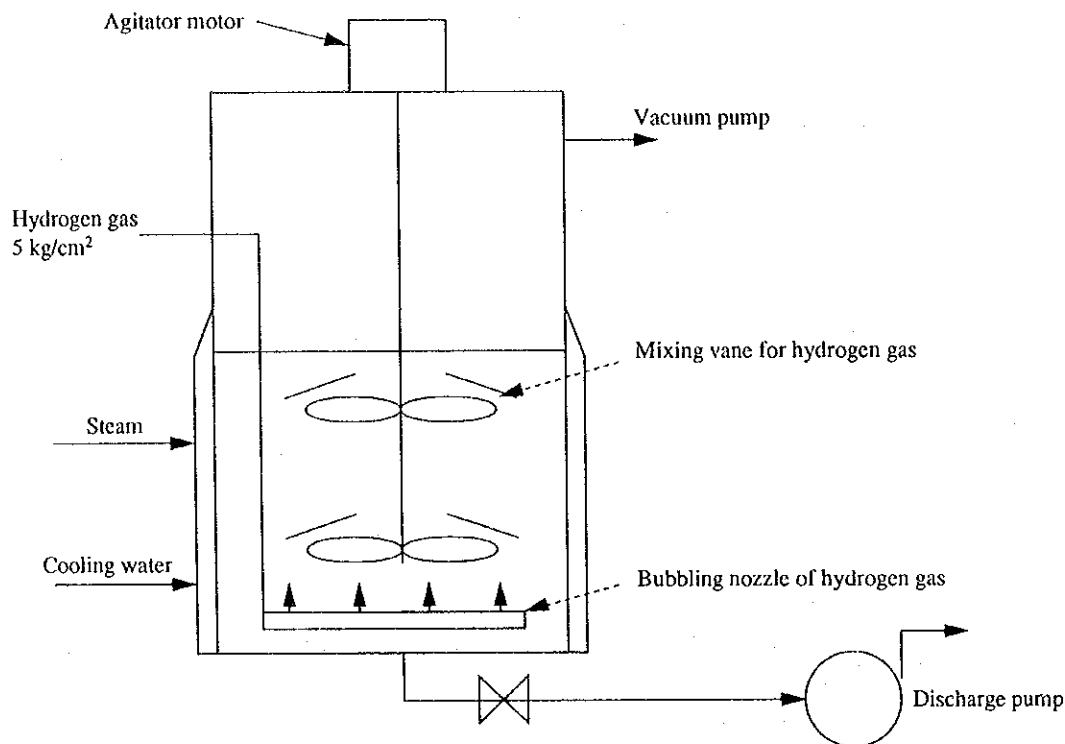
Hydrogen reacts with the oil while it is ascending through the oil, and non-reacted hydrogen that accumulates in the head space is so designed as to be drawn in the oil and thereby to be reacted with it by the effect of the agitator and the plate installed on the upper part of the agitator. Upon the completion of reaction, the hydrogen in the head space is discharged outside.

b. Oil-circulating type hydrogenation system

In this system, hydrogenation takes place when the circulating oil is scattered on the hydrogenation tank. Compared with the conventional type, this system consumes less hydrogen and allows a shorter reaction time. The hydrogenation tank inside is made vacuum before the air in the line is removed, thereby improving the efficiency of hydrogen reaction.

Figure 5.1.17 Oil-circulating Type Hydrogenation System
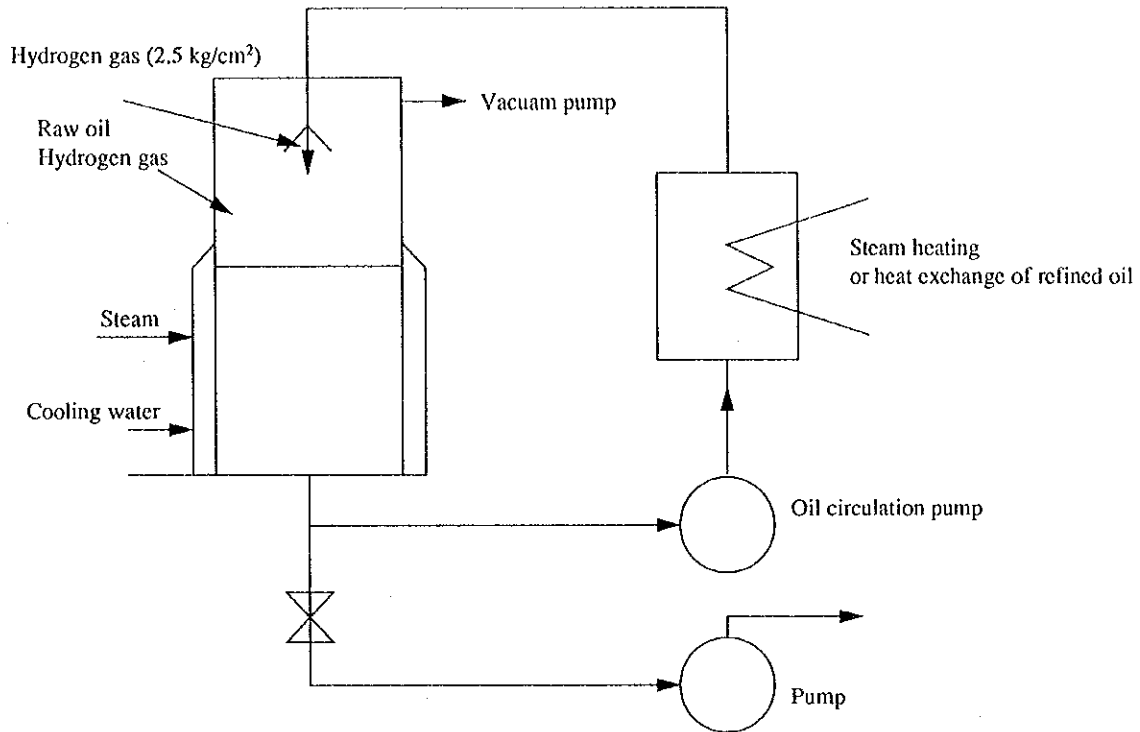
The processing order is producing a vacuum → charging → reaction.

The hydrogen pressure is 2.5 kg/cm².

The hydrogenation temperature is 175 to 180 °C.

The temperature for reaction to be completed is 210 °C

Heating of raw oil should preferably be performed through heat exchange with refined oil; however, when the refined oil seems easily susceptible to hardening, steam should be used for heating.

5.2 Energy Conservation in the Meat Processing Industry

5.2.1 Manufacturing Processes

Typical products of processed meat include ham, sausage, and bacon. Meat processing factories are categorized into the following three types:

1) Factory with butchery where carcass processing, ham processing, and can processing are performed in a continuous integrated line.

2) Factory with butchery where carcass processing is performed

3) Factory where ham processing, can processing, etc. are performed by using carcasses purchased from outside

Types of meat include pork, beef, chicken, and mutton, etc. This survey focuses on a factory with its own butchery for cattle and pigs used in carcass processing, ham processing, and sausage processing.

Ham and sausage are processed as meat preserved for a long time and thus include many types. Ham is originally the term used for the pig's thigh. Hence, salted or smoked meat of this portion is called ham. There is also a type called pressed ham that is made by mixing residual meat from boneless ham (roast ham) or bacon processing, beef, horsemeat, etc. and compressing them together. Pressed ham is ranked between ordinary ham and sausage in terms of manufacturing method and material. Chicken ham is made by processing chicken meat in the same manner as for the meat in pressed ham. The main ingredients of mixed pressed ham include salted lumps of meat (pork, beef, horsemeat, mutton, and goatmeat), poultry meat, and rabbit meat, to which salted fish flesh is added. Tuna and spearfish are used for fish flesh. Bacon is made by forming, salting, and smoking ribs of pork.

Figure 5.2.1 shows an example of the meat processing flow.

Figure 5.2.1 Process Flow

Pig
↓

```
┌─────────────────────────┐
│ Killing by electric shock │
└─────────────────────────┘
```

```
┌──────────────────┐      ┌──────────────┐
│ Gathering blood  │      │   Washing    │◄──────── Steam
└──────────────────┘      └──────────────┘
         │                        │
     ( Blood )              ┌──────────────┐
                           │   Peeling    │- - -►( Leather )
                           └──────────────┘
                                  │
                           ┌──────────────┐          Freezed beef
                           │   Cutting    │                │
                           └──────────────┘                ▼
                                  │              ┌──────────────┐
   ( Raw material          ┌──────────────┐     │  Defreezing  │
     of sausage )◄─────────│  Separating  │     └──────────────┘
                           └──────────────┘            │
                                  │            ┌──────────────┐
                           ┌──────────────┐   │ Beef preparing │
                           │ Refrigerating │   └──────────────┘
                           └──────────────┘         │      │
                                  │                 │   ( Bone )
   Steam          ┌──────────────┐
     │            │  Preparing   │
     ▼            └──────────────┘
 ( Fats (Lard) )  ( Bone )   ( Pork )      ( Beef )
```

```
Steam - - -►┌────────────────┐   ┌──────────────────┐◄- - - - - Steam
            │ Ham processing │   │ Sausage processing │
            └────────────────┘   └──────────────────┘
                    │                    │
                 ( Ham )             ( Sausage )
```
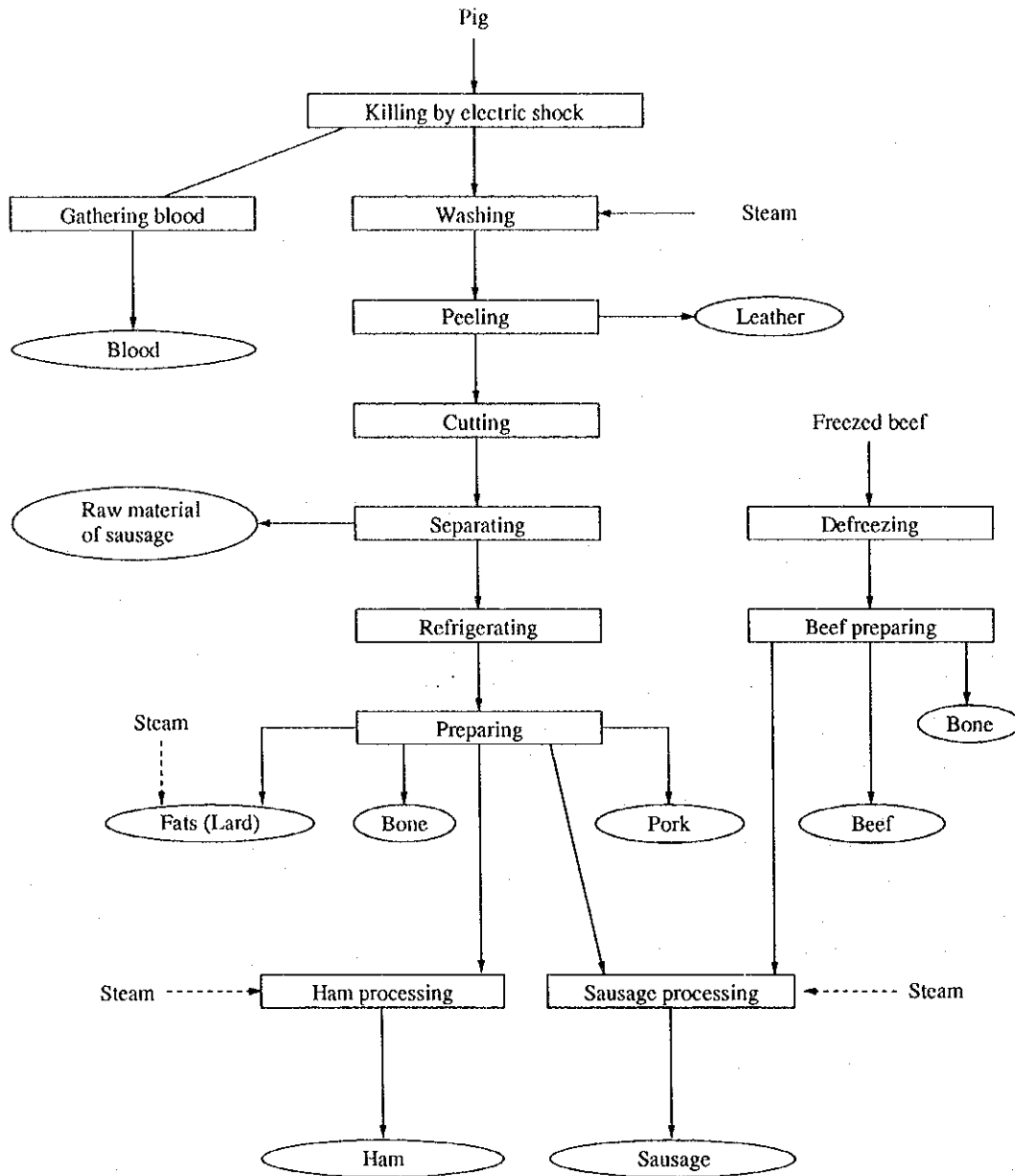
(1)   Ingredient processing

The ingredient processing ranges from butchery to completion of dissection.

The ingredient processing in a meat processing factory having its own butchery factory is as follows:

A pig is killed by applying an electric shock, the blood is removed, and then the pig body is washed with hot water of 75 °C. After this, the pig skin is peeled off, the internal organs are removed, and the pig body is divided into two portions (right and left), which are transferred to and stored as carcasses in the cooling room. Carcasses are divided into those to be shipped after refrigeration and those that are dissected for further processing in the dissection factory and used as meat for ham and sausages.

Of the internal organs, the intestine is used to make sausage. The room temperature in the butchery factory is maintained at 10 °C. The room temperature in the cooling room is maintained at 4 °C.

Carcasses of pigs refrigerated and stored in the cooling room are sub-divided in the dissection factory according to usage. The room temperature in the dissection factory is maintained at 10 °C.

Figure 5.2.2 shows applications of dissected meat. In a meat processing factory that does not have a butchery, the purchased raw meat that was sub-divided and frozen is defrosted and used. Tendons, excessive grease, etc. are removed from the meat, which is reshaped as required according to usage. The main source of ham and sausage meat is pork.

Figure 5.2.2 Meat Processing Flow
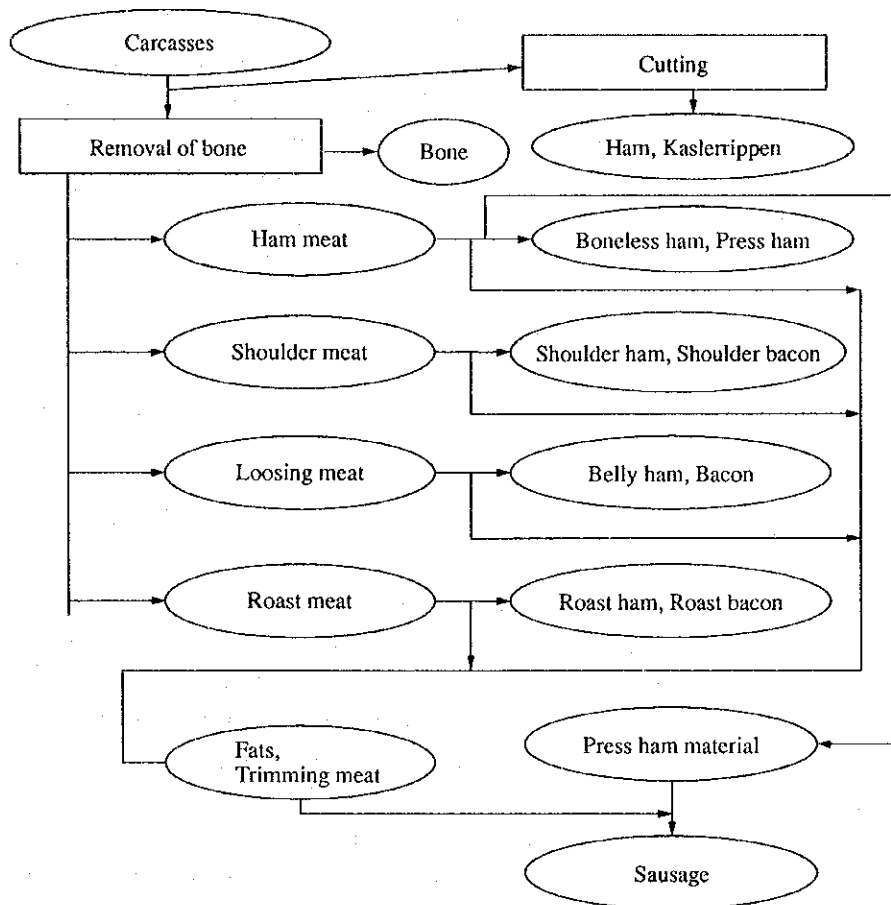
(2) Salting process

The standard salting process for ham is as follows:

A salting solution is injected into the shaped meat by an injector, the meat is softened by a meat softener, and then the injected solution is permeated into the meat by means of a salting aid such as massage machine or tumbler. On the other hand, injector is not used in the conventional method. Instead, the meat is salted (also for maturing) for 4 to 7 days simply applying the salt's permeation pressure. This conventional method is currently used for manufacturing high-class handmade products. Unlike in ham, the injection process is not used for bacon due to quality requirements. Generally, a salting agent is coated and rubbed into meat, which is kept in salt for 4 to 7 days depending on the size of the piece. Salting is performed at temperatures of 2 to 7 °C in the refrigeration room.

(3) Packing process

Meat that has been salted, other than those to be pressed and those for bacon is cut according to the size and weight of the final product and then packed into a sheath by a packing machine. The ham is packed in fiber sheaths (cellulose material). Sheep intestines are used for pressed ham. Bacon is skewered on steel spits with the original shape of the meat intact or placed on a metal net stand and transferred to the smoking process.

Pork and additional mutton, horsemeat, beef, chicken, etc. for making sausages are loaded on a silent cutter (1,500 to 5,000 rpm) to produce emulsion consisting of meat protein, water, and grease. Recently, instead of using the silent cutter, the meat and supplementary ingredients are mixed in a mixer and then fed to an fine emulsifying machine such as a vacuum micro cutter, mince master, or colloid mill to obtain uniform emulsion. These methods are suitable for a continuous production system. Sausage emulsion is packed by a vacuum automatic weighing and packing machine, continuous automatic twist packing machine, air stuffer, or equivalent. When one of the two above-mentioned machines is being used for packing, an artificial casing (collagen, fi-plas, vinylidene) is usually used. For natural intestines, a twist machine connected to an air stuffer or vacuum air stuffer is used.

(4) Heating process

Packed ham or sausage is transferred to the heating process. Ham or sausage packed in sheaths with permeability (natural intestines, cellophane, etc.) is smoked and then boiled. Ham or sausage packed into airtight sheaths is transferred to the boiling process and boiled. Heating is performed at temperatures of 70 to 80 °C. The heating time is set so that the center part is heated to at least 63 °C for 30 minutes. Most smoke generators are automated and their performance is greatly improved, and therefore smoking can be performed in 1/5 of the time required by conventional smoking methods. However, care must be taken as to the flavor. For the heat source for smoking, steam is generally used.

(5) Wrapping process

After heating, the product is cooled by a cold water shower or cold air and then transferred to the wrapping process. Wrapping is performed by a rotary continuous vacuum bundling machine. The Vienna sausage or sliced ham product goes through the Vienna sausage cutter/slicer or ham slicer, electronic scale weighing machine, sorting machine, etc. and is then wrapped by a vacuum wrapping machine, pillow type wrapping machine, or equivalent in a bio-clean room or equivalent sanitized room.

5.2.2 Measures for Rational Use of Energy

Equipment that consumes a large amount of energy in the meat processing factory include the factory air conditioner, cooling device in the refrigeration/freezing room, and ham/ sausage smoking device using steam.

To proceed with the rationalization of energy use, it is necessary first to know the current energy consumption.

To measure steam consumption, an orifice or vortex flowmeter is used for direct steam. When indirect steam is used, the volume of drain from the drain trap is measured to estimate the steam consumption. Also, when direct steam is used, the steam inlet position, nozzle shape, steam pressure, period of contact with the material, and exhaust utilization should be considered to reduce the volume of steam consumption. For indirect steam, reuse of the steam pressure and condensate and substitution with any other heat source should be considered. In a continuous process, the material temperature is raised or lowered for processing under optimum conditions, and therefore it is necessary to examine whether a mutual heat exchange between processes is possible.

(1) Energy intensity and energy use rate

Table 5.2.1 shows examples of energy intensity in the butchery/carcass processing factory and ham/sausage processing factory in Japan.

Table 5.2.1 Energy Intensity of a Meat Factory

Factory name	Production	Energy intensity	
		Fuel	Electricity
Butchery and carcass factory	24,353 t/y	844 MJ/t	221 kWh/t
Ham and sausage factory	14,400 t/y	2,832 MJ/t-ham	292 kWh/t-ham

(2) Recovering the condensate in the ham/sausage process

Ham or sausage packed into a sheath is transferred to the smoking and heating process and heated by steam. Energy conservation can be achieved by recycling the condensate of the steam used.

Generally, heat energy which accounts for 50 % of the total energy of heat and electricity used in the entire factory is used for manufacturing sausages. Steam for indirect heating used in the smoking process is 10 %, which can be recovered about 30 % and used for heating boiler feedwater and producing moisture for smoking. About 3 % of the energy for the entire factory can be saved for energy conservation. (10 % × 0.3 = 3 %).

(3) Intake of outside air

There is an example of reducing the load for the refrigeration room freezer by sterilizing and filtering the outside air and taking it into the workshop during the winter season. In the meat processing factory, there is a problem in sanitation because bare meat is directly exposed to air. Therefore, the outside air is used only in the limited areas. Outside air intake is used for ventilation and air conditioning of high-humidity rooms such as the heat treatment room and washing room. Figure 5.2.3 shows the outside air treatment system. This device is also used when a clean room is to be installed. The aseptic filter is a paper filter, which is replaced every three months.

Figure 5.2.3 Outline of an Outside Air Treatment System
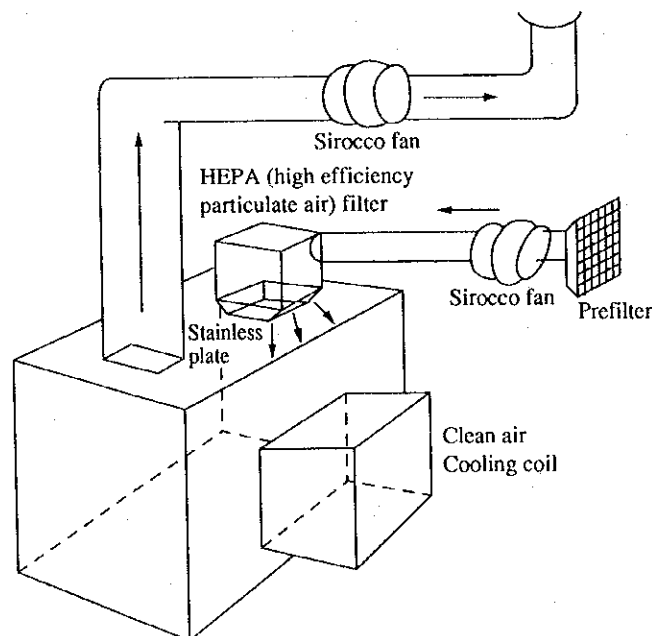
(4)   Installation of an automatic door at entrance/exit

The room temperature in the meat processing factory should preferably be 10 °C in the butchery, 4 °C in the refrigeration room, and 10 °C in the processing room. Since the lard factory uses a double caldron, the room temperature is often high. If the door between work rooms at different temperatures is kept open, an automatic door should be installed to reduce the electrical load for air conditioning. If the temperature of outside air is high in the summer season, an automatic door should be installed at the entrance/exit of the processing room so that cold air in the processing room will not flow out. If it is hard to install an automatic door, at least a curtain should be installed at the entrance/exit for saving of the electricity used for air conditioning.

(5)   Full-automatic smoking device

The full-automatic smoking device performs drying, smoking, and cooling continuously. The packed product hung in the smoke cage enters this device. The device is so adjusted that the automatic controller performs all processes at the preset temperature/humidity for the preset time to allow a uniform-quality, high-yield product to be produced. The full-automatic smoking device consists of a steam spray pipe, temperature/humidity control solenoid valve, cooling water spray nozzle, smoking duct, and hot air circulation pipe installed on the body as shown in Figure 5.2.4. In addition, a smoke generator and gas combustion device are provided.

Figure 5.2.4 Outline of Automatic Smoking Unit for Ham and Sausage

A – A section

Air | For circulation

Cooling zone (2nd floor)

Steam outlet

A spray is provided in front of the heater to cool it down when the temperature becomes too high.

(1st Floor)

A

Blowoff ports at both sides

Sirocco fan

Heater

Air

Duct

65 °C

Relative humidity: 70 to 80%
Low-pressure steam

Steaming zone

Heating smoke zone

Dry smoke zone

A
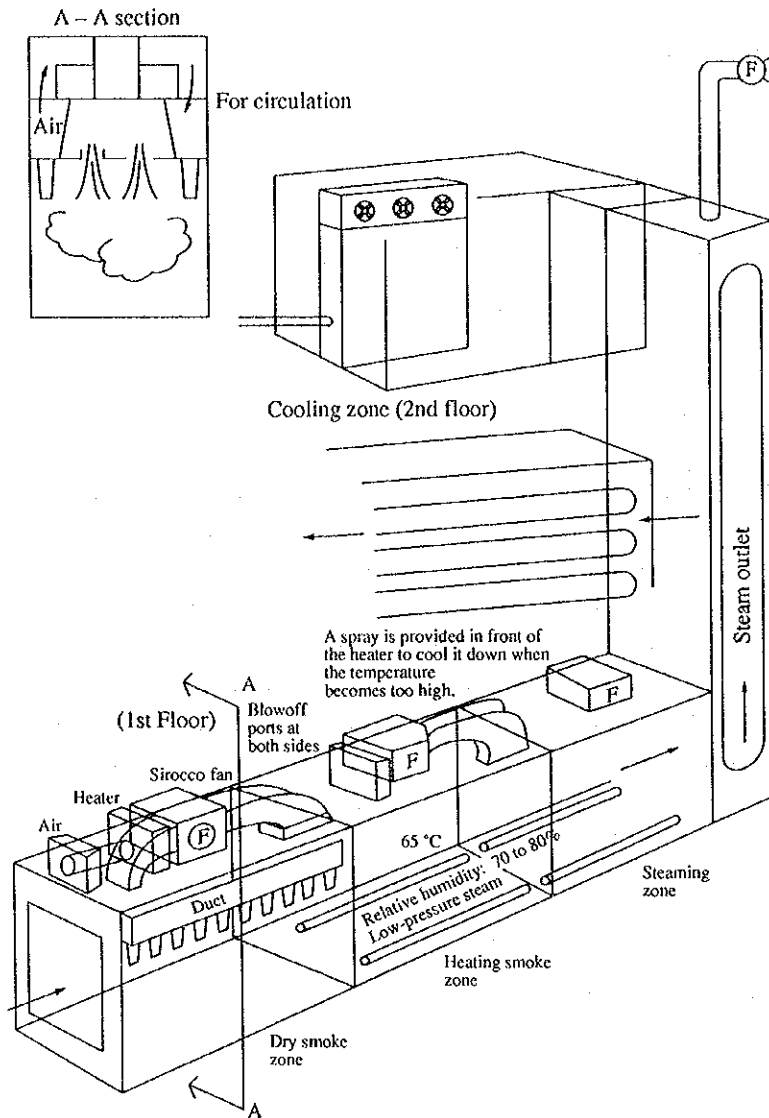
(6) NH₃ freezer

In a food factory requiring low temperature control, energy conservation for electricity can be achieved by making efforts to improve the efficiency of an NH3 freezer.

An actual case in which a substantial energy conservation has been achieved is described below. In this factory, two chilled water coolers were used at the worksites, with the main power source at 150 kW. Having reviewed the load conditions, it was concluded that 110 kW would suffice as a regular power source. Thus, it was determined that the coolers should be integrated into one large-capacity cooling tank in the refrigeration room which the operator can easily monitor, and that the main power source should be operated at 110 kW. Additionally, the 11 kW chilled water pumps were running during both the peak-load and light-load times, resulting in a waste of electricity. Hence one of the two 11 kW pumps was replaced by a 7.5 kW pump so that pump operation would automatically be switched to the 7.5 kW pump under light-load conditions.

Mixing with two 11 kW chilled water agitators was changed to mixing with one 7.5 kW type agitator.

A thermo sensor was installed for temperature control in the refrigerator for automatic start/stop. As a result, a total improvement of 48 kWh was achieved in cooling equipment capacity. This means energy conservation of 30% in terms of electricity intensity.

For the NH_3 freezer, evaluation of freezer performance involves many factors to be considered depending on the use conditions. In this regard, it is necessary to check the performance of the current model using 0.9 kURT (1 URT = 3,020 kcal = 12,642 kJ) as a guide for the chilled water cooling capacity. Production of freon-based refrigerants is to be stopped in the year 2010, and thus attention has been increasingly focused on the use of NH3 among various refrigerants. An NH3 freezer needs to be adequately maintained to prevent gas leakage.

(7)   Others

There are many important matters, such as improvement of the heat recovery rate in the heat exchanger and can sterilization process and heat insulation of equipment, to be considered in everyday efforts toward energy conservation. It should be understood that constant and continuing daily effort will produce a substantial conservation of energy. For improvement of the product yield, it is equally necessary to reduce loss with the understanding that an improvement in the product yield can lead to an improvement in energy conservation.

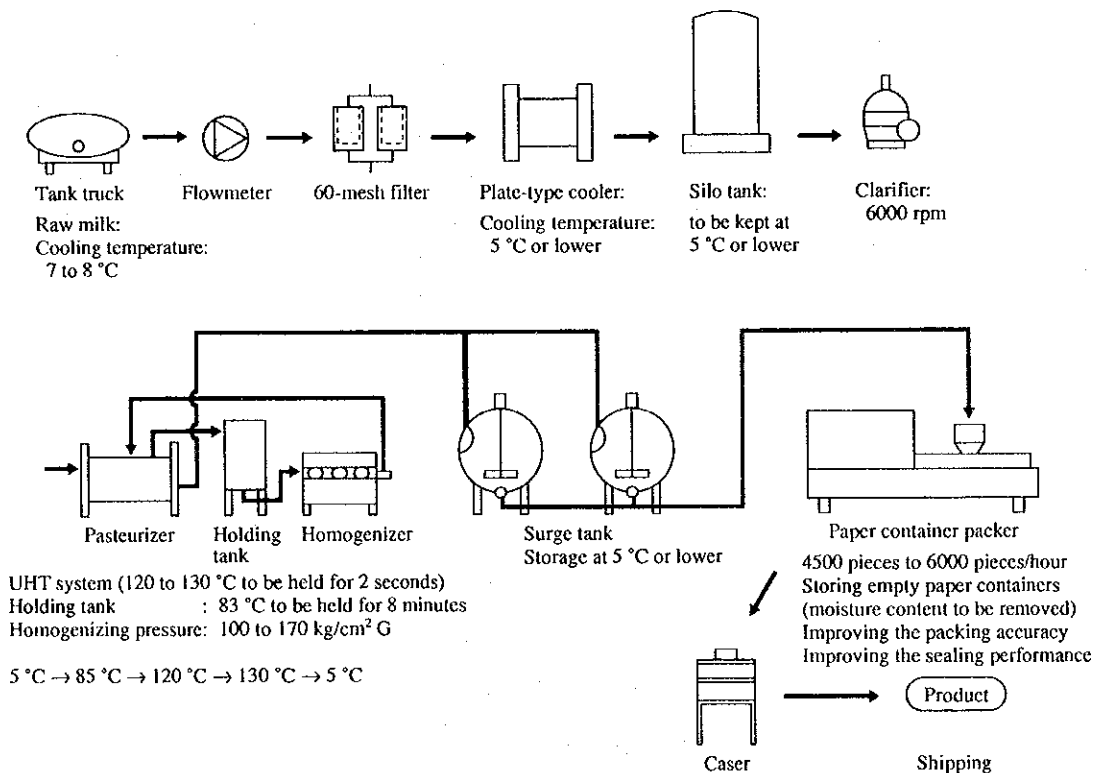## 5.3 Energy Conservation for the Dairy Products Industry

5.3.1 Manufacturing Processes

Milk is a product made purely from raw cow's milk and available as a beverage. The packaging of milk products is being increasingly shifted from conventional 180-mL and 200-mL bottles to 1,000-mL, 500-mL, and 200-mL paper containers.

The major processes for the milk include removal of foreign matters from raw milk, processing of fat in raw milk, the raw milk pasteurization/sterilization process, homogenizing, and packing process. The UHT(Ultra Heat Treated) milk (120 to 135 °C, pasteurization for 2 seconds) is popular for pasteurization conditions. With the recent improvement of dairy farming, milking and raw milk control technologies, however, the germs in the raw milk supplied to a factory have been greatly reduced. Additionally, the recent trend of the consumer taste for natural food has led to using the low-temperature pasteurization process.(HTST 72 °C for 15 seconds; LTLT 63°C for 30 minutes). These factors have contributed to the production and supply of high-quality raw milk.

Figure 5.3.1 shows the milk production flow.

Figure 5.3.1 Milk Processing Flow

Tank truck   Flowmeter   60-mesh filter   Plate-type cooler: Silo tank: Clarifier:
Raw milk: Cooling temperature: to be kept at   6000 rpm
Cooling temperature: 5 °C or lower   5 °C or lower
   7 to 8 °C

Pasteurizer   Holding   Homogenizer   Surge tank   Paper container packer
            tank   Storage at 5 °C or lower

UHT system (120 to 130 °C to be held for 2 seconds)   4500 pieces to 6000 pieces/hour
Holding tank   : 83 °C to be held for 8 minutes   Storing empty paper containers
Homogenizing pressure: 100 to 170 kg/cm^2 G   (moisture content to be removed)
                                                   Improving the packing accuracy
5 °C → 85 °C → 120 °C → 130 °C → 5 °C   Improving the sealing performance

Caser   Shipping

(Product)

(1) Milk collection

Raw milk is transported from the depot where it is collected to the milk factory or directly from a dairy farmer to the milk factory by a tank truck. Nowadays, raw milk taken from a cow is immediately cooled by a cooler in the farm and then transported to the depot for collecting raw milk or to the factory. Therefore, the raw milk is maintained at 10 °C or lower even in the summer season and supplied to the factory in a preserved state.
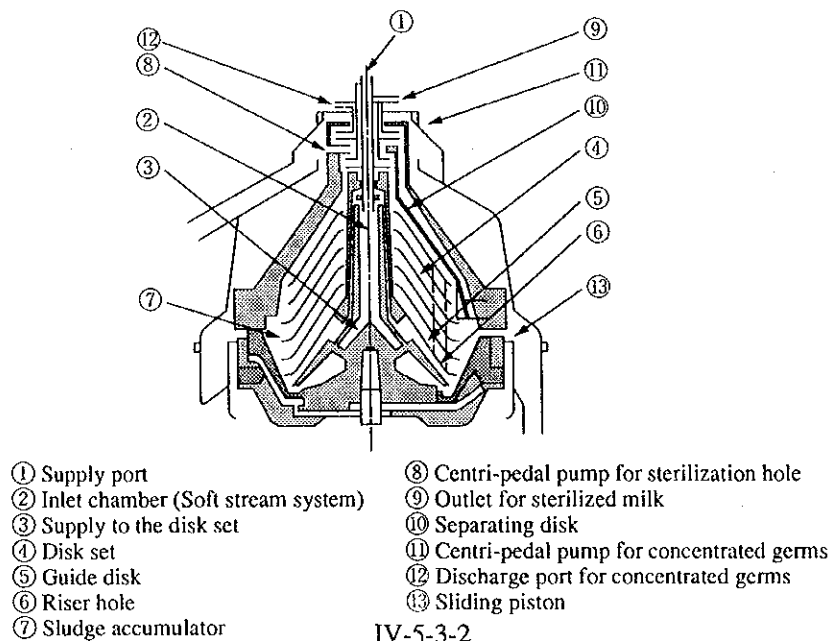
The raw milk is sampled from the tank truck, and the quality (acidity, specific gravity, fat rate, number of germs, etc.) is checked. Only the raw milk that passes the specified criteria is accepted and used. The criteria for acceptance in Japan for the number of germs is 100,000 germs/cc or fewer. In Poland, some factories use the same criteria as that in Japan. If the number of germs is larger, energy used for pasteurization is increased.

Raw milk is pumped out of the tank truck through a rough basket filter with a 60-mesh filter cloth to filter out dust particles, etc. cooled to 5 °C or lower by a plate type cooler, and then stored in a silo tank. Chilled water of 1 to 2 °C in an ice bank (cold heat storage tank) is used as the cooling medium. Although the size of the silo tank depends on the volume of milk collected in one day and the scale of the factory, larger sizes are used in recent years to accept and store raw milk even on holidays. For example, there are factories where several 100-ton silos are installed.

(2) Clarification

Filtering with just the filter cloth is insufficient to remove very fine dust particles, etc. from the raw milk. Normally, a centrifugal separator, called a clarifier, is used. In this process, bacteria that adhere on dust can also be removed. The separated dust is discharged automatically. Figure 5.3.2 shows the structure of a clarifier.

Figure 5.3.2 Cross-section of a Wesfaria-type Clarifier

① Supply port
② Inlet chamber (Soft stream system)
③ Supply to the disk set
④ Disk set
⑤ Guide disk
⑥ Riser hole
⑦ Sludge accumulator
⑧ Centri-pedal pump for sterilization hole
⑨ Outlet for sterilized milk
⑩ Separating disk
⑪ Centri-pedal pump for concentrated germs
⑫ Discharge port for concentrated germs
⑬ Sliding piston

Raw milk supplied through supply port 1 is fed into the flow paths with a small pitch, consisting of multiple conical bowls that rotate at high speed. Since raw milk is rotated at the same high speed as that of the bowl, a centrifugal force is applied to riser hole 6 of the bowl, and thereby dust particles and bacteria with a larger specific gravity are fed to the sludge accumulating part 7. The raw milk flows to the center of the bowl via riser hole 6 and then fed to delivery port 9 by pump 8.

The processing capability ranges from 500 L/h to 25,000 L/h. During operation, the deposited sludge is discharged to the outside of the machine according to the timer setting. A similar cream separator system using a centrifugal force is available for separating fat from milk. Although the structure is almost the same, the position of the riser hole for separation in the cream separator is closer to the center. Therefore, even cream with a small specific gravity can be separated. Germs, particularly spore forming germs, can be removed by the clarifier and separator using this centrifugal separation system. These machines are suitable for processing low-temperature pasteurized milk that is becoming popular in the market today.

(3)   Homogenization

Milk usually contains 3 to 4.5 % fat, the fat globes of which are 1 to 18 μm in size and suspended in the product. Normally, if raw milk is left standing (as it is), the fat rises to the surface and is separated. Therefore, these globes of fat are destroyed physically to attain a 2 μm particle size on an average and thereby maintain a stable suspension state for a long time. This operation is called the homogenizing process. A pressure of approximately 150 kg/cm^2 is applied to raw milk, which is made to pass through a narrow flow path to reduce the size of the globes of fat significantly. In recent years, consumers have developed a liking for the flavor of the original raw milk. Therefore, the particle size in some cream separation processes is kept larger to satisfy the current taste. Figure 5.3.3 illusrates the theory of the homogenizing mechanism.

Figure 5.3.3 Theory of Homogenizing Mechanism
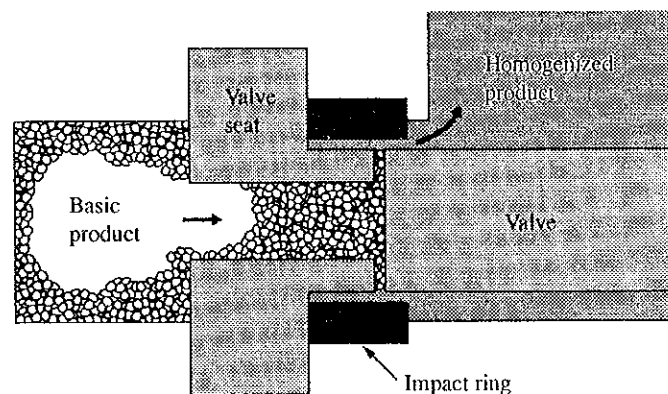
Raw milk passes through small clearances in the valve seat, the speed is increased abruptly, and it is sprayed to the low-pressure section, which makes the globes of fat very fine. When raw milk passes through the valve at high speed, steep turbulence and cavitation generate a shearing force between particles, which destroys the globes of fat. Then, the raw milk is sprayed to the low-pressure section. The explosion effect on the globes caused by a sudden pressure change from high pressure or the impact pressure to the impact ring crushes the particles.

(4)   Pasteurization

Generally, milk is pasteurized by heating with a plate type heat exchanger that uses steam as the heating source. The plate type heat exchanger has a higher thermal conductivity compared with the tube type heat exchanger. It also takes a shorter time to heat up to the pasteurization temperature, and a shorter time to cool milk to the storage temperature as well. In Japan, 90 % or more of milk is pasteurized using a pasteurization process called UHT (ultra-high temperature momentary pasteurization). Although this high-temperature pasteurization is performed at 130 °C for 2 seconds, losses of the raw milk original flavor and nutritive value due to thermal denaturation can be minimized and pasteurization can be accomplished due to development of the plate type heat exchanger.

Figure 5.3.4 shows the milk UHT pasteurization flow. Raw milk cooled and stored at approximately 4 °C is pumped to primary heat exchanger and primary heater of the plate type heat exchanger and heated to 85 °C. Then, the milk is held for approximately 6 minutes in a retention tank to denature the protein that is easily susceptible to thermal denaturation and to prevent scale adhesion on the high-temperature plate surface of secondary heat exchanger and primary heater. After retention, the homogenizer makes globes of fat very fine. The milk is heated to 130 °C via the secondary heat exchanger and secondary heater. After retention for 2 seconds, the milk is immediately cooled to 4 °C or lower via the secondary heat exchanger, primary heat exchanger, and cooling unit. If the 6-minute retention time is excluded, heating to 130 °C is achieved in approximately 30 seconds and then cooling to 4 °C is achieved in a shorter time, about 30 seconds. Figure 5.3.5 shows an example of the time elapse. The UHT pasteurizer can be made compact with the plate type heat exchanger provided in the center.

Figure 5.3.4 Flow Sheet of UHT Milk
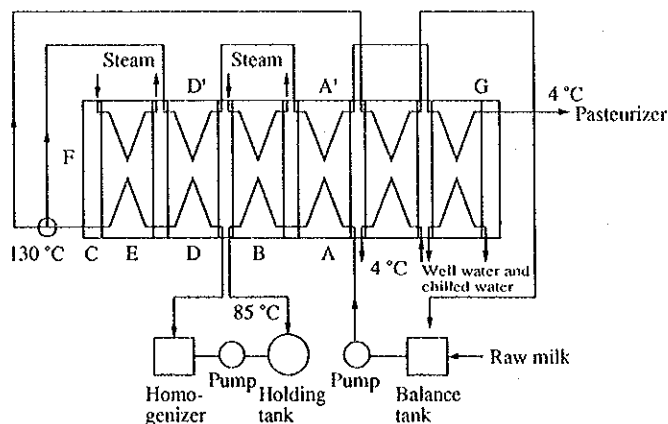
Figure 5.3.5 Temperature Change in the Pasteurization Time of UHT Milk

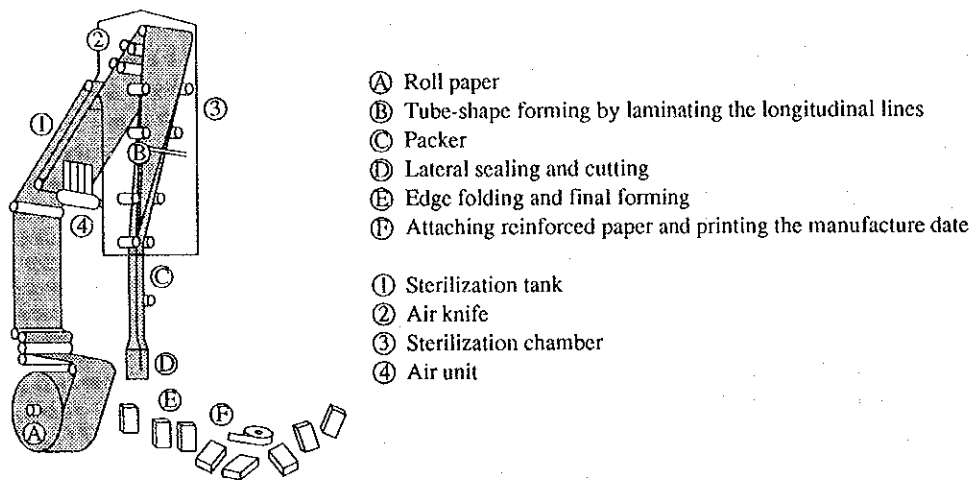|		
A, A'	No. 1 heat exchanger	4 → 75 °C
		24 ← 95 °C
B	No. 1 heating unit	75 → 85 °C
C	Unit holding heat for 6 minutes	85 °C
D, D'	No. 2 heat exchanger	85 → 120 °C
		95 ← 130 °C
E	No. 2 heating unit	120 → 130 °C
F	Unit holding the pasteurization termperature for 2 seconds	130 °C
G	Cooling unit	24 → 4 °C
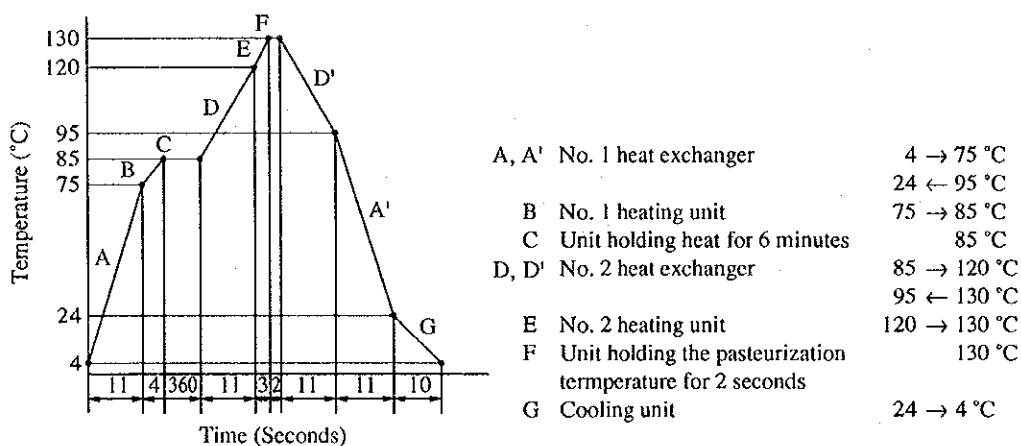
(5)   Packing

In recent years, most milk containers are made of paper. The main reason is that the paper container packing machine has been developed and improved for the following needs:

①   Speedup
②   Mass processing
③   One-way disposal
④   Storage improvement
⑤   Larger containers

On the other hand, use of glass containers must be reviewed again from the standpoint of the global environment, resource recycling, and energy resources. There are two types of paper container packing machines; one that performs forming, packing, and sealing with roll paper (made by Tetra Brick. See Figure 5.3.6.) and the other that punches the paper in advance, makes folding lines, forms the container and packs milk with a packing machine (made by Yasuda Finch). For both systems, packing machines allowing aseptic packing have been developed, contributing to the propagation of long-life milk. Of these machines, the Tatra Brick type packing machine requires height rather than area for installation, while the pure pack type packing machine requires a space with length rather than height.

Figure 5.3.6 Tetra Brick Type Aseptic Packing

Ⓐ Roll paper
Ⓑ Tube-shape forming by laminating the longitudinal lines
Ⓒ Packer
Ⓓ Lateral sealing and cutting
Ⓔ Edge folding and final forming
Ⓕ Attaching reinforced paper and printing the manufacture date

① Sterilization tank
② Air knife
③ Sterilization chamber
④ Air unit

(6) Flushing

After completion of pasteurization and packing, each component and piping line should be flushed. Most factories today use the C.I.P. (Cleaning In Place) method for this purpose. First, the milk product remaining in the equipment, components, and piping line are flushed and collected as much as possible using aseptic water. Then, the insides of the piping line and equipment are sealed and flushed with liquids in the order of hot water rinse, alkali flushing, hot water rinse, acid flushing, hot water rinse, and aseptic water to prevent secondary contamination of the inner surfaces due to the entry of outside air and to maintain a germ-free state after flushing. Acid flushing is used for the UHT pasteurization machine only. Generally, flushing with hot water and alkali is enough for other equipment and piping lines.

a. C.I.P. unit

Most machines in the dairy industry are not disassembled and flushed manually. Instead, C.I.P is used to save man-power and assure safety. Merits of C.I.P. are:

① Reduction of work time: Disassembly and assembly are not required.

② Stabilization of flushing performance: No variation due to the human factor occurs, thus allowing flushing under fixed conditions.

③ Extension of equipment life: Possible damage by disassembly can be prevented.

④ Saving of energy and resources: Losses can be eliminated because of operation under fixed conditions.

⑤ Assurance of labor safety: Hazards caused by exposure to strong detergents can be reduced.

C.I.P by the UHT pasteurizer offers the capacity to remove scales from the heating surface of the plate of the plate type heat exchanger which is a high-temperature heating part. Possible causes of scale adhesion include:

① Heating temperature
② Heating surface flow distribution
③ Heating surface temperature
④ Presence of air
⑤ Surface roughness of the heating surface

Table 5.3.1 shows an example of analyzing the contents of the scales on the heating surface of the plate of a plate type heat exchanger in the UHT milk pasteurizer. Thick yellow-brown scales, mainly containing protein, are deposited on the primary heat exchanger and No.1 heater. White thin-film scales, mainly consisting of minerals, spread on secondary heat exchanger and secondary heater. The detergent to be used must be changed depending on the contents of the scale. To remove the scales mainly containing protein, a 2 to 3 % alkaline detergent is used. To remove scales containing minerals, an approximately 1 % acid detergent should be used. Figure 5.3.7 shows the C.I.P. unit flow. For flushing the pipeline, flushing liquid is introduced at a high flow rate so that Re will be larger than 30,000 to remove scales from the inner surface of the pipe.

Figure 5.3.8 shows the C.I.P. spray ball fitted in the tank. The C.I.P spray ball hole position and spray speed must be so determined as to ensure that all inner surfaces of the tank are cleaned.

Table 5.3.1 Components of Milk Scales (Unit: % in dry milk)

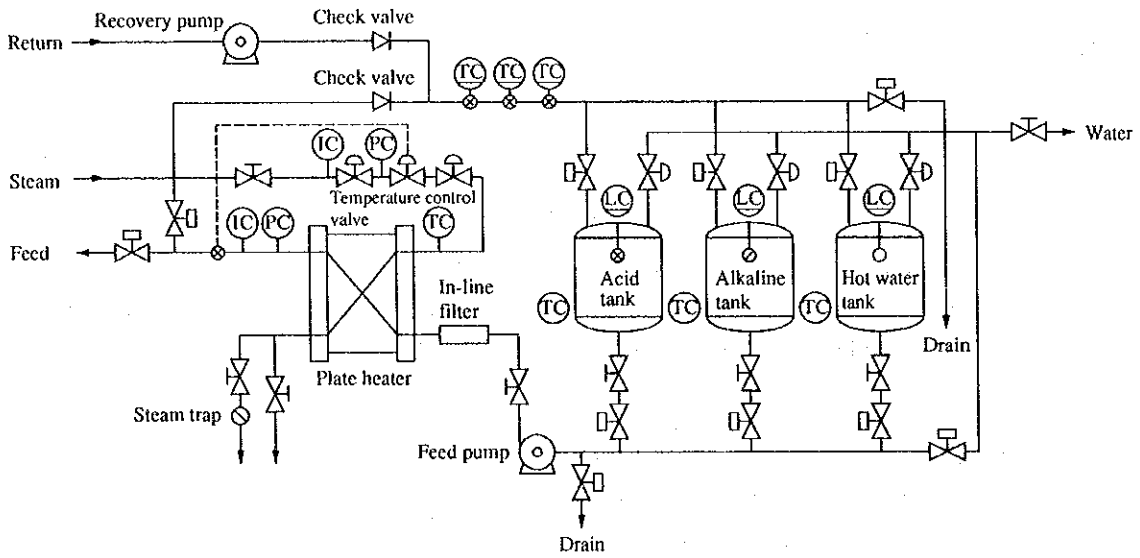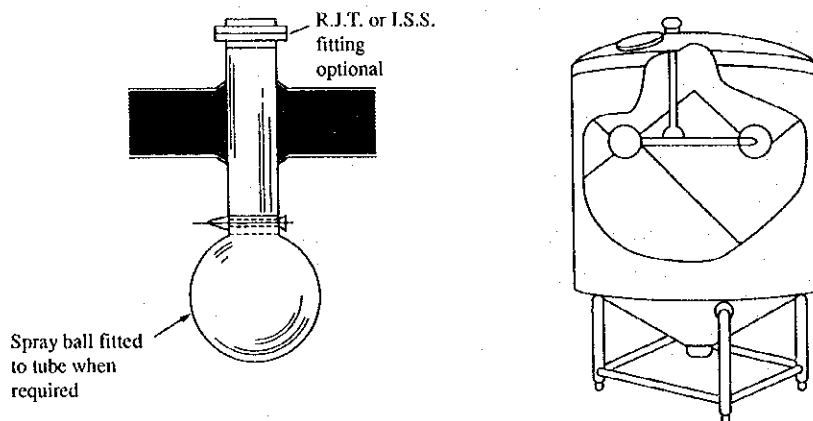|	Protein	Fat	Ash
Primary heat exchanger	59.7	12.8	25.8
Primary heater	62.1	24.1	14.6
Secondary heat exchanger	13.0	5.0	72.0
Secondary heater	19.4	8.3	68.2

Figure 5.3.7 Flow Sheet of C.I.P. Unit

Figure 5.3.8 C.I.P. Spray Ball and Tank

b. Automatic sanitary valve

Conventionally, efforts for automation and centralized management have been made for all manufacturing and flushing processes in the manufacturing plants of dairy factories in terms of stabilization, safety and sanitation of the production operation. It is equally important to automatize the production line, employ automatic switching to the flushing process and prevent mixing of different products or mixing of a cleaning agent in a product. To this end, automatic valves play a significant role and have been improved and developed in many ways. Thus, automatic air-operated valves are recently employed by most food factories.

5.3.2 Measures for Rational Use of Energy

Equipment that consumes a large amount of energy in a milk factory includes the cooling device for the raw milk in the storage silo of the milk acceptance process, the heat pasteurization device using steam in the pasteurization process, and the cooling device in the wrapping and preservation process.

To proceed with rationalization of energy use, the volume of energy currently consumed should be known first.

(1) Energy intensity and energy use rate

Table 5.3.2 gives an example of energy intensity in a dairy products factory in Japan. This factory produces milk (80 %) and other products (20 %) including beverages, creams, and desserts.

Table 5.3.2 Energy Intensity in Milk Factory

Energy	Intensity
Fuel	2,320 MJ/t
Electricity	1,128 MJ/t
Total	3,448 MJ/t

(2) Fluctuation of energy intensity due to air temperature

In a milk factory, electricity consumption is high in the summer season and low in the winter season if same volumes of the same products are produced in both seasons. In contrast, the volume of fuel for boilers is less in summer season and more in the winter season. The reason is that chiller and heater operations are greatly affected by air temperature. If, for example, the difference in energy intensity between summer and winter seasons is 30% or larger in a factory, heat insulation of the factory building will serve as an effective means for energy conservation. In this regard, improvement of the building structure may have to be taken into consideration.

(3) Heat pasteurization

A milk factory uses steam for heating pasteurization. The continuous operation time for pasteurization of milk with a plate type heat exchanger is generally 3 to 4 hours. Longer operation could lead to a possible reduction in the efficiency of the heat exchanger due to deposition of solid matters. The time, however, depends on the quality of the material milk (particularly on its acidity). Pasteurization flushing is performed by C.I.P operation, after which the operation is restartable. Low-temperature pasteurization is becoming increasingly popular in recent years; in this regard, the heating surface area of the heat exchanger is made larger and also the heating source is being changed from steam to hot water in order to minimize thermal denaturation of milk.

(4) Case of saving electricity through improvement of the cooling equipment

Items produced in the factory: Milk and milk beverages

Energy consumption   : Fuel (fuel oil) — 328 kL/y
                             Electricity — 859 MWh/y

This factory improved its cooling equipment over 3 years and reduced the use of electricity in the cooling equipment process by 41 %. Figure 5.3.9 shows electricity consumption by the process before and after improvement.

Figure 5.3.9 Electricity Use by Process before and after Improvement

Before improvement

After improvement
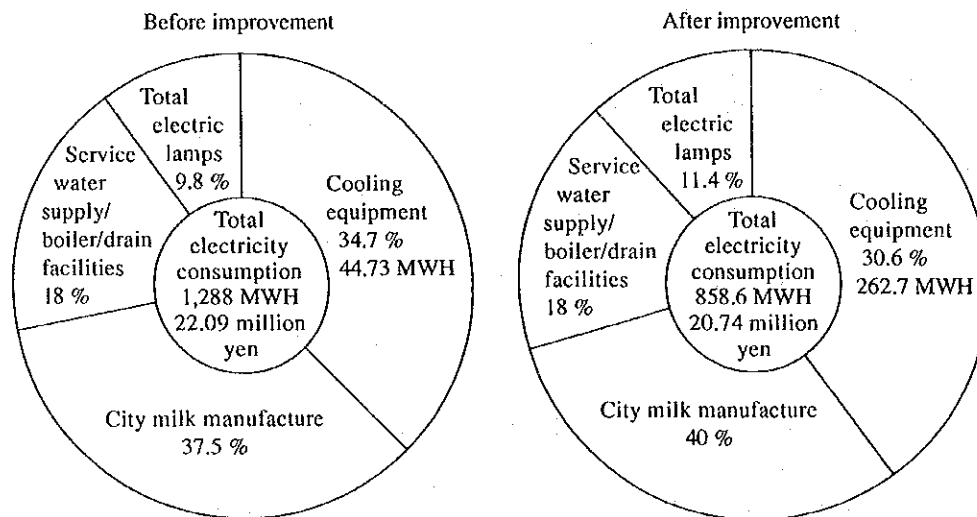
As shown in Figure 5.3.10, the cooling equipment is used to cool the raw milk stored after acceptance and cleaning, cool the milk after pasteurization, and refrigerate the finished product in storage. In this factory, chilled water is used for cooling.

Figure 5.3.10 Process Flow and Chilled Water Supply

Table 5.3.3 lists the problems and measures for the cooling equipment. Figure 5.3.11 shows the flow of the freezing/cooling equipment after improvement.
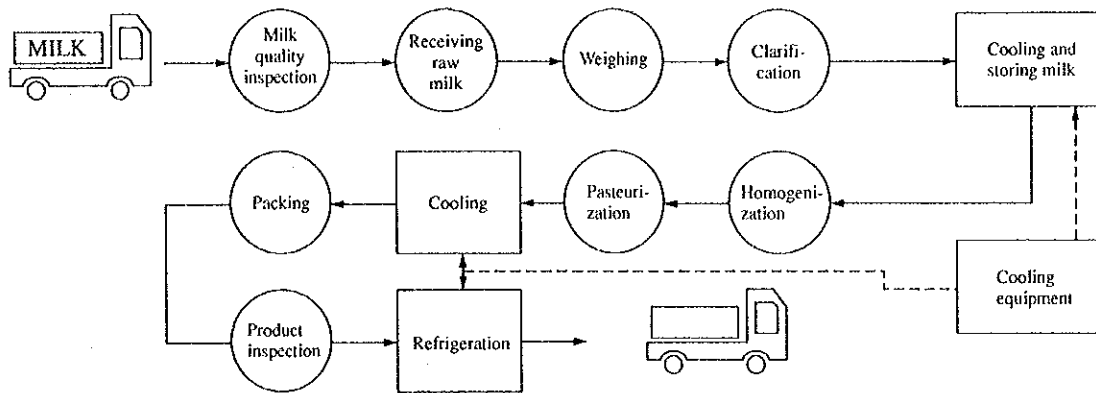
Table 5.3.3 Problems and Measures related to the Chiller and Cooling system

Problems	Measures
1. There are two chilled water coolers, whose capacity is too large.	These coolers should be integrated with the large-capacity cooling tank in the chiller room, and can be easily monitored by the operation. (Implemented in the third year)
2. The low-efficiency 150 kW chiller is often used for light-load operations.	Operation should be mainly based on the 110 kW type. (Implemented in the first year)
3. The 11 kW chilled pump is run during both in peak-load time and light-load time, resulting in a waste of electricity.	One of the two 11 kW pumps should be replaced by a 7.5 kW type. During the light-load time, operation is automatically switched to the 7.5 kW type. (Implemented in July, 1983)
4. Two 11 kW chilled agitators are used for mixing. Can energy-saving be achieved by replacing one with a 7.5 kW type?	A spare 7.5 kW agitator should be used. (Implemented in the third year)
5. The operator runs the cooler by checking the thermometer visually for temperature control of the refrigerator. Therefore, this operation depends on each operator's ability.	A temperature sensor is installed for automatic start/stop. (Implementation in the second year)
6. The condenser fan is manually operated by the operator. Therefore, this operation depends on each operator.	Two pressure sensors are installed on the high-pressure side for automatic start/stop. (Implementation in the third year)
7. The boiler monitoring room is set apart from the chiller monitoring room; thus two operators are always required.	The chiller operation annunciator panel is installed in the boiler monitoring room. (Implementation in the third year)
8. Chiller operation does not immediately respond to the load.	A temperature sensor was installed for precise unloader control. (Implemented in the third year)

Figure 5.3.11 Flow Sheet of the Chiller and Cooling System after Improvement
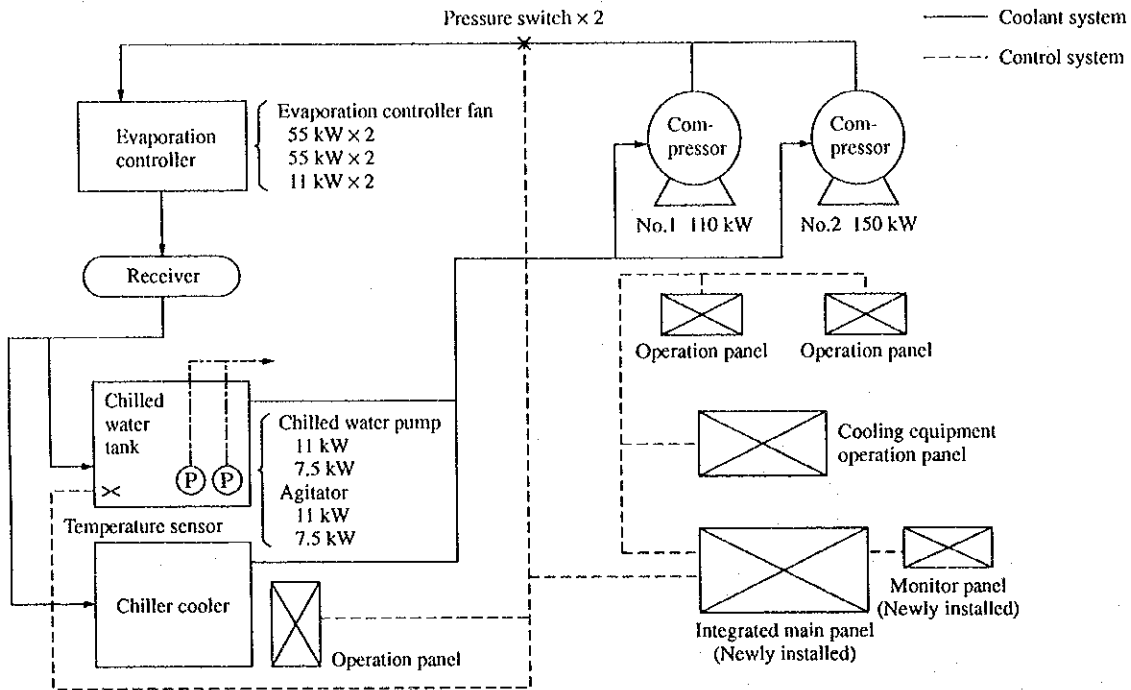
(5)   An example of power saving by a gas engine-operated refrigeration system

Factory production items: Milk and yoghurt
Number of employees   : 200
Annual energy costs:
    Electricity: 95,000,000 yen
    Gas   : 134,000,000 yen
    Total   : 229,000,000 yen

The refrigerating compressor of an ice storage refrigeration system is operated by a gas engine. The hot water produced at the gas engine jacket is utilized in production processes.

An exhaust gas boiler using exhaust gas from the gas engine is used to generate steam, which is utilized in production processes.

    Equipment investment cost   : 130,000,000 yen
    Payback years due to electricity savings: About 3 years

This improvement resulted in the elimination of the existing boiler. Although 120,000,000 yen was required to newly install an exhaust gas boiler, an ice builder, etc., the savings of fuel cost through the effort subsequent to the installation of this equipment has allowed the investment to be recovered as scheduled.

Figure 5.3.12 Conceptual Diagram of Flow for Gas Engine-operated Refrigeration System
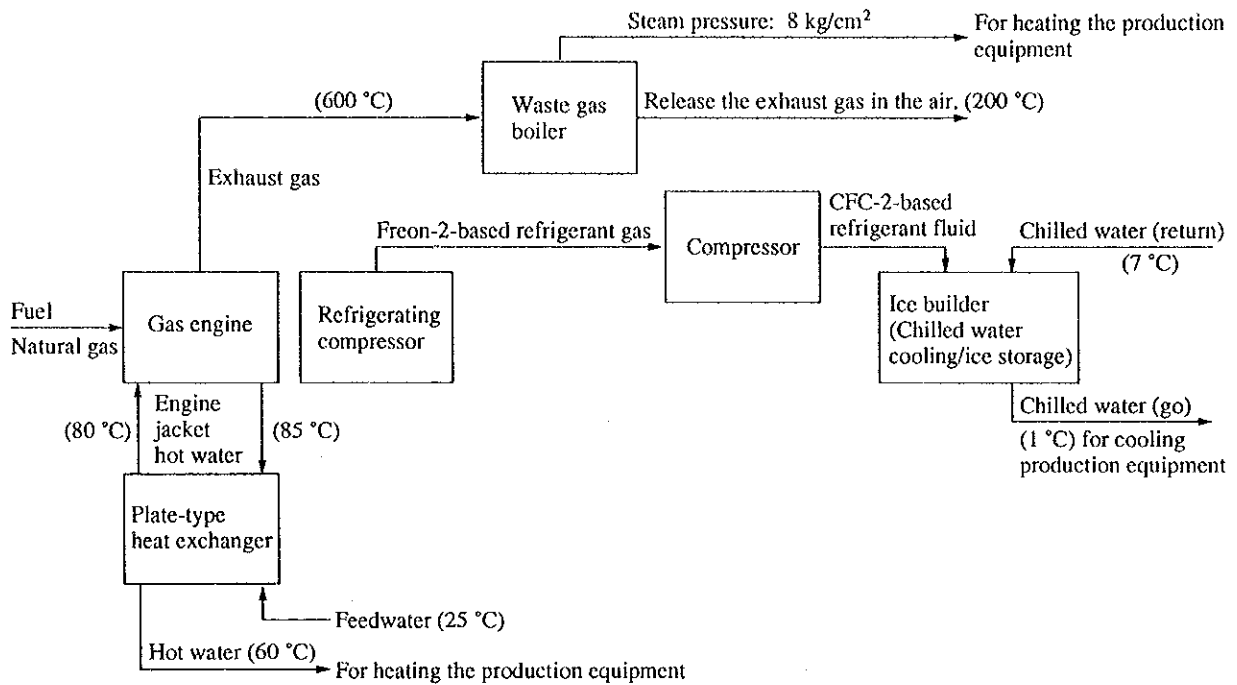
(6) Case of heat recovery from the gas discharged by the chiller

Items produced in the factory: Milk, raw cream, and ice cream
Annual energy consumption : Fuel (city gas)— 2,500,000 m³
                              Electricity   — 8,500 MWh

In food factories, many chillers are used as cooling equipment. The chillers use up 60 to 70 % of electricity consumed in the factory. Since the temperature of the gas delivered by a chiller is approximately 100 °C, hot water is made by recycling heat of the gas delivered by the chiller for the milk chilling water and used for flushing components. By reducing the fuel intensity from 38.2 m³/kL-Milk to 35.0 m³/kL-Milk, an 8 % improvement is achieved. The details are as follows.

The heat quantity that can be logically recovered from the chiller for milk-chilling water (Refrigerant NH_3, reciprocating type 170 kW, chilling capability 191 JRT, condensation capability 220 JRT) is 3.06 GJ/h (= 220 JRT × 13,900 kJ/JRT/h). For service water to be used in the factory, industrial service water is used for cooling and city water is used for washing components and drinking. Except for the water for drinking, all water is heated by steam. The temperature for use is 35 to 45 °C for normal hand washing and 60 °C for C.I.P rinsing.

Table 5.3.4 gives the temperature of city water. For six months during which the water temperature is 15 °C or lower, the condensation heat quantity of NH_3 gas is recovered. For six months during which the water temperature is higher than 16 °C, approximately the compression heat quantity is recovered. For economic calculation, the heat quantity recovered in six months from November to April was used. Table 5.3.5 givess the plan of the water temperature by month, condensation temperature, and collected heat quantity.

Table 5.3.4 Average Temperature of City Water by Month

Month	4	5	6	7	8	9	10	11	12	1	2	3
Temperature	14	18	22	25	25	23	19	15	11	9	7	8

Table 5.3.5 Plan of Water Temperature, Condensation Temperature and Recovered Heat

Month	Primary heat exchanger		Secondary heat exchanger		Condensation temperature	JRT recovered heat value	Remarks
	Inlet	Outlet	Inlet	Outlet			
4	24	29	14	26	35	73967	
5 to 10						No recover	
11	25	30	15	27	35	80730	
12	26	33	11	23	33	67363	
1	24	31	9	21	31	54500	
2	22	30	7	19	30	50820	
3	23	30	8	20	30	63085	
					Total	390465	

To give priority on safety in the food factory, a double heat exchanger was used for the heat recovery device. For the primary heat exchanger, a horizontal type shell and tube condenser is installed before the evaporation controller. The hot water after being heat-exchanged in the condenser is further heat-exchanged with city water to be used in the field, by means of a plate heater. In case the refrigerant (NH_3) should leak from the device, it is not mixed into city water to be used. A highly heat-retaining underground tank with a capacity of 200 m^3 is used as the city water storage tank after heat recovery.

Figure 5.3.13 shows the flow of the heat recovery device.

Figure 5.3.13 Flow Sheet of Heat Recovery System

730,000 kcal/M 120 m²
shell & tube heat recovery device

Air cylinder valve
temperature detection

Overheat tank

Over-
heat
tank

To the site (field)

Evaporation controller

Rooftop

2nd floor

Chiller

Receiver

Plate-type
heat exchanger

Active carbon

Mixing

SV

FMV

1st floor

Jacket;
milk freezing

Water
receiving
tank

Under-
ground
water tank

P
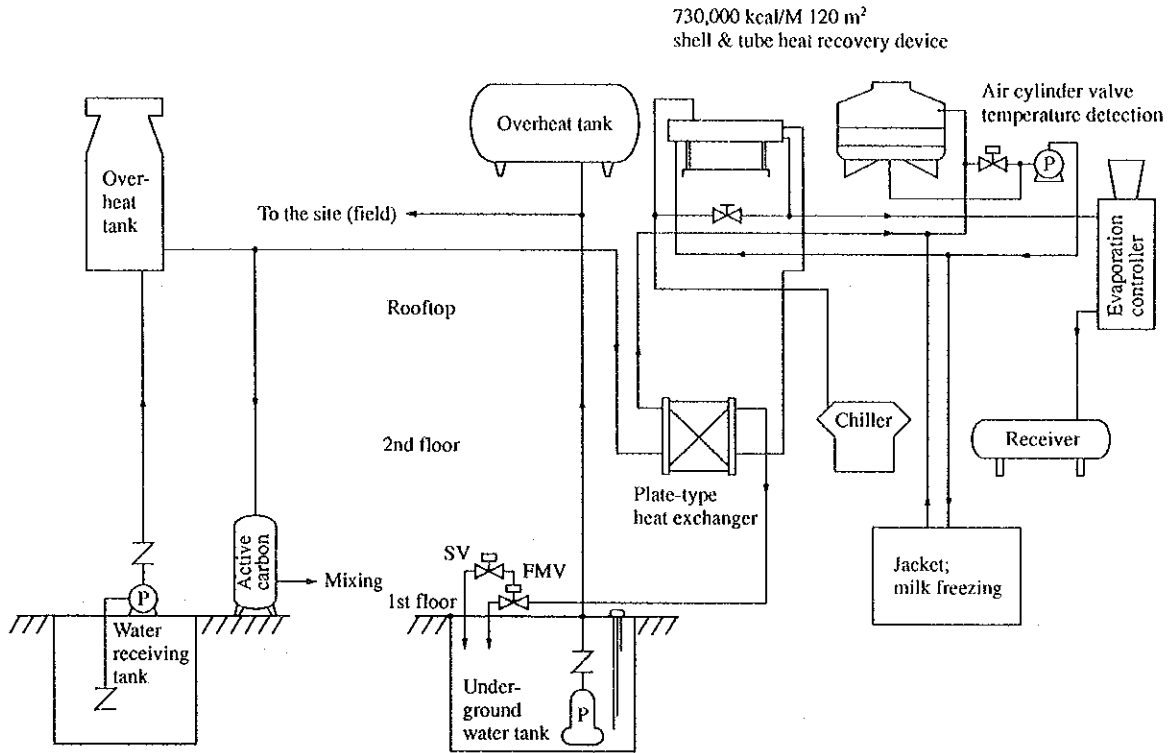
Figure 5.3.14 shows the transition of the fuel intensity before and after heat recovery. The volume of fuel used in the winter season, during which the fuel cost is high, is reduced. The demand contract volume (maximum time) is reduced from 980 m³ to 930 m³, so that fuel cost reduction can be achieved.

Figure 5.3.14 Trend of Fuel Intensity before and after Heat Recovery

1982
1983

Fuel intensity (m³/kl)

50

40

30

20

4 5 6 7 8 9 10 11 12 1 2 3 (Month)
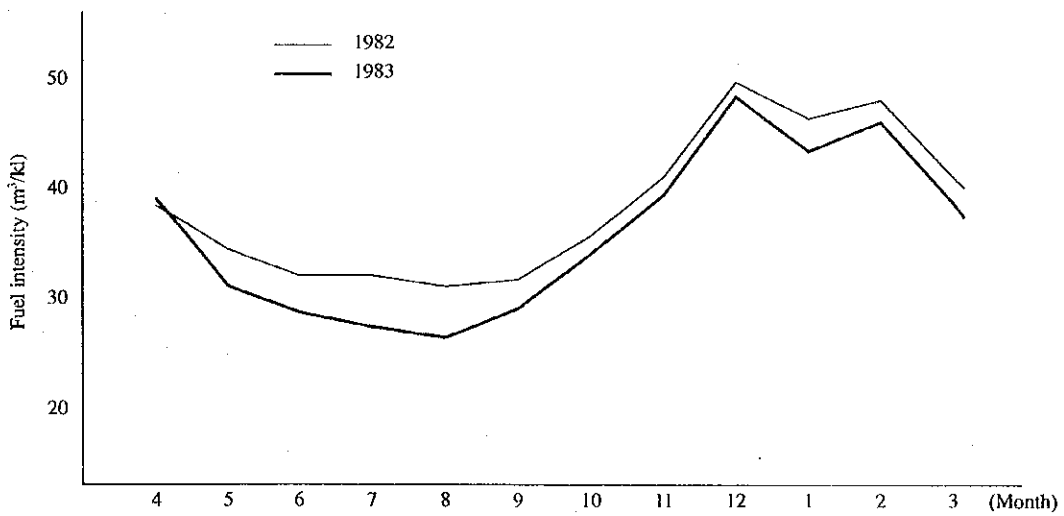
6. ENERGY CONSERVATION IN LIGHTING

6. LIGHTING

6.1 Terms and Unit of Lighting

6.1.1 Luminous Flux

A light source radiates various wavelength energies. Among these, only the energy levels between wavelengths 380 and 780 nm can be sensed by the human eye as light. The amount of radiant energy which passes through a given plane in unit time is called radiant flux. The amount of radiant flux passing through a filter that has the sensitivity of the human eye (luminosity factor) is called luminous flux. Luminous flux is expressed in lumens (lm).

6.1.2 Luminous Intensity

Even when light is radiated in all directions from a light source, the strength of light often varies depending on the direction. Luminous intensity is used to express the strength of light in such a direction and is given by the luminous flux per unit solid angle in a given direction. Luminous intensity is expressed in candela [cd].

6.1.3 Illuminance

Illuminance is used to express the degree of brightness of a surface illuminated by a light source. It is given by the incoming beams per unit area. Illuminance is expressed in lux (lx).

6.1.4 Luminance

Some light sources radiate brighter than others when viewed. This happens because the amount of light which enters the eye from each portion varies. Luminance is the amount of light corresponding to the brightness sensed by the human eye looking at an object. The luminance in a given direction at a specific point on a luminescent plane is calculated by dividing the luminous intensity in a given direction of an extremely small area, including this point, by a projected area in this direction. Luminance is expressed in candela per square meter (cd/m^2).

6.1.5 Luminous Exitance

Luminous exitance is the degree of brightness sensed by the human eye. It is given by the luminous flux emitting from a unit area. Luminous exitance is expressed in lumens per square meter (lm/m^2).

6.1.6 Distribution of Luminous Intensity

The distribution of luminous intensity for each direction of a light source or luminaire is called light distribution. The curve which expresses the luminous intensity distribution of light radiated in all directions in a space from the center of a light source or the light measuring center of the luminaire is called the luminous intensity distribution curve.

6.2 Color Temperature and Color Rendering Properties of a Light Source

6.2.1 Color Temperature

When a blackbody (ideal radiator) is heated and its temperature increases, it starts emitting light. This light has a dependence on the surface temperature of the blackbody, and the luster increases as temperature increases. The color gradually turns whiter from red. The color will change in the following manner: red → yellowish red → white → bluish white. The color temperature of a light source is expressed by the absolute temperature (K: Kelvin) of a blackbody when the color of the light of this body equals the apparent color of the light of a specific light source.

6.2.2 Color Rendering Properties

If the composition of the lighting varies, the composition of the light reflected from an identical object also varies. As a result, the color will be different. The influence of lighting made on the appearance of the color of an object is called color rendering. The color rendering index is used as a scale to determine whether the color rendering of a light source is good or poor. The color rendering index is a numeric value obtained by comparing the appearance of the selected 8 types of test colors among 15 types produced by a lamp with that produced by a standardized light source (the color temperatures of both lamp and light source are the same), and expresses the difference in color. The average color rendering index Ra is calculated and expressed by an average value of the color difference in an individual test color with 8 hues (the middle brightly colored hues with equal brightness) among the 15 types of test colors.

6.3 Light Source

6.3.1 Performance Factors of Light Source

An incandescent lamp, fluorescent lamp and High Intensity Discharge (HID) lamp are used as light sources for general-purpose lighting. (HID lamp is a generic name for high-pressure mercury lamps, metal halide lamps and high-pressure sodium lamps.) Table 6.1 summarizes the main factors which indicate the performance of these light sources.

Table 6.1 Performance Factors of Light Source

Element	Description
1. Total luminous flux	The amount of light radiated from a light source per unit time. Unit: lm
2. Lamp efficiency	Value obtained by dividing the total luminous flux of a light source (lamp) by the input power of a lamp. Unit: lm/W
3. Overall efficiency	Value obtained by dividing the total luminous flux of a light source (lamp) by the input power of a lamp and a lighting circuit. Unit: lm/W The loss of input power is 5 to 20 % depending on the type of lighting circuit.
4. Light color	The color temperature (K) serves as a guide. The color of an incandescent lamp is approximately 2,850K, and that of a daylight is approximately 6,500 K.
5. Color rendering properties	Expressed by the color rendering index Ra. A lamp whose Ra value is closer to 100 has better color rendering properties.
6. Luminance	When a lamp has high luminance, it will affect glare. Unit: cd/m^2
7. Life	The period until the life of a light ends or until the luminous flux drops below the specified value, whichever comes first. The rated life indicated by a manufacturer means average life when a number of light sources are used under normal conditions.
8. Lumen maintenance factor	A value (%) obtained by dividing the luminous flux value of the rated life period by the initial luminous flux value.
9. Starting characteristics	Indicates the initial startup state of lighting. The luminous flux of an incandescent lamp and fluorescent lamp stabilizes comparatively fast. However, it takes several minutes or more until the luminous flux of a HID lamp becomes stable.
10. Dimming	Dimming may be necessary for power saving. Incandescent and fluorescent lamps can be dimmed in a continuous dimming operation. A mercury lamp and high-pressure sodium lamp can be dimmed stepwise only.

6.3.2　Incandescent Lamp

The current is passed along the filament in a bulb to heat it to 2,000 °C or more. Thus, the lamp utilizes the luminescence produced by thermal radiation to give light. The characteristics of this lamp are given below.

(1)　Close to a point light source and easy light control.
(2)　Excellent color rendering properties and warm whitish light.
(3)　Easy to light; no need of a ballast stabilizer. (A stabilizer is required for others than incandescent lamp)
(4)　Allows dimming in a continuous operation.
(5)　Excellent lumen maintenance factor.
(6)　Low efficiency and short life.
(7)　Easily affected by power voltage fluctuations (the life in particular).
(8)　Large heat wave radiation (infrared radiation).

6.3.3　Fluorescent Lamp

The ultraviolet rays (mainly the wavelengths of 253.7 nm and 185 nm) radiated by electric discharge in low-pressure (0.6 - 0.8 Pa) mercury vapor excite the luminophor and the light is converted into visible light. The lamp gives off this visible light. The characteristics of this lamp are given below.

(1)　High efficiency and long life.
(2)　Variety of light colors.
(3)　Tube-shaped lamp. Low surface luminance and less flare.
(4)　Low surface temperature.
(5)　Easily affected by ambient temperature.
(6)　Comparatively large size (length).
(7)　High output lamps not available (maximum 220 W).
(8)　Allows dimming in a continuous operation.

6.3.4　High-pressure Mercury Lamp

A high luminance discharge lamp which gives off light radiated by an arc discharge in a mercury vapor atmosphere of 100 kPa or more. The characteristics of this lamp are given below.

(1)　Compact luminous lamp portion and comparatively easy light control.
(2)　Available in a large number of sizes (wattage). (40 W to 20 kW)
(3)　Long life.
(4)　Starting and restarting take time.
(5)　Inadequate color rendering properties.
(6)　Allows dimming stepwise only.

6.3.5 Metal Halide Lamp

A high luminance discharge lamp utilizing a unique metal structure which gives off light radiated by an arc discharge in a vapor of a metal halogen compound (iodide compounds such as sodium, thallium, indium, scandium, dysprosium, and tin used singly or in a combination). The characteristics of this lamp are given below.

(1)   Compact luminous lamp portion and comparatively easy light control.
(2)   Available in various sizes (wattage). (50 W to 2 kW)
(3)   Variety of light colors and high color rendering properties.
(4)   Starting and restarting take time.
(5)   Light color dispersion occurs sometimes with the lapse of lighting time.
(6)   No dimming.

6.3.6 High-pressure Sodium Lamp

A high intensity discharge lamp which gives off light radiated by arc discharge in a sodium vapor of approximately 10 kPa. The characteristics of this lamp are given below.

(1)   Highest efficiency among general-purpose lighting sources (near-white light source).
(2)   Compact luminous lamp portion and comparatively easy light control.
(3)   Available in various sizes (wattage). (35 W to 1 kW)
(4)   Long life and excellent lumen maintenance factor.
(5)   Starting and restarting take time. Shorter than other HID lamps.
(6)   The light color of a general high-pressure sodium lamp is yellowish white with low color rendering properties. There are lamps, however, which offer high color rendering properties.
(7)   Large change of luminous flux caused by power supply voltage fluctuation.
(8)   Allows dimming stepwise only.

6.3.7 Low-pressure Sodium Lamp

A hot cathode discharge lamp which gives off light of yellowish orange D rays (589.0 nm and 589.6 nm) radiated by an arc discharge in sodium vapor of approximately 0.5 Pa. The efficiency of this lamp is highest among practical light sources. The color rendering properties of this lamp are extremely poor because of the single light color (yellowish orange). It is not possible to identify colors under this light.

6.3.8 Comparison of Characteristics of Various Light Sources

Incandescent, fluorescent, high-pressure mercury, metal halide, and high-pressure sodium lamps are used as general-purpose light sources. These light sources have individual characteristics and must be selected after considering the purpose and application of lighting. As a reference for proper selection of a light source, Table 6.2 provides the comparison table of various light sources while Table 6.3 lists their applications.

Table 6.2 Comparative Examples of the Characteristics of Various Light Sources

	Type of light source	Lamp power (W)	Total luminous flux[1] (lm)	Lamp efficiency (lm/W)	Overall efficiency[2] (lm/W)	Color temperature (K)	Average color rendering index Ra	Life (h)
Incandescent lamps	White coated lamp	100	1,520	15.2	15.2	2,850	100	1,000
	White thin film coated lamp*	95	1,520	16.0	16.0	2,850	100	1,000
	White coated ball lamp	100	1370	13.7	13.7	2,850	100	2,000
	Floodlighting tungsten halogen lamp	500	10,500	21.0	21.0	3,000	100	2,000
	Small tungsten halogen lamp	500	9,500	19.0	19.0	3,000	100	2,000
Fluorescent lamps	Fluorescent lamp White	40	3,100	78	61	4,200	64	12,000
	Fluorescent lamp High color rendering	40	2,400	60	47	5,000	92	12,000
	Fluorescent lamp* White	37	3,100	84	67	4,200	64	12,000
	Fluorescent lamp* 3-wavelength zone luminescence type	37	3,350	91	73	5,000	84	12,000
	Rapid start fluorescent lamp White	40	3,000	75	59	4,200	64	12,000
	Rapid start fluorescent lamp High color rendering	40	2,380	60	47	5,000	92	12,000
	Rapid start fluorescent lamp 3-wavelength zone luminescence type	40	3,450	79	68	5,000	88	12,000
	Rapid start fluorescent lamp* White	36	3,000	83	65	4,200	64	12,000
	Compact type fluorescent lamp (Dual-tube type) 3-wavelength zone luminescence type	36	2,900	81	67	5,000	88	7,500
	Bulb type fluorescent lamp (ball shape) Bulb color	17	760	45	45	2,800	82	6,000
	Hf fluorescent lamp (Dedicated lamp for high frequency lighting)	32	3,200	100	84	5,000	88	12,000
HID lamp	Mercury lamp Transparent	400	20,500	51	48	5,800	23	12,000
	Fluorescent mercury lamp	400	22,000	55	52	4,100	44	12,000
	Mercury lamp with built-in ballast stabilizer	500	14,000	28	28	4,200	57	9,000
	Metal halide lamp Diffusion type	400	32,000	80	76	5,000	65	9,000
	Metal halide lamp, low starting voltage type Diffusion type	400	38,000	95	87	3,800	70	9,000
	Metal halide lamp High color rendering	400	19,000	48	41	5,000	92	6,000
	High-pressure sodium lamp Diffusion type	400	50,000	125	111	2,100	25	12,000
	High-pressure sodium lamp, high color rendering type Diffusion type	400	21,500	54	48	2,500	85	9,000
	High-pressure sodium lamp, with built-in starter* Diffusion type	360	48,500	135	121	2,100	25	12,000
	High-pressure sodium lamp, improved color rendering type* Diffusion type	360	36,000	100	90	2,100	60	12,000
	Low-pressure sodium lamp	180	31,500	175	140	–	–	9,000

Lamps marked with an asterisk (*) have a power-saving design.

*1: The total luminous flux for an incandescent lamp indicates a zero-hour value; that for other lamps indicates a 100-hour value.

*2: Indicates the efficiency including the ballast stabilizer loss. The calculation is performed assuming that the ballast stabilizer is a 200 V single-lamp high-power-factor model.

# Table 6.3 Selection of Lamps from Standpoints of Typical Applications

		Incandescent lamp			Fluorescent lamp			Mercury lamp				Halide lamp		Sodium lamp		Xenon lamp
	Class of lamps	General lamp	Reflector lamp	Halogen lamp	General fluorescent lamp	High color rendering properties	High output type	Transparent mercury lamp	Fluorescent mercury lamp	Reflector mercury lamp	Stabilizer built-in type	General type	High lustrous type	High pressure	Low pressure	Xenon lamp
Residence		◎	○	△	◎	○	×	×	×	×	×	×	×	×	×	×
Office	General office	△	△	△	◎	△	○	×	×	×	×	△	△	×	×	×
	High-ceiling office, lobby	○	○	○	○	△	○	×	○	○	△	◎	○	×	×	△
	Single room, drawing room	○	○	△	◎	○	×	×	△	×	×	△	△	×	×	×
Store	General stores	◎	◎	○	◎	◎	○	×	○	△	△	△	△	×	×	×
	High-ceiling stores	○	○	○	○	○	◎	×	○	○	○	◎	○	△	×	△
	Exhibits, showcase	◎	◎	◎	◎	◎	○	×	△	△	○	○	○	×	×	△
Factory	Low-ceiling factory	△	△	○	◎	○	○	×	△	△	△	△	△	△	×	×
	High-ceiling factory	△	△	○	△	△	◎	×	◎	○	○	◎	○	○	×	△
	Warehouse	○	△	○	◎	△	○	△	◎	○	○	○	△	○	×	×
School	Class room	△	△	△	◎	○	△	×	△	×	×	△	△	×	×	×
Hospital	Operating room	○	○	△	◎	◎	△	×	×	×	×	×	×	×	×	×
Theater, hall	Spectator's seats	◎	◎	◎	◎	○	△	×	△	△	△	○	○	×	×	△
	Stage	◎	◎	◎	◎	○	○	×	△	△	△	△	△	×	×	△
Art museum, museum	General	◎	◎	○	○	◎	△	×	△	△	△	○	○	×	×	△
	Exhibits	◎	◎	○	○	◎	△	×	×	×	×	○	○	×	×	△
Roads	Automobiles exclusive roads	×	×	×	△	×	×	△	◎	×	×	△	×	○	○	△
	Automobiles exclusive tunnel	×	×	×	△	×	×	△	○	×	×	△	×	○	◎	×
	Streets	△	×	×	○	×	×	△	◎	△	△	△	△	○	△	×
	Shopping streets	○	×	○	○	△	◎	×	◎	△	△	◎	△	○	×	×
	Roads in resident area	○	×	×	○	×	×	△	◎	△	×	△	×	○	×	×
Parking zone	Indoor	△	△	△	◎	×	○	×	○	△	△	△	△	○	×	×
	Outdoor	△	△	△	○	×	×	△	◎	○	△	△	△	○	△	△
Open space, park, garden		○	△	△	○	△	×	△	◎	△	△	○	△	○	×	△
Floodlight lighting	Structure	○	○	○	×	×	×	△	◎	◎	○	○	○	○	△	○
	Advertisement, signboards	○	◎	◎	○	○	○	△	◎	◎	△	○	○	△	×	○
Sports	Indoor	○	○	◎	○	○	○	△	◎	○	△	◎	○	△	×	△
	Outdoor	○	○	○	×	×	×	△	◎	○	△	◎	○	◎	×	○

Figure 6.1 shows the residual percentage characteristics and lumen maintenance factor which are the life characteristics of various light sources.

Figure 6.1 Life Characteristics of Various Light Sources
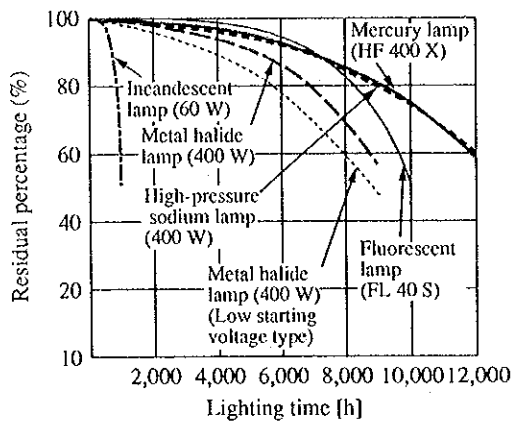
(a) Residual percentage curves of various light sources
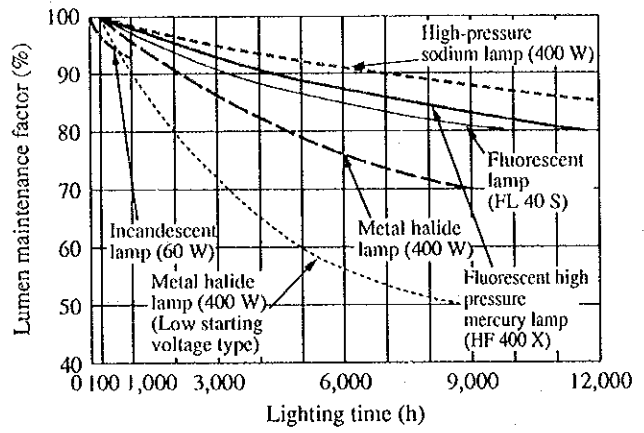
(b) Lumen maintenance characteristics of various light sources(based on 100-hour lighting as 100 % for lamps other than incandescent lamps)