

## 6.3 Theoretical Background

### 6.3.1 Blending of Raw Materials

The material composition of portland cement is usually expressed by the following indexes.

$$\text{Hydraulic modulus (H.M.)} = \frac{\text{CaO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 1.7 \text{ to } 2.4$$

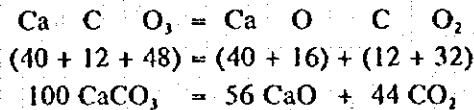
$$\text{Silica modulus (S.M.)} = \frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 1.2 \text{ to } 4.0 \text{ (usually } 2.4 \text{ to } 2.7)$$

$$\text{Iron modulus (I.M.)} = \frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3} = 1.0 \text{ to } 4.0 \text{ (usually } 1.5 \text{ to } 2.5)$$

In addition, as a reference for limestone content, limestone reference "k" (indicated in %; lime saturation degree L.S.D.) is used, which is 90 to 95 for ordinary portland cement, while it is 95 to 98 for early-strength portland cement.

$$K = \frac{100 \text{ CaO}}{2.8\text{SiO}_2 + 1.1\text{Al}_2\text{O}_3 + 0.7\text{Fe}_2\text{O}_3}$$

Provided that the blending ratio of lime materials is given, the amount of materials necessary to produce 1 kg of clinker is expressed as follows: First, when limestone is decomposed by heating, 44% carbon dioxide is released as shown in the following equation, resulting in weight reduction.



Approximately 7% water of crystallization is taken out of the clay. Therefore, the ratio of the amount of the required blending material and the clinker to be obtained can be calculated by the following formulas.

$$a = 1 - \frac{0.44 \times \% \text{ CaCO}_3}{100} - \frac{0.07 \times (100 - \% \text{ CaCO}_3)}{100} = \frac{\text{Clinker kg}}{\text{Blending material kg}}$$

$$b = \frac{1}{a} = \frac{\text{Blending material kg}}{\text{Clinker kg}}$$

$$c = \frac{\% \text{ CaCO}_3 \times 56}{a \times 100} = \text{CaO percentage in clinker}$$

For example, ignition loss (ig. loss) when the blending material including 76 % limestone is heated can be obtained as follows:

$$\begin{array}{r} \text{From CaCO}_3, 0.76 \times 0.44 \text{ kg CO}_2 = 0.3344 \text{ kg CO}_2 \\ \text{From Clay } 0.24 \times 0.07 \text{ kg H}_2\text{O} = 0.0168 \text{ kg H}_2\text{O} \\ \hline \text{Total ig. loss} = 0.3512 \text{ kg} \end{array}$$

This means that about 0.649 kg of clinker can be produced from 1 kg of blending materials including 76 % CaCO<sub>3</sub>. In other words, 1.541 kg of raw materials is theoretically required for producing 1 kg of clinker.

Raw materials actually used are composed of various constituents, which should be skillfully blended to produce such raw materials as will satisfy the values within the index range. If the components thus obtained fail to satisfy the requirement, the third substance will have to be added to fill the insufficiency.

(1) When the component ratio of CaCO<sub>3</sub> necessary in the blending material is given:

The blending ratio of two raw material components can easily be obtained by applying a proper value to X.

Supposing that X (CaCO<sub>3</sub> content required in the material mixture) is 76 %, a formula can be obtained based on the following material content, as given below.

$$a = \text{CaCO}_3 \text{ contained in limestone} = \frac{52.9 \times 100}{56} = 94.5\%$$

$$b = \text{CaCO}_3 \text{ contained in clay} = \frac{4.3 \times 100}{56} = 7.7\%$$

$$\begin{array}{r} a \quad \nearrow y \\ \quad X \\ b \quad \nwarrow x \end{array} \quad \begin{array}{l} x = 94.5 - 76 = 18.5 \\ y = 76 - 7.7 = 68.3 \end{array}$$

%	Material analytical value (Example)						
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	ig.loss	S.M
Limestone	2.9	1.1	0.8	52.9	0.3	42.0	1.53
Clay	50.4	22.2	8.5	4.3	2.1	12.5	1.64

$$\text{Conclusion: } \frac{\text{Limestone}}{\text{Clay}} = \frac{68.3}{18.5} = \frac{3.69}{1}$$

(provided that the molecular weight of CaCO<sub>3</sub> and CaO is 100 and 56, respectively.)

(2) When hydraulic modulus (H.M) is given:

The blending ratio can be expressed by the following formula.

$$\frac{\text{Limestone}}{\text{Clay}} = \frac{\text{H.M.} \times \text{S} - \text{C}}{\text{C}_1 - \text{H.M.} \times \text{S}_1}$$

where

H.M. (hydraulic modulus): 2

S : Ratio of ( $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ ) in clay

C : Ratio of (CaO) in clay

$\text{S}_1$  : Ratio of ( $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ ) in limestone

$\text{C}_1$  : Ratio of (CaO) in limestone

By applying the analyzed values of the raw material indicated in a), the following result can be obtained.

$$\frac{\text{Limestone}}{\text{Clay}} = \frac{2 \times 81.1 - 4.3}{52.9 - 2 \times 4.8} = \frac{3.65}{1}$$

As a result, the composition of the blending material will be as follows:

	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	CaO	MgO	ig.loss
Raw blending material	13.12	5.64	2.45	42.45	1.69	35.65
Post-ignition material	20.39	8.76	3.81	65.97	1.07	

S.M: 1.62

I.M: 2.3

K : 95.1

(3) Calculation based on the CaO content in cement

$$x = \frac{\text{CaO \% (Raw lime ash)} - \text{CaO \% (Cement)}}{\text{CaO \% (Cement)} - \text{CaO \% (Clay)}}$$

Here, X is the ratio of clay to limestone 1; the values of post-ignition material are applied to CaO % (Raw lime ash) and CaO % (clay).

(4) Calculation for blending 3-constituent materials

Supposing that the mixing ratios of limestone, clay and silica sand in the blending materials are X, Y and Z, respectively, and that hydraulic modulus and silica modulus are given, the following 3 formulas will be established.

$$X + Y + Z = 1 \quad (1)$$

$$\frac{\text{CaO \% (Limestone)} \times X + \text{CaO \% (Clay)} \times Y + \text{CaO \% (Silica sand)} \times Z}{(\text{SiO}_2 + \text{R}_2\text{O}_3) \% (\text{Limestone}) \times X + (\text{SiO}_2 + \text{R}_2\text{O}_3) \% (\text{Clay}) \times Y + (\text{SiO}_2 + \text{R}_2\text{O}_3) \% (\text{Silica sand}) \times Z} = \text{H.M.} \quad (2)$$

$$\frac{\text{SiO}_2 \% (\text{Limestone}) \times X + \text{SiO}_2 \% (\text{Clay}) \times Y + (\text{SiO}_2) \% (\text{Silica sand}) \times Z}{(\text{R}_2\text{O}_3) \% (\text{Limestone}) \times X + (\text{R}_2\text{O}_3) \% (\text{Clay}) \times Y + (\text{R}_2\text{O}_3) \% (\text{Silica sand}) \times Z} = \text{S.M.} \quad (3)$$

where  $\text{R}_2\text{O}_3 = \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$

Solving these simultaneous equations by giving H.M and S.M values, and composition ratios of raw materials allow X, Y and Z to be obtained. Concerning the composition of raw materials, the value corresponding to each condition will be obtained irrespective of use of the value for raw materials, or the use of post-ignition materials.

The following example is based on the composition of the raw materials, where H.M is 2.0 and S.M is 1.6.

	%	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	ig.loss	Blending ratio
Limestone	X	4.4	2.7	2.5	49.3	0.5	40.6	0.825
Clay	Y	32.5	22.5	10.6	21.5	2.1	10.8	0.111
Silica sand	Z	94.4	2.5	1.8	0.5	-	0.8	0.064
Blending material		13.27	4.89	3.36	43.09	0.64	34.75	1.000

There are other calculation formulas recommended, and simple methods for obtaining an approximate value by means of diagram, which are omitted herein.

To obtain a product of high strength and stable quality, higher H.M and S.M values are preferable. This, on the other hand, makes raw materials difficult to burn, consuming a considerable amount of fuel if the burning technique is insufficient. Therefore, the blending ratio in actual cases should be decided depending on the actual situation after many trial and error operations within the allowable range of the above-mentioned calculated values for the ratio.

### 6.3.2 Theory of Grinding

#### (1) Required energy

The following equations have been so far proposed to express the relationship between the power necessary for grinding and the grain diameter of the material to be ground

$$\text{Lewis} \quad dE = -C \frac{dx}{x^n} \quad (1)$$

$$\text{Rittinger} \quad E = C \left( \frac{1}{x_2} - \frac{1}{x_1} \right) \quad (2)$$

$$\text{Kick} \quad E = C \log \left( \frac{x_1}{x_2} \right) \quad (3)$$

$$\text{Bond} \quad E = C \left( \frac{1}{\sqrt{x_2}} - \frac{1}{\sqrt{x_1}} \right) \quad (4)$$

where

C, n : Constant

x : Grain diameter

$x_1, x_2$  : Representative diameters of a grinding material and a ground product, respectively

Formula (1) expresses the relationship between grinding work and a change in the grain diameter in a general form. This formula was originally proposed based on the unique idea. Integrating Formula (1) with n as 1, 1.5 and 2 allows (3), (4) and (2) to be obtained, respectively.

Formula (2) is called Rittinger's theory, which was derived from the hypothesis that the energy required for grinding is directly proportional to the increase in the surface area of a material. This equation may hold good under the ideal condition of physical grinding of a single grain, but it does not apply so well to the actual industrial situation, because of inter-granular friction and mechanical loss.

Formula (3) is called Kick's theory, which is based on the hypothesis that when two geometrically similar objects are subjected to similar deformation, the work amount required for this is proportional to the volume of the both objects or their weight. This formula can be used for crushing homogenous materials but is not applicable to the pulverizing zone.

Formula (4) was proposed by Bond in 1952; this formula is called the 3rd theory different from the above-mentioned two theories. Assuming that the energy required for grinding a cubic body with a side length  $x$  is initially proportional to  $x^3$ , and then to  $x^2$  in the pulverizing zone, it can be considered actually proportional to  $x^{2.5}$ , an intermediate value between the two. On the other hand, the number of grains in the unit volume is reversely proportional to  $x^3$ ; therefore the grinding power per unit weight will be proportional to  $1/\sqrt{x}$ .

Each of these formulas represents a different part of the complicated grinding mechanism in spite of some theoretical ambiguity. However, by giving the coefficient  $c$  according to the situation through extensive experiments, the use of these formulas will allow comparative calculations of power required for various kinds of grinders.

Bond's third theory is applied in the following formulas to ball mills generally used in the cement industry.

$$W = C_n W_i \left( \frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}} \right) \quad (5)$$

where

- $W$  : Power required for grinding materials      kWh/sh.t
- $W_i$  : Work index according to Bond's test mill      kWh/sh.t
- $P$  : Microns 80% of the product passing       $\mu$
- $F$  : Microns 80% of the feed passing       $\mu$
- $C_n$  : Constant

$$W_i = \frac{16}{G_{bp}^{0.82}} \sqrt{\frac{P_i}{100}} \quad (6)$$

where

- $W_i$  : Work Index      kWh/sh.t
- $G_{bp}$  : Grindability index according to Bond's ball mill method
- $P_i$  : Product size (microns ( $\mu$ ) of sieve)

Actual power required can be obtained by calculating  $G_{bp}$ , i.e., the grindability of an object to be ground according to the Bond's wet-process test mill method, converting  $G_{bp}$  thus obtained into a specific power consumption index, and then correcting the value according to the characteristics of actual mill by the use of some correction factors.

As a method of calculating the grindability index other than the above method, there is Hardgrove's theory available. The relationship between these two is expressed in the following empirical formula.

$$Wi = \frac{435}{Hg^{0.91}} \quad (7)$$

Hg: Grindability index according to Hardgrove's test mill

These calculation formulas with their own clear characteristic are adequate enough to conduct a comparative evaluation in terms of energy conservation, though they involve some difficulty in determining a correction factor. The performance of other similar equipment can be estimated by conducting comparative tests of material physical properties using the same test mill. An accurate estimation of the result is also available when the operating conditions alone are to be changed with the equipment remaining as they are, since the material physical values and various coefficients remain unchanged.

(2) Ball mill driving power

The load power for the cross-sectional model in Figure 6.24 is expressed by the following formula.

$$N = \frac{W}{102} \times Y \sin \alpha \times 60 \frac{2\pi n}{60} \quad (1)$$

where

- N : Load power                      kW
- W : Weight of medium              kg
- Y : Distance from the center mill to the powder gravity    m
- $\alpha$  : Dynamic angle of repose      deg
- n : Rotation speed                    rpm

With some modifications, this can also be expressed as follows:

$$N = C \times G \times Di \times n \quad (2)$$

$$C : \text{Dynamic coefficient} = \frac{2\pi Y \sin \alpha}{6.120 Di} \quad (3)$$

- G : Weight of medium    t
- Di: Mill effective inner diameter    m

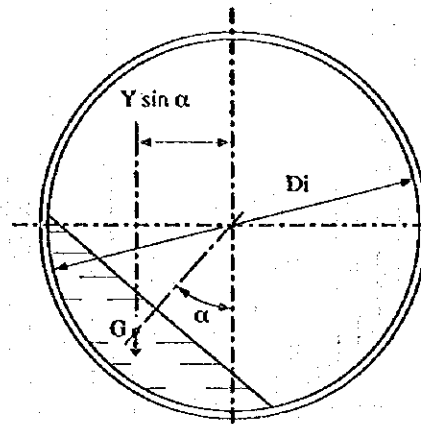
Or, it can be represented in the following formula.

$$N = C_1 \times G \times \sqrt{Di} \quad (4)$$

where

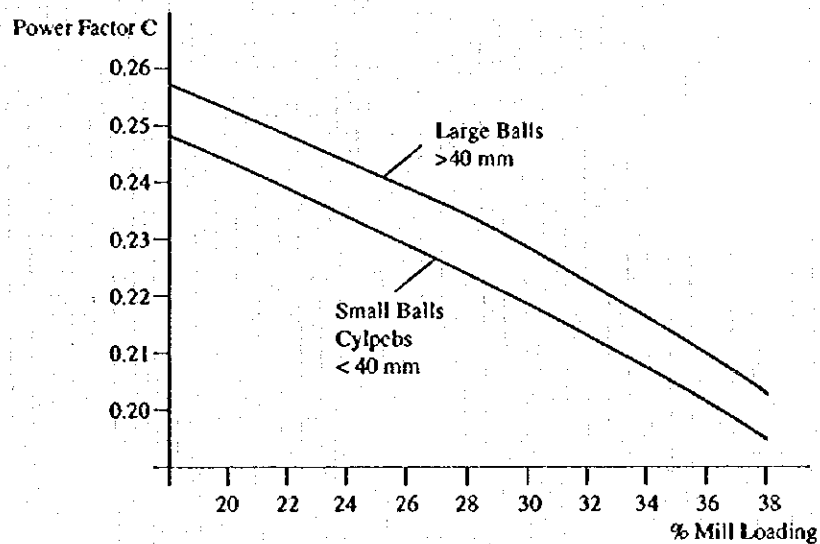
- n : 0.7 to 0.75  $n_o$                       rpm
- $n_o$  : Critical mill speed =  $\frac{42.5}{\sqrt{Di}}$     rpm

Figure 6.24 Mill Cross-sectional Model



Power factor  $C$  in Formula (2) is not constant as also found from Formula (3). It decreases as the volume filling factor of the grinding medium increases as shown in Figure 6.25.

Figure 6.25 Power Factor  $C$  for Determining the Mill Drive Power



An example for calculation;

When for a mill

$D_i$ : 2.93 m

$n$  : 16.8 rpm

$G$  : 95 t

and the filling factor  $\psi$ : 33 %



then,

$$C : 0.22$$

therefore,

$$N = 0.22 \times 95 \times 2.93 \times 16.8 = 1029 \text{ kW}$$

(3) Measurement of particle size

For raw materials and clinkers of larger diameters, a screening method by means of a standard sieve is employed, while for fine products such as mill products, an air separating method and an elutriation method are employed. An example of air-separating method is shown in Figure 6.26. Here, particles dispersed in the air are separated into the fine and coarse groups in a gravitational field with the desired particle diameter as a boundary by a specified ascending current to obtain a particle size distribution with the mass reduction at the coarse grain side as a standard.

Figure 6.26 Chujo-type Air Sieve

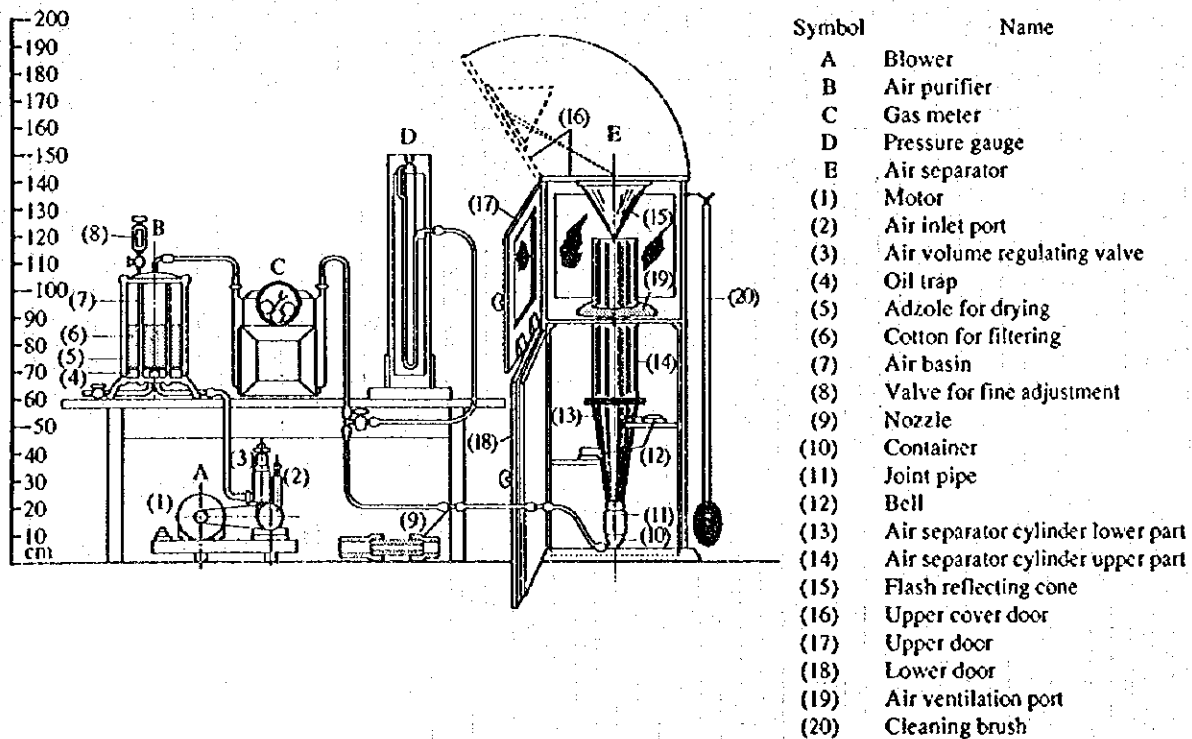
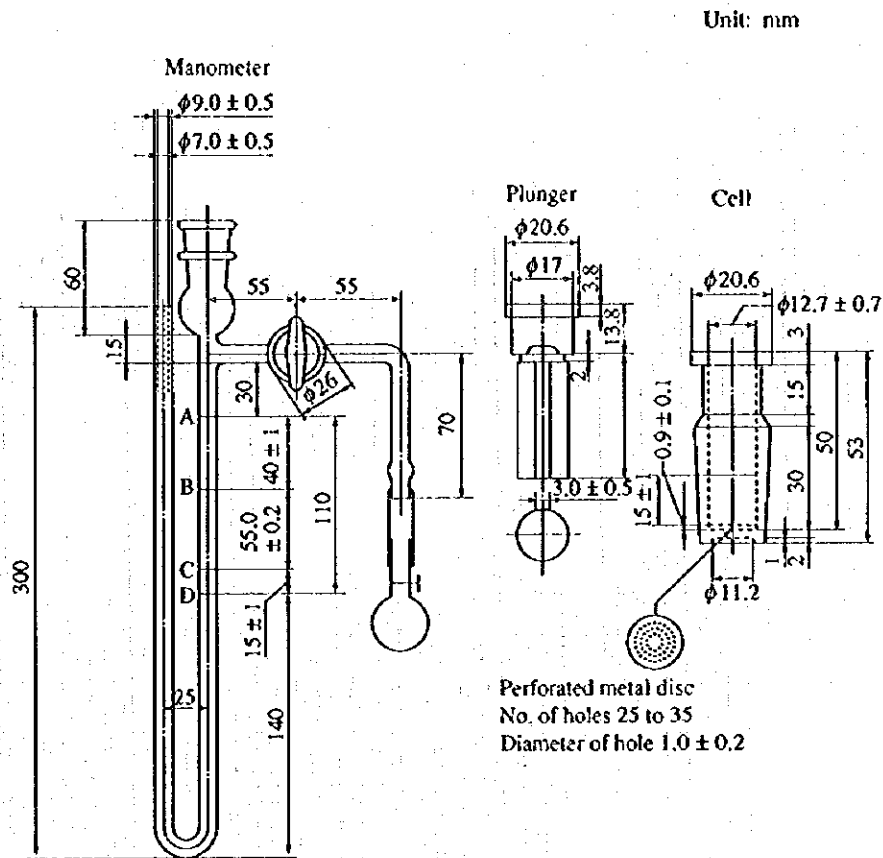


Figure 6.27 shows the device for measuring a Blaine value by means of the elutriation method specified in JIS R5201.

The measurement results can be obtained in terms of specific surface area (cm<sup>2</sup>/g).

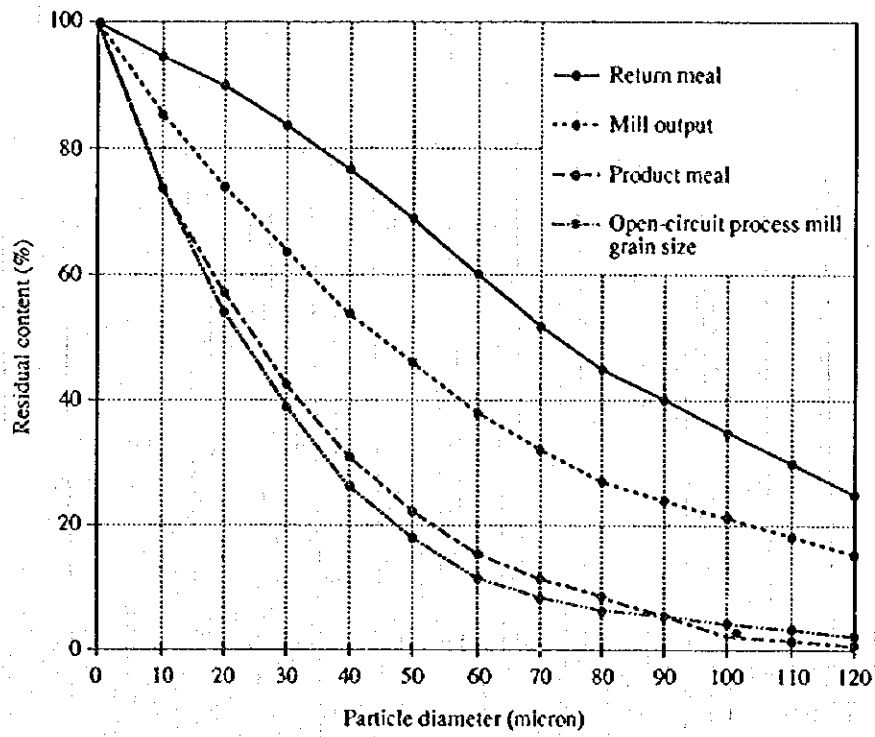
Figure 6.27 Blaine Value Measuring Device



(4) Particle size distribution and classification

Table 6.9 shows an example of particle size distribution of the cement mill product. The measuring results, usually represented as shown in Figure 6.28 and 6.29, are used for technical analyses. These figures allow evaluating the performance of the separator used for the mill and the closed-circuit system. Logarithmic cross-ruled paper, logarithmic probability paper, Rosin-Rammler diagram, etc. are used for expressing the measurement results, because they can represent particle size distributions in the form of index function, and because the particle diameters range widely from 1 to 100  $\mu$ .

**Figure 6.28 Particle Size Distributions of Cement Mill Products**



**Figure 6.29 Distribution Ratio to the Return Meal**

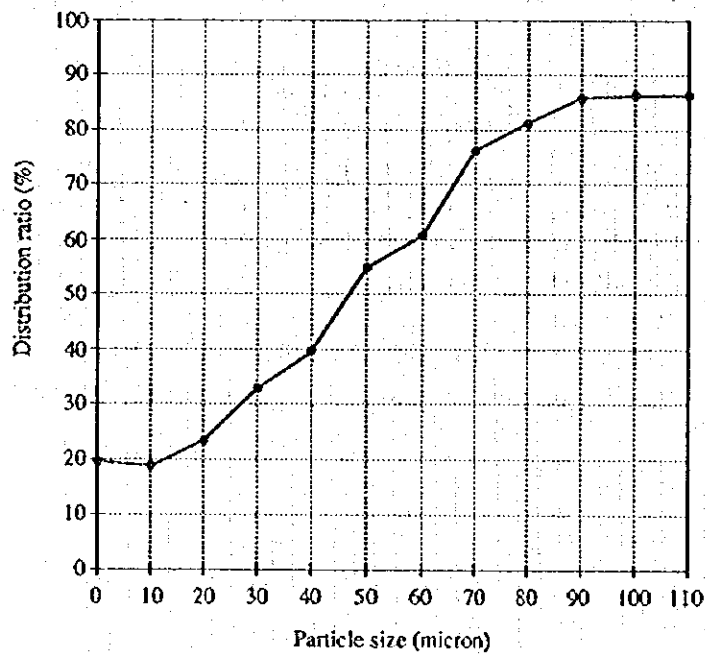


Table 6.9 Cement Mill Product Particle Size Distribution

Closed circuit process cement mill (Blaine value: 3160)													
Particle dia. range (micron)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120- Total
Return meal													
Distribution (%)	5	5	6	7	8	9	8	7	5	5	5	5	25
Passing product 1-R	0	5	10	16	23	31	40	48	55	60	65	70	75
Residue R	100	95	90	84	77	69	60	52	45	40	35	30	25
Weight (t)	1.45	1.45	1.74	2.03	2.32	2.61	2.32	2.03	1.45	1.45	1.45	1.45	7.25
Fine meal													
Distribution (%)	26	20	15	13	8	7	3	2	1	1	1	1	2
Passing product 1-R	0	26	46	61	74	82	89	92	94	95	96	97	98
Residue R	100	74	54	39	26	18	11	8	6	5	4	3	2
Weight (t)	5.98	4.6	3.45	2.99	1.84	1.61	0.69	0.46	0.23	0.23	0.23	0.23	0.46
Mill outgoing powder													
Distribution (%)	14	12	10	10	8	8	6	5	3	3	3	3	15
Passing product 1-R	0	14	26	36	46	54	62	67	72	75	79	82	85
Residue R	100	86	74	64	54	46	38	33	28	25	21	18	15
Weight (t)	7.43	6.05	5.19	5.02	4.16	4.22	3.01	2.49	1.68	1.68	1.68	1.68	7.71
Blending ratio to the return meal (%)	19.5	24.0	33.5	40.4	55.8	61.8	77.1	81.5	86.3	86.3	86.3	86.3	94.0
Open circuit process cement mill (Blaine value: 3250)													
Particle dia. range (micron)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120- Total
Mill outgoing powder													
Distribution (%)	26	17	15	11	9	7	4	3	3	3	1	1	0
Passing product 1-R	0	26	43	58	69	78	85	89	92	95	98	99	100
Residue R	100	74	57	42	31	22	15	11	8	5	2	1	0
Weight (t)	4.55	2.975	2.625	1.925	1.575	1.225	0.7	0.525	0.525	0.525	0.175	0.175	0

### 6.3.3 Heat Conduction between Powder & Granular Material and an Aerial Current

#### (1) General convective heat transfer

Many heat exchangers such as rotary dryers, rotary coolers, etc. conventionally used in cement production factories include the two types available according to the flow direction of hot gas and the material, which are each called parallel flow type and countercurrent type. The relationship between the heat conduction volume and the outlet/inlet temperature of the equipment is expressed by the following formula.

$$Q = U_a \cdot \Delta\theta_m \cdot V_a \quad (1)$$

where

$Q$  : Total heat exchange volume kcal/h

$U_a$ : Heat capacity coefficient kcal/h°Cm<sup>3</sup> (usually 30 to 100)

$$\Delta\theta_m = \frac{\theta_1 - \theta_2}{\log_e \frac{\theta_1}{\theta_2}}$$

Here,  $\theta_1 = T_1 - t_1$

$\theta_2 = T_2 - t_2$

(For parallel flow)

or,  $\theta_1 = T_1 - t_2$

$\theta_2 = T_2 - t_1$

(For countercurrent)

$V_a$ : Effective internal volume of an equipment m<sup>3</sup>

Figure 6.30 Parallel Flow Model

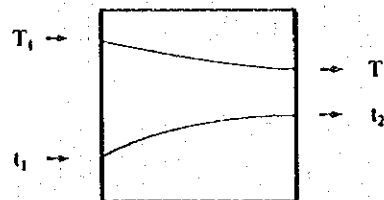
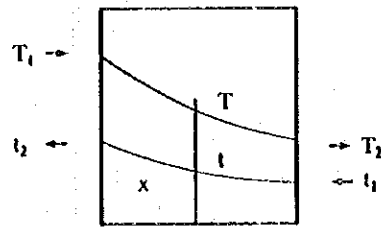


Figure 6.31 Countercurrent Model



For rotary kilns, only the burning amount per internal volume is generally discussed.

The following are the approximate value for each type of kiln.

Type of kiln ( $t/dm^3$ )	Wet-process long kiln	SP kiln	NSP kiln
	0.45 ~ 0.8	1.4 ~ 2.0	2.0 ~ 3.0

(2) Heat conduction inside the filling layer

Since the contact heat transfer between a particle and fluid is the main heat conduction for grate-type preheaters, coolers, shaft kilns, etc., the calculation formulas are complicated. However, providing some assumption allows approximate values to be obtained. If only the heat generated by the fuel and endothermic reaction of raw materials are to be neglected, the countercurrent model shown in Figure 6.31 just applies to the vertically moving bed such as for shaft kilns. The temperature at a desired place can be given by the following formulas:

$$\Theta = \frac{T - t_1}{T_1 - t_1} = \frac{1 - \exp\{-\alpha(1-\gamma)X\}}{1 - \gamma \exp\{-\alpha(1-\gamma)\}} \quad (2)$$

$$\theta = \frac{T_1 - t}{T_1 - t_1} = \frac{1 - \exp\{-\alpha(1-\gamma)X\}}{1 - \gamma \exp\{-\alpha(1-\gamma)\}} \quad (3)$$

where

$$\gamma = \frac{C_f \rho_f V_f \varepsilon}{C_s \rho_s V_s (1 - \varepsilon)}$$

$$\alpha = \frac{3h_p(1 - \varepsilon)}{C_f \rho_f V_f \varepsilon} \cdot \frac{x_0}{r_p}$$

$$c = x/x_0$$

Concerning grate-type heat exchangers, there are the following formulas available for the horizontally travelling bed shown in Figure 6.32. It is advisable to use such a diagram as shown in Figure 6.33 because of a difficulty in numerical calculation.

$$\Theta = \Psi(X, \eta) = \exp(-\eta) \int_0^{\eta} \exp(-\zeta) I_0(2\sqrt{\eta\zeta}) d\zeta \quad (4)$$

$$\theta = 1 - \Psi(X, \eta) \quad (5)$$

where

$$X = \frac{h_p}{C_f \rho_f V_f} \cdot \frac{3(1-\epsilon)}{\epsilon} \cdot \frac{x}{r_p}$$

$$\tau = \frac{h_p}{C_f \rho_f V_s} \cdot \frac{3(1-\epsilon)}{\epsilon} \cdot \frac{y}{r_p}$$

$$h = (\tau - X)C$$

$$C = \frac{1-\epsilon}{\epsilon} \cdot \frac{C_s \rho_s}{C_f \rho_f}$$

Figure 6.32 Model of Horizontally Travelling Bed

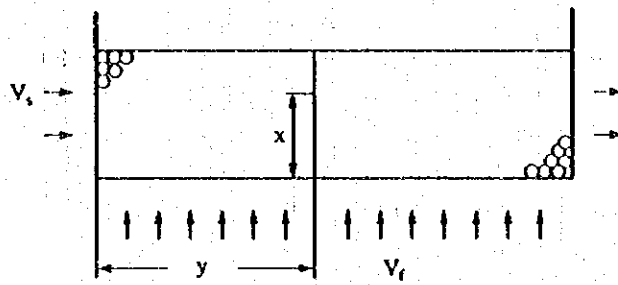
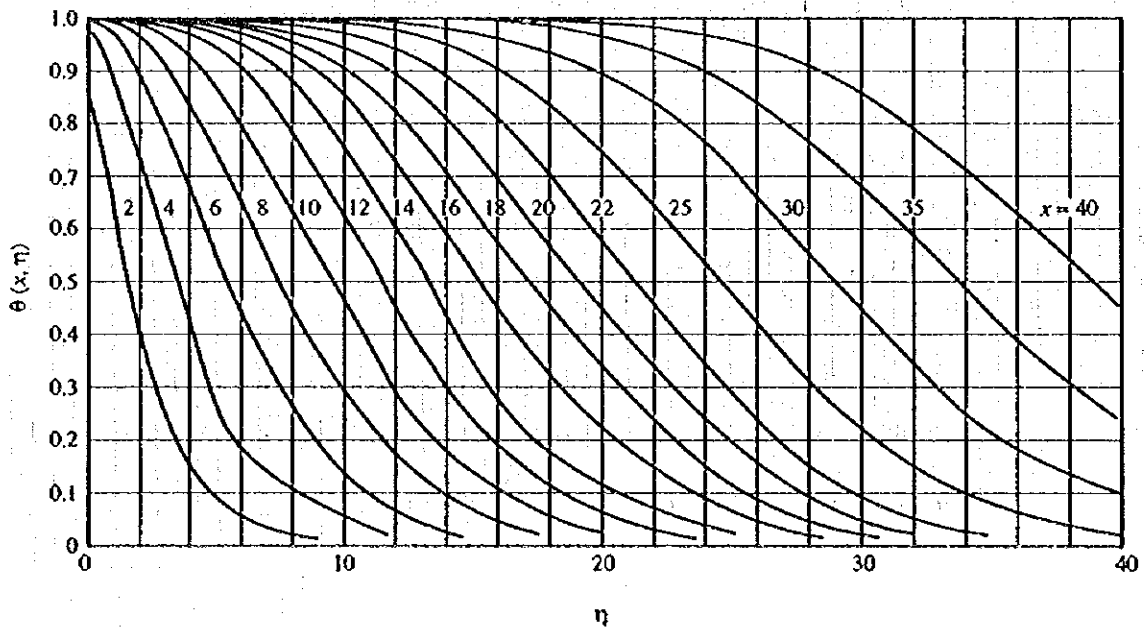


Figure 6.33 Schumann-Furnas Diagram

$$\theta(x, \eta) = e^{-\eta} \int_0^{\eta} e^{-\zeta} I_0(2\sqrt{\zeta\eta}) d\zeta$$



(3) Heat conduction in a multi-stage model

Supposing that a suspension preheater has a cyclone of  $n$  stages and that the heating decomposition of the material is disregarded, the gas and raw material temperature on its  $i$ th stage,  $T_i$ , can be obtained by the following formula based on the heat balance on each stage in Figure 6.34.

$$T_i = \frac{1}{C^{n+1} - 1} \{ C^i (C^{n-i+1} - 1) T_g + (C^i - 1) T_s \} \quad (6)$$

where

$$C = \frac{C_f G_f}{C_s G_s}$$

$C_f$  = Mean specific heat of gas      kcal/Nm<sup>3</sup> °C

$C_s$  = Mean specific heat of material   kcal/kg °C

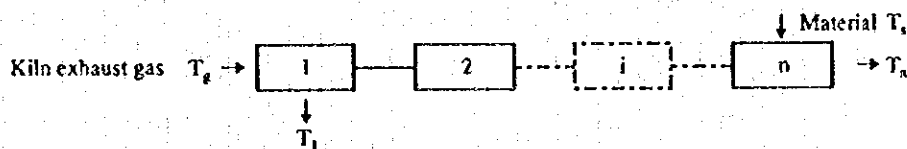
$G_f$  = Gas consumption rate              Nm<sup>3</sup>/kg-cl

$G_s$  = Material consumption rate        kg/kg-cl

$T_g$  = Kiln exhaust gas temperature    °C

$T_s$  = Material inlet temperature        °C

Figure 6.34 Multi-stage Model



Considering some amount of heating decomposition,  $T_f$  can be used instead of  $T_g$  after being corrected as shown in the following formula.

$$T_f = T_g - \frac{k q G_s}{C_f G_f} \quad (7)$$

where

$k$ : Material decomposition rate    %/100

$q$ : Material decomposition heat   kcal/kg cl

Following is an example of calculation.

Conditions:

$C = 1.48$

$G_f = 1.47$  Nm<sup>3</sup>/kg-cl

$G_s = 1.53$  kg/kg-cl

$T_g = 1050$  °C

$T_s = 50$  °C

$k = 15$  %

$q = 470$  kcal/kg-cl



## 6.4 Promotion of Energy Conservation

### 6.4.1 Managerial Method

#### (1) Promotion procedure

Generally, energy conservation measures which have been taken in the process industries as well as in the cement industry can be classified into the following three steps.

##### Step 1 - Thoroughgoing management:

First of all, energy conservation efforts start with elimination of waste, then followed by a review of the existing operation standards, more effective information communications, re-education of employees, revitalization of minor group activities, etc., through which the present situation should be reviewed to make necessary improvements. This can lead to a substantial result without much equipment investment. A measure to be taken in the next step will not be identified until as much effort as possible is made under various restrictions.

##### Step 2 - Equipment improvement:

The productivity and the energy efficiency of the entire plant can be improved by partial modification without changing the process of the existing equipment. Efforts in this step include the changing of the duct-connecting positions, replacement of fans or motors, addition of a monitoring and control meters, addition of a waste heat recovery equipment and so forth. Although this step involves some amount of expense, the profitability of investment can be rather easily estimated with regard to specific items. Therefore, these efforts should start with short-term profit recovery equipment.

##### Step 3 - Process improvement:

This phase aims to change the production process itself, e.g., from the wet process to the dry process, or from an open circuit mill to a close circuit mill. Needless to say, this requires a large amount of equipment investment, and in some cases involves a loss due to the shut-down for a certain period. The purpose of this investment is not merely to promote energy conservation but also to improve the additional value of products as well as productivity through the modernization of the process, thus recovering or maintaining the long-term competitive power. Hence, differently from steps 1 and 2, this step requires a high-level managerial judgement to be made at a good timing.

Table 6.10 summarizes the measures actually taken in Japan for each above-mentioned step.

**Table 6.10 Examples of Energy Conservation Measures Taken in the Japanese Cement Industry**

	Raw material process	Clinker burning process	Finish grinding process
First step	Selection of raw materials	Prevention of shut-down due to a failure	Management of product fineness
	Management of product fineness	Selection of fuels Prevention of leak	Management of grinding media
	Management of grinding media	Combustion control	Improvement of operation rate at night
Second step	Use of industrial waste material (flyash, slag)	Changing of fuels and use of substitutes	Use of waste plaster Modification of separators
	Replacement of a fan rotor	Use of industrial waste (waste tires)	Introduction of sound control
	Control of fan rotational speed	Use of exhaust gas from preheaters and coolers (drying of materials and generation of electricity)	Addition of spare crushers
	Addition of mixing equipment	Replacement of dust collectors	Use of admixture Mill internal modification
	Computerization of raw material mixing ratio	Change of cooler layer thickness	
Third step	Conversion from wet process to dry process	Change from wet process to dry process	Conversion from open circuit process to close circuit process
	Conversion to roller mills	Modification of SP to NSP	
		Replacement of coolers	

(2) Recognition of the present situation

Efforts to search for a new phase should normally start with avoiding the stereotyped manner to recognize the present situation accurately.

The recognition should be objective and yet rational. To achieve this end, the logical approaches mentioned above will be useful. The heat balance of kilns, for example, is specified in JIS R0303, the actual examples of which are shown in Table 6.11.

These examples were obtained through the surveys conducted by Japan Cement Association on the heat balances of SP and NSP kilns operating in around 1985.

Table 6.11 Heat Balance Results of All the Kiln Systems

Unit: 10<sup>3</sup> kcal/t-cl (percentage is given in parentheses)

Item	Type (No. of kilns)	SP kilns							NSP kilns			
		Deball (21)	Funbolt (14)	Pedarg (7)	Smith (1)	Total (43)	MFC (6)	SF (1)	KSV (1)	Total (8)		
Thermal input	Combustion heat of heavy oil	(97.1)	(97.6)	(97.1)	(97.1)	(97.3)	(97.1)	(97.5)	(97.4)	(97.2)		
		816.7	828.9	785.8	782.0	814.8	787.6	806.1	789.1	790.1		
	Others	(2.9)	(2.4)	(2.9)	(2.9)	(2.7)	(2.9)	(2.5)	(2.6)	(2.8)		
		243	20.6	23.4	23.1	23.0	23.1	20.5	21.4	22.6		
	Total of heat input	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)		
		841.0	849.5	809.2	805.1	837.8	810.7	826.6	810.5	812.7		
Thermal output	Calorific value for clinker burning	(50.6)	(47.3)	(52.3)	(53.7)	(49.8)	(52.5)	(48.9)	(53.0)	(52.0)		
		425.9	401.1	423.1	432.9	417.5	425.9	403.4	429.2	423.5		
	Sensible heat of preheater exhaust gas (including latent heat of evaporation of spray water)	(20.2)	(22.2)	(20.9)	(21.9)	(21.0)	(19.6)	(23.5)	(22.0)	(20.4)		
		169.5	188.6	169.1	176.1	175.8	158.5	194.1	178.4	165.4		
	Calorific value taken away by clinker	(2.9)	(1.9)	(2.9)	(4.1)	(2.6)	(2.4)	(3.0)	(2.2)	(2.5)		
		24.0	16.4	23.2	33.3	21.6	19.4	25.0	18.0	19.9		
	Sensible heat of cooler exhaust gas	(14.2)	(13.2)	(12.6)	(0)	(13.3)	(16.0)	(15.9)	(15.4)	(15.9)		
		119.4	112.3	102.2	0	111.5	129.9	131.7	125.1	129.5		
	Heat loss by heat radiation etc.	(11.0)	(13.4)	(9.3)	(19.2)	(11.7)	(8.5)	(6.7)	(5.3)	(7.9)		
		92.2	114.0	75.1	154.3	98.0	68.6	55.7	43.2	63.8		
	Others	(1.1)	(2.0)	(2.0)	(1.1)	(1.6)	(1.0)	(2.0)	(2.1)	(1.3)		
		10.0	17.1	16.5	8.5	13.3	8.4	76.7	16.6	10.5		
	Total of heat output	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)		
		841.0	849.5	809.2	805.1	837.8	810.7	826.6	810.5	812.6		
Kiln efficiency (%)		51.1	47.0	52.2	53.5	50.0	52.6	48.6	52.4	52.1		
Burning efficiency (%)		50.8	46.8	51.9	52.9	49.7	52.3	48.0	52.1	51.7		

The kiln efficiency and burning efficiency for dry-process kilns are nearly identical, i.e., around 50 %. In the wet process, a large amount of heat is consumed to evaporate water content, resulting in a large reduction of burning efficiency. The heat loss is mostly caused by the sensible heat taken away by the pre-heater and the cooler. To improve this situation, the total volume of exhaust gas need to be reduced or the exhaust gas temperature should be lowered. Radiation heat or other heat loss, most of which is the radiation heat from the kiln surface, should not be neglected either. In NSP kilns, heat loss is smaller than in NSP kilns. This is probably due to the difference in the kiln size.

(3) Preventive maintenance

Supposing that a kiln which daily produces 500 tons of cement stops operation because of a failure, loss of energy and loss due to decreased production occur at the same time. For example, the following calculation can be made. When the energy cost is 15.5 \$/t, marginal profit is 29.5 \$/t, then the loss will amount to as much as 5,600 \$ for a single time.

Energy loss:

$$15.5 \text{ \$/t} \times \frac{500 \text{ t/d} \times 12 \text{ h}}{24 \text{ h/d}} \times 50 \% \text{ or equivalent} = 1,938 \text{ \$}$$

Lost profits due to output reduction:

$$29.5 \text{ \$/t} \times \frac{500 \text{ t/d} \times 12 \text{ h}}{24 \text{ h/d}} \times 50 \% \text{ or equivalent} = 3,687 \text{ \$}$$

Also in some cases where low-level operations due to malfunction of the equipment cannot be avoided, if not leading to a shutdown, there occur similar types of heat loss. These losses tend to be neglected since they do not appear visibly in the form of cash expense. It is, however, obviously advantageous to take a preventive measure in advance. The proper maintenance of the equipment's soundness is essential for the promotion of energy conservation in the process industries.

(4) Substitute raw materials and fuels

Table 6.12 shows the substitute materials and fuels recently used in the cement industry in Japan.

**Table 6.12 Utilization of Industrial Wastes and By-products in the Cement Industry**

(Unit: 1,000 t)

Kind	Year	1994	1995	Ratio to the previous year
Blast furnace slag		12,860	12,486	97.1
Converter slag		970	1,181	121.8
Coal ash		2,872	3,103	108.1
By-product gypsum		2,286	2,502	109.4
Debris		1,923	1,666	86.6
Non-ferrous slag		1,415	1,396	98.7
Sludge		785	905	115.3
Unburnt ash and dust		367	487	132.5
Molding sand		350	399	114.0
Waste tire		245	266	108.3
Waste oil and reclaimed oil		202	233	115.3
Waste China clay		59	94	158.9
Others		347	379	109.2
<b>Total</b>		<b>24,683</b>	<b>25,097</b>	<b>101.7</b>

Source: Japan Cement Association

In Japan, blast furnace slag is employed in two ways, that is, as a raw material and as a raw material to be mixed into the product. Japanese Industrial Standard (JIS) provides quality standards concerning the mixing of blast furnace slag into the product.

Waste tires have been effectively used because of the introduction of NSP kilns. They are now used as they are without being finely cut.

Various substitute materials and fuels may be found depending on the region. In this regard, however, these substitutes should be used under strict quality control, lest the use of them should result in lowering the quality of the product.

## 6.4.2 Improvement of Equipment

### (1) Flowrate control of raw material and fuel

Powder and granular materials stored in the silo or the hopper are occasionally influenced by the shape of the equipment and the angle of repose, displaying an unexpected behavior. This often causes a blockage or an outbursting phenomenon and prevents a smooth operation, which pose a serious problem in large dry-process plants. Theoretical or practical countermeasures for such problems have been so far taken, but fundamentally the shape of the hopper itself should be improved. Thus, the selection of an extraction device and the installation of an automatic control device will be secondary measures. The outflowing mode of the powder & granular material should be taken into full account at the designing stage to avoid a failure.

Figure 6.35 Outflow Mode from the Orifice

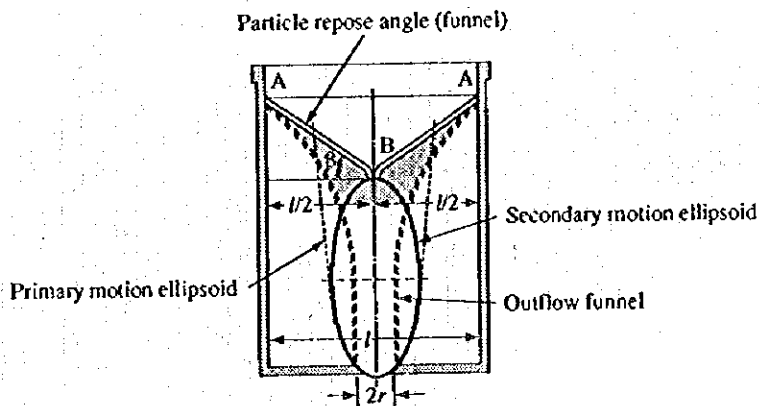
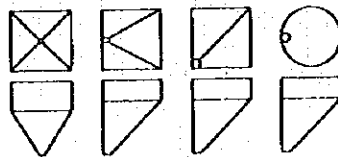


Figure 6.36 Various Hopper Shapes



### (2) Countermeasures against troubles of fan and duct

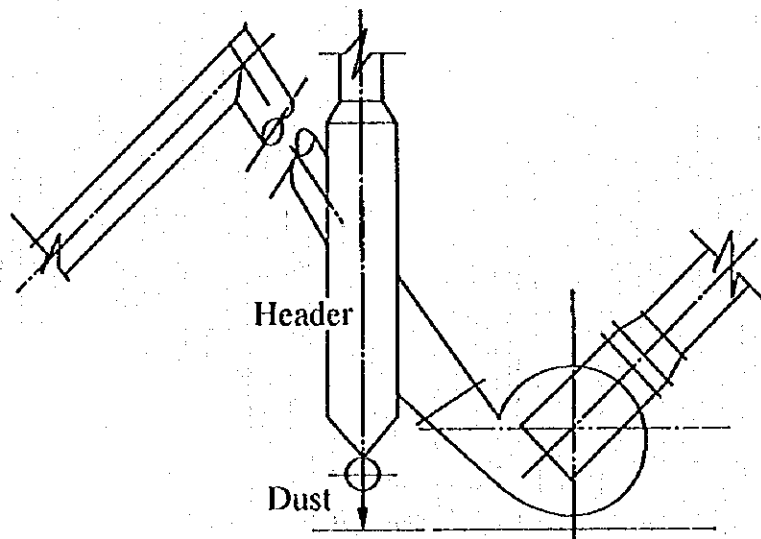
An attempt to make effective use of waste gas and its retained heat will inevitably make the piping system more complicated and the extension longer. Waste gas usually contains 40 to 70 g/m<sup>3</sup> dust, which, when accumulated in the piping, is difficult to be removed by human power, and causes various kinds of trouble when left unremoved. Hence, horizontal installation of piping must be avoided, and due consideration should be taken such as providing heat insulation to prevent dew condensation.

As a fan becomes larger, sudden vibration sometimes occurs and makes the continuation of operation impossible. This may probably be caused by the following:

- 1) Temporary mixing of a large amount of dust
- 2) Fan generating the surging
- 3) Fan's rotation number being close to the resonance point.

1) can be, in many cases, avoided by some improvement of piping method. 2) is due to the characteristic of the fan, and occurs in the low wind volume area. This can be avoided by changing from the damper control system to the rotational speed control system. 3) occurs when a large amount of dust stick on the blade of the fan or when a thick liner is attached as a wear-resistant measure. This is because the increased weight of the rotating body has lowered its resonance point in the design, and made it approach the rotational speed at operation. The only possible measure is to replace the shaft.

**Figure 6.37 Piping at Fan Outlet**



**Figure 6.38 Fan Performance Curve**

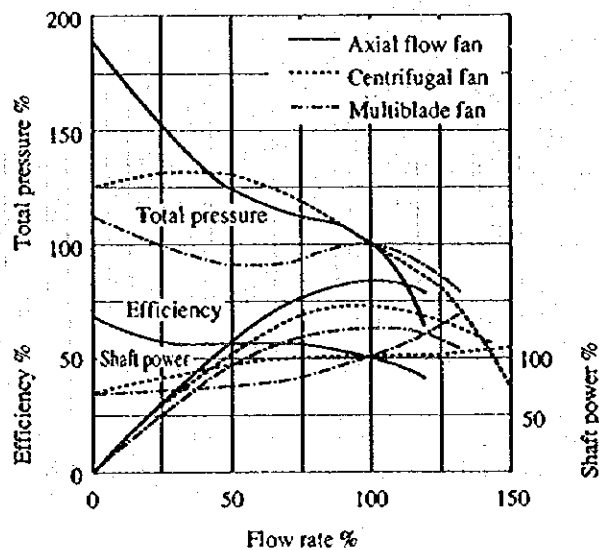
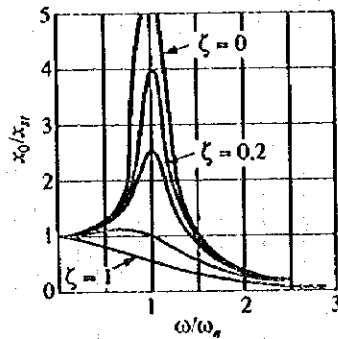


Figure 6.39 Resonance of a Rotor



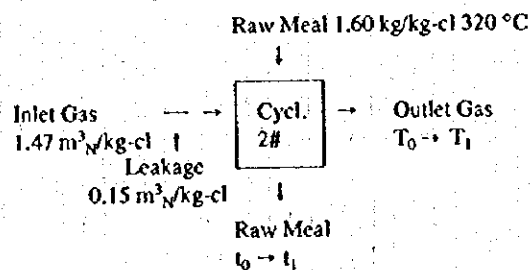
(3) Saving of airflow amount

In order to reduce the heat taken away by the exhaust gas, it is necessary to take a measure to reduce the gas amount as well as to lower the temperature as mentioned above. This will lead to the reduction of the airflow pressure loss in the entire process and then to the saving of electric power. As is common to other combustion equipment, measures to enhance the performance of the burner and to lower the excessive air ratio should be taken. When a grate cooler is used, an effort to increase the secondary air temperature is also made by increasing the layer thickness of the clinker.

The process is generally operated by the negative pressure, allowing the excessive air to easily flow in. The figure below shows a trial calculation with one stage of the preheater as a model to estimate how much energy loss the leak air will cause. The result reveals that allowing an about 10 % air leak will cause a loss of 18 kcal/kg-cl.

Figure 6.40 Heat Loss due to Leak Air

$C_p = 0.36 \text{ kcal/m}^3_N$	$0.36 \times 553 \times (1.47 + 0.15) = 310 \text{ kcal/kg-cl}$
$C_s = 0.21 \text{ kcal/kg}$	$0.36 \times 533 \times 1.47 = 292 \text{ kcal/kg-cl}$
$T_0 = t_0 = 553 \text{ }^\circ\text{C}$	Balance: 18 kcal/kg-cl
$T_1 = t_1 = 533 \text{ }^\circ\text{C}$	





### 6.4.3 Process Change

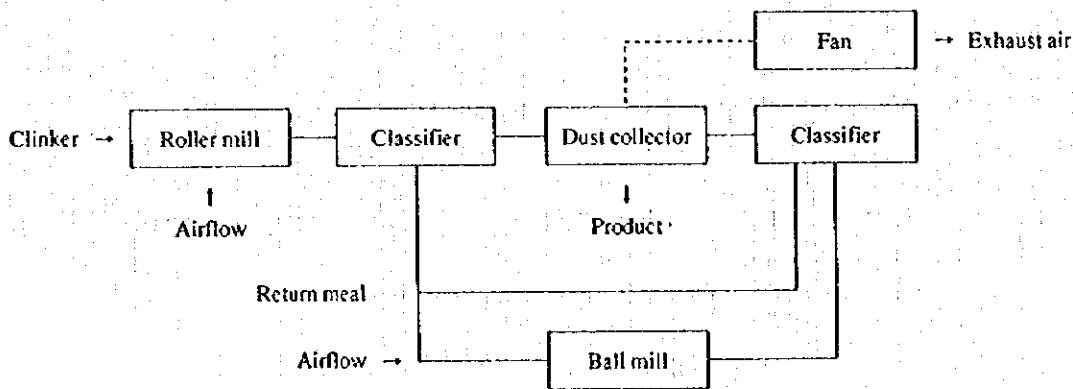
#### (1) Grinding equipment

When the kiln type is to be changed from the wet process to the dry process, the mill type should be changed accordingly. In such a case, it will be advantageous to employ anew a vertical mill for raw materials, while modifying the conventional ball mill into a cement mill.

The open-circuit mill can be converted to the close-circuit system by adding a separator, but in this case the mill internal structure requires some degree of modification.

An attempt to employ a roll press and a roller mill is now being made for crushing clinker, but this still leaves some problems to be solved. Rather than this, the use of a roller mill as a pre-crusher is supposed to spread more rapidly.

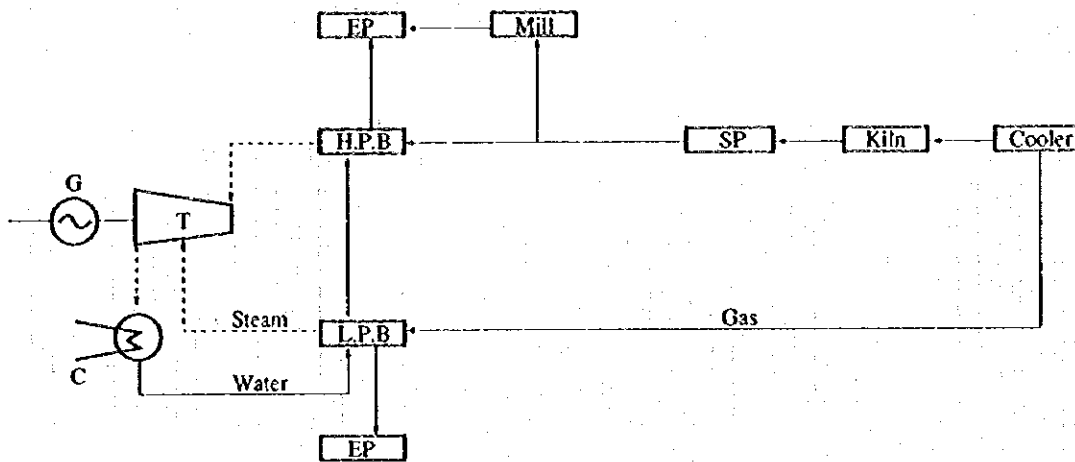
Figure 6.41 2-stage Clinker Grinding System



#### (2) Cogeneration

Table 6.11 indicates that the preheater exhaust gas sensible heat for SP kilns (43 units) amounts to 21.0 % in total, and that for NSP kilns (8 units) 20.4 % in total, and that likewise the cooler exhaust gas sensible heat for SP kilns amounts to 13.3 % and that for NSP kilns 15.9 % respectively. Ideally, the loss of about 35 % in total should be reduced by the improvement of the process. For the present, however, it is utilized for the drying of raw materials and cogeneration. Figure 6.42 shows a plant where two boilers are used to generate steam by which the turbine generator is rotated to provide the electric power necessary for the plant. In Japan, this is generally said to pay only for large-scale plants with an annual production of 0.6 million ton or more. However, this range may not necessarily apply to such regions as cannot afford sufficient electric power, and are often subject to power failure or load restrictions.

Figure 6.42 Cogeneration (Waste Heat Recovery Power Generation)

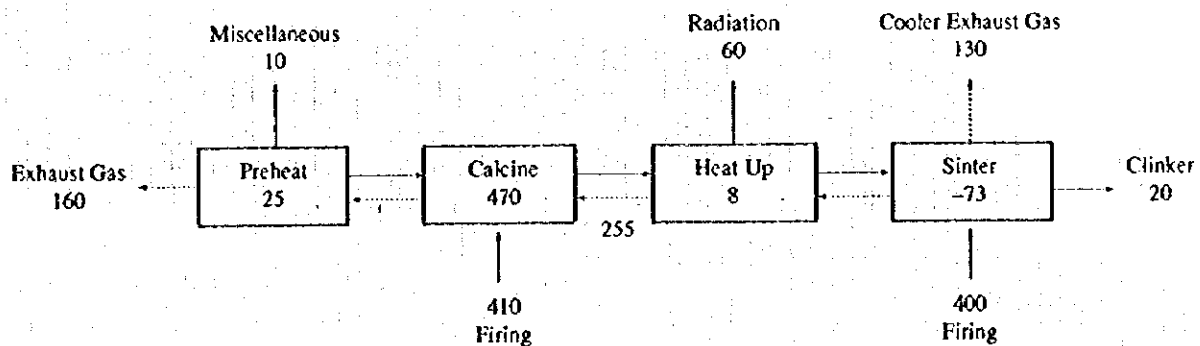


H.P.B. :High Pressure Boiler  
 L.P.M. :Low Pressure Boiler  
 T :Turbine  
 G :Generator  
 C :Condenser  
 SP :Suspension Preheater  
 EP :Electrostatic Precipitator

(3) Kiln type

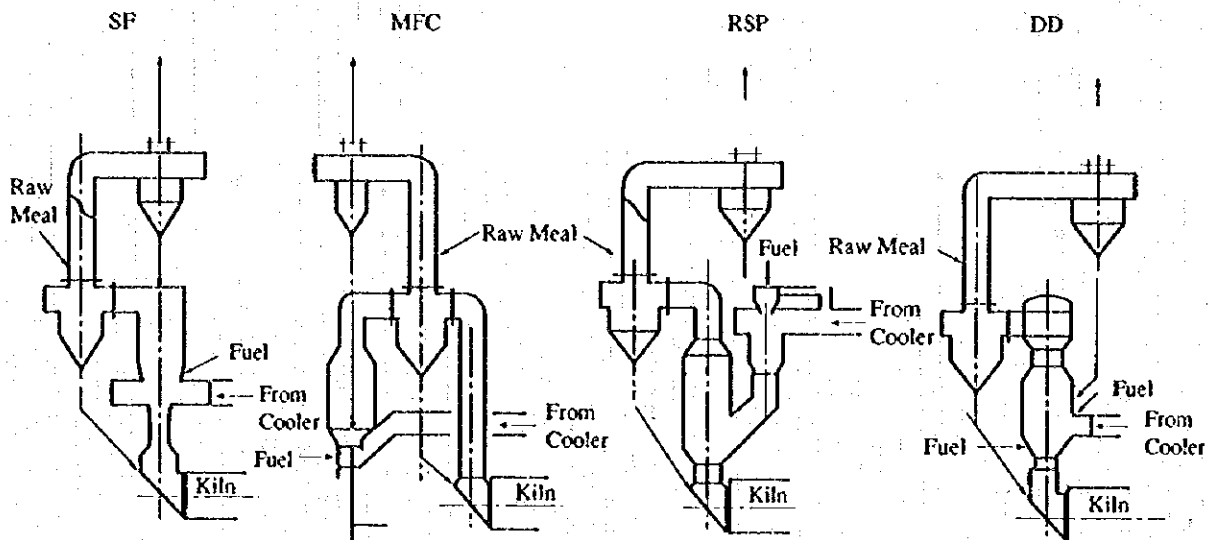
Figure 6.43 is prepared based on the data of Table 6.11. Most of the 810 kcal/kg-cl thermal input is consumed for the decarbonation (calcining) of limestone. This chemical reaction is conducted at a temperature of 900°C or less as mentioned earlier. To supply this heat to the kiln by a burner, the temperature must be raised to 1,650°C once for maintaining the temperature of the sintering zone. Just separating the sintering zone and feeding the fuel directly in this zone can lower the thermal load of the kiln.

Figure 6.43 Heat Balance Model for the Burning Process



The NSP system is based on the foregoing concept, which was at first highly regarded as the most effective method to make the kiln capacity larger. As this NSP system is widely used and various kinds of calciners (Figure 6.44 Calciner) are developed, it has gradually been found that the NSP system, if only it is properly designed, has also other more advantages such as stabilization of the entire system operation, a fifty-percent reduction of nitrogen oxides (NOx), etc., irrespective of the size of a kiln. Nowadays the NSP system is highly evaluated as one of the most rational combustion systems.

Figure 6.44 Various Kinds of Calciners



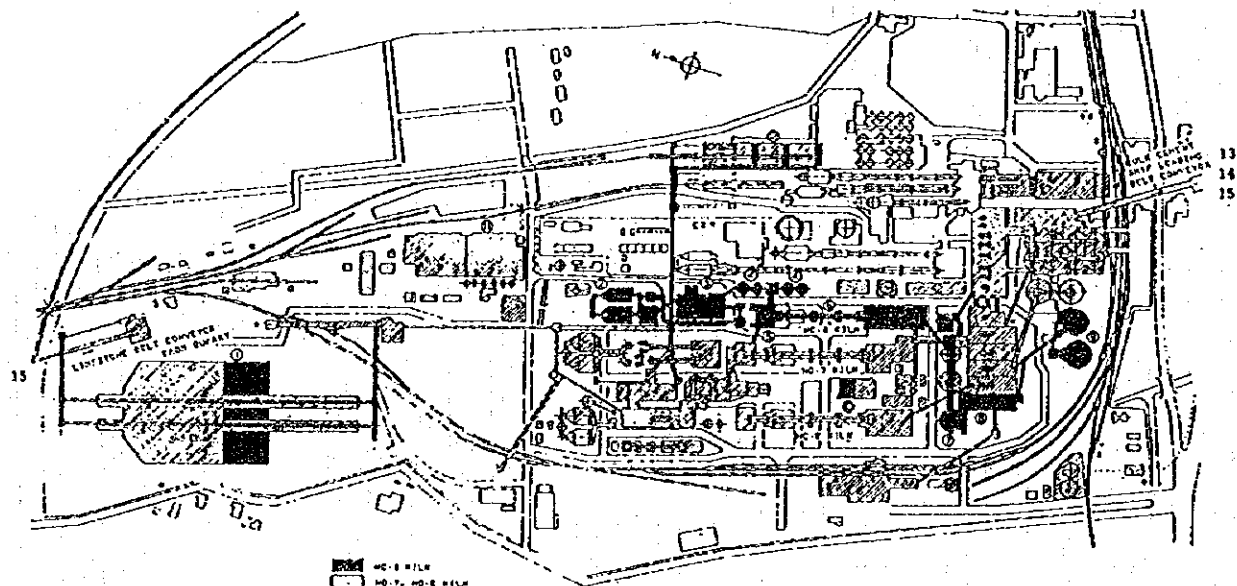
(4) Change of the production process of the entire plant

Figure 6.45 shows an example of traditional plant with 6 wet-process kilns which have produced cement of 1.5 million ton annually. To cope with an ever-increasing demand as well as to attain modernization, this plant successively installed two SP kilns capable of producing one million tons of cement annually, which is indicated by the hatched portion in the layout figure. During the construction period, both the wet-process and dry-process lines were operated in parallel.

After completion of addition of the dry-process kilns, the modification work of the wet-process No. 6 kiln into an NSP kiln was started. Upon completion of the work about 1.5 years thereafter, the operation of all the wet-process line was stopped, while the equipment available were all converted into the dry-process line. The work area at this time is indicated by the portion painted black in the figure.

The modification of the wet-process No. 6 kiln into NSP has increased its daily cement production from 1,680 to 3,960 ton, thus allowing only 3 dry-process kilns to produce 3.5 million tons of cement annually. Fuel consumption has also decreased from 1,500 kcal/kg-cl to 740 kcal/kg-cl.

Figure 6.45 Plant Layout



- |                            |                             |
|----------------------------|-----------------------------|
| 1. Limestone stock yard    | 9. Cement silo              |
| 2. E. P.                   | 10. Central control room    |
| 3. Raw mill                | 11. Power station           |
| 4. Blending (storage) tank | 12. Clay stock yard         |
| 5. NSP                     | 13. Bulk cement             |
| 6. Rotary kiln             | 14. Ship loading            |
| 7. Clinker silo            | 15. Limestone belt conveyor |
| 8. Cement mill             |                             |



## 7. ENERGY CONSERVATION IN THE GLASS INDUSTRY



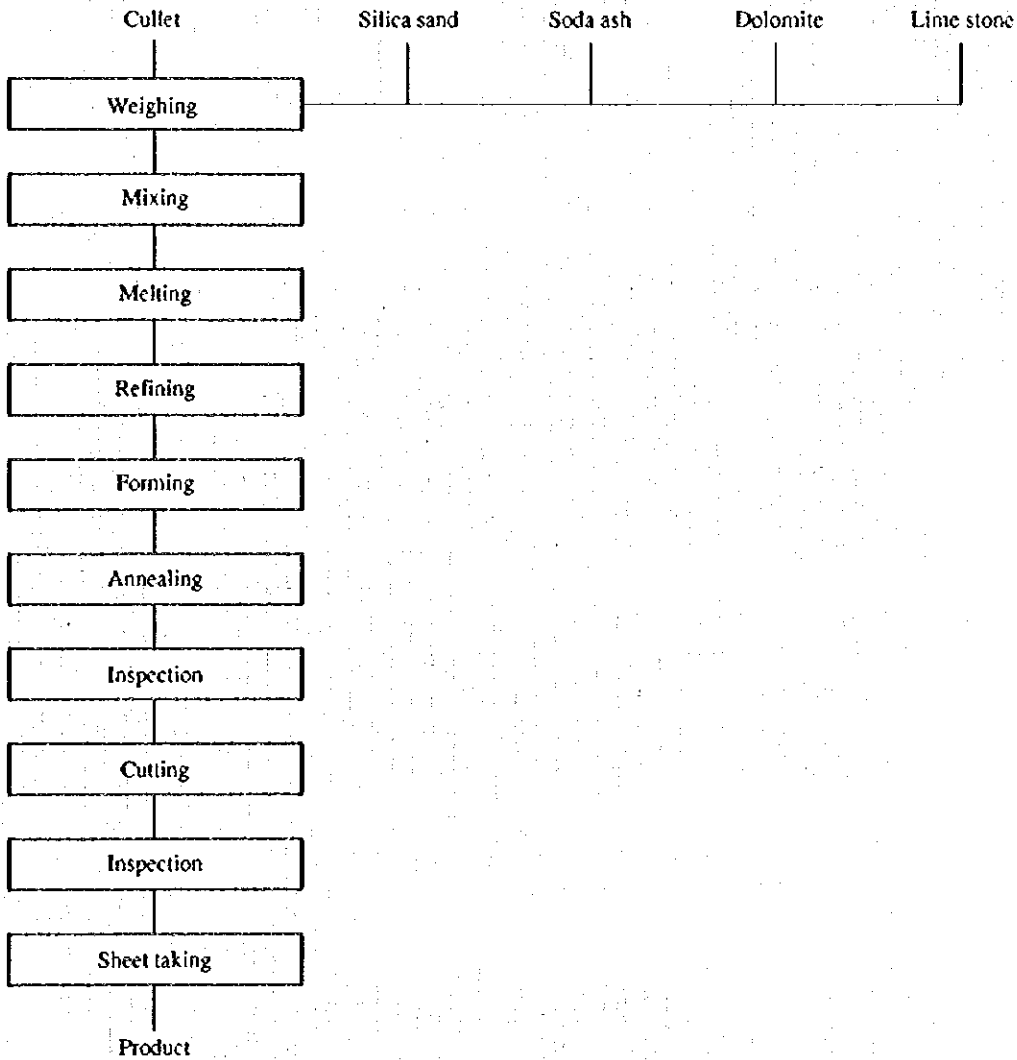
## 7. ENERGY CONSERVATION IN THE GLASS INDUSTRY

### 7.1 Characteristics of Use of Energy

#### 7.1.1 Manufacturing Process and Main Equipment

The manufacturing process of sheet glass is relatively simple as shown in Figure 7.1.

Figure 7.1 Manufacturing Process



The composition of glass varies from one application to another. Sheet glass is made of soda lime glass of the composition shown in Table 7.1.



**Table 7.1 Composition of Glass**

Components	Contents
SiO <sub>2</sub>	70~74 %
Al <sub>2</sub> O <sub>3</sub>	1.5~2.0
Fe <sub>2</sub> O <sub>3</sub>	
CaO	8~12
MgO	
Na <sub>2</sub> O	13~16
K <sub>2</sub> O	

**(1) Manufacturing process**

According to the glass composition required for the manufacturing process, silica sand, soda ash, limestone, dolomite, etc. are mixed, and small amounts of auxiliary materials, such as refining aids, colorant, and decolorant, as well as an appropriate amount of cullet, are blended with the mixture into a composite material.

The composite material is charged into the furnace (see Figure 7.2) that is kept at about 1,500 °C, where the material is heated and melted by the radiating heat of flames in the upper space. Then the molten material is refined and its bubbles are separated. The center part of the furnace is kept higher in temperature than the rest so that unmolten material in the furnace will not flow out to the working hearth.

The molten, refined glass runs to the working hearth, from which it is supplied through the forehearth or the canal to the forming machines. When the molten glass is in the working hearth and forehearth or the canal, its temperature is adjusted to suit the forming of products. There, the material is, in some cases, heated by a number of small burners or directly by applying electricity.

There are various forming methods including Fourcault method, Colburn method, etc. for ordinary sheet glass, a roll-out method for figured sheet glass and a float bath for float glass.

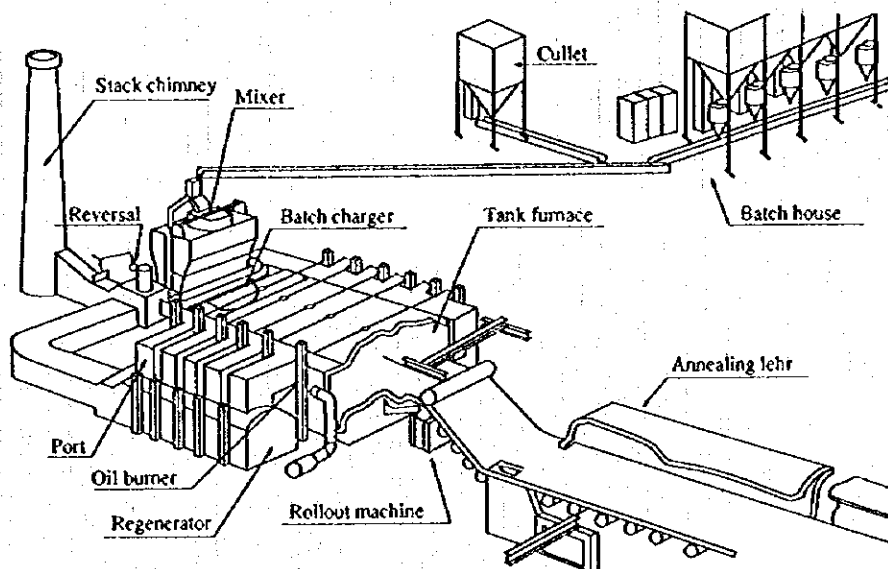
Formed products are annealed in an annealing lehr so that there will be no thermal strain left in the products. Annealing temperature and time vary depending on the glass composition, product thickness, etc. Generally, however, formed products of 6 mm in thickness are gradually cooled from 500 °C ~ 550 °C to about 400 °C at a speed of about 20 °C per minute. Although annealing lehr includes the gas heating type and the electric heating type, an electric heating type continuous furnace is mostly used for recent lehrs for the float glass.

After annealing, the products are inspected and packed.

## (2) Main equipment

There are two types of furnace for melting glass material: the tank furnace that is suited to continuous, mass production, and the pot furnace for producing a variety of kinds in small quantities. From now on we describe tank furnaces only. Figure 7.2 shows a typical tank furnace.

Figure 7.2 Outline Sketch for Tank Furnace (Side Port Type)



A high temperature of about  $1,500^{\circ}\text{C}$  is necessary to melt glass so that combustion air must be preheated by heat exchange with combustion exhaust gas. A regenerator or recuperator such as shown in the figure is used for this preheating. Instead of heating with fuel, or as a boosting means, an electrode may be directly inserted into molten glass to directly heat it with electricity.

The melting furnace is constructed of erosion-resistant electrocast bricks of  $\text{ZrO}_2\text{-Al}_2\text{O}_3\text{-SiO}_2$  in the lower part which is exposed to molten glass, and of silica bricks in the upper part.

The burners are arranged in the both sides of the furnace (side port type) in large-sized furnaces. A furnace that has a regenerator is burned every one side, and the reversal of the combustion side is made every specific time, usually every 15 to 20 minutes.

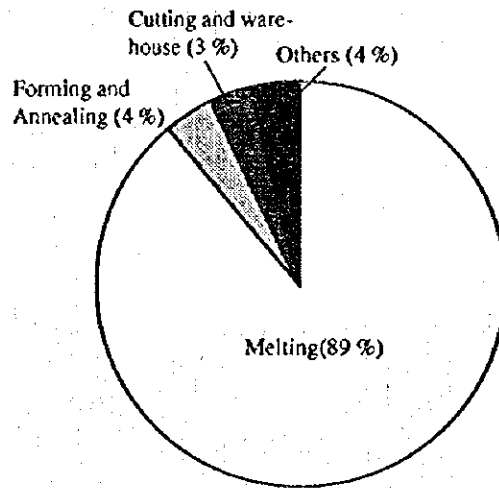
A regenerator is provided on each of the right and left sides. The one on the side of the operating burner is used to preheat combustion air, and the other heats the checker bricks through combustion exhaust gas to store the heat in the bricks. Some regenerators have the chambers separated for each port so that combustion control will be easily performed.

### 7.1.2 State of Use of Energy

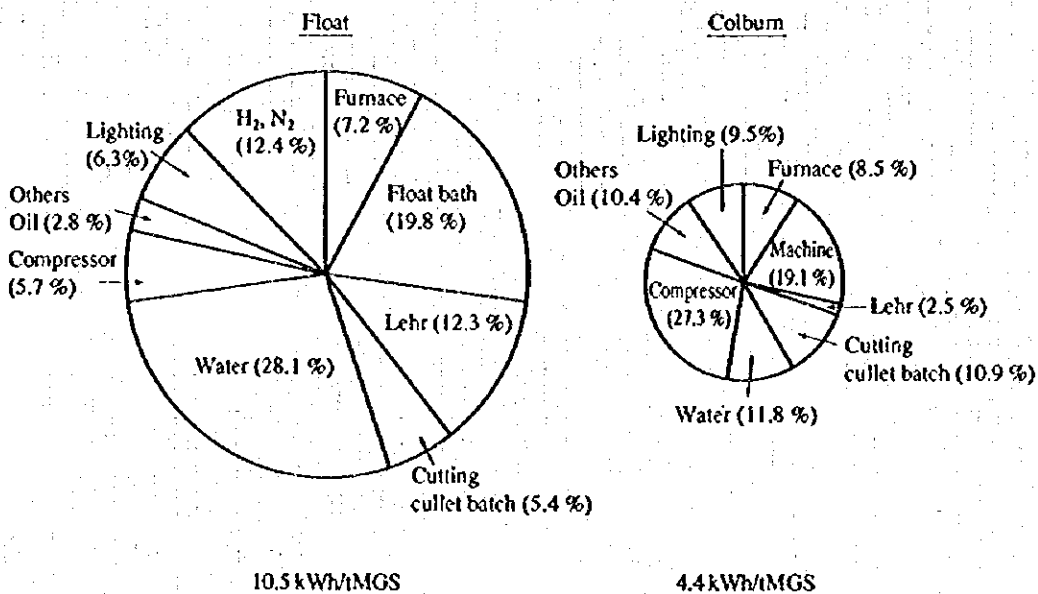
In glass factories, energy is consumed as shown below.

Figures 7.3 and 7.4 show an example of energy consumption by purpose of use at some sheet glass factories. As is clear from these figures, energy conservation is important for the melting and other furnaces.

**Figure 7.3 Share of Total Energy Consumption**

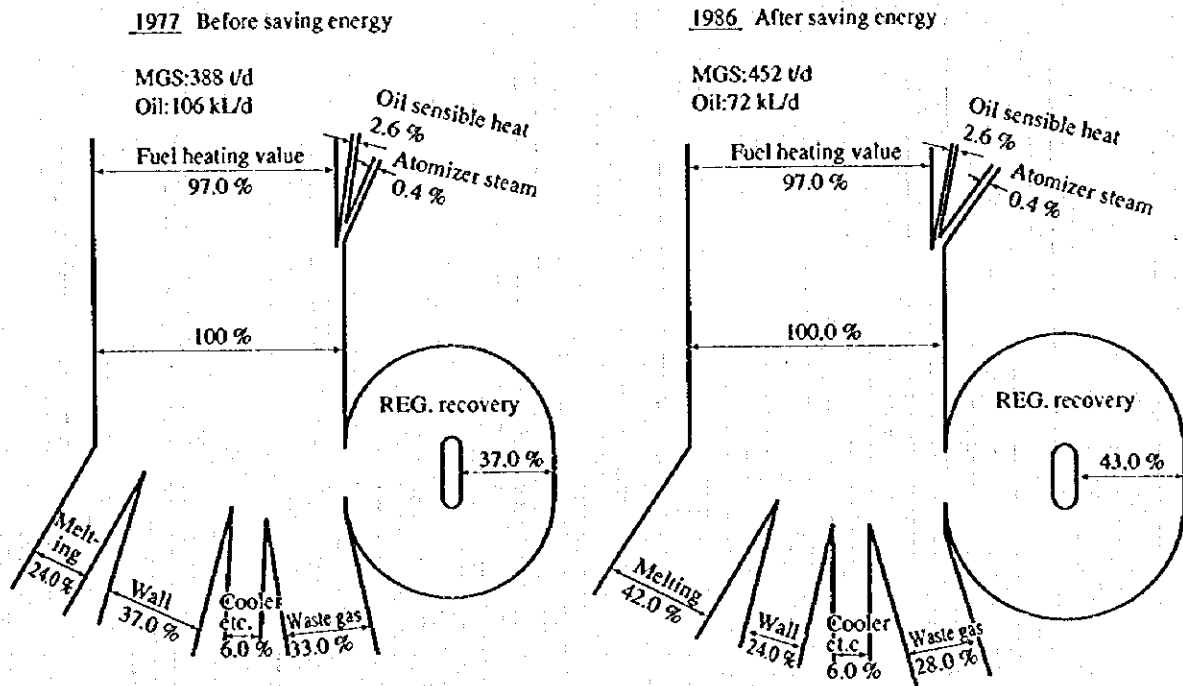


**Figure 7.4 Share of Electricity Consumption**



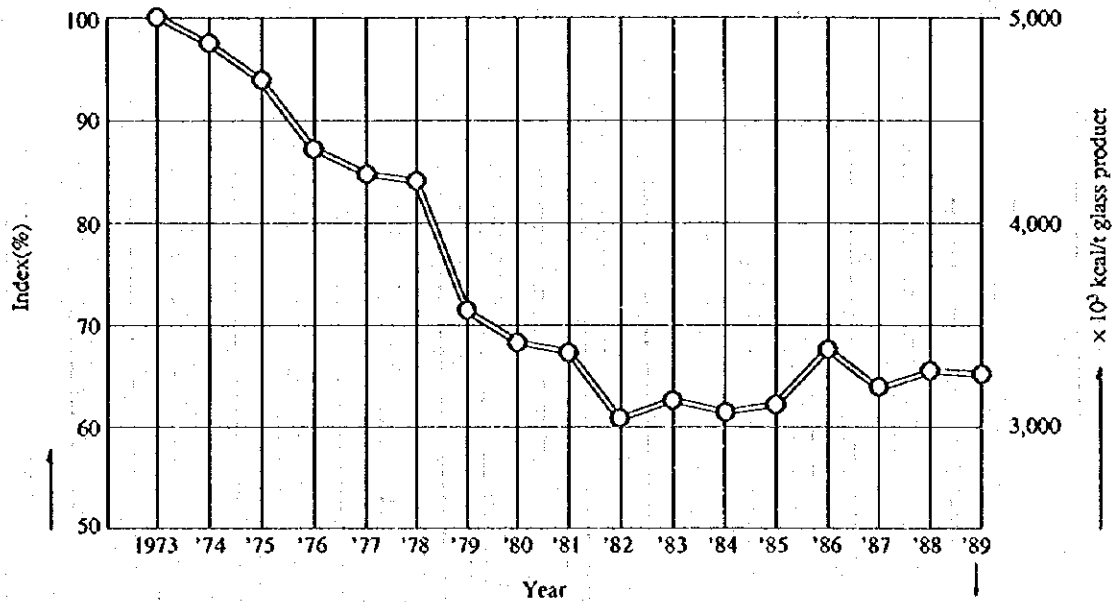
For your reference, a heat balance chart for a sheet glass furnace in Japan is shown in Figure 7.5. The thermal efficiency of this furnace is 24 % before taking energy conservation measures, and 42 % after taking them. Heat loss is mostly from exhaust gas and the furnace wall.

Figure 7.5 Heat Balance Chart for Glass Melting Tank



The example in Japan for your reference shown in Figure 7.6 reveals that overall energy intensity for sheet glass, including power consumption, was improved by about 35 % in 1989 over the reference year of 1973.

Figure 7.6 Trend of Energy Intensity Index in Sheet Glass Manufacturing

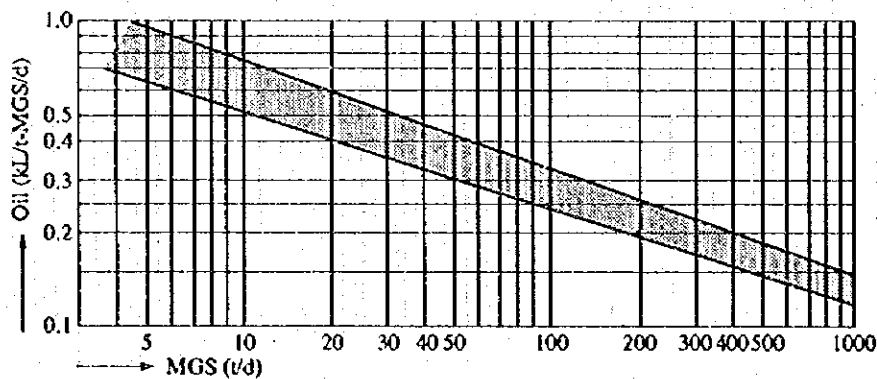


Details of Energy Conservation Items in Melting Furnace	
Scale up of furnace by Float system	15 %
Improvement of insulation	10 %
Improvement of yield	5 %
Improvement of waste heat recovery	5 %

Heavy Oil	9,900 kcal/L	... 82 %
LPG	12,000 kcal/kg	... 2 %
Electricity	2,450 kcal/kWh	... 16 %

Energy intensity for a glass melting furnace largely varies depending on the scale of the furnace. If the molten glass size (MGS) produced by a melting furnace is plotted on the horizontal axis, and heavy oil consumption rate on the vertical axis, a straight line is formed on the logarithmic scale. Figure 7.7 shows the relationship between the furnace size and the energy intensity. The width of the shaded portion in the figure represents the range occurring from disparities in the required product quality, an increase of fuel oil consumption rate with the aging of the furnace, etc.

Figure 7.7 Relation between Intensity of Heavy Oil and Size of Melting Furnace in Sheet Glass



## 7.2 Rationalization of Use of Heat Energy

### 7.2.1 Melting Furnace

#### (1) Optimization of air ratio

Glass is melted at a high temperature of about 1,500 °C, and heat is conducted predominantly by radiation at such a high temperature. The quantity of heat,  $Q$ , radiated from an object  $T_1$ K in absolute temperature to another object  $T_2$ K in absolute temperature can be expressed by the following equation.

$$Q = 4.88\epsilon \left\{ \left( \frac{T_1}{100} \right)^4 - \left( \frac{T_2}{100} \right)^4 \right\} \text{kcal/m}^2\text{h}$$

where  $\epsilon$  is the emissivity.

It is known from the above equation that the amount of heat transferred increases as flame temperature rises. Because flame temperature lowers as excess air increases, however, the air ratio must be lowered within a range in which incomplete combustion will not occur.

It is also important to decrease the amount of exhaust gas because it still has a temperature of about 500 °C after waste heat recovery.

If the actual amount of exhaust gas is  $G$ , the theoretical amount of exhaust gas  $G_0$ , the theoretical amount of combustion air  $A_0$ , and the air ratio  $m$ ,

$$G = G_0 + (m - 1) A_0 \text{ m}^3/\text{kg (m}^3/\text{N) fuel}$$

As expressed above, lowering the air ratio will help reduce the amount of exhaust gas. Although  $G_0$  and  $A_0$  should be calculated from the composition of the fuel, they can be approximately calculated from the lower heating value of the fuel by the equation (Rosin's equation) of Table 7.2.

If the amount of exhaust gas decreases from  $G_1$  to  $G_2$  by improving the air ratio, the decreased exhaust gas loss will reduce the amount of fuel to further decrease the amount of exhaust gas. In this case, the percentage of fuel saving can be expressed by the following equation.

$$\text{Fuel saving(\%)} = \frac{100R \left( 1 - \frac{G_2}{G_1} \right)}{100 - RG_2/G_1}$$

(there  $R$  is the percentage of exhaust gas loss before the improvement.)

Table 7.2 Relationship between Low Calorific Value  $H\ell$  and  $G_0, A_0$  (By Rosin)

Fuel	$G_0$	$A_0$
Solid fuel ( $H\ell$ : kcal/kg fuel)	$\frac{0.89H\ell}{1,000} + 1.65m^3_N/\text{kg fuel}$	$\frac{1.01H\ell}{1,000} + 0.5m^3_N/\text{kg fuel}$
Liquid fuel ( $H\ell$ : kcal/kg fuel)	$\frac{1.11H\ell}{1,000} m^3_N/\text{kg fuel}$	$\frac{0.85H\ell}{1,000} + 2.0m^3_N/\text{kg fuel}$
Low calorific value gaseous fuel ( $H\ell$ : 500 to 3,000 kcal/m <sup>3</sup> <sub>N</sub> fuel)	$\frac{0.725H\ell}{1,000} + 1.0m^3_N/m^3_N \text{ fuel}$	$\frac{0.875H\ell}{1,000} m^3_N/m^3_N \text{ fuel}$
High calorific value gaseous fuel ( $H\ell$ : 4,000 to 7,000 kcal/m <sup>3</sup> <sub>N</sub> fuel)	$\frac{1.14H\ell}{1,000} + 0.25m^3_N/m^3_N \text{ fuel}$	$\frac{1.09H\ell}{1,000} - 0.25m^3_N/m^3_N \text{ fuel}$

Tank furnaces in Japan are generally operating in the range where  $m = 1.05$  to  $1.15$ . As the amount of excessive air increases, the amount of  $\text{NO}_x$  also increases. It is, therefore, also important for the prevention of air pollution to control excessive air.

An amount of combustion air cannot be directly measured because, apart from preheated air for combustion, there is air entering through the openings. Thus, it is determined by measuring the concentration of oxygen or  $\text{CO}_2$  in the exhaust gas and calculating the material balance. If fuel has only small nitrogen content, burns completely, and if the nitrogen content of the exhaust gas is 79 %, air ratio can be calculated by the following equation.

$$m = \frac{21}{21 - (\text{O}_2) + 0.5(\text{CO})}$$

where  $(\text{O}_2)$  is the concentration of oxygen in exhaust gas (%).

$(\text{CO})$  is the concentration of CO in exhaust gas (%).

or,

$$m = \frac{1 - (\text{CO}_2) - 1.5(\text{CO})}{\frac{1 - (\text{CO}_2)_{\text{max}}}{0.79} \times \frac{(\text{CO}_2) + (\text{CO})}{(\text{CO}_2)_{\text{max}}}} + 0.21$$

where  $(\text{CO}_2)$  is the concentration of carbon dioxide gas in exhaust gas (%).

$(\text{CO}_2)_{\text{max}}$ , the maximum concentration of carbon dioxide gas in theoretical dry exhaust gas (%).

$$(\text{CO}_2)_{\text{max}} = \frac{1,867.C}{G_0} \times 100\% (\text{solid/liquid fuel})$$

$$G_0' = G_0 - (11.2 h + 1.244 W) m^3_N/\text{kg}$$

where  $h$  is hydrogen content (kg) in 1 kg fuel;  
 $W$ , water content (kg) in 1 kg fuel;  
 $C$ , carbon content (kg) in 1 kg fuel.

In the case of gas fuel, the same can be calculated from analyzed values of the components.

The following values may also be used for  $(CO_2)_{max}$ .

Coal (18.5 %); fuel oil (15.7 %); natural gas (12 %); LPG (14.5 %)

To keep the air ratio appropriate, the following must be borne in mind.

a. In the case of liquid fuel, observe the following:

- i Preheat it to an appropriate level of viscosity.
- ii Remove solids from the fuel using a filter.
- iii Keep the burner tips clean.
- iv Adjust atomizing steam or air to appropriate pressure.

There was an instance in which fuel consumption was reduced by 2 or 3 % by atomizing natural gas instead of air.

b. Preventing air leakage and radiation heat loss from the openings

Air leakage through the dog house, around the burners, peepholes, etc. will not only increase the amount of exhaust gas but also lower the temperature inside the furnace because that air is cool.

It is necessary to take the following steps in order to reduce air leakage to a minimum and prevent radiation heat loss.

- Make the openings as small as possible by, for example, completely sealing the joints, narrowing the clearances around the burners, or sealing the dog house with batch.
- Adjust the damper to maintain the correct furnace pressure.



c. Control

Control the amount of secondary air in proportion to the amount of fuel. In cases, a computer is employed for more accurate control, involving compensation for changes in crown temperature,  $O_2$  concentration in exhaust gas, and secondary air temperature, and shortening of reversal time.

(2) Improving flame emissivity

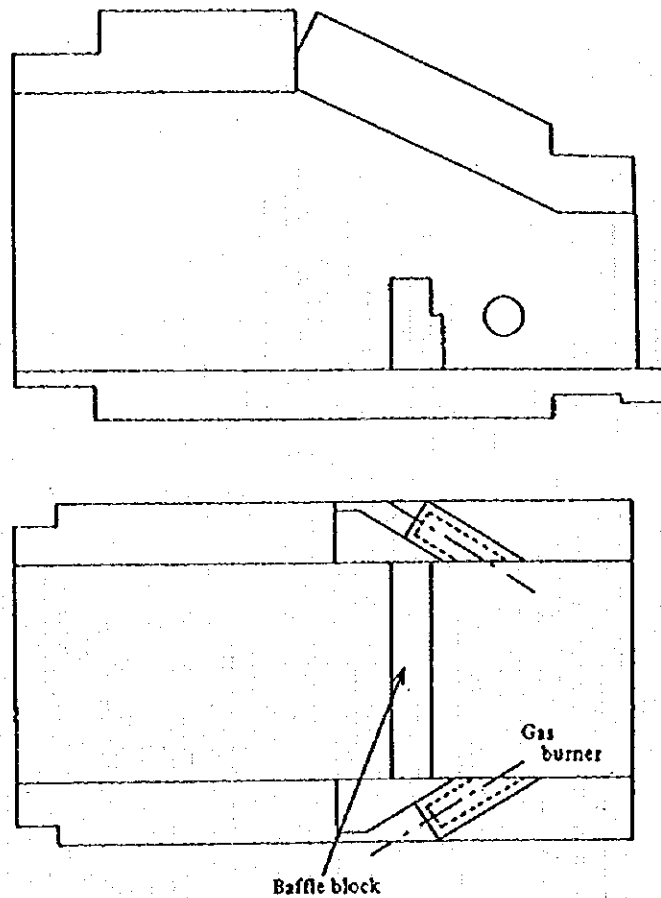
In gas combustion, heat is transferred mainly by radiation from the clear flames of high-temperature carbon dioxide gas, water vapor, and other triatomic gas.

In fuel oil combustion, heat is transferred by luminous flame radiation, and solid radiation from the suspended carbon particles that are generated in the flames during combustion plays an important role.

Emissivity  $\epsilon$  of radiation heat transfer differs between fuel oil (0.6 to 0.8) and natural gas (0.3 to 0.4) in the initial phase of combustion. In actual furnaces, the effect will be less because there is re-radiation from the furnace walls in addition to radiation from the flames, but gas has less amount of radiation heat transfer than fuel oil.

Figure 7.8 shows an instance, in which a baffle is provided in the port. Fuel gas is injected in back of it to be burnt in a state of rather insufficient air so that fine carbon particles will be generated and they will be burnt into luminous flames in secondary combustion.

Figure 7.8 Baffle Block in the Port



(3) Reinforcing heat insulation

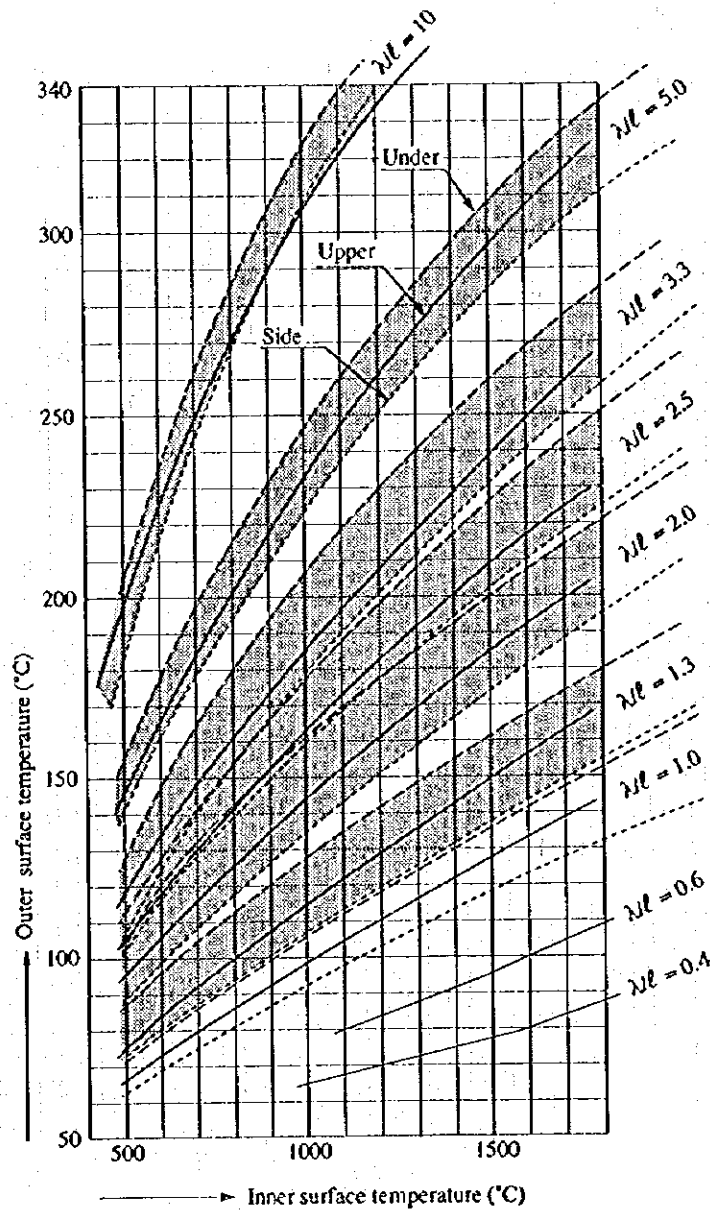
The refractories of the melting furnace are exposed to very severe conditions in terms of temperature and corrosion by the glass. Consequently, they had not been sufficiently heat-insulated, and the outer surface of wall of molten glass level was cooled by air. As is clear from the heat balance chart, heat radiation from the furnace walls accounts for a large percentage of heat loss, so the furnace was being improved in heat insulation using high-grade refractories. Specifically, the furnace crown was constructed of super-duty silica bricks having small alkali or alumina content; the tank block and bottom were constructed of electrocast bricks of alumina, zirconium, silica inside and with clay refractory bricks, insulating bricks, or ceramic fiber outside.

The outer surface temperature of the furnace wall can be obtained by giving the inner surface temperature of the furnace wall, the material and thickness of the refractories composing the furnace wall. More specifically, the heat conductivity of the furnace material is obtained from Table 7.3, and the overall  $\lambda/L$  is calculated based on the heat conductivity and the thickness of the furnace material. Then the outer surface temperature can be obtained from the graph in Figure 7.9.

**Table 7.3 Heat Conductivity of Refractory**

Material	$\lambda$ (kcal/mh°C)
Elect. cast AZG	3.2~3.7
Elect. cast Al ( $\alpha$ , $\beta$ )	3.4~3.8
Magnesia	3.2~3.8
Zircon (Bonded)	1.8~2.2
AZG (Bonded)	1.7~2.1
Mullite	1.3~1.6
Hiplex	1.6
SK34	1.2~1.4
SK31	1.1~1.3
Silica	1.4~1.7
VRC	1.2
Liplex	0.55
Chrome-mag.	1.4~1.8
Isolite ISB	0.35~0.5
Isolite C2S	0.33
Isolite C1	0.28
Isolite B7P	0.26
Isolite B5	0.18
Isolite B3	0.16
Isolite B1	0.14
Cast. IC100FR	0.13
KAOWool 1600	0.1~0.26
Super Board H	0.09>
Super Board L	0.045>
Silica Board	0.047>

Figure 7.9 Relationship between Inner and Outer Wall Temperatures



If the outer surface temperature of the furnace wall is given, the amount of heat loss can be calculated by the following equation.

$$Q = 4.88 \times 0.9 \left[ \left( \frac{T_o + 273}{100} \right)^4 - \left( \frac{T_a + 273}{100} \right)^4 \right] + 1.58 (T_o - T_a)^{1.25}$$

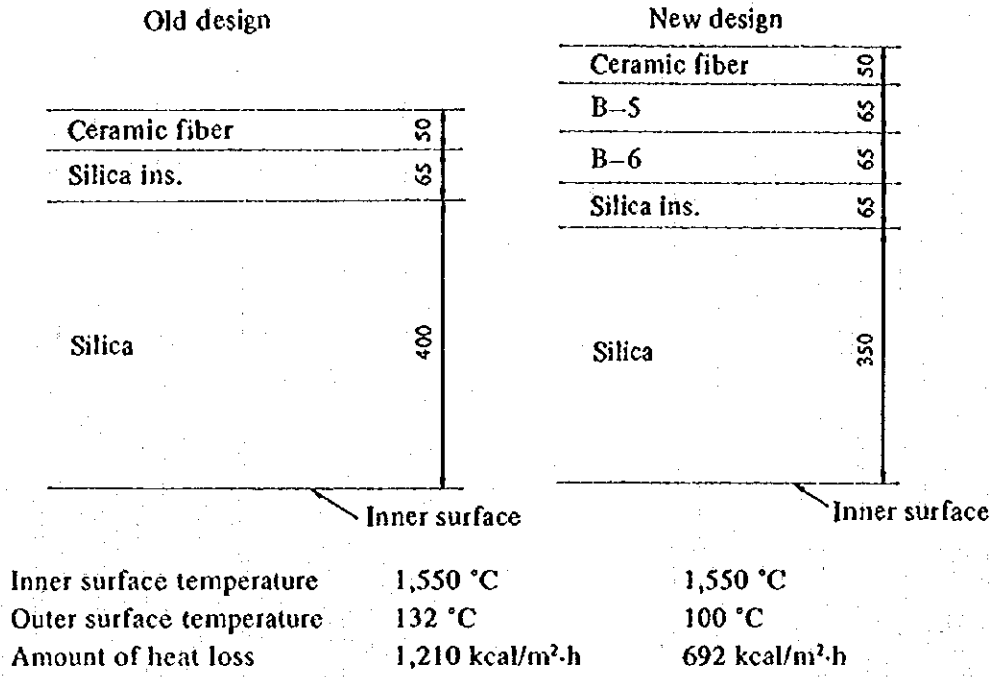
Q: kcal/m<sup>2</sup> h

To: Outer surface temperature °C

Ta: Ambient temperature 40 °C

Figures 7.10 to 7.18 show the brick composition for each part of the old and new furnaces, and the difference in their heat loss amount.

**Figure 7.10 Heat Insulation of Melting Furnace Crown**



**Figure 7.11 Heat Insulation of Working Hearth Crown**

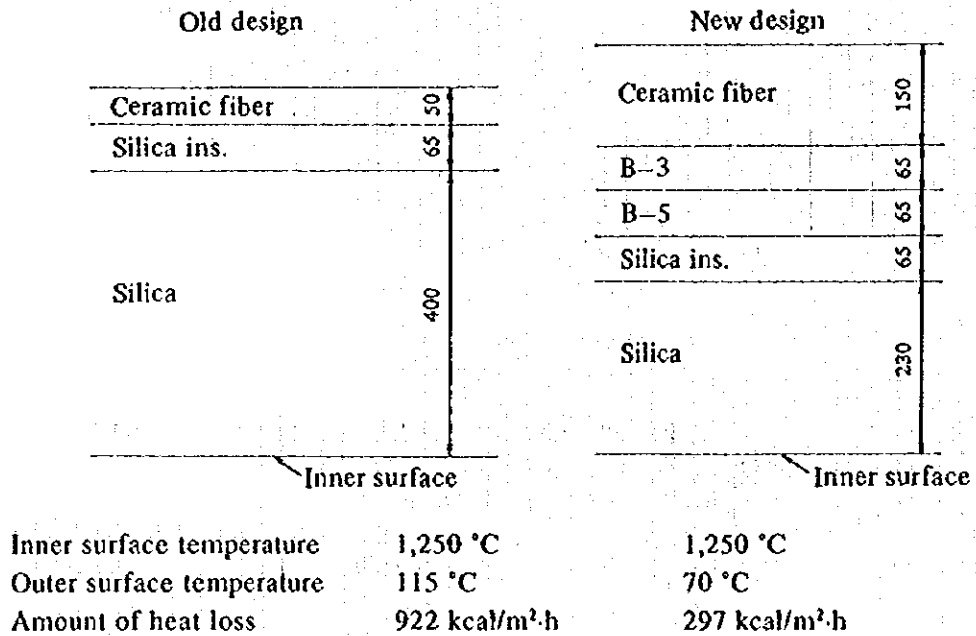


Figure 7.12 Heat Insulation of Regenerator Crown

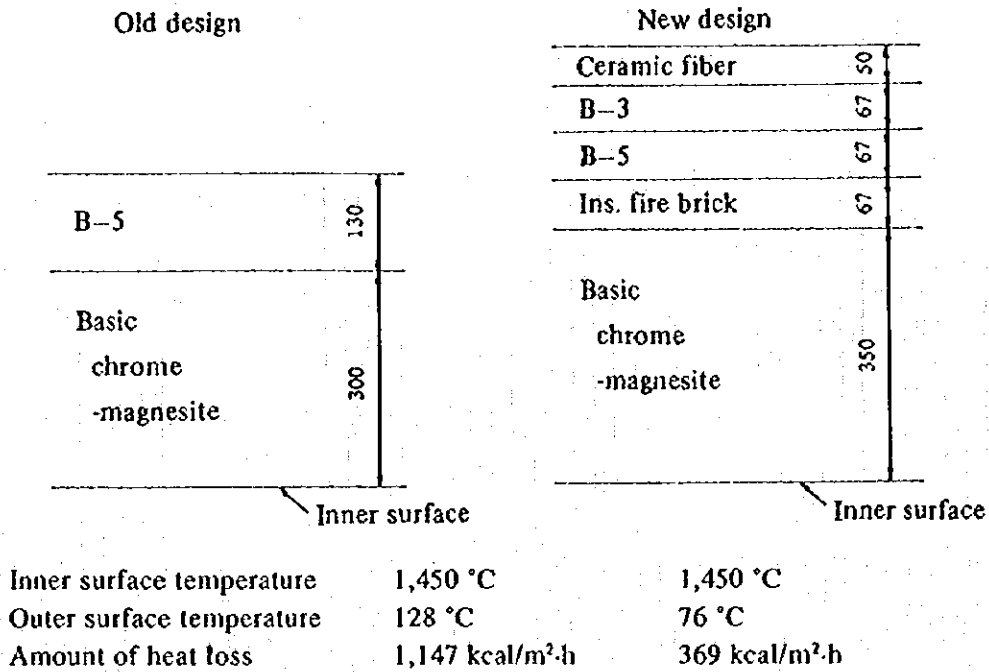
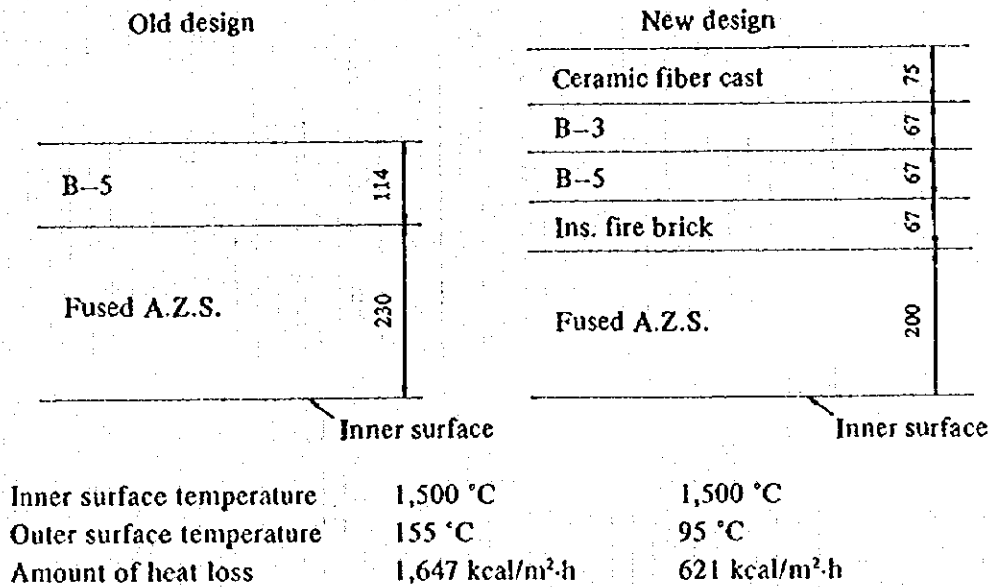
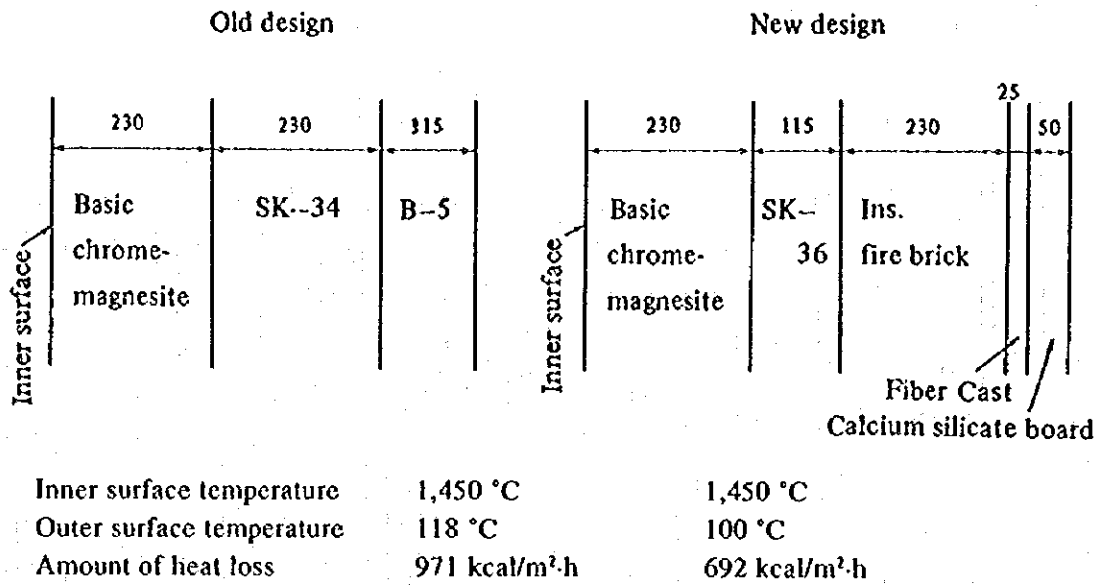


Figure 7.13 Heat Insulation of Port Crown



**Figure 7.14 Heat Insulation of Regenerator Sidewalls (Upper Part)**



**Figure 7.15 Heat Insulation of Melting Tank Block**

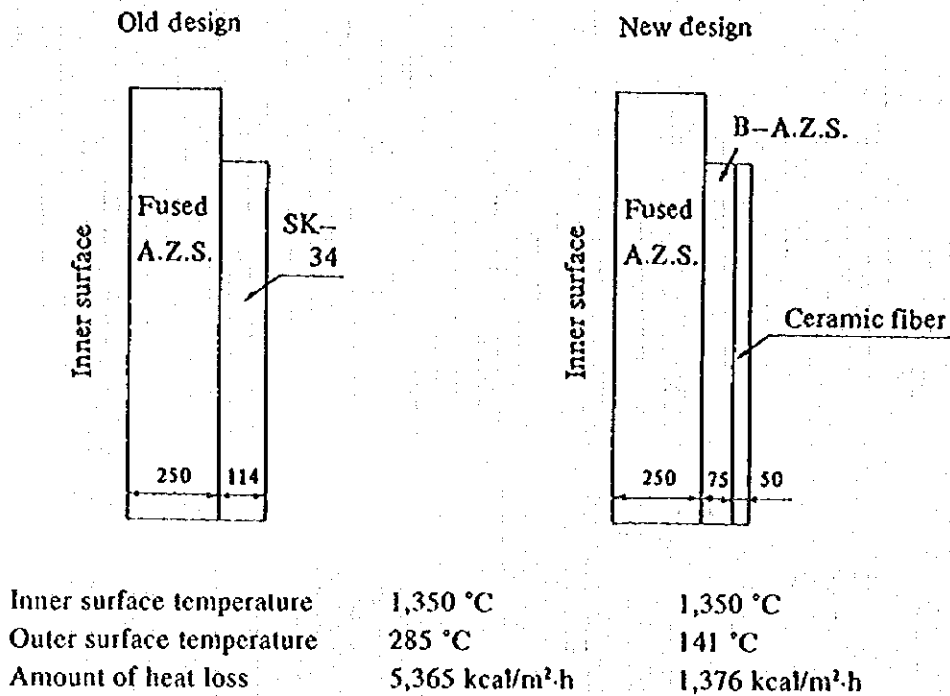


Figure 7.16 Heat Insulation of Working Hearth Tank Block

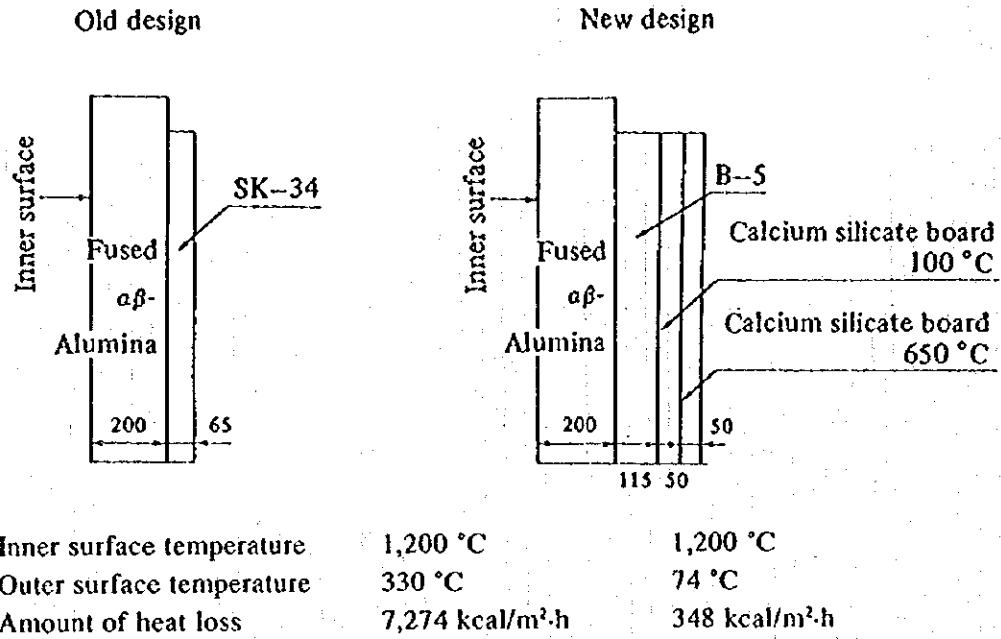
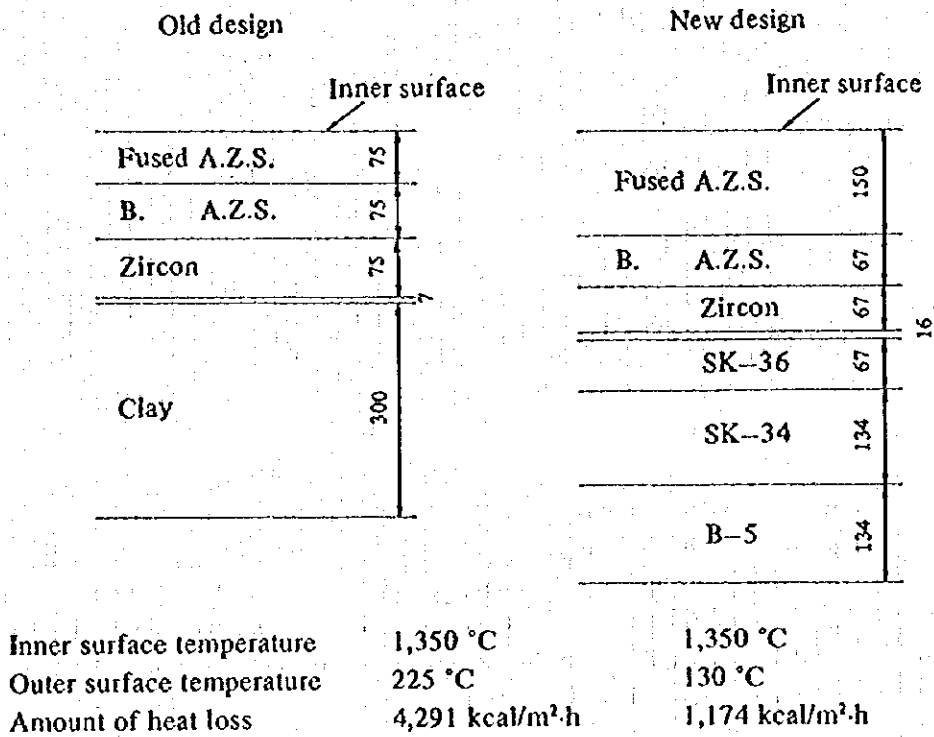
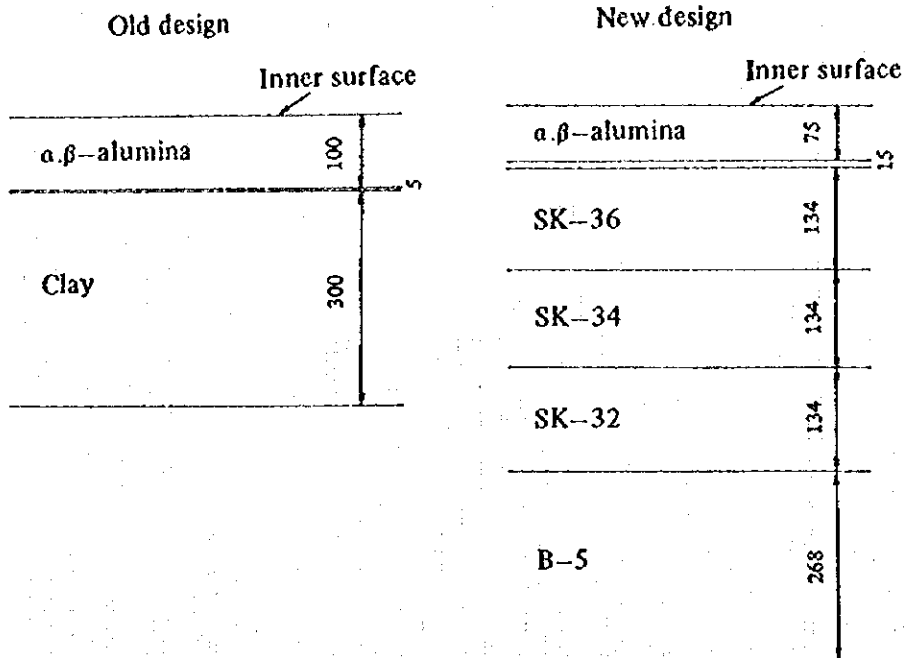


Figure 7.17 Heat Insulation of Melting Tank Bottom





**Figure 7.18 Heat Insulation of Working Hearth Bottom**



Inner surface temperature	1,100 °C	1,150 °C
Outer surface temperature	250 °C	80 °C
Amount of heat loss	4,126 kcal/m <sup>2</sup> .h	446 kcal/m <sup>2</sup> .h

Compared with the calculated values, the actual amount of heat loss increases considerably because of heat loss from the joints of the furnace material or through the metal parts.

**(4) Waste heat recovery**

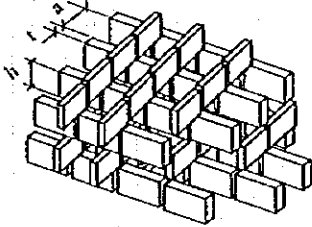
Because a melting furnace requires high temperature, the waste heat of burnt exhaust gas is recovered to preheat secondary air. Either a regenerator or recuperator is used as a waste heat recovery unit. Generally, a regenerator is used except for small-sized furnaces.

The heat recovery ratio of the regenerator can be improved by decreasing the thickness of checker bricks, increasing the velocity of exhaust gas running through the checker bricks, and raising the height of the regenerator and thus increasing the amount of checker bricks. Figure 7.19 shows the types of checker work and the unit surface area for heat conduction. Figure 7.20 shows an example of relationship between the height of checker and air preheating temperature.

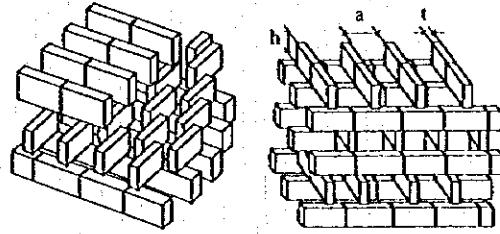
Figure 7.19 Type of Checker Work and Unit Surface Area for Heat Conduction

(A) Straight Pigeon Hole

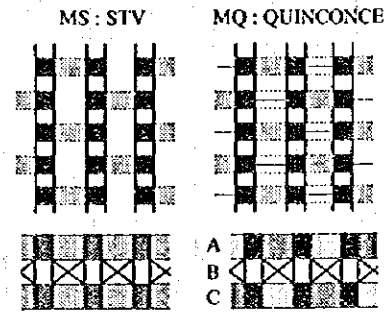
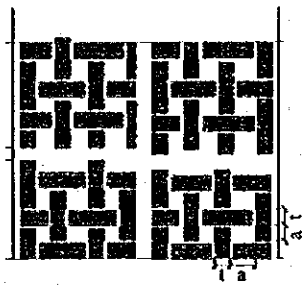
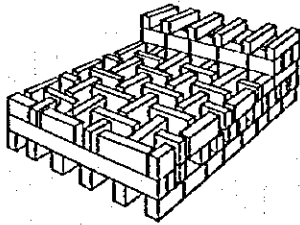
$$A = \frac{a + 2(a+t)h}{(a+t)^2 h} \times 1000 \text{ (m}^2/\text{m}^3\text{)}$$



(B) MAERZ Pigeon Hole



(C) Open Basket Weave (OBW)

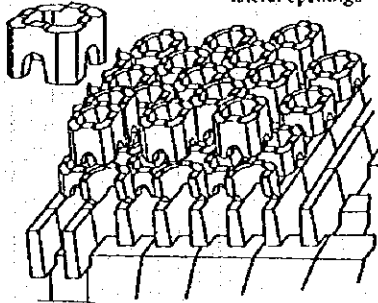


$$A_0 = \frac{2(a+t)h + 2th + (a-t)h}{(a+t)^2 h} \times 1000$$

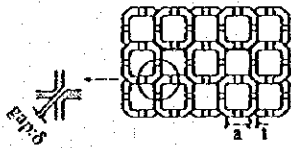
$$A = A_0 + \frac{at}{(a+t)^2 h} \times 1000$$

(D) Chimney Box Type (VEITSCHER)

Closed blocks with lateral openings

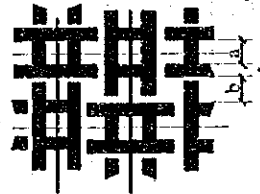
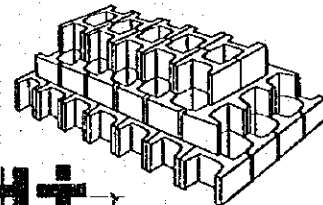


$$A = \frac{4a}{(a+t)^2} \times 1000$$



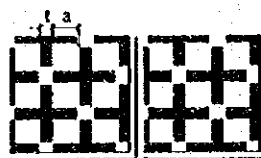
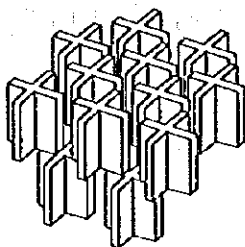
$$A = \frac{4a - 0.485t}{(a+t)^2} \times 1000 \quad (\delta = 10 \dots \dots \times 0.88)$$

(E) Interweave (National Ref.)



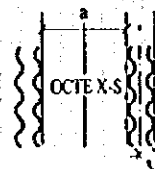
$$A = \frac{8(a+b)}{(a+b+2t)^2} \times 1000$$

(F) Cruciform (SEPR)



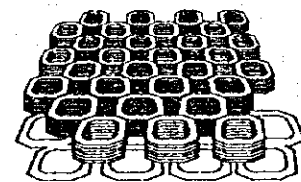
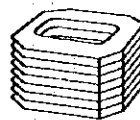
$$A = \frac{4a}{(a+t)^2} \times 1000$$

(G) OCTEX-S (Toshiba Monofrax)

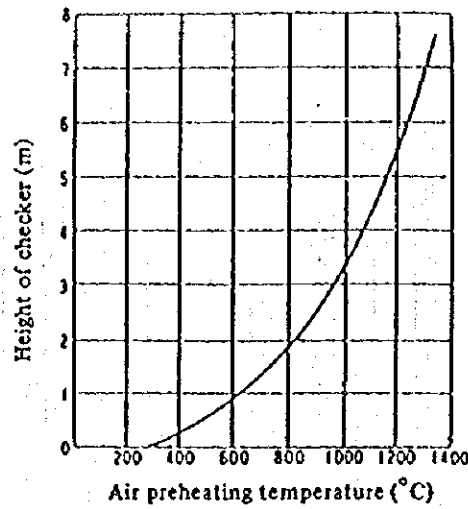


$$A = \frac{4.8a - 0.582t}{(a+t)^2}$$

(gap  $\delta = 10 \dots \dots \times 0.88$ )

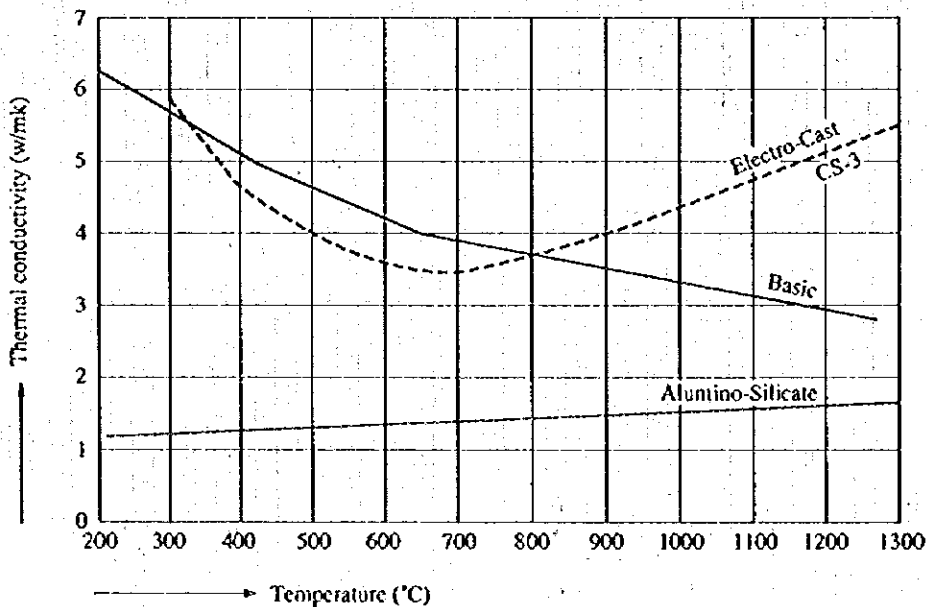


**Figure 7.20 Relationship between Height of Checker and Air Preheating Temperature**



Normally, secondary air is preheated to about 1,150 °C to 1,300 °C. The checker bricks cause breaking down by reaction with the dust in exhaust gas over years of use, clogging up the gaps and reducing the heat exchange area. Therefore, magnesite bricks and electrocast bricks of high corrosion resistance have come to be used to last as long as the melting furnace itself. The heat conductivity of magnetite bricks and electrocast bricks is two or more times as large as that of the conventionally used aluminosilicate bricks. (See Figure 7.21) This considerably contributes to improving the heat recovery rate (increasing the air preheating temperature).

**Figure 7.21 Thermal Conductivity of Checker Refractory**



As for recuperator, the radiating type recuperator which is free of clogging with dust is mostly used, but a multiple ceramic tube recuperator is also used. There is also a type which withstands gas temperatures of up to about 1,500 °C, but its heat recovery ratio is low because preheated air temperature is up to about 800 °C. However, it is used for small-sized furnaces for reasons that it costs low to install and does not require much floor space.

To make maximum use of preheated air, it is necessary to reduce the leakage air of normal ambient temperature through the openings.

(5) Raw material and cullet

The energy used for melting can be reduced if cullet is mixed in a larger percentage, provided that product quality will not be adversely affected by their increased percentage. The relationship between the percentage of cullet and required heat is shown in Figure 7.22 and Table 7.4.

Figure 7.22 Heat Consumption Rate for Cullet and Fuel Saving Rate

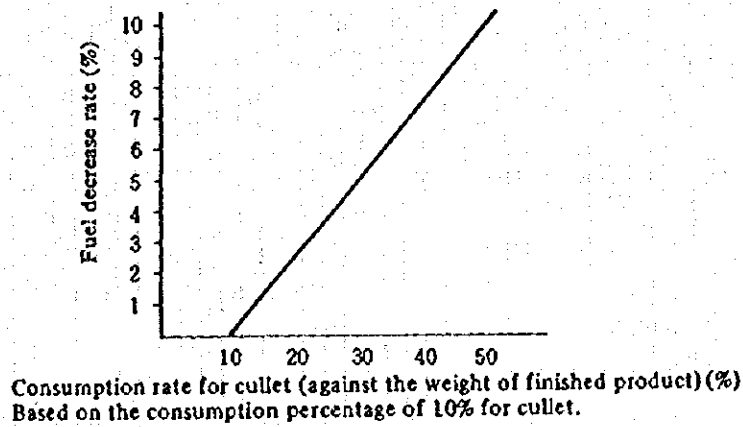


Table 7.4 Heat Required for Production of Various Kinds of Glass (Theoretical Value)

Kind of glass	Temperature °C	Heat required for melting glass (kcal/kg glass)					
		Cullet addition rate %					
		0	20	40	60	80	100
Tableware glass	1,400	576	543	510	477	444	411
	1,250	530	497	464	431	398	365
Sheet glass	1,500	706	652	598	545	491	437
	1,400	666	614	561	509	456	404
	1,150	568	519	470	420	371	322
Laboratory appliances	1,400	508	482	455	429	402	376
	1,300	477	451	424	398	371	345
Lead glass	1,400	496	472	448	424	400	376
	1,100	391	367	343	319	295	271

The heating value for sheet glass here is obtained with 20 °C as a reference temperature for the charging material. Moreover, in the case of sheet glass the heat required for melting the material and heating it up to 1500 °C is defined as effective heat. Batch melting heat varies depending on the composition of each product, but it does not necessarily follow that the composition requiring less heat leads to energy conservation. Specifically, reducing the alkali content lowers the melting heat theoretically, but actually it decreases the solubility. In this case, therefore, it is necessary to raise the melting temperature or to decrease the charging material quantity, which will eventually result in energy increase.

Use of refining aids will shorten the refining time, and result in saving energy. A type and quantity of refining aids must be selected to suit the furnace conditions.

(6) Electric melting

This method uses an electrode inserted into the melting furnace to directly apply electricity to glass which becomes electro-conductive at about 800 °C. If it is used in a fuel-heating furnace as an auxiliary means to increase the amount of pull and adjust the temperature inside the furnace, it is called booster. About 100 kW of electricity is required to increase quantity by 3 tons or more per day. If the efficiency of conversion from fuel oil to electricity is 35 % and if the fuel intensity is 175 liters or more per ton, energy can be saved by using a booster.

Table 7.5 shows an example of heat output ratio of electric melting furnace. In some cases of small-sized furnace, electric melting is more economical even in consideration of energy prices and auxiliary equipment. Furthermore electric melting has advantages such as smaller air pollution, easy control of temperature and easy production of high quality products.

**Table 7.5 Heat Output Ratio of Electric Melting Furnace**

	Heat output (kcal/h)	Ratio (%)		Heat output (kcal/h)	Ratio (%)	
Heat release from ceiling	28	(0.07)	Ceiling	1,800	2	} 30
Heat release from furnace bottom	5,883		Side wall	10,700	15	
Heat release from throat side wall	5,200		Bottom	9,300	13	
Other walls	7,850		Cooling water for electrode	1,400	2	2
Total	18,961	44.1	Calorific value required for vitrification	2,200	3	} 68
Loss by water cooling for electrode	10,455	24.3	Soaring temp. of glass	46,600	65	
For glass heating	13,584	31.6	Total	72,000	100	100

(Capacity 750 kg, pull quantity 400 kg/day) (Pull quantity 60 t/day)

### 7.2.2 Forming Machine and Float Bath

For Colburn machines and roll out machines, gas burners are used to adjust glass temperature, though in small numbers.

By contrast the float bath for forming float glass is a large hearth of about 50 m length, for which electric heating is employed. Heat insulation of the hearth needs to be reinforced from the viewpoint of energy conservation.

### 7.2.3 Annealing Lehr

Formed glass ribbons still have a temperature of over 600 °C, so if they are taken into the lehr without losing this heat, heating should be theoretically unnecessary, provided that the following conditions are met. Actually, however, heating is required in the annealing zone, where temperature must be controlled to correct the temperature difference particularly between the upper and lower surfaces of the glass ribbon, and that between the side and the center.

Lehrs have conventionally been of brickwork structure, but recently there have appeared some lehrs of steel-plate structure lined with heat-insulating materials. Heating methods include gas heating and electric heating. Lehrs for float glass are mostly of steel-plate structure and electric heating type. In either case, heat insulation should be reinforced for the purpose of energy conservation. Lehrs of steel-plate structure is preferable in terms of preventing leakage of hot air and entry of cold wind.

Indirect cooling by cold air is mostly used in the cooling zone, where a lot of cooling fans are necessary, but from the viewpoint of energy conservation, adoption of inverter control and centralization of fans are performed.

#### 7.2.4 Melting Load and Energy Conservation

##### (1) Melting load and forming capacity

The molten amount per unit area is called melting load. Maximizing this melting load leads to energy conservation. This, however, requires a sufficient allowance of forming capacity and follow-up.

##### (2) Melting load and product type

The standard of melting load differs depending on the product type. In the case of figured sheet glass, for example, melting load can be increased by about 40 % as compared with ordinary sheet glass and float glass. It can be increased by about as much as 90 % for bottle glass.

Even for the same type of glass, melting load varies according to the difference in the required quality; for example, there is an about 10 % difference between glass for construction and glass for mirrors.

An absolute value for unit area is not mentioned herein because each company has its own way of its definition.

##### (3) Melting load and melting capacity

Melting load differs depending on melting capacity, which is determined based on the total of all the factors including the structure of a furnace, operating techniques, control techniques, raw materials, etc. In this regard, particular attention should be given to a disparity in material composition and particle size distribution. Since melting capacity is not an instant value but a mean value stably obtained, it is important to reduce the disparity by means of process control and quality control.

##### (4) Melting load and scale merit

The scale merit is as earlier shown in Figure 7.7.

Aggregating small furnaces into large ones leads to a substantial energy conservation. In Japan, for example, 29 furnaces have been combined into 17 furnaces for the 10 years since 1973, achieving an about 15% energy saving. (See Figure 7.23)

Figure 7.24 shows the changes in the production amount.

Figure 7.23 Trend of Numbers of Melting Furnaces in Operation in 3 Sheet Glass Companies

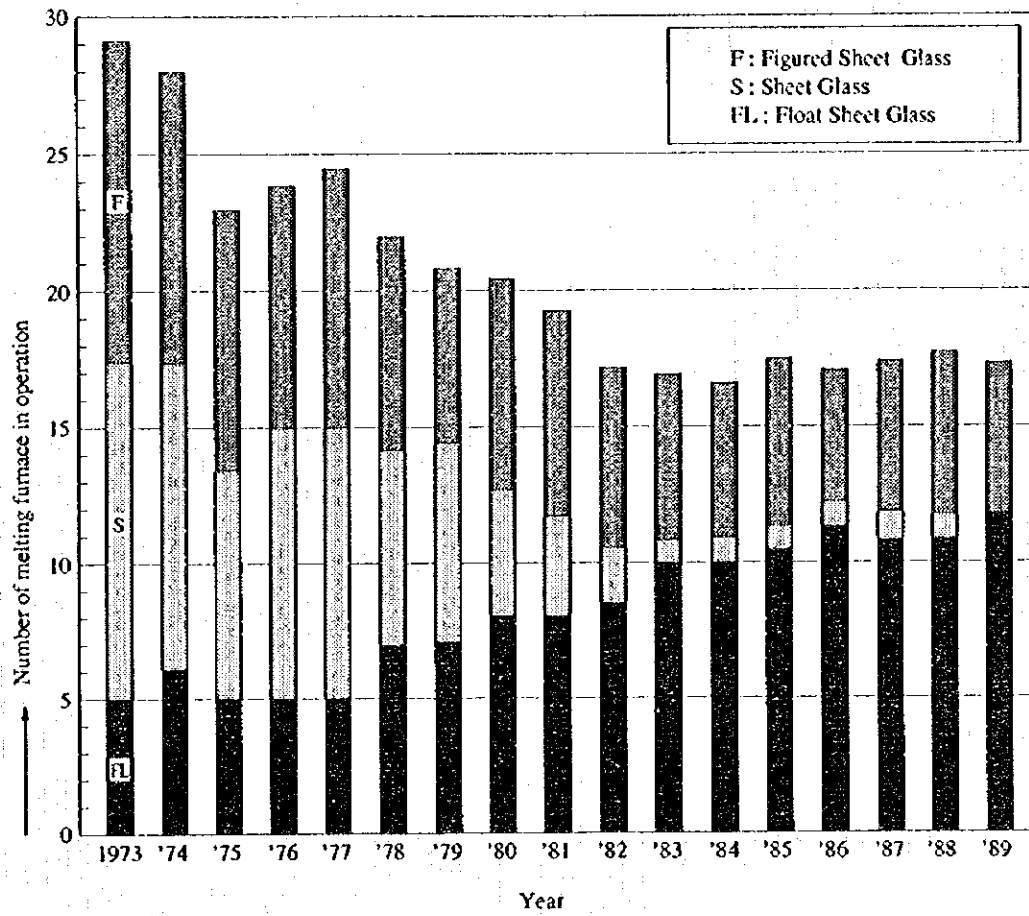
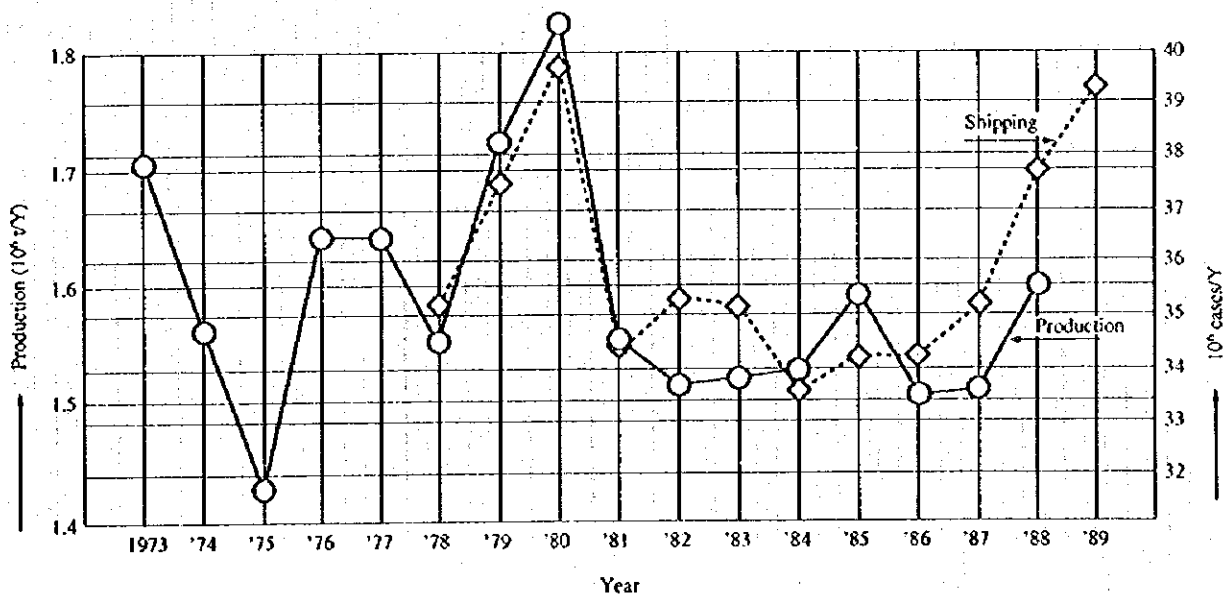


Figure 7.24 Trend of Production of Sheet Glass in Japan





### 7.2.5 Improvement of Yield and Energy Conservation

Energy conservation is finally evaluated in terms of energy intensity per unit of production. Hence, improving the yield leads to energy conservation.

Generally, the yield in a narrow sense means the quantity of product for the quantity of pull total production amount, but the yield here refers to that in a broad sense including the operation rate. In order to improve the yield, it is necessary to ensure a stable operation through reinforcement of TQC, decrease the accident loss through enhancement of TPM and improve the operation rate through reduction of color-change loss, etc.

Note: TQC: Total Quality Control

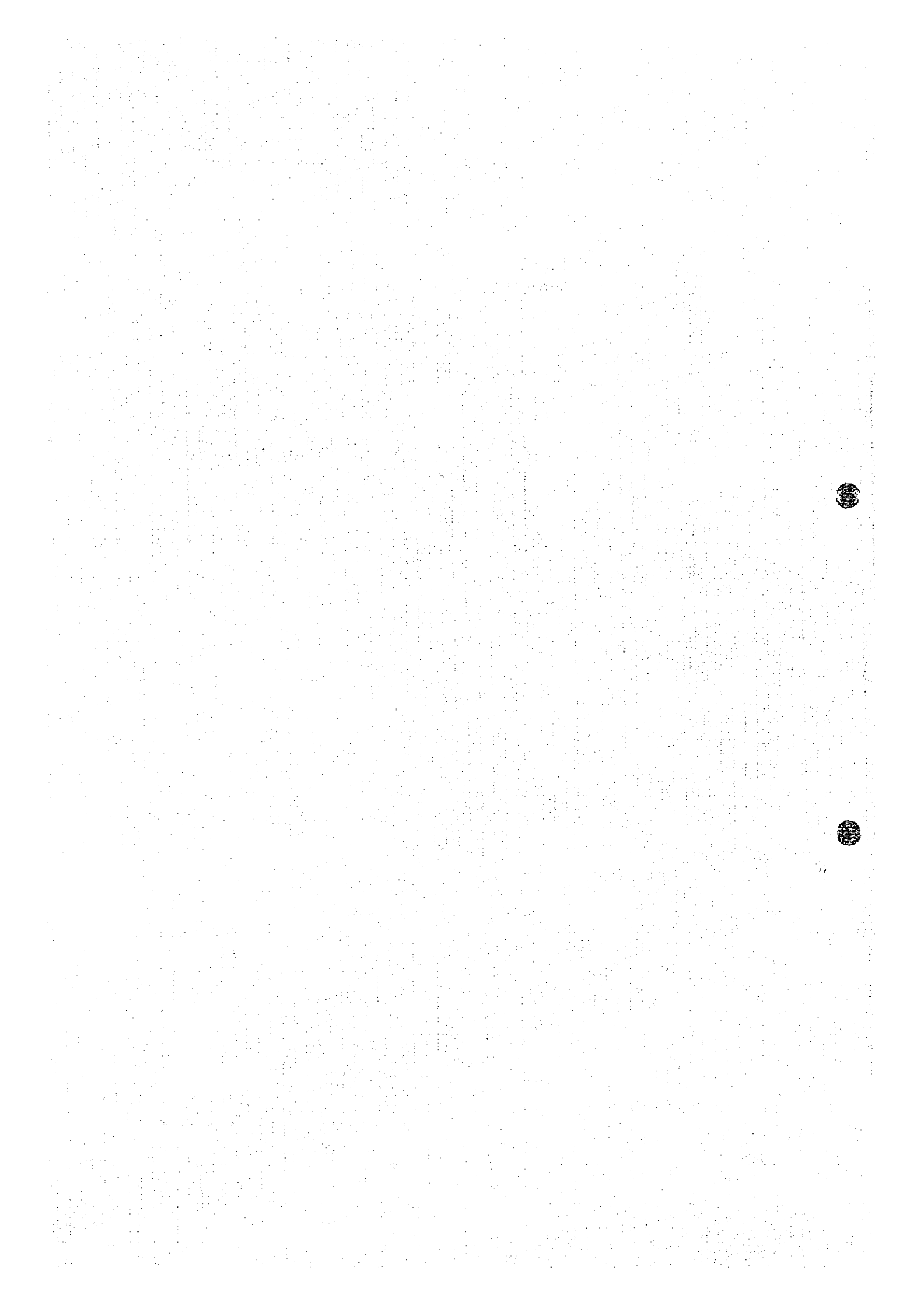
Company-wide activity in which all the members in all the departments of a company are involved to proceed with QC activities in order to achieve the company's operation target

TPM: Total Productive Maintenance

Maintenance of production as a total system in which all the employees of a company participate

To maximize the equipment's life cycle efficiency is the purpose of TPM, which is participated in by all the members of a company from the top management to the employees working at the first front.

**8. ENERGY CONSERVATION IN THE  
TEXTILE INDUSTRY**



## **8. ENERGY CONSERVATION IN THE TEXTILE INDUSTRY**

### **8.1 Current Situation of Energy Utilization**

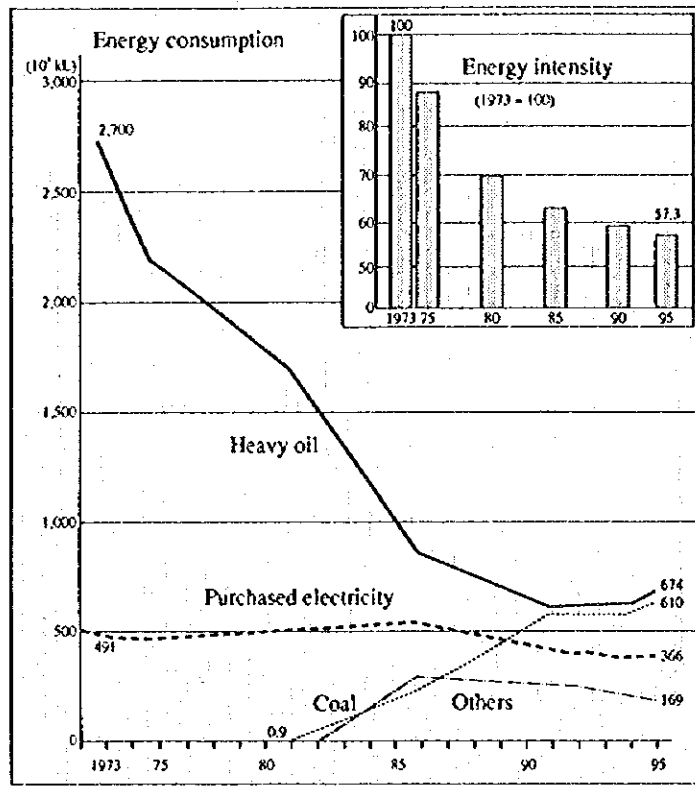
#### **8.1.1 Energy Intensity**

Energy intensity is one of the measures for evaluating properness of energy management. There are two methods for the evaluation: One is that the level of the energy intensity is checked in comparison with that of competitors, and the other is that the trend of energy intensity is checked, that is, it is checked whether it is improving or on the downgrade.

If it is unknown whether energy intensity is in course of improvement or deterioration, the comparison with others at the same period does not lead to an exact evaluation. It is preferable to examine energy intensity in the industry over a time span of several years or more.

Figure 8.1 and Figure 8.2 show the trend of energy intensity in the chemical fiber industry and the dyeing industry--the most typical energy-intensive categories in the Japanese textile industry.

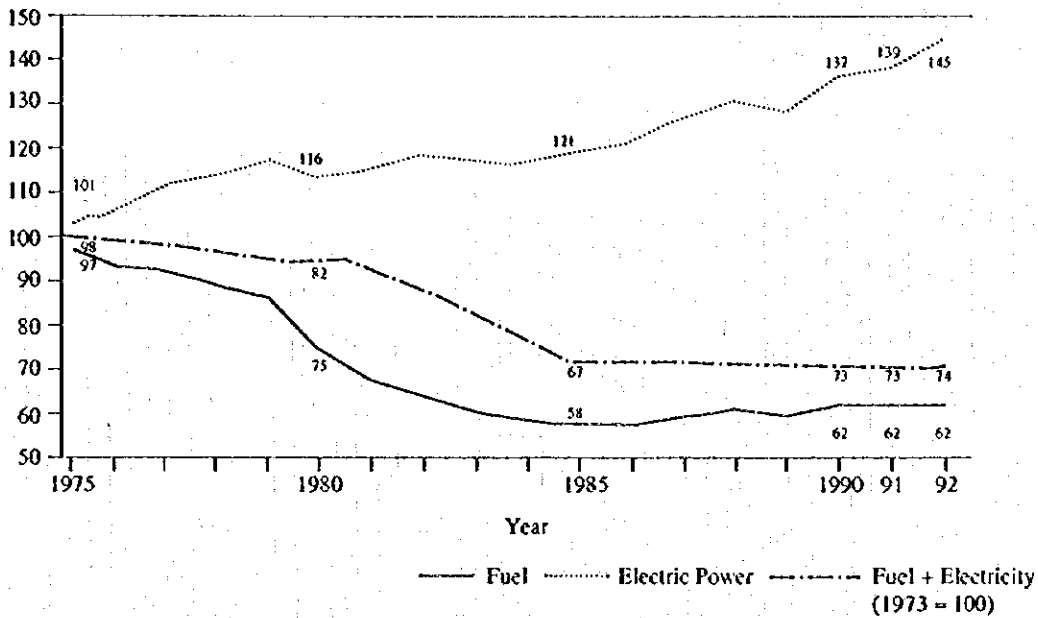
**Figure 8.1 Trend of Energy Consumption and Energy Intensity in the Chemical Fiber Industry**



Source: "Year Book of Textiles Statistics" and "Year Book of Current Survey of Energy Consumption in Manufacturing" by MITI

- Note 1: Energy consumption calculated in terms of crude oil.  
 Note 2: Energy intensity means crude oil consumption (kL) required to produce 1 ton of chemical textile.  
 Note 3: Others include oil coke, hydrocarbon oil, kerosine, LPG, etc.

**Figure 8.2 Trend of Energy Intensity Index in Dyeing Industry**



An approximately 40 % reduction of energy intensity has been achieved over the period of 20 years since the first oil crisis in 1973. In this regard, the energy consumption of chemical fiber industry accounts for 2 % in the entire manufacturing industry, which means 3 % in the entire textile industry.

The overall energy intensity in the dyeing industry was reduced by 26 % in 1992 as compared with that in 1973.

(1) Fuel intensity

Fuel intensity had been rapidly improving until 1985 but thereafter it has tended to increase due to the oil price reduction, the multikind smaller lot production system, the upgraded processing techniques, and so forth.

(2) Electricity intensity

Although measures to conserve electric power have been positively taken along with those for fuel conservation, the increase in power consumption has overtaken the effect of power saving. The possible factors for this include installation of pollution-preventive facilities, introduction of labor-saving equipment, the multikind small quantity production system, higher values added by the development of composite materials.

(3) Energy intensity by type of industry

Table 8.1 shows the statistical data on the fuel intensity and electricity intensity by product type of the textile and dyeing industry.

**Table 8.1 Energy Intensity by Major Textile Industry  
(Average for the three years up to 1990)**

Type of Industry Category	Subcategory	Fuel Intensity (L/ton)	Electricity Intensity (kWh/kg)	Item Manufactured
Textile		278.8	2.91	
	Cotton, staple fiber textile industry	233.9	2.31	Cotton, chemical fiber, staple fiber, synthetic short fiber fabrics; blanket
	Silk, rayon textile industry	305.0	5.03	Silk, chemical fiber, synthetic long fiber fabrics, tire cord
	Woolen textile industry	669.0	1.68	Worsted cloth, woolen fabric, woven felt
	Flaxen fiber textile industry	71.0	4.27	Flax and jute fabrics
	Others	576.2	2.29	Moquette, other fabrics
Dyeing		820.9	1.10	
	Cotton, staple fiber, and flaxen fiber fabric dyeing	1,046.2	3.82	Scouring, bleaching and dyeing for cotton, flax fiber, staple fiber and synthetic fiber spinning fabrics
	Silk and rayon fabric dyeing	593.6	0.74	Scouring, bleaching and dyeing for silk, rayon and synthetic long fiber fabrics
	Wool fabric dyeing	2,187.2	2.62	
	Fabric general finish	265.9	0.37	
	Cotton fiber and yarn dyeing	810.2	1.22	Dyeing for cotton yarn, synthetic fiber yarn and others
	Knit and lace dyeing	1,145.3	1.48	
	Miscellaneous textile goods dyeing	1,917.3	2.16	Including raising

- 1) Fuel intensity = Annual fuel consumption by items (kL) ÷  
[Quantity of processing by items (m<sup>3</sup>) × Specific weight (kg/m<sup>3</sup>)]
  - 2) Electricity intensity = Power consumption by items (kWh) ÷  
[Quantity of processing by items (m<sup>3</sup>) × Specific weight (kg/m<sup>3</sup>)]
- [Source: Industrial Statistics (Item)]

## 8.2 General Description of the Fiber Manufacturing Process

There are a wide variety of textile products, and the process from the stage of raw material to that of products includes the following steps: Step to make synthetic fiber from chemical material, step to spin yarn from natural and synthetic fibers, step to weave fabrics from yarn, and step to dye yarn and fabrics. In the stage of spinning yarn, a wide variety of types of yarn are produced depending on the type and length of fibers, methods of twisting, and thickness of yarn.

Texture is the specific standard for grading fabrics. To obtain fabrics of a unique texture, there are a wide variety of weaving and finishing methods. For the same purpose there are also various dyeing techniques, including vat dyeing and printing.

Here, the general description of the relation between common manufacturing processes and utilities is given.

### 8.2.1 Chemical and Synthetic Fibers

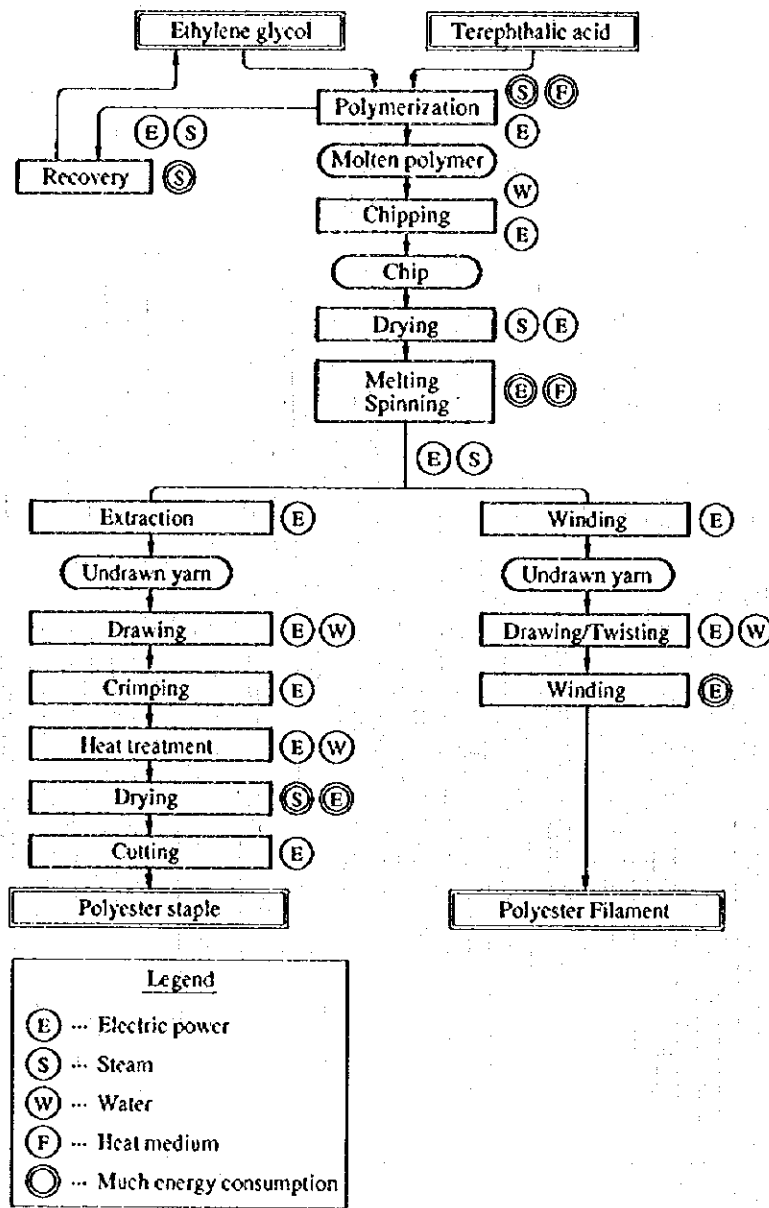
Each manufacturing process of polyester, acrylic and nylon fibers, which are the main synthetic fibers, will be described below in relationship with the energy consumption required therefor.

#### (1) Polyester fiber

Figure 8.3 shows the Japanese common batch process in which ethylene glycol (EG) and terephthalate (TPA) are used as raw materials.



Figure 8.3 Process Flow Chart of Polyester Fiber



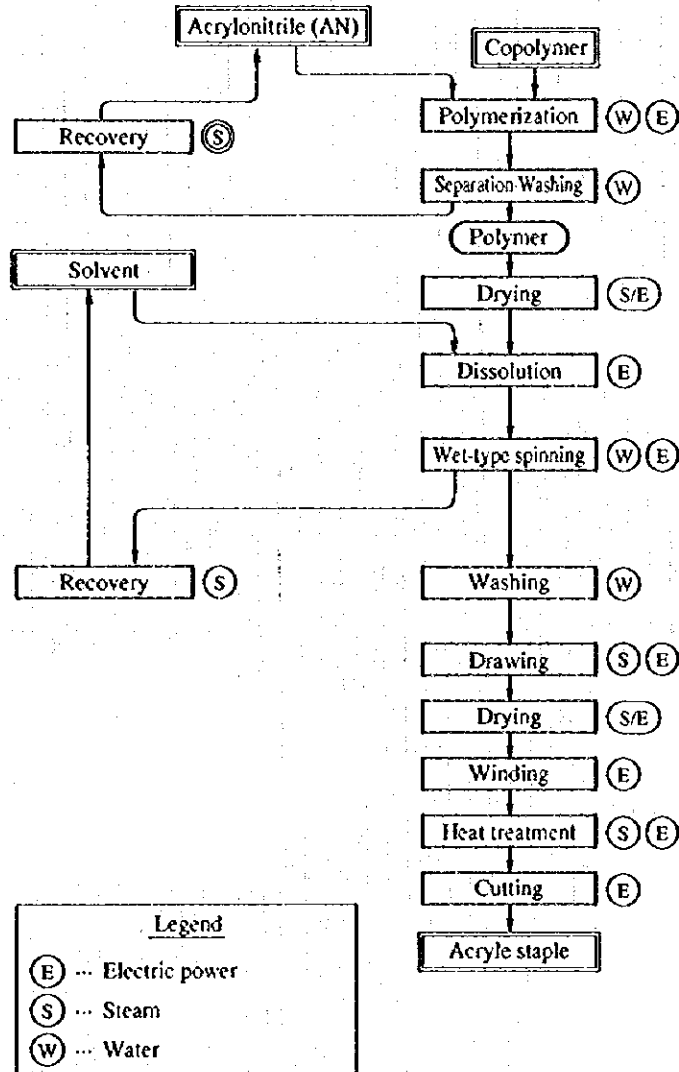
Drastic reduction of the time for esterification and polymerization is attempted in the continuous process recently used.

The mainstream of the methods for processing filament bulky yarn is false twisting. This is a method that yarn is finished by feeding and further passing it through a false twist spindle and a heater and thus performing heating, thermal fixation, and untwisting in continuous processes. The finished yarn has many applications, including knits and fabric.

(2) Acrylic fiber

Figure 8.4 shows the wet type spinning process, which is the mainstream in Japan.

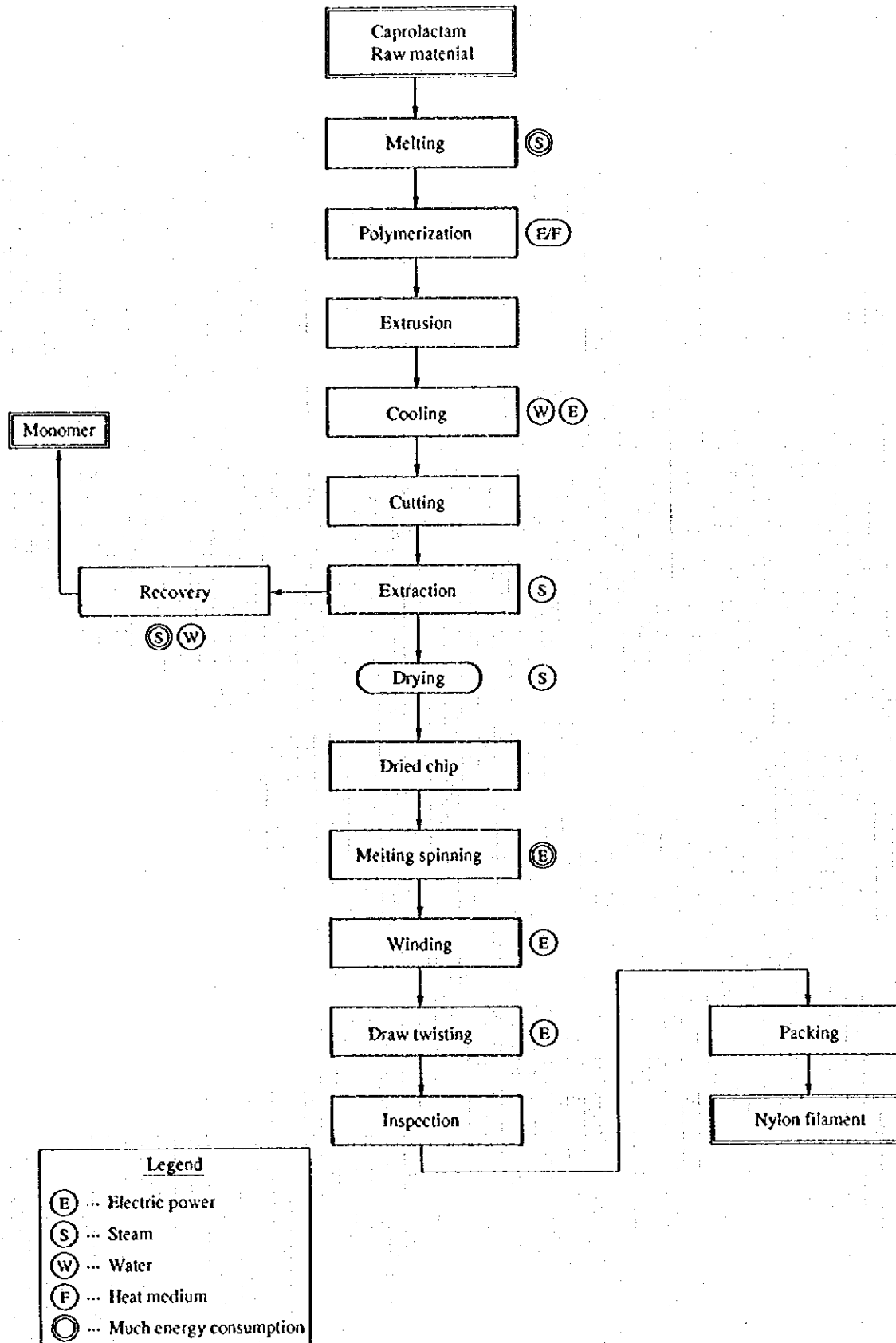
Figure 8.4 Process Flow Chart of Acryl Fiber



(3) Nylon fiber

Figure 8.5 shows the general nylon fiber manufacturing process.

Figure 8.5 Process Flow Chart of Nylon Fiber



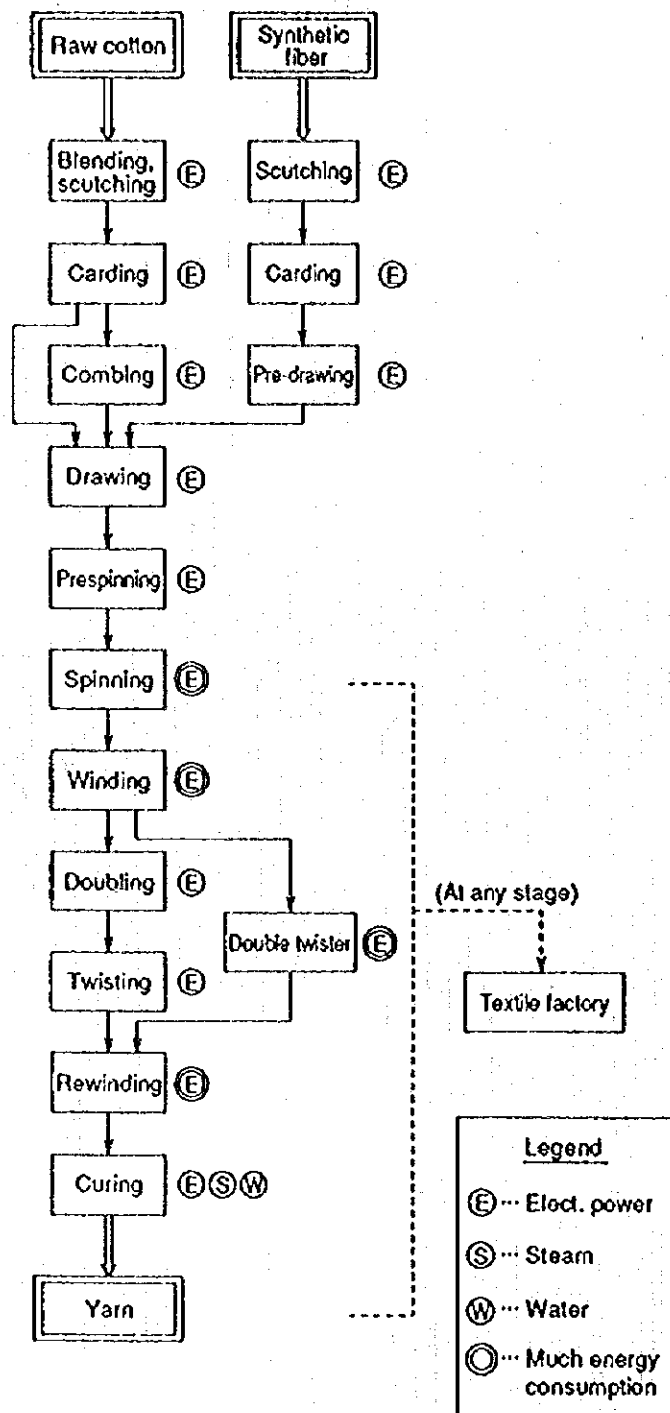
Also in the recent nylon fiber manufacturing process, such steps as chipping, drying and remelting are omitted since the continuous polymerization process, in which molten nylon is directly fed to the spinning machine without making any chip, is employed.

## 8.2.2 Cotton Spinning

### (1) Short fiber spinning

A standard short fiber spinning process for making yarn from raw cotton and chemical and synthetic fibers consists of the steps shown in Figure 8.6. This process is common to mixed spinning with synthetic fibers and single and mixed spinning of man-made fibers, such as rayon and acetate.

Figure 8.6 Process Flow Chart of Cotton Spinning



The drawing processes from scutching to pre-spinning are to unravel fibers, remove foreign matters therefrom, and subsequently make them parallel and uniform for the improvement of yarn quality. A higher quality yarn requires a larger number of times of repeating the drawing processes.

Spinning is the process to stretch crude yarn fed by a prespinning machine, properly twist it, turning it into yarn of a specified yarn number, and then wind it on a bobbin.

The scale of production of a spinning mill is measured by the number of spindles in spinning machines. Nearly 50 % of electric power for production in a spinning mill is consumed in the spinning process.

After spinning, single yarn on bobbin is wound and shaped in accordance with the production facility of weaving factories and carried into them. Single yarn on bobbin is usually rewound by rewinding machines into cheese shape before shipment.

Many winding processes are provided with high speed automatic winders for productivity improvement and labor saving, and most modernized in spinning facilities. However, the automation of knotting, waste yarn collection, and cleaning requires larger pneumatic power, and thus increases electric power load; there are cases where the electric power load exceeds 20 % of that of the entire spinning process.

## (2) Wool spinning

### a. Classification of wool yarn by spinning method

Wool yarn is classified into worsted yarn and woolen yarn according to the spinning method.

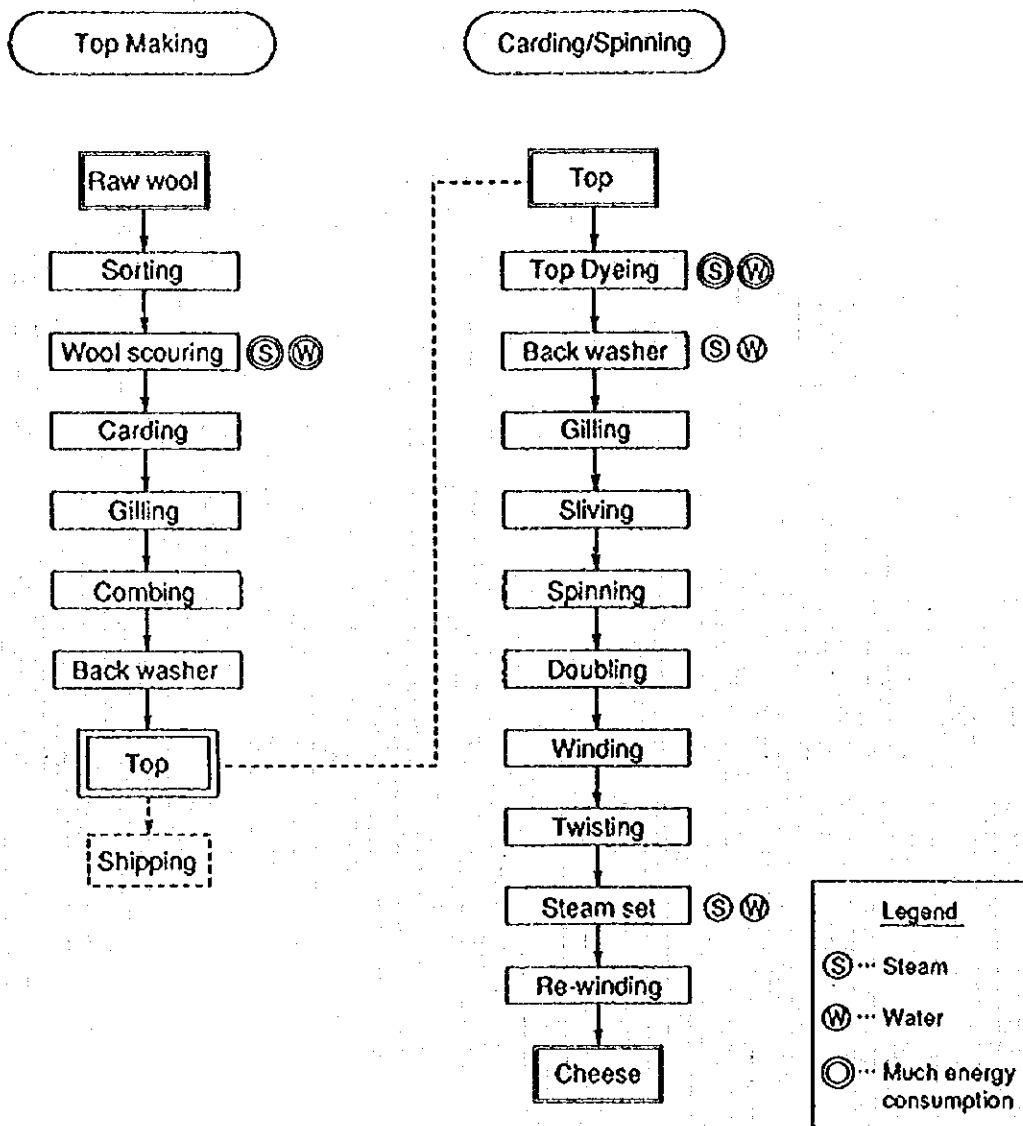
Worsted yarn is a wool yarn with relatively smooth surface, and is obtained by combing raw wool to remove short fibers and performing spinning such that long fibers are arranged in parallel. Woolen yarn is, on the contrary, a wool yarn spun such that fibers are twined around each other and maintains crimps specific to sheep wool fiber. Worsted yarn is finished into relatively thin fabric or fabric of intermediate thickness; woolen yarn is finished into thick fabric.

### b. Features of spinning process

The worsted spinning process is almost the same as the cotton spinning process, except for top making processes to intermediate products. Bulky synthetic fibers, such as acrylic fiber, are processed in accordance with worsted spinning. Figure 8.7 shows a standard wool spinning process from raw wool.

Another feature of the wool spinning process is that dyeing is usually performed at the stage of raw material.

Figure 8.7 Process Flow Chart of Worsted Spinning

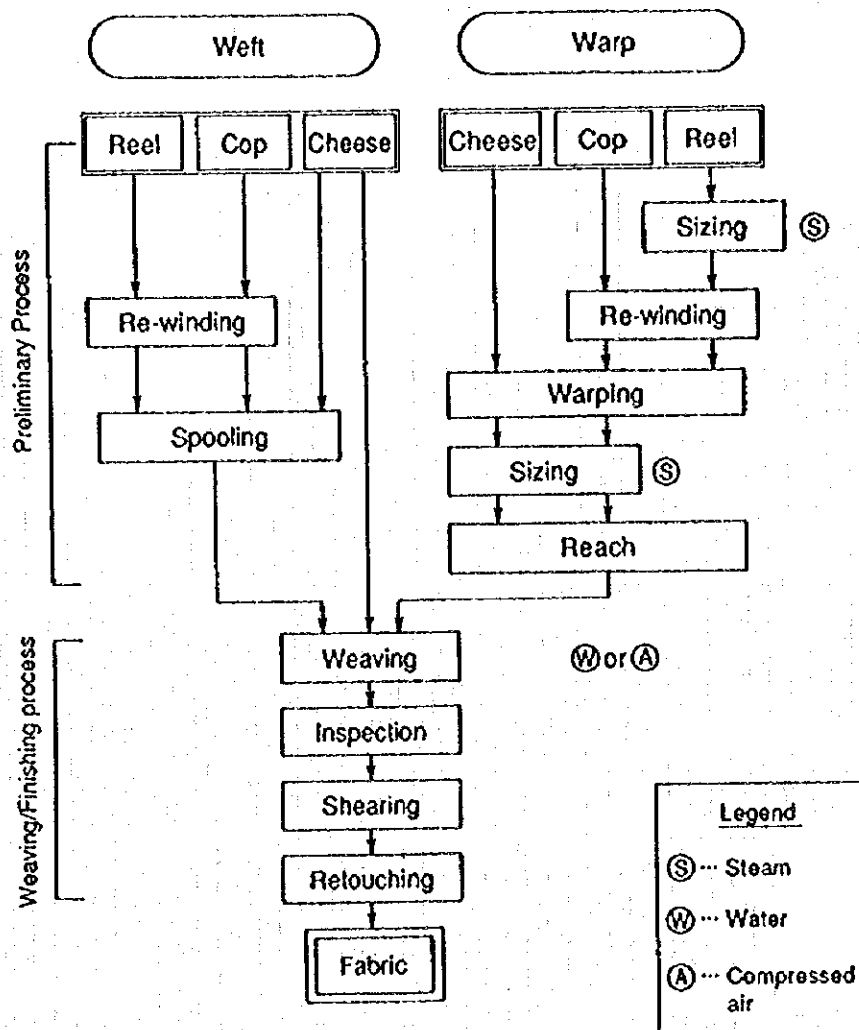


- ① Wool dyeing: Scoured raw wool is dyed before spinning. This is often used for woollen yarn.
- ② Top dyeing : Top, an intermediate product from raw wool, undergoes dip (batch) dyeing before spinning. This is usually used in ordinary cases.

### 8.2.3 Weaving

The weaving process is roughly divided into the preparation process and the weaving process. Figure 8.8 shows a standard weaving process.

Figure 8.8 Weaving Process



(1) Preparation process

The introduction of rewinders of higher winding speed and automation is promoted in the rewinding process for productivity improvement and labor saving. On the other hand, extensive automation causes the power consumption to considerably increase.

The sizing process is for improving the efficiency of weaving. After stuck size has been dried by hot air or heat cylinders, yarn is wound around loom beams.



## (2) Weaving process

A fabric is made by crossing the weft and the warp at right angles. The mechanism is based on the motion of passing the weft through two groups of the warp, alternately located in the upper and lower positions, and tightening the crossed weft and warp with a reed. Conventionally, a mechanism to drive a shuttle was used to pass the weft. Recently, the shuttleless loom, such as the air jet loom (mainly for short fibers) and the water jet loom (for synthetic fiber filaments), has been developed, and the productivity of weaving has been remarkably improved. Those are methods that air or water is jetted, instead of driving a shuttle, and the weft is fed by making it ride the stream. These methods produce less vibration and noise.

The wool fabric process is basically the same as the process mentioned above, except that sizing is unnecessary in the preparation process and weaving machines are different.

## 8.2.4 Dyeing

### (1) General description

Dyeing is roughly classified into two types: Dyeing at the stage of raw material or spinning, such as cotton wool, top and yarn, and dyeing at the stage of fabric.

#### a. Basic operation in dyeing

The basic operations in dyeing are the following five as shown in Table 8.2: "Washing", "Adding", "Dehydration", "Drying" and "Setting". In addition, the dyeing process includes the preparation process, composed of singeing, desizing, bleaching, and mercerization. Also, special processing, such as shrink resistant finish, crease resistant finish and water proof finish, is performed at the stage of finishing in the dyeing process.

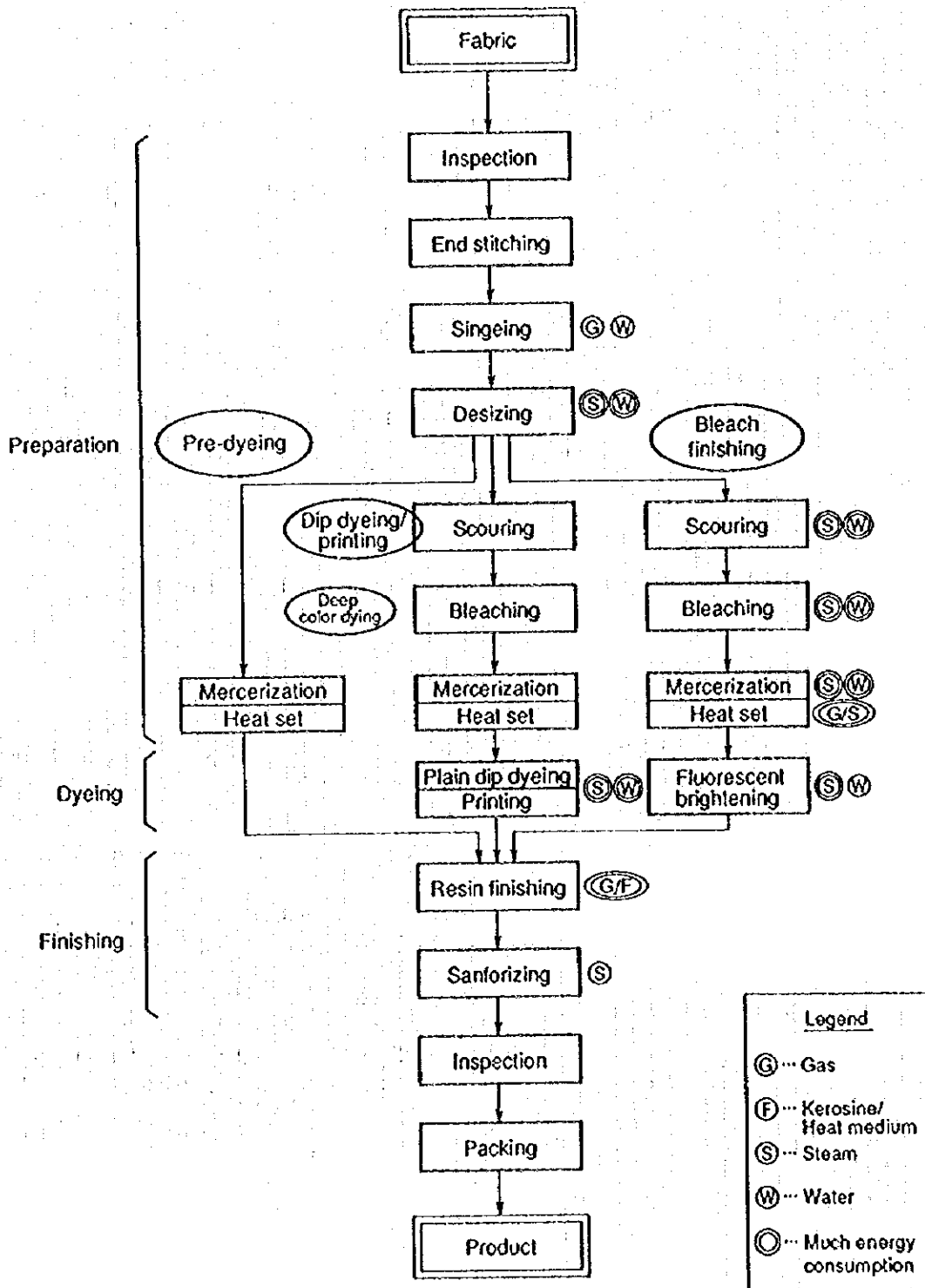
Table 8.2 Operations in Dyeing Process

Item	Operation
Cleaning	A fabric is cleaned using cold water or hot water to remove impurities, unfavorable content, and extra additives and auxiliaries.
Padding	Dye and auxiliaries are applied to ground fabric by dipping, padding, printing, coating and transferring.
Dehydration	Extra moisture content in ground fabric is removed by applying physical force, such as squeezing, vacuum and centrifugal force.
Drying	Moisture content and solvent in ground fabric is vaporized using cylinders, hot air and infrared rays to dry the ground fabric.
Setting	Dye and pigment are stuck to fibers using dry or wet heat.

(2) Short fiber fabric

Figure 8.9 shows a standard dyeing process for short fiber fabrics using cotton and chemical and synthetic fibers.

Figure 8.9 Dyeing and Finishing Processes (Short-Fiber Textiles)



a. Preparation process

- ① Singeing : Process to burn fluff on the surface of fabrics and remove it.
- ② Desizing : Process to decompose size on the warp and remove it.
- ③ Scouring : Process to remove fat, pectin and coloring matter a large quantity of which is contained in natural fibers, using alkali and surface-active agent.
- ④ Bleaching : Process to decompose coloring matter contained in fibers through oxidation and remove it therefrom. Hydrogen peroxide and chlorite soda are in wide use for bleaching agent.
- ⑤ Mercerization: Process to immerse a taut cotton fabric in a concentrated caustic soda solution to provide the ground fabric with gloss. After the process, high concentration alkali effluent is recycled.
- ⑥ Heat setting : Process to heat-treat polyester and cotton blended fabric and thereby improve the form stability and the dye affinity of products.

b. Dyeing process

The dyeing process is roughly classified into dip dyeing (solid dyeing) and textile printing.

<Dip dyeing>

A method that a fabric is immersed in low concentration dye solution and the dye is almost completely set. Typical processes in dyeing are as follows:

- ① Padding : Process to apply dye through dyeing and tie dyeing. For drying after the application of dye, severe drying conditions are required to prevent uneven dyeing.
- ② Color development and setting: Process following the padding process to set dye and develop color. Dye is often set using steam and hot air.

### <Textile printing>

A method that dye, pigment and auxiliaries are mixed in size and set on the surface of the ground fabric by pressing. A typical process for machine textile printing is described here.

- ① Textile printing : There are three methods for textile printing: Roller printing, automatic screen printing and rotary screen printing, which is the combination of the two methods. The method of the combination efficiently provides a sharp and high printing effect.
- ② Color development and setting: Process to heat the printed ground fabric using steam. Steamers and agers are used for this purpose.
- ③ Posttreatment : To sufficiently clean the color-developed and dye-set ground fabric and then dehydrate and dry it to provide more excellent texture.

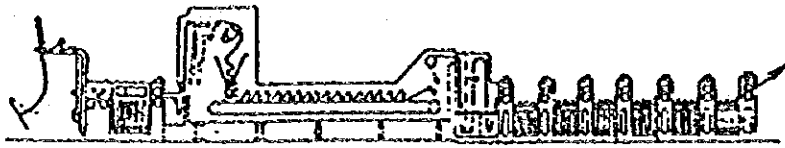
#### c. Finishing

A process to provide fibers with softness, water repellency and water proof depending on the application of them.

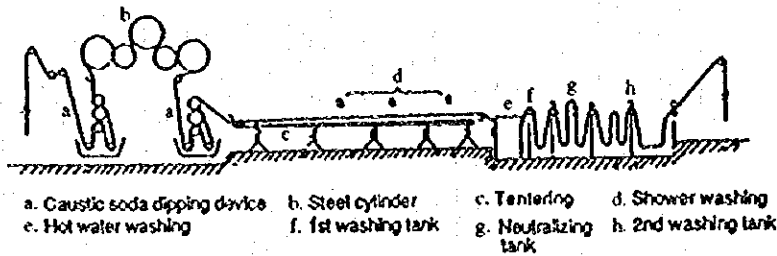
In addition, the finishing process includes sanforizing (shrink preventive processing), raising (fluffing), and calendaring (glazing).

Figure 8.10 illustrates the outline of the structure of major continuous type equipment; Figure 8.11 shows the outline of the structure of major batch type equipment.

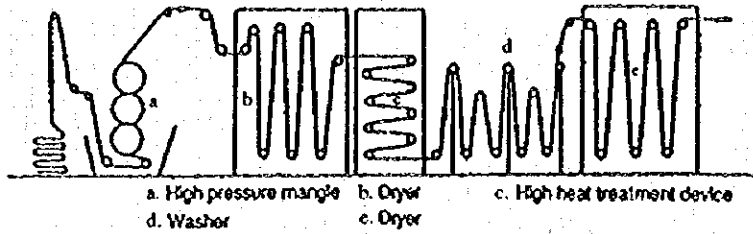
Figure 8.10 Continuous Dyeing Machine



Conveyer Steamer Type Continuous Bleacher

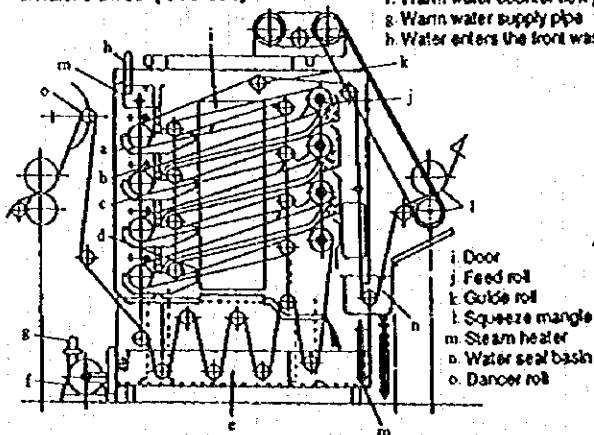


Mercerization Unit Process Chart



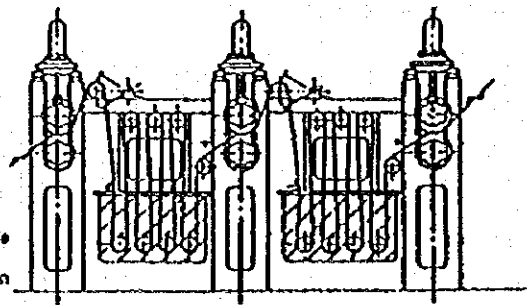
Sketch of Resin Treatment Equipment

- a. Water bag (small bag)
- b. Pinch bar
- c. Touch bar
- d. Water drain bar (removable)



Counter Current Type Water Saving Washer

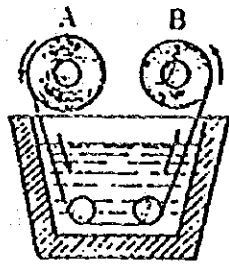
- e. Small basin
- f. Warm water counter flow pump
- g. Warm water supply pipe
- h. Water enters the front washer



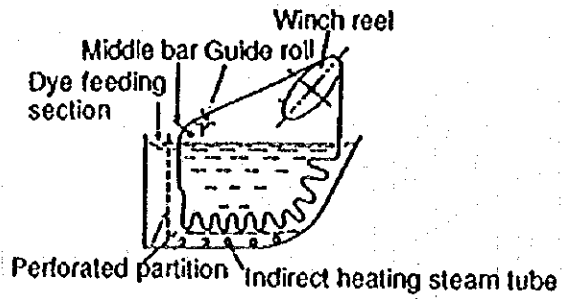
Conventional Washer

- i. Door
- j. Feed roll
- k. Guide roll
- l. Squeeze mangle
- m. Steam heater
- n. Water seal basin
- o. Dancer roll

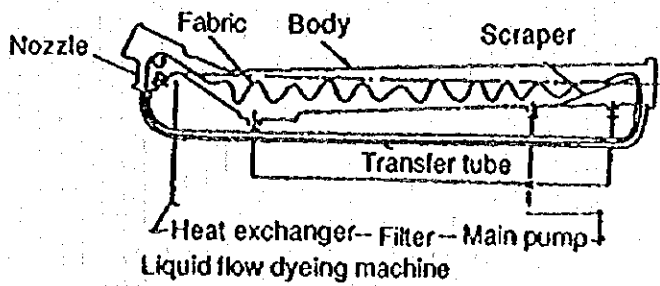
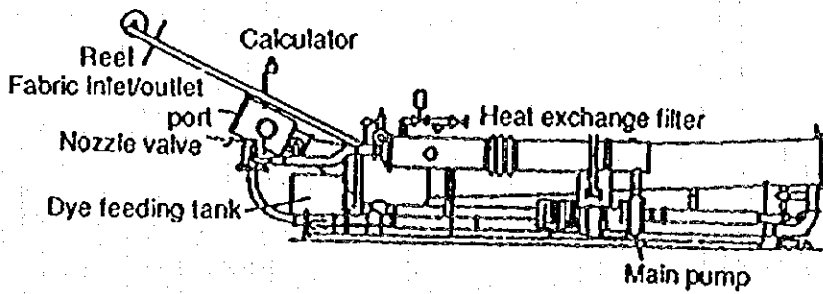
Figure 8.11 Batch Type Dyeing Machine



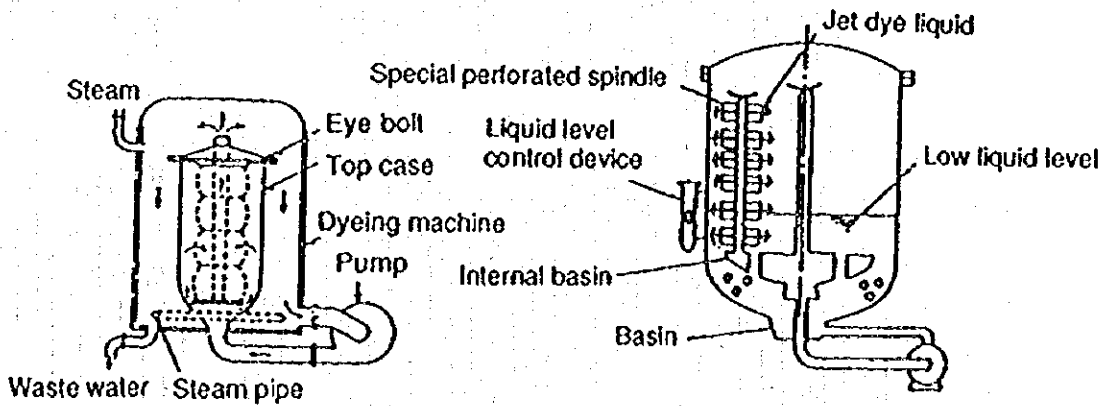
Jigger Dyeing Machine



Wince Dyeing Machine



Liquid flow dyeing machine



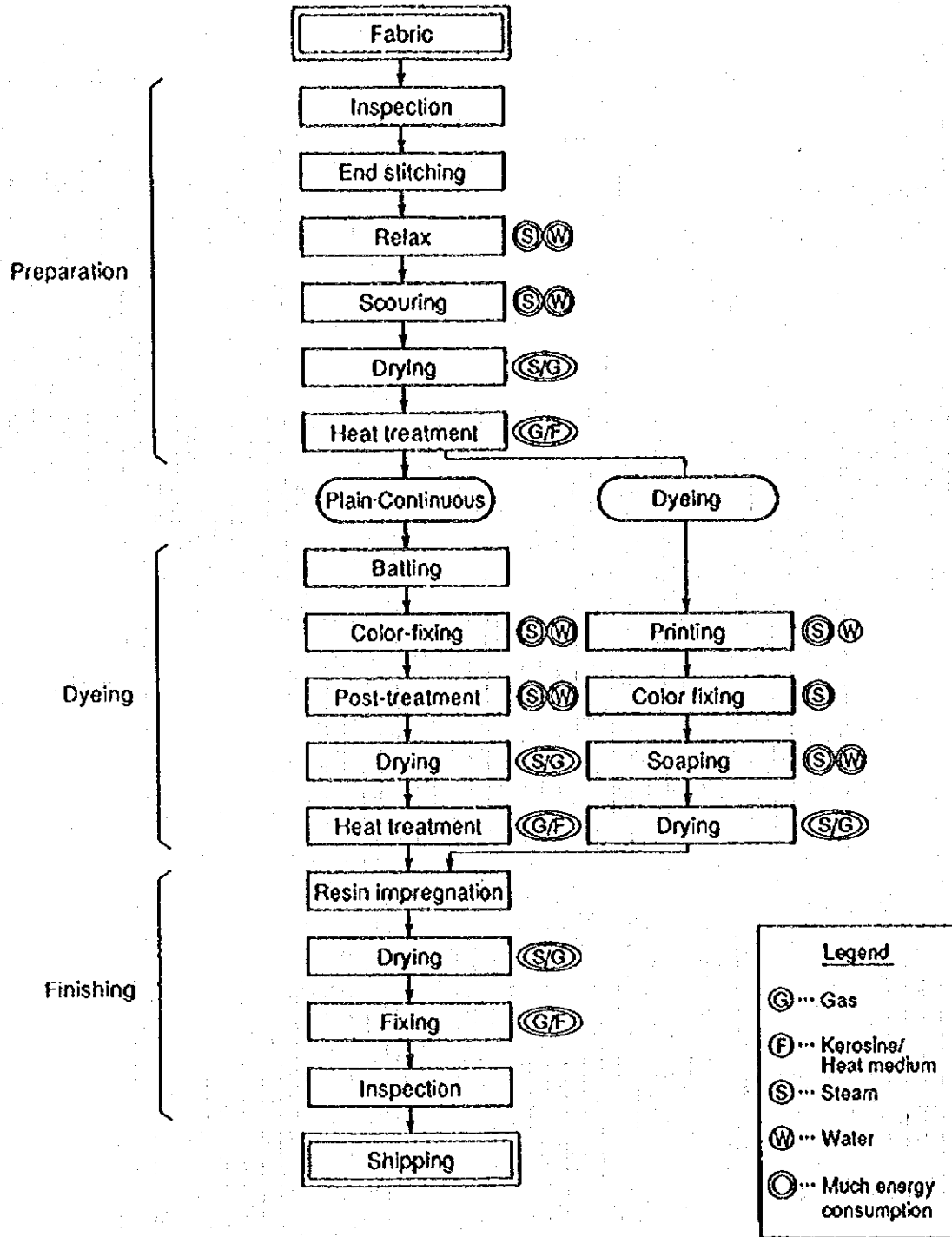
Woolen Top Dyeing Machine

Jet Type Yarn Dyeing Machine

(3) Synthetic long fiber fabric

Figure 8.12 shows a standard process for polyester fiber finished yarn fabrics.

Figure 8.12 Dyeing Process for Long-fiber Fabric (Example of Polyester)



Operations specific to long fiber fabric manufacture are described below.

a. Preparation process

- ① Craping : Distortion produced in fabric processing is eliminated by swelling and breaking to provide the fabric with bulkiness. The equipment for this purpose is called relaxer.
- ② Scouring : Process to remove fat, size and any other impurities applied to ground fabric.
- ③ Drying : Process to evaporate and remove the moisture contained in the ground fabric by a hot air dryer, a cylinder dryer, etc.
- ④ Heat setting: Heat treatment to remove synthetic fiber waste and stabilize the form. There are two types of heat setting: Indirect heating system using heat medium and kerosine and direct heating system using gas. Recently, the direct heating system is in wide use because of its high thermal efficiency and easiness for maintenance.

b. Dyeing process

The dyeing process has two types: High pressure dyeing and normal pressure dyeing. The high pressure dyeing activates molecules of dye and fiber using high temperature high pressure thermal energy to make the dye penetrate into the fiber.

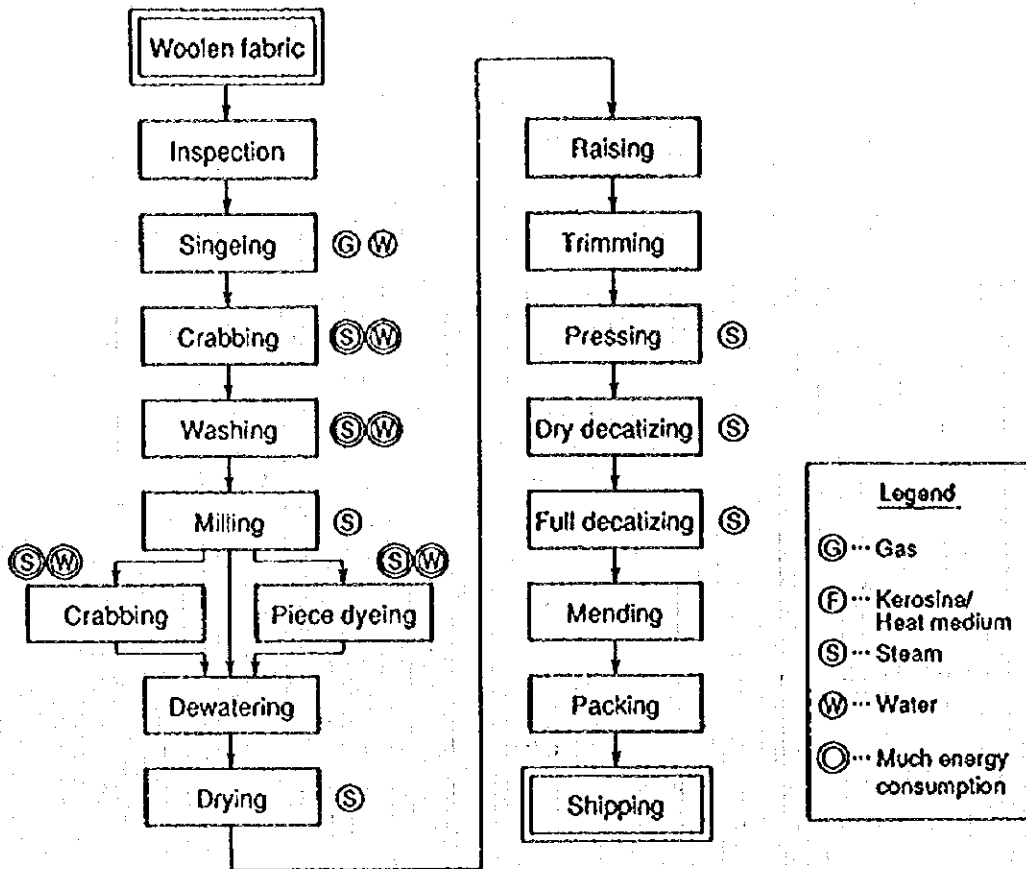
Refer to the section of short fiber fabric for the textile printing and the finishing processes.

(4) Wool fabric finishing

The product value of a wool fabric depends on its texture. Unlike the other fabrics, the wool fabric is of felt, and accordingly, the mainstream of the manufacture thereof is the batch system. The wool fabric requires more complicated finishing process than any other fabrics. Figure 8.13 shows a common finishing process for worsted fabric, and description is given to the difference between it and the dyeing process for other fabrics.



Figure 8.13 Worsted Finishing Process



a. Preparation process

- ① Crabbing: Process to prevent distortion and provide texture specific to fabric.

Rolled fabric is boiled, and subsequently, rapidly cooled in cold water through substitution.

- ② Milling : Process optional but important for providing woolen fabric with texture. The rotary milling machine is used in general.

b. Dyeing process (Fabric dyeing)

The normal pressure dyeing (wince dyeing machine) is common. The high pressure jet dyeing is also used.

c. **Finishing and touching processes**

Excessive distortion in wool fabric is eliminated through dry decalizing to prevent products from spontaneously shrinking. Pressing is also carried out to enhance gloss.

A wool fabric general finishing process requires a large quantity of hot water.

## 8.2.5 **Special Fabrics**

(1) **Velvet fabric**

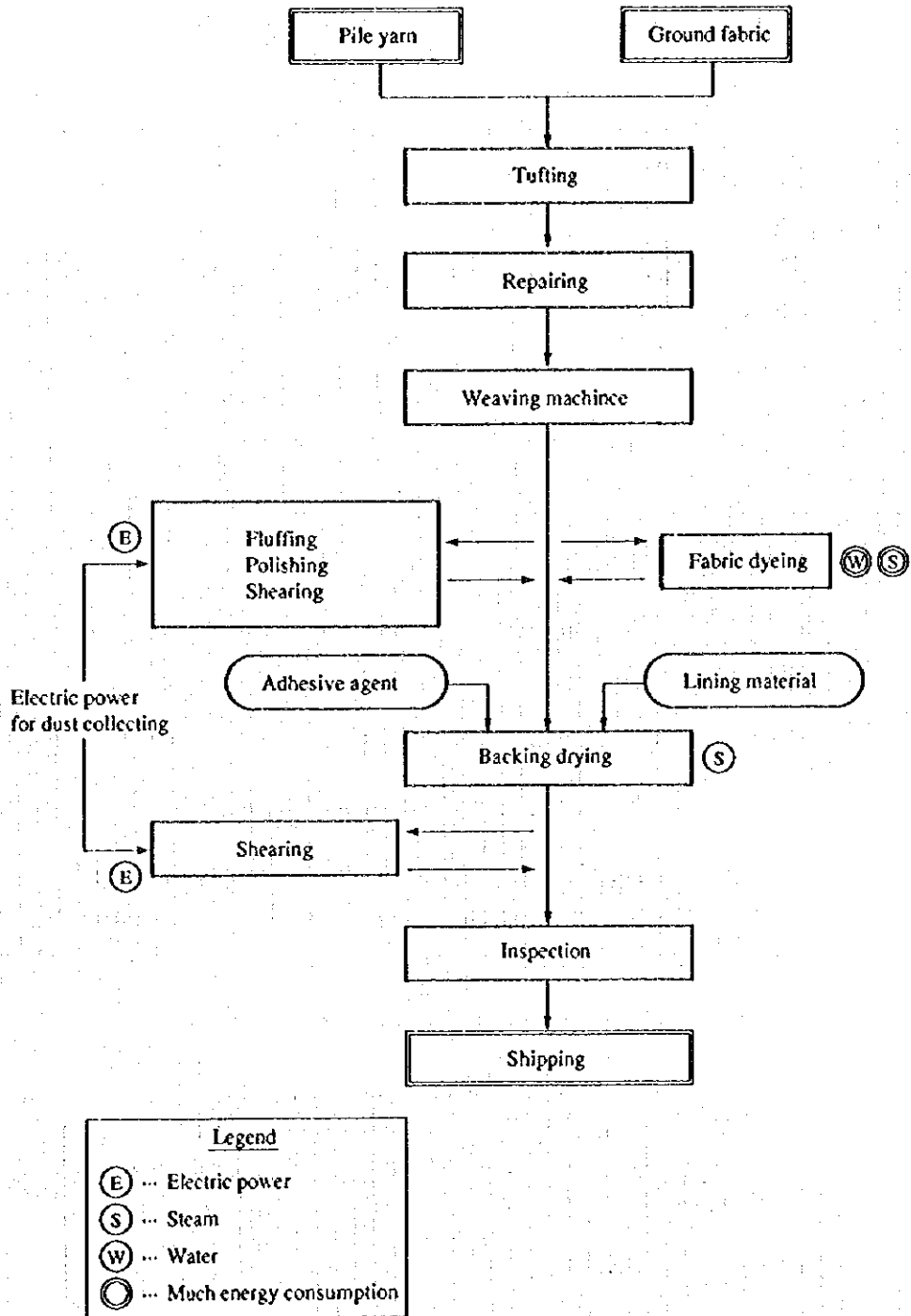
The warp and the weft are twined with a pile yarn and woven into a fabric. While at the same time the woven fabric is being cut at the center by a knife just in the same manner as cutting the fish open, two pieces of the cut fabric are wound up at the same time, and through the subsequent processes, they are finished into products.

Figure 8.14 shows the velvet fabric manufacturing process.



Figure 8.15 shows the manufacturing process of a tufted carpet for general use.

Figure 8.15 Process Flow Chart of Tufted Carpet



There are two processes of dyeing: fiber or yarn dyeing and piece dyeing. This process chart shows an example of piece dyeing.