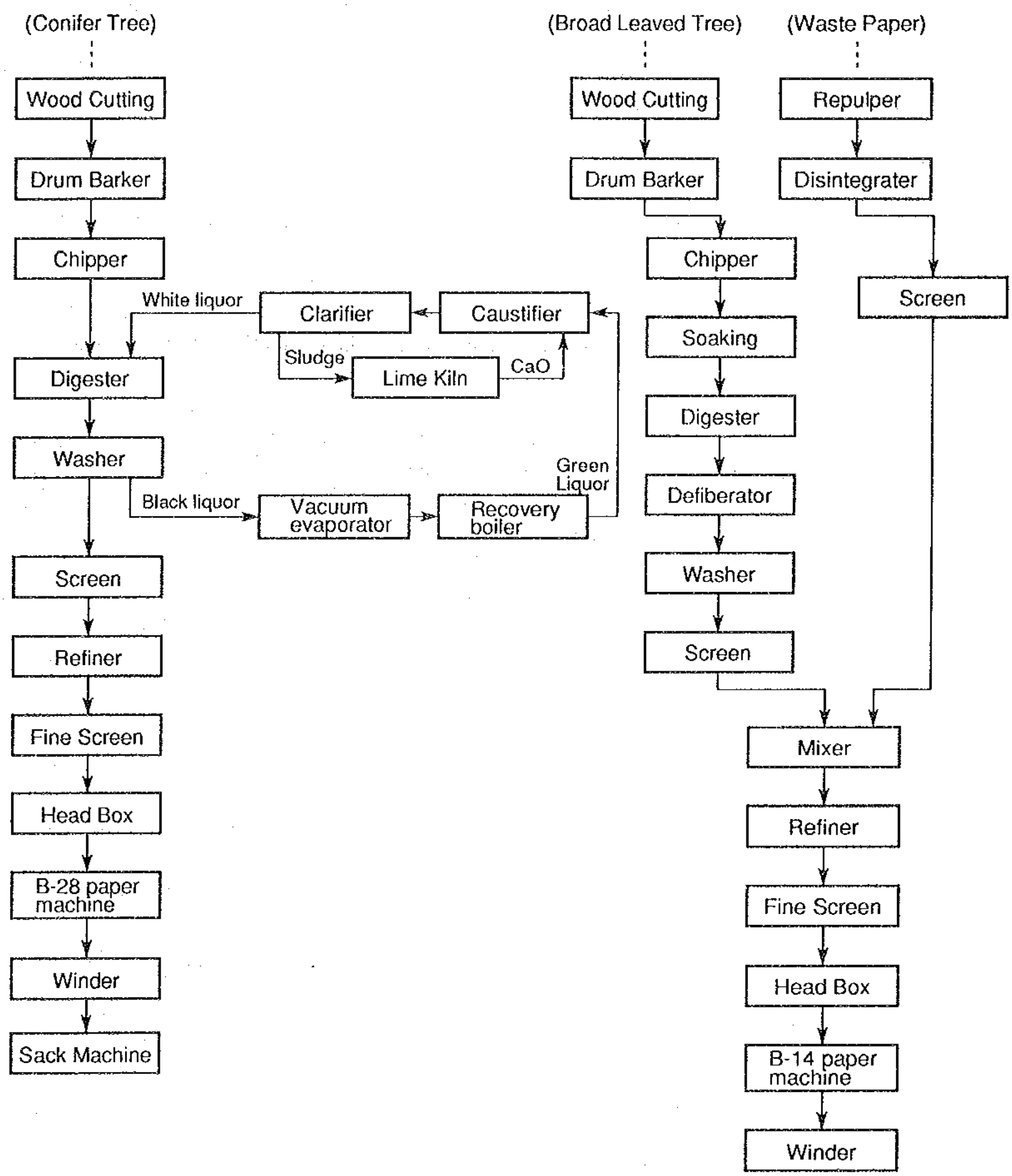
6. Energy Conservation in Pulp and Paper Industry

6. PAPER

6.1 Paper Production Process

Figure 6.1 shows the flow of a paper production process.

Figure 6.1 Production Process



The paper production process is composed of the steps of screening and refining wood fibers to prepare sheets of fibers, of gradually dehydrating such uniformly distributed sheets, and of evaporating about double more moisture with steam. The process needs 500 to 1,000 tons of water, and very much electric power for use in transporting water, operating machines. This is the reason why the paper production industry is referred to as an energy-intensive industry.

6.2 Stages of Actions for Energy Conservation

It is recommended that actions for energy conservation in a paper production factory be taken by following such stages as shown in Table 1.1.

The first stage is aimed at improving the way of operations without much investment.

The second stage is focused on improvement entailing some investment.

The third stage targets the modification of facilities and processes through necessarily much investment.

As shown above, the first stage for stepwise energy conservation promotion is aimed at efficiently utilizing present facilities and enhancing the control. This means that the first stage consists in judging by data whether or not energy is utilized efficiently.

Reducing energy consumption maximally to increase revenues calls for continuously running the equipment without any stop at a load factor of nearly 100 %. This also applies to the paper production industry. The operation of facilities at the full production capacity without any stop by paper chips is a major energy conservation factor.

It must be recognized that nearly all data on heat balance, as well as on production, quality, process, and raw and minor material control is related to energy conservation.

Table 6.1 Example of Stepwise Promotion Plans

Stage	Equipment	Others
First stage Effective utilization of and sufficient management of existing equipment	Maintenance of various equipment Pressure gauge washer, insulation, repair of steam leakage installation of steam flow meter.	Keeping a daily report in order . . . data collection. Setting qualitative standard. Setting operating standard. Setting standard for equipment, maintenance. Carrying out quality tests Checking the quality of blanket and canvas.
Second stage Recovery of waste heat	Maintenance of dryer Condensate recovery system White water circulating system Improvement of ventilation for dryer part. Updating of faulty equipment.	Data analysis Re-evaluation of standard.
Third stage Introduction of new equipment.	Completion of equipment maintenance services. Remodeling of screen, press for high concentration Recovery of heat from dryer.	

6.3 Kraft Cooking

Cooking is affected by a lot of complicated factors. Presented below are the major factors.

1) Pulpwood

2) Cooking reaction

3) Composition of kraft chemicals

The impact of pulpwood 1) is different depending on the tree kind, especially on the conifer tree or the broad leaves tree. The degree of cooking reaction 2) is fixed by a combination of cooking temperature and period. The composition of kraft chemicals 3) should be considered along with the chemicals concentration and the volume of added chemicals.

From the standpoint of energy conservation, factors of temperature and period related to cooking reaction should be noted. The target is to produce desired quality pulp in an appropriate yield on the basis of fixed chemicals addition rate and liquid volume corresponding to the tree kind. The key points of this production are to effectively and efficiently use the energy depending on the rate of reaction and conditioned by temperature and period and to recover as much discharged energy as possible for effective use.

(1) Cooking facilities

The heat required for cooking is given by indirectly heating cooked liquid with steam for circulation or by injecting steam directly into the cooking digester. A batch type cooking digester is based mainly on indirect heating, while a continuous type cooking digester is heated either indirectly or directly. Figure 6.2 shows an example of the batch type cooking digester and Figure 6.3 an example of the continuous type cooking digester

Figure 6.2 Batch Type Cooking Instruments

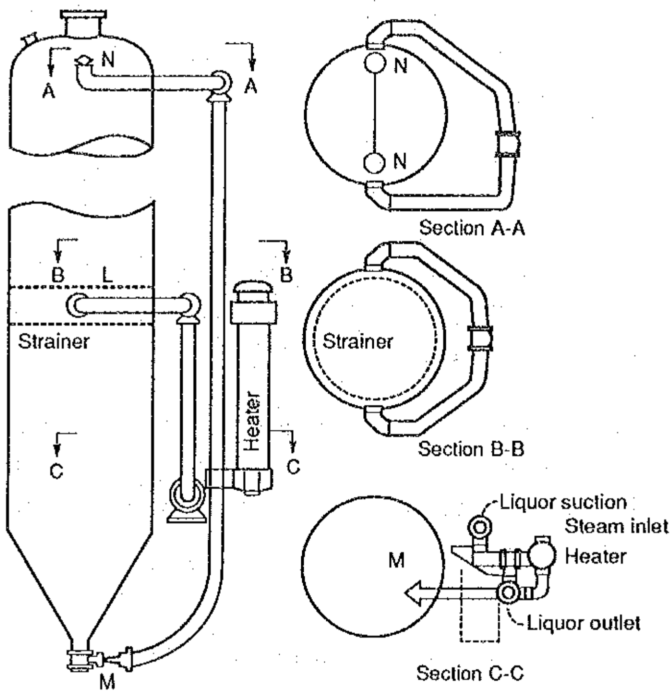
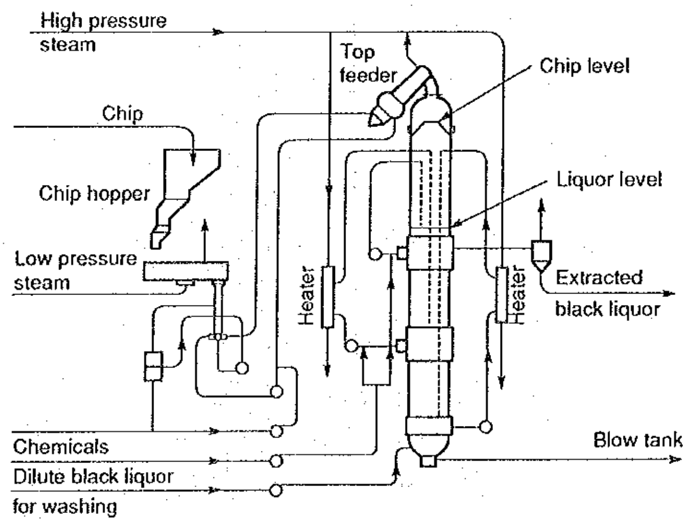


Figure 6.3 Continuous Type Cooking Instruments



(2) Heater

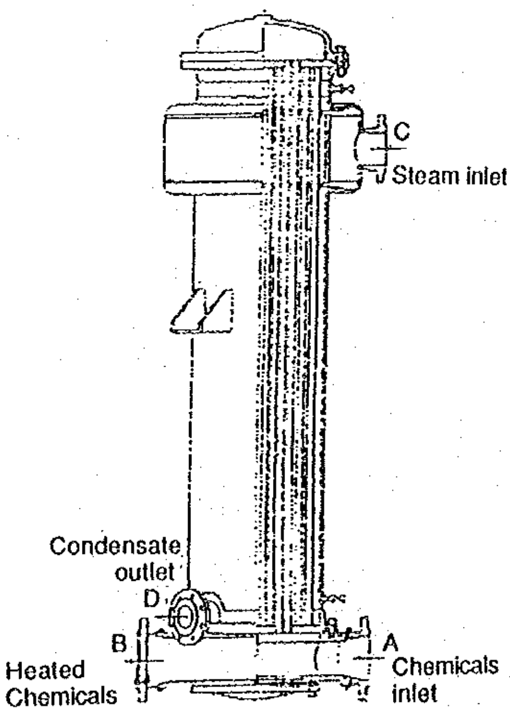
Indirect heating is accomplished by forcibly circulating chemicals and, thus, consumes much electric power energy. A tubular heater is used typically as the heater. Figure 6.4 shows its structure.

Chemicals are entered through inlet A, ascend through the right tubes, turn at the upper cap, descend through the left tubes and are discharged from outlet B, and enter the circulating pump.

Steam is entered through steam inlet C, and condensates are discharged through outlet D, entering the condensate tank.

A heating tube has an outside diameter of about 30 mm and a length of about 4 m ± 0.5 m, with the total heat transfer coefficient being about 1,000 to 3,500 kcal/m²h°C. The total coefficient is varied depending on the flow velocity, the tube thickness and the weight scale adhering to the tube wall.

Figure 6.4 Heater



The typical design is based on a flow velocity of 2.5 m/sec. and a total heat transfer coefficient of 1,500 kcal/m²h°C. During actual operations, the heater should be inspected periodically so as to prevent the thermal efficiency from being dropped. Should the thermal conduction be decreased, the adherent scale must be removed to keep the thermally conductive surface always clean.

Scale adheres inside the heater, as well as to circulating tubes and valves, and the strainer, reducing the flow velocity and lengthening the reaction period and, thus, lowering the productivity. In addition, adherent scale prevents the temperature in the digester from being kept uniform, resulting in the production of chips not cooked and a reduction in the yield.

Adherent scale brings about improper thermal conduction resulting in the loss of thermal energy, the deterioration of facility running efficiency due to lowered productivity, and lowered unit energy consumption rate originating in a decreased yield. As adherent scale is the critical cause of a decrease in cost efficiency, particular care should be taken so as to remove scale in cooking facilities.

(3) Cooking chemicals

Cooking chemicals are composed mainly of white liquor, or NaOH, Na_2S, Na_2CO_3 and Na_2SO_4. Figure 6.2 shows chemical components of the white liquor.

The chemicals contributing to cooking as the removal of lignin are referred to as effective alkali and expressed as $(NaOH + \frac{1}{2} Na_2S)$g/l as Na_2O, being 102 g/ℓ. A key of kraft cooking is the contents of Na_2S that affect the yield and quality of pulp. Their control calls for marking sulfidity, which is articulated as $\frac{\text{sodium sulfide}}{\text{active alkali}} \times 100\ \%$. The approximate appropriate value of Na_2O is $\frac{Na_2S}{NaOH + Na_2S} \times 100\ \% = \frac{36}{84+36} \times 100\ \% = 30\ \%$.

The rate of added effective alkali is different depending on the conifer tree or the broad leaves tree, and on the target pulp quality, being 12 to 18 % as Na_2O with respect to dry chip weight. The ratio of total liquid volume to dry chips is called a liquid ratio, being 4.0 to 4.5. The total liquid means white liquor plus chip moisture, and black liquor.

Table 6.2 Chemical Components of White Liquor

Na_2O compound	g/ℓ as Na_2O
NaOH	84
Na_2S	36
Na_2CO_3	19
Na_2SO_4	0.2
Na_2SO_3	0.2
$Na_2S_2O_7$	0.5

(4) Control of cooking reaction

The phases of cooking reaction are distinguished from one another by features of temperature. They are divided into the three phases.

1) Temperature rise phase

2) Constant temperature phase

3) Temperature drop phase

Following chip loading, steaming and chemicals injection, heating by steam is started, with the temperature rising. At a temperature of nearly 140 °C, incondensable gas is produced. As the incondensable gas is dischanged, the chips are heated to the highest temperature.

The cooking temperature is set at 160 to 180 °C. Like other typical reaction, within this range, a temperature rise of 10 °C allows the cooking period to be halved. The optimum temperature and period should be selected depending on the pulp quality. Cooking nearer the highest temperature provides better energy conservation.

The degree of cooking is determined by a combination of temperature and period. Here, we introduce a concept of an "H factor" which covers both temperature and period, and which is generally used to control cooking.

Now, we assume that the relative reaction speed is 1 at a temperature of 100 °C. Then, on the basis of this value, the relative reaction speed at each temperature is fixed with Arrhenius' equation. The product of such fixed relative reaction speed and the processing period at the processing temperature is defined as the "H factor". Table 6.3 shows data on H factor based relative speed at temperatures of 100 to 179 °C.

Figure 6.5 shows a curve which provides the relation between the cooking temperature and period, as well as the relation between the cooking period and the relative reaction speed.

Integrating the lower curve in Figure 6.5 provides the "H factor". A combination of a period and temperature under the same "H factor" offers nearly the same quality.

Now, we assume that spruce is cooked using chemicals with a sulfidity of 31 % at three different levels of temperature. Figure 6.6 covers such cooking and plots the relation between the pulp yield and lignin contents with respect to the "H factor".

Table 6.3 H-Factor Relative Velocity

°C	Relative Velocity	°C	Relative Velocity	°C	Relative Velocity	°C	Relative Velocity
100	1.0	120	9.0	140	65.6	160	397.8
101	1.1	121	10.0	141	72.1	161	433.4
102	1.3	122	11.1	142	79.2	162	472.4
103	1.4	123	12.3	143	86.9	163	613.9
104	1.6	124	13.6	144	95.4	164	559.2
105	1.8	125	15.1	145	104.6	165	608.3
106	2.0	126	16.7	146	114.7	166	661.5
107	2.2	127	18.5	147	125.7	167	719.1
108	2.5	128	20.4	148	137.7	168	781.3
109	2.8	129	22.6	149	150.8	169	848.7
110	3.1	130	24.9	150	165.0	170	921.4
111	3.5	131	27.5	151	180.6	171	1000.0
112	3.8	132	30.4	152	197.4	172	1086.1
113	4.3	133	33.5	153	215.8	173	1176.9
114	4.8	134	36.9	154	235.8	174	1275.9
115	5.3	135	40.7	155	257.5	175	1382.8
116	5.9	136	44.8	156	281.2	176	1498.1
117	6.6	137	49.3	157	306.8	177	1622.5
118	7.3	138	54.3	158	334.7	178	1756.6
119	8.1	139	59.7	159	365.0	179	1901.1

Figure 6.5 Relative Reaction Velocity, Cooking Time or Temperature

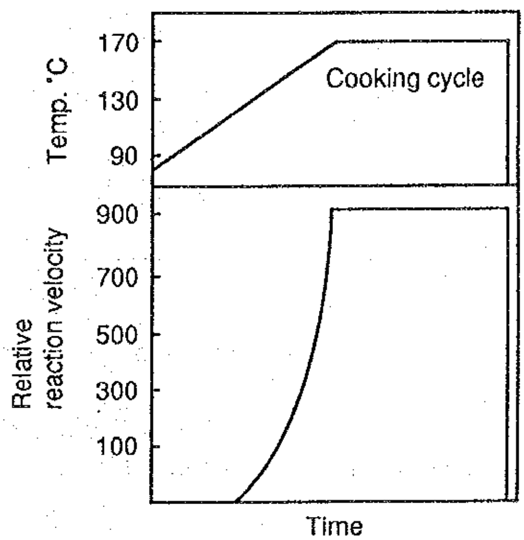
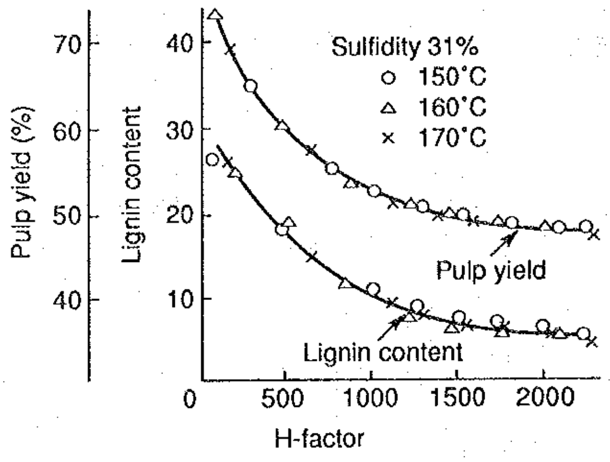


Figure 6.6 Relation of H-Factor, Pulp Yield and Lignin Content



(5) Cooking process and energy conservation

The cooking process consumes much steam and electric power for chemicals circulation. Table 6.4 shows the Japanese actual development of energy conservation for cooking based on the conifer tree and the broad leaves tree, and on the batch type digester and the continuous type digester.

Table 6.4 Comparison of Energy Unit Consumption in Batch Digester and Continuous Digester

		Steam (ton/pulp ton)		Electricity (kwh/pulp ton)	
		1980	1990	1980	1990
Batch Digester	N	1.45	1.3	200	215
	L	1.1	1.1	120	115
Continuous Digester	N	1.1	0.75	240	220
	L	0.9	0.7	130	115

This process is marked by the necessity to cook thoroughly resulting from modified paper quality accompanying the economic growth, and by partially more energy consumption. However, the general trend is toward energy conservation, which has been implemented through tackling such control items as shown in Table 6.5.

Table 6.5 Control Items

1	Stable quality	Cooking control by H factor
2	Yield enhancement	Quality stabilization and suppression of deviation by improved chemicals circulation
3	Complete cleaning of thermally conductive surface in heater	Periodic scale removal by pickling
4	Thorough cleaning of chemicals circulation line	Periodic scale removal of strainer, tubes and valves
5	Prevention of radiation heat loss	Perfect insulation of such naked parts as valves and flanges
6	Preventive maintenance of steam trap	Maintenance and arrangement of trap
7	Prevention of air and liquid leakage	Maintenance and arrangement of valves, flanges, pumps and seals
8	Promotion of recovering waste heat from gas and blow gas	Periodic cleaning of heat exchanger and condensers
9	Increase in digester loads and in digester output	Increase in chip loads for batch type digester
10	More accurate basic data identification	Arrangement of thermometers, pressure gages and regulators

The accumulation of small effects of energy conservation leads to great achievements. Warm water recovered from relief gas, low pressured gas and blow gas by a heat exchanger covers the cleaning process and increases the process temperature, contributing to energy conservation in the subsequent processes.

The maintenance of facilities is essential for energy conservation promotion. The more efficient operation of equipment functions enhances the quality and yield and stabilizes the running over a long period, leading to energy conservation and significant cost-effectiveness.

6.4 Cleaning of Brown Stock

The cleaning is intended to recover all soluble materials from brown stock as highly concentrated black liquor. Although it is ideal to wholly replace black liquor by warm water having a temperature of 50 to 60 °C, the black liquor is diluted by cleaning water, being less concentrated. The lower concentration results in higher costs of evaporation. Thus, it is needed to recover highly concentrated black liquor by a minimum of cleaning water.

A counterflow type multi-stage cleaner and a diffusion washer can be used. The counterflow type multi-stage cleaner comprises a few drum washers connected serially. The diffusion washer cleans pulp of a concentration of about 10 % blown from a continuous cooking digester at temperatures of 85 to 90 °C.

a. Counterflow type multi-stage cleaner (See Figure 6.7.)

This cleaner is also called a continuous multi-stage cleaner. The following are the conditions of its operations:

1) The pulp concentration must be made to be uniform.

2) The pulp throughput must not be varied.

3) The pulp flow must be distributed uniformly.

4) Shower spray must be made to be uniform.

The solid recovery rate and the dilution factor should be linked to each other to fix the most efficient cleaning warm water volume.

The dilution factor is determined by:

$$\frac{\text{warm water volume (t/h)} - \text{pulp cleaning water volume (t/h)}}{\text{pulp not weathered (t/h)}}$$

$$\frac{\text{warm water volume (t/h)}}{\text{pulp not weathered (t/h)}} - \frac{\text{moisture in pulp cleaned (\%)}}{\text{concentration of pulp cleaned (\%)}} \times 0.9$$

The dilution factor is fixed by the evaporator capacity, steam costs, the solid concentration in black liquor, the degree of pulp cleaning and chemicals costs. Larger evaporator capacity and lower steam costs allows a somewhat high dilution factor.

The application of a three-stage washer to a conifer tree with (PN)30 provides a dilution factor of 2.2 and a solid recovery rate of 96 to 97 %.

b. Diffusion washer (See Figure 6.8.)

The diffusion washer is connected directly to a continuous cooking digester. Cold-blown material is entered through the diffuser bottom and elevated as being cleaned through the screen zone, scraped from the top, and stored into the chest.

It takes about 40 minutes for such material to reach the outlet after its entry to the inlet. The material passes through the screen zone in about eight minutes. The screen is lifted slightly earlier than the pulp, and dropped abruptly. The cycle is vertical movement. During a dropping period, the equalizing tank backflushes the screen. This prevents the screen from being clogged, leading to more efficient cleaning.

The diffusion washer provides a standard dilution factor of about 2.5.

It is the object of cleaning to recover soluble material from brown stock completely as highly concentrated black liquor. By cleaning, the volume of steam used when black liquor is concentrated by the evaporator can be reduced and, thus, the volume of mirabilite to be supplied at the recovery boiler can also be decreased. Thus, operating conditions of the cleaner and the dilution factor are important elements.

Figure 6.7 Continuous Washer

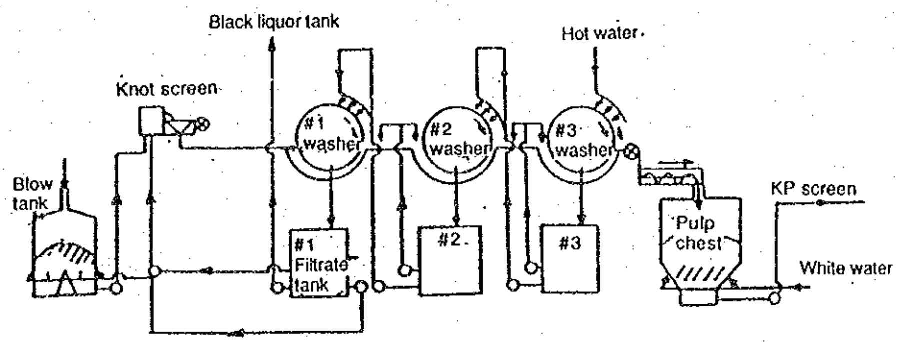
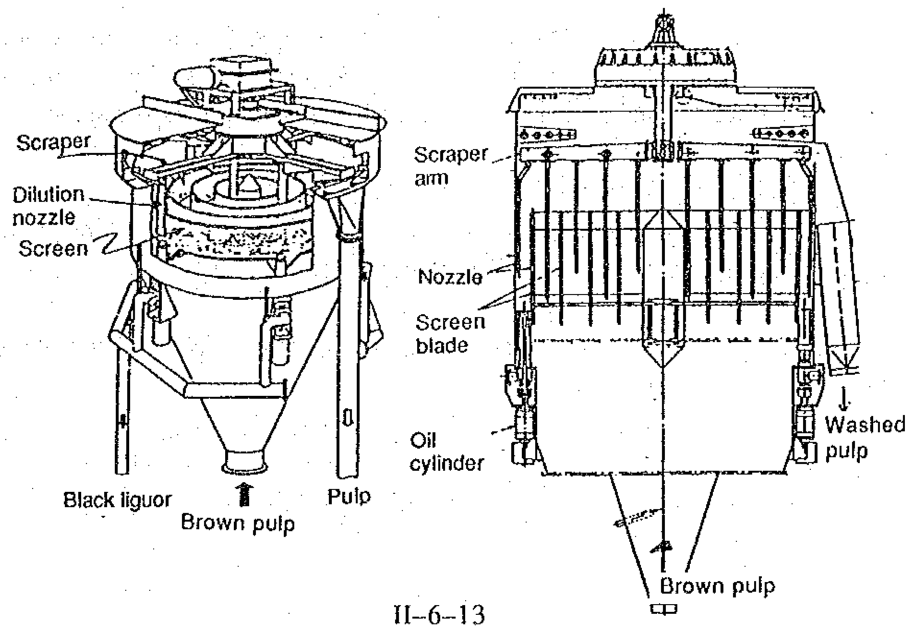


Figure 6.8 Diffusion Washer



6.5 Concentration of Kraft Black Liquor

A multiple effect evaporator is used to concentrate kraft black liquor. Its evaporation capability is directly proportional to a total temperature difference. Thus, such temperature difference should be made to be large. Heating steam in the first evaporator and the vacuum degree of the end condenser depend on operating and economic conditions of the plant. Total temperature difference is distributed to each multiple effect evaporator.

For n-fold effect evaporator, the heating steam per 1 kg of evaporation is about 1/n kg. Actually, however, the radiating loss and the increased boiling point reduce a significant temperature difference, with the ratio of heating steam to evaporated water being larger than 1/n.

The typical ratio is about 1/1.6 for a double effect evaporator, about 1/2.2 for a triple effect evaporator, about 1/3.6 for a four-fold effect evaporator, about 1/3.8 for a five-fold effect evaporator, about 1/4.7 for a six-fold effect evaporator, and about 1/5.5 for a seven-fold effect evaporator. With the capability of evaporation used as the parameter, the total temperature difference is fixed by the vacuum degree in the end effect evaporator, its evaporation temperature and the pressure of heating steam in the first effect evaporator. Fixed total temperature difference (Δt) provides the capability of evaporation, as it is proportional to the speed of heat transfer.

An increase in the number of evaporators results in an increase in unavailable temperature difference caused by boiling point raise. Thus, the effective temperature difference (Δt) is lower than for a single effect evaporator despite the same end conditions. An increase in the number of evaporators to get a certain volume of vapor reduces consumed heating steam (in the first effect evaporator) per unit of evaporation. But the total evaporation is decreased and fixed equipment costs are increased. Thus, an increase in the number of effect evaporators may lower the efficiency. So, the appropriate number of effect evaporators must be determined. Currently, the economical number of effect evaporators is considered to be 6 or 7.

(1) Promotion of heat transfer in evaporator

Naturally, evaporation in an evaporator is fixed by the temperature gradient of thermal conduction. What hinders thermal conduction most considerably is inorganic scale and organic sludge adhering to the wall, which scale and sludge increase the resistance with an elapsed operating period.

Hence, the thermally conductive surface in an evaporator must be kept clean and, in particular, scale must be removed periodically on the liquid side.

Enhancing the speed of heat transfer on the liquid side should consider the liquid viscosity and the speed of liquid circulation.

To improve the heat transfer, condensate must be removed from the vapor chamber, and air and non-condensable gas must be eliminated periodically.

(2) Requirements of condenser

The vacuum degree of the end evaporator depends on the water temperature and volume. The typical vacuum degree is 610 to 680 mm/Hg. A vacuum degree not higher than 610 mm affects the capability of evaporation, being less efficient. A vacuum degree not lower than 680 mm significantly increases a temperature difference in thee evaporator. As the liquid temperature is lowered, however, the capability of evaporation is not enhanced relatively.

The other point to be taken into account on vacuum evaporation is a significant increase in the vapor volume. The increase results in an increase in the vapor speed. This calls for making larger the diameters of the steam head and tube in the end evaporator. Otherwise, spatters may be brought about.

Fully condensing by a jet condenser after warm water recovered in the heat exchanger further encourages energy conservation. The use of low-temperature water discharged from another process as the jet reduces unit consumption of water.

(3) Evaporation ratio

This means the evaporated water volume per ton of heating steam applied to an evaporator. The evaporation ratio is a factor of controlling black liquor.

The evaporation ratio is increased with an increase in the number of effect evaporators. It can be enhanced by increasing the number of stages where condensate is flashed. During actual operations, scale adherent to a heating surface or changes in the temperature of condensate or finishing black liquor lower the evaporation ratio.

The evaporation per ton of solids in an evaporator can be expressed as follows:

$$\text{Evaporated water} = \frac{100}{a} - \frac{100}{b}$$

where

a: concentration of dilute black liquor at the inlet (g/100cc)

b: concentration of concentrated black liquor at the outlet (g/100cc)

Evaporating water more economically calls for making "a" as high as possible, depending on the cleaning process. An increase in the number of cleaning stages or the installation of a pressing squeezer before the washer is a positive means to make the dilution factor smaller. An increase in the number of equipment pieces should be determined through comparison with the amount of steam reduction. As stated above, "b" can be increased by removing trouble resulting from adherent scale or non-condensable gas.

The evaporation ratio is different depending on the number of evaporators, the structure and the preheating process, as shown in Table 6.6.

Table 6.6 Evaporation Ratio

Number of effect evaporators	4	5	6
Evaporation ratio $\frac{\text{evaporated water (ton)}}{\text{steam (ton)}}$	2.6 ~ 3.1	3.3 ~ 3.8	4.0 ~ 4.5

(4) Current trends of evaporator

A large economizer without cascade evaporator is getting a mainstream for recovery boiler to cope with odor. Eliminating a cascade evaporator calls for concentrating black liquor at a high level. A falling film type evaporator has replaced the past multi-tube forced circulation cascade evaporator that requires a high-capacity circulation pump. The falling film type evaporator is classified into a plate type and a multi-tube type. The plate type evaporator featuring the advantage that scale can be removed easily is often applied to highly concentrated black liquor. Figure 6.8 shows its structure, while Figure 6.9 compares the tube and the plate type evaporators with each other. The evaporator for highly concentrated black liquor is divided into three partitions. Two partitions are for evaporation and the other is for cleaning the evaporator by dilute black liquor. These two groups of partitions are switched every certain period. The concentration is about 70 %.

Differences in energy unit consumption between the tube and the plate type evaporators are as shown below.

Table 6.7 Unit Energy Consumption of Evaporator

Unit consumption	Steam (t/t)		Electric power (kWh/t)	
Model / Tree	Tube-type evaporator	Plate type evaporator	Tube-type evaporator	Plate type evaporator
N (Conifer tree)	1.7	1.4	125	75
L (Broad leaves tree)	1.6	1.2	95	80

To prevent the thermal conduction from being lowered by adherent scale, one evaporator is added along with a pickling bath and a pump to pickle each evaporator for scale removal. Thus, in many factories, the thermally conductive surface is kept clean and the optimum heat efficiency is maintained for long-period continuous running.

Figure 6.9 Falling Film Type Evaporator

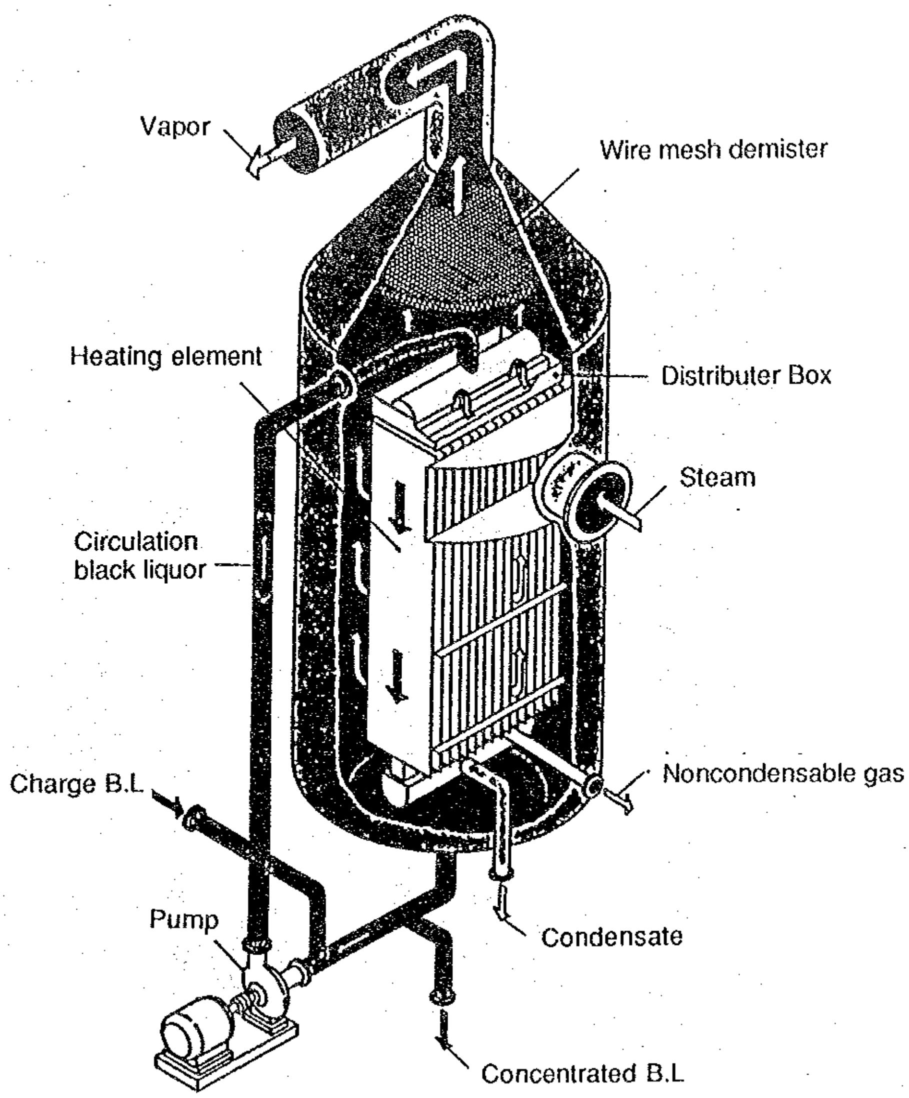
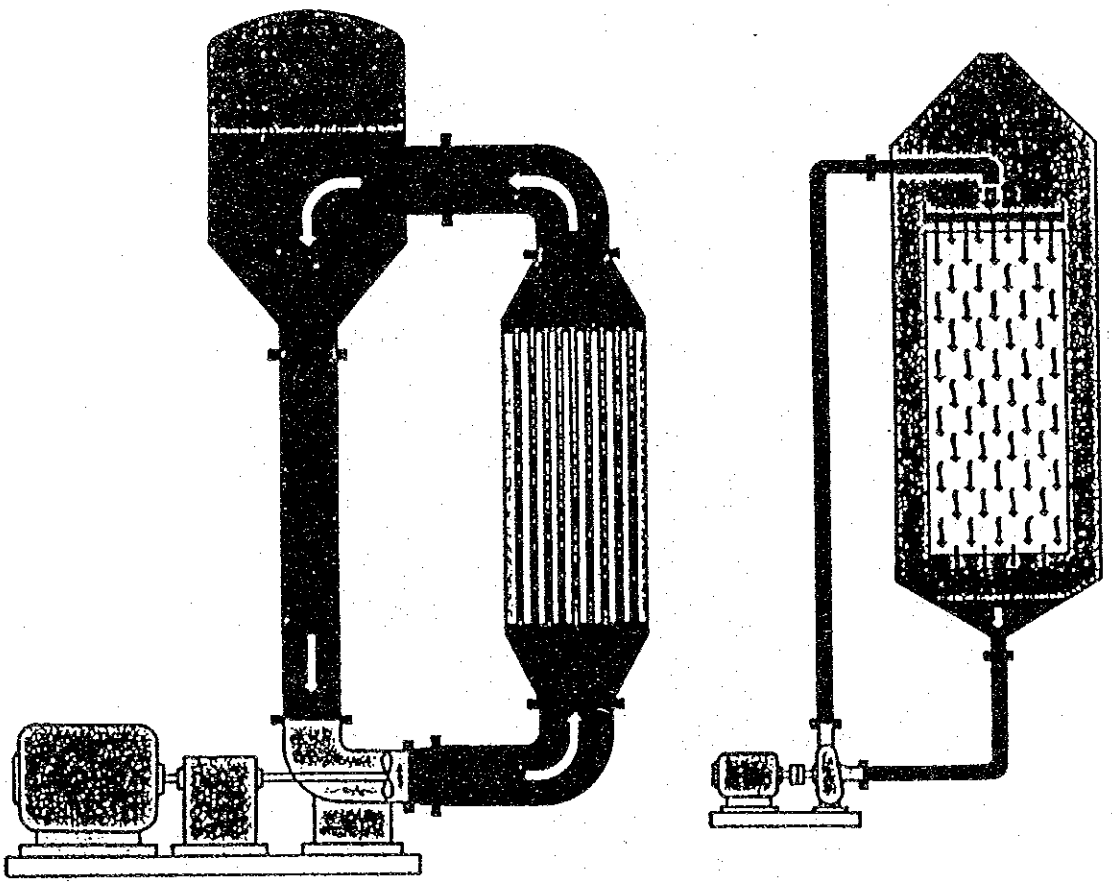


Figure 6.9 Comparison with Forced Circulation Evaporator and Falling Film Evaporator

- Forced Circulation Evaporator (Tube Type)
- Falling Film Evaporator (Plate Type)



(5) Oxidation of black liquor

Dilute black liquor, after having been oxidated in a oxidating tower, is fed to an evaporator. This oxidation is for:

① keeping the sulfidity of black liquor at a high level;

② oxidating odor elements to reduce odor trouble in a kraft pulp factory; and

③ reducing the corrosion of an evaporator and a recovery boiler.

A corroded tube in an evaporator contributes to diluting concentrated black liquor, resulting in steam loss. Corroded furnace wall, water pipe or super-heater tube in a recovery boiler may bring about such great trouble as blowout. Black liquor oxidation is an indispensable process as actions against environmental pollution by odor.

6.6 Recovery Boiler

The recovery boiler is installed to:

① burn organic compounds to separate and recover soda elements;

② reduce mirabilite (Na_2SO_4) to sodium sulfide (Na_2S); and

③ utilize burning heat to produce steam.

Burning organic compounds in black liquor to utilize available heat to produce steam is critical for energy conservation in a paper pulp plant. 80 to 90 % of power or steam is supplied by this burning in a factory equipped with a complete system for kraft pulp and paper.

Some current boilers are rated at pressures of 100 to 120 kg/cm^2 and a temperature of about 450 °C.

Black liquor to be burned in the recovery boiler is concentrated up to 50 % in a multiple effect vacuum evaporator. The resulting black liquor is concentrated to 65 to 70 % in a cyclone evaporator or a cascade evaporator by means of heat of exhaust gas from the recovery boiler.

The present plate type evaporator allows concentration up to 70 %, replacing the cyclone or the cascade evaporator. As a result, the thermally conductive surface of the economizer has been made to be twice to three times higher, with the boiler efficiency enhanced and odor decreased. Now, we get the recovery boiler causing no pollution. Black liquor produces low heat of 3,100 to 3,500 kcal/solid kg compared with heavy oil. Jetted black liquor contains much moisture and is difficult to burn. The black liquor boiler requires double or more operators for cleaning and surveillance than the heavy oil boiler.

Steam produced from a recovery boiler is referred to as by-product steam. Enhancing the efficiency of a recovery boiler reduces steam and power generation costs, encouraging the factory to focus on the control of burning black liquor. Particularly, being triggered off by a rise in the concentration of jetted black liquor (70 to 75 %), the cleaning of the black liquor jet nozzle and the primary and secondary air ports is automated. Further, facilities have been positively developed to regulate dust carry-over clogging the thermal convection part, as well as control the char bed fermation.

Infrared rays and ultrasonic waves are often used to monitor dust layers in a furnace and observe char bed shapes and temperature.

Figure 6.10 shows the outline of a typical recovery boiler (CE type and B & W type).

Figure 6.10 Recovery Boiler

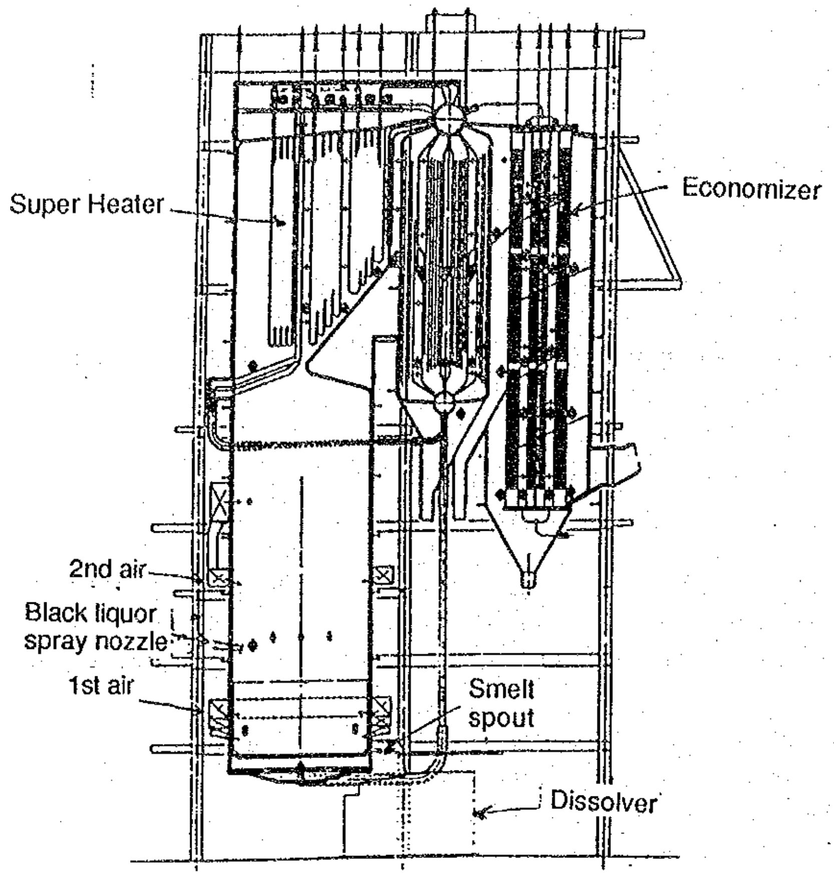


Table 6.8 shows an example of chemically analyzing elements contained in black liquor.

Table 6.8 Chemical Element of Black Liquor

Carbon	Hydrogen	Nitrogen	Oxygen	Burning Sulphur
38.5 %	3.14 %	6.86 %		1.36 %
Total sulphur	Ash	Moisture	Calory kcal/kg solid	
2.74 %	50.45 %	51.27 %	3400	

One ton of kraft pulp generates four to five tons of steam.

For the long-period running of a recovery boiler, note the points below.

① Actions against efficiency lowered by adherent dust, as well as normal running of a sootblower and facility control

② Removal of adherent smelt from air port

③ Maintenance of the shape of the char bed

④ Arrangement of black liquor injection nozzle

⑤ Setup of equipment inspection and maintenance system covering actions for preventing explosion

6.7 More Effective Dehydration by Press

(1) Theory of water squeezing on the press

Generally, it is estimated that cost for drying the wet paper in the drying process would be more than 5 times the cost for mechanical dehydration in the press part. Therefore, if the moisture in the press part is dehydrated for an extra 1 %, it will be possible to save the steam quantity in the dryer part by 3 to 5 %. The key point of drying the wet paper is whether it is possible to dehydrate moisture evenly in the width direction and as much as possible in the press part.

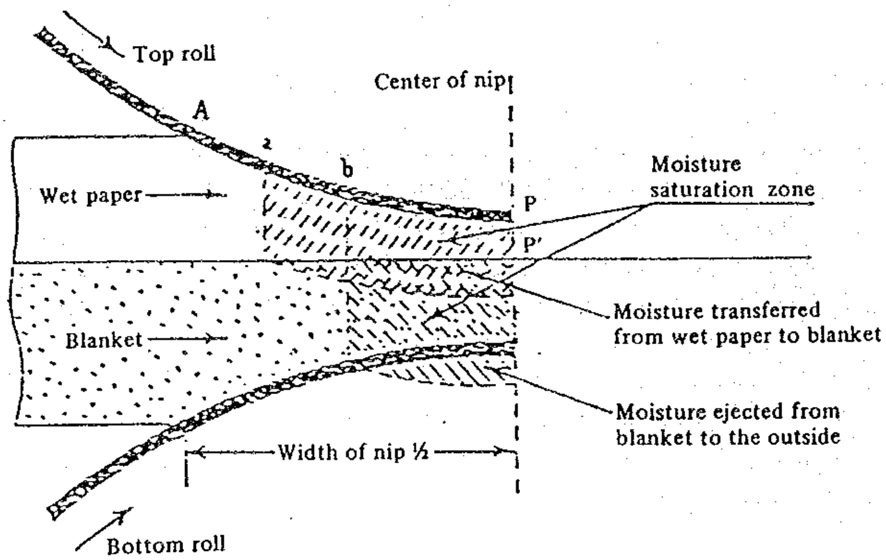
However, in order to make sure that the pressing in the press part is carried out, it is necessary to take sufficient pre-treatment procedures such as dusting and beating (refining) prior to entering the paper machine and sheet formation in the wire part. If there are large amounts of shines and foreign matter, it is impossible to expect the formation of high quality sheets in the wire part. Also the moisture distribution will be uneven, so that if pressed by the press roll, paper will often be cut. This situation does not allow sufficient pressing operation. In addition, because of their moisture content, shines and foreign matter darken the paper, i.e. causing fish eyes. In order to hide fish eyes, overdrying tends to be carried out. As a result, paper shrinkage and paper break is apt to occur, if foreign matter exists at the end. High frequency of paper break means an overload on the shoulder of operators and their subsequent negligence to concentrate in assigned work. Further, waste paper is also circulated, resulting in an unstable quality of paper and an inefficient consumption of energy.

Water squeezing on the press is carried out by passing wet paper through the weighted nip formed by two pieces of press roll together with felt as a water squeezing medium. The reason why felt is used is that it has a capillary structure, elasticity and surfacial flexibility. The number and configuration of presses used vary according to the paper machine. The fourdrinier paper machine having 2 to 3 sets of presses is generally most popular. However, recently the squeezing capacity of a press has been increased and the number of pressing steps has shown a tendency to decrease, following the development of new technologies for the past few years.

As basic types of press, the following two types are available: 1) the historically oldest plane roll type provided with a combination of a top roll using granite, etc. and an elastic bottom roll having an approx. 25 mm-thick rubber wound around an iron core; and 2) the suction press type provided with water squeezing and suction functions by perforating numerous suction holes of 6 to 7-mm diameter on the rubber surface of the bottom roll and setting a fixed suction box in the roll. The debut of the suction press has played an important role in improving the sheet making rate.

There are a few water squeezing theories for the press. However, in the age of the plane press, it was theorized that the wet paper and blanket are compressed by the press and the blanket begins to expand when passing the center of the nip and, simultaneously, moisture contained in the paper is transferred to the blanket. Yet during the suction press age, a theory as shown in Figure 6.11 was advocated.

Figure 6.11 Water Movement In Press Nip



As the compression goes further, moisture in the paper gradually reaches a saturation point. Following the increase of density in the sheet, a fluid pressure is generated, causing a differential pressure between the unsaturated blanket and the paper. Thus the moisture moves from the paper to the blanket.

If the rotation is advanced and the compression increased, the blanket is also in a saturated state, and the squeezed surplus water is flooded over and sucked into the suction hole.

In the plane press age, the sheet making rate was limited because of wet sheet crushing occurring in the press. However, this limit was eliminated by the development of the suction press method, making the high-speed sheet making process possible. Reviewing this situation, it is considered that the excess overflowing water in the press nip should have been responsible for wet sheet crushing. The suction press is very effective for increased pressure application as well as for increasing the sheet making speed. Thus it may well be an equipment contributing toward energy conservation.

(2) Adjustment of moisture in wet sheet and moisture distribution

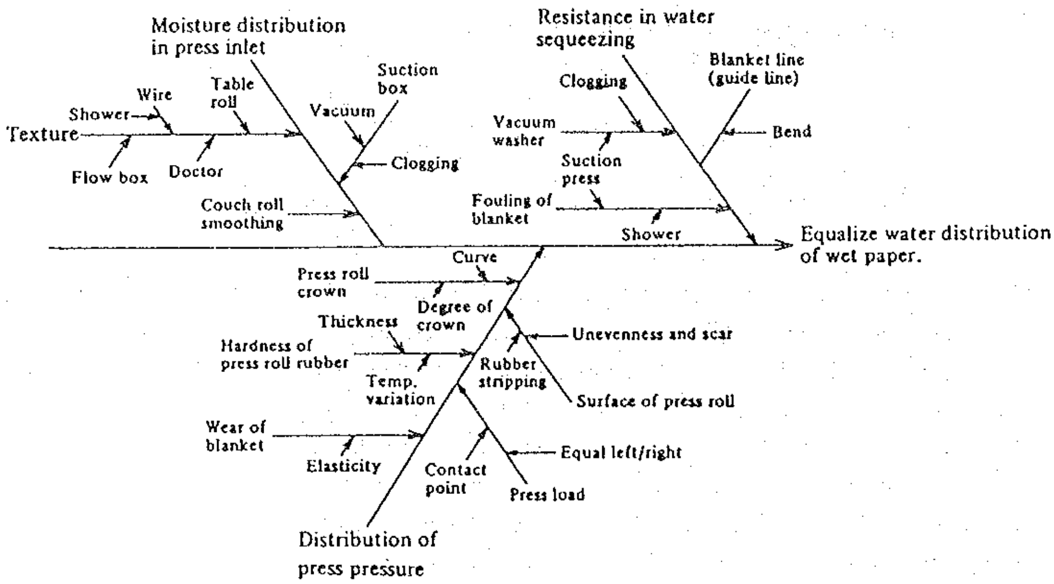
Even if the moisture content after pressing could be decreased, it would be quite useless, unless an uneven moisture distribution in the width direction is improved. The factors for adjusting the moisture distribution in the width direction is graphically described as shown in Figure 6.12.

With regard to these factors, make sure that the following are periodically checked:

- Measurement of moisture content in the width direction
- Measurement of press nip pressure in the width direction
- Measurement of crown and hardness of roll

The moisture content is normally measured in the width of the paper machine. It is recommended, however, that the measurement be made at an interval of approx. 10 cm.

Figure 6.12 Chart for Characteristic Factors



The nip pressure means a pressure generated per unit area, but not a linear pressure. If the same linear pressure load is applied to a soft rubber roll and a hard rubber roll, the width of the contact part of the soft rubber roll becomes larger than that of the hard rubber roll. On the other hand, the nip pressure per unit area (average) of the hard rubber roll becomes higher than that of the soft rubber roll.

Since it is the pressure per unit area that controls water squeezing, the nip width generated by the contact deformation of the roll is also as important as the linear pressure.

If pressure applied to the roll is changed, the nip width will change in proportion to the square root of the nip pressure as shown in Figure 6.13. Accordingly, the change of the linear pressure on the same conditions signifies the change of the average nip pressure as follows:

$$\overline{P} = \frac{P_L}{k \cdot \sqrt{P_L}} = k' \sqrt{P_L}$$

$\overline{P}$: Average nip pressure
P_L : Linear pressure
k· k': Constant

Based on the above, if the linear pressure is doubled, the pressure per unit area related to a water squeezing effect will be only 1.4 times as much.

Under a constant linear pressure, the nip width is increased or decreased in proportion to the rubber hardness indicated by the P & J hardness (refer to Figure 6.14).

Figure 6.13 Nip Pressure and Nip Width

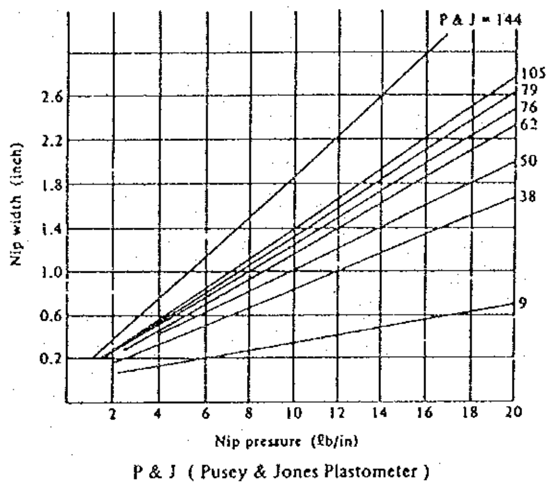
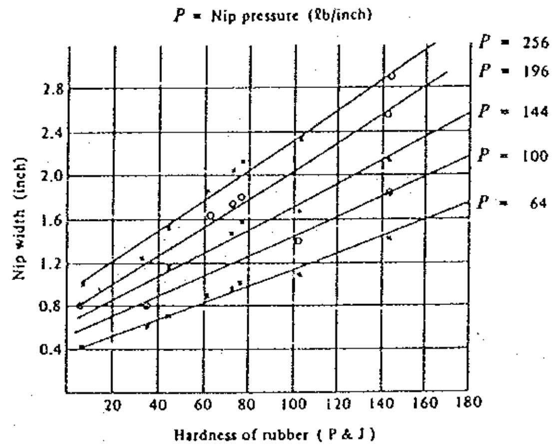


Figure 6.14 Nip Width and Rubber Hardness



The nip width has to do with the diameter of the roll. The smaller the diameter of the roll, the smaller the nip width. In addition, the nip width varies according to the sheet making speed. If the sheet making speed is increased under the same conditions, the nip width is reduced. The nip width also changes depending on the thickness of rubber and is proportional to the thickness of coat.

The hardness and thickness of rubber must be selected considering sheet making quality, sheet making speed, machine width, equipment strength, roll material quality, etc. When studying the selection, it is suggested that an experienced specialist manufacturer be consulted for opinions, and sufficient discussions with him be carried out. Necessary data such as moisture distribution, nip pressure condition, crown, paper quality (thickness, density, tension, tear, air permeability) must always be collected for use at any time.

A) Hardness of rubber roll

There are a variety of ways to measure the hardness of rubber roll. In Japan, the spring hardness testers Model A and Model C and the constant load system Pusay Johns type hardness tester are available under JIS (K6301). In addition, the Shore hardness tester Model A is available. Regarding the referential value of rubber hardness of rolls used for the paper machine, data furnished by the Voith Co. are shown in Table 6.9.

The hardness of rubber roll, if left alone, shows an increase of approx. 2 on account of the oxidation of its surfacial layer. The press roll shows a change in the hardness of its surfacial layer after a long time of use. The roll may sometimes become soft or hard depending on its materials. The change of rubber hardness by temperature is comparatively significant; the higher the temperature becomes, the lower the hardness. Although the difference is significant according to the kind of rubber, the difference of rubber hardness generated is approx. 3 to 5 at a temperature difference of 50 °C. Accordingly, it is necessary to designate a temperature during the measurement when the hardness is designated.

Table 6.9 Kind and Hardness of Rolls

No.	Kind of roll	Hardness by Pusey & Jones 1/8" sphere
1	Pressed roll	5~10
2	Table roll	0~5
3	Wire roll	0~5
4	Lamp roll for suction couch	180~200
5	Lower roll for the first press	65~70
6	Lower roll for the second press	60~65
7	Lower roll for the third press	50~55
8	Lower roll for the 4th press	40~45
9	Suction press roll	28~32
10	Upper roll for ringer plane press	10~15
11	Lower roll for ringer plane press	70~75
12	Upper roll for ringer suction press	60~65
13	Suction roll for ringer suction press	28~32
14	Wet felt roll	0~5
15	Transfer roll and draw roll	0~5
16	Paper roll	0~5
17	Top roll for offset press	30~40
18	Pressed rolls for cylinder dryer and yankee dryer	25~30
19	Gloss press roll for yankee dryer	25~30
20	Suction touch roll for yankee dryer	28~30
21	Coating or size press roll	
	Roll of high hardness	5~40
	Roll of low hardness	30~50

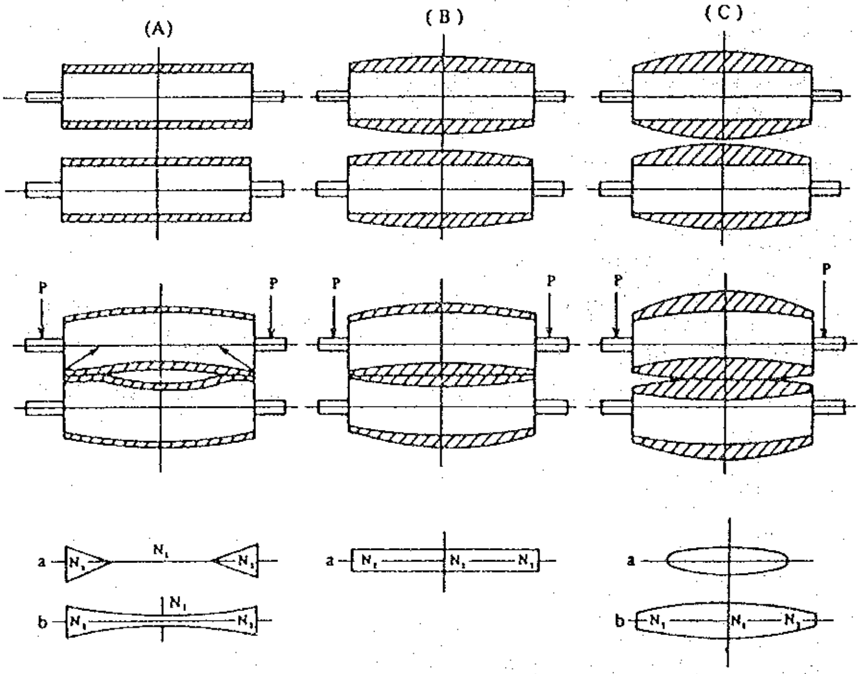
Quoted literature: Voith Tech. Bellage 1966 S. 45

B) Check on the crown

It is not exaggerating to mention that the stableness of operation of the paper machine and product quality can almost be achieved by the scheduled grinding of rolls. It is necessary to regrind the rubber-coated suction roll every 3 to 6 months considering the hardness of rubber or the pressure of press nip. The rubber roll should be used by repeating its grinding until the thickness becomes 13 to 15 mm.

When carrying out grinding, attention should be paid to the crown. The roll is in the form of a beam whose ends are supported, so it sags by its own weight. In case of a pair of upper and lower press rolls, the lower roll is curved downward by its own weight. In the meantime, although the upper roll sags downward by its own weight, it is curved upward as a whole, because the upward sag caused by a load applied to the journals of its both ends is generally more significant (refer to Figure 6.15).

Figure 6.15 Crown and Nip Width



When a) the crown is not attached at all or b) the crown is small, the nip has a large width on both ends.

When the crown is normal, the nip has a rectangular width.

When a) the crown is very large and b) the crown is a little large, the nip is wide in the middle.

Consequently, a clearance is formed at a center part, even if both ends of the roll tightly adhere to the core. Padding for filling this clearance is called "crown."

If the crown is inappropriate, it is impossible to obtain a uniform nip pressure across the width. For a simple visual determination of the crown state, the undermentioned objects are inserted between the rolls to confirm their marks or traces.

a. Carbon and tracing paper

b. Pressure-sensitive paper

c. Aluminium foil with embossed surface

Place any of these on the lower roll and apply pressure so that both ends of the upper roll may touch the lower roll simultaneously. If the upper roll is raised, excepting a load, the nip will be recorded across the entire width.

If a narrow mark appears at one side, it means that the load on the front and back is not uniform or the roll is deviating out of its right position.

The equation for calculating a crown value based on the marked nip width is as follows:

$$C = \frac{(N_2^2 - N_1^2)(D_1 + D_2)}{2D_1 D_2}$$

C : Crown value to be corrected
N_1: Nip width at the center of roll marked
N_2: Nip width at both ends of roll marked
D_1: Diameter of upper roll
D_2: Diameter of lower roll

If the diameters of the upper and lower rolls are the same, the following equation is established:

$$C = \frac{N_2^2 - N_1^2}{D}$$

If the calculation showed a negative result, it signifies the necessity to reduce the crown value by this negative amount. Here attention should be given to the fact that the difference of $\frac{1''}{10}$ of the nip width appears as a change of $\frac{15''}{1000}$ of the crown. When measuring the nip width, be extremely careful about the selection of pressure-sensitive materials which print a clear mark because it is necessary to read the mark correctly.

6.8 More Effective Drying

(1) Mechanism for drying wet paper containing approx. 60 % of moisture to approx. 5 % level.

a. Steam injected into the dryer cylinder heats the surface of the cylinder and becomes condensate.

b. The wet paper touches the smooth surface of the heated cylinder and absorbs heat effectively and uniformly over the entire width. Then the temperature of the wet paper is increased, resulting in the evaporation of moisture.

c. The wet paper, coming in touch with the cylinder, covers approx. 65 % of the entire external circumference of the cylinder. However, the porous canvas travels on the exterior of the wet paper, holding down the latter, so the evaporated steam is condensed inside the canvas.

d. The temperature of the canvas containing a condensate rises and consequently the partial pressure of the internal vapor also rises. Then the canvas instantaneously evaporates moisture absorbed by the former in the free space between cylinders.

e. In order to make sure that the moisture ejection action of absorbing, condensing and releasing steam is carried out effectively, the canvas must be highly air-permeable, at high temperatures and well dried.

f. The wet paper retains a considerably high temperature when passing from the cylinder to the free space. Consequently, its vapor pressure is so high that the evaporation action on both surfaces of the paper is very effective.

g. The evaporation rate at that time is in proportion to the difference between the partial pressure of vapor in the surface of the paper (almost equals to the saturated steam at the temperature of paper surface), and the partial pressure of water vapor in the air. Accordingly, it is a means for improvement of efficiency to reduce the humidity of air in the surroundings of the paper.

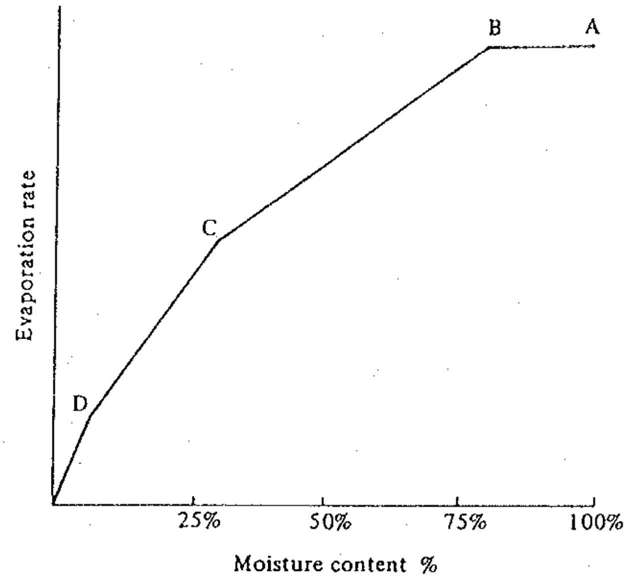
h. If the condensate inside the cylinder is resident or formed into a water film ring, the thermal efficiency drops so that the condensate should be discharged effectively.

The above is a summary explanation on the drying mechanism of the dryer part. It is necessary for effective drying operation to have sufficient knowledge about the movement of moisture in the paper layer during the drying cycle.

(2) Movement of moisture in the paper layer

It is essential for the understanding of the drying mechanism to look into the relationship between the evaporation rate of moisture and the moisture content of paper during the process of moisture evaporation from the paper layer. The typical paper drying curve is shown in Figure 6.16.

Figure 6.16 Drying Curve of Paper



A → B: The evaporation rate is constant during the drying process under a high moisture content state. This is due to the fact that under a condition where the paper surface is covered by water, the moisture, even if evaporated, is continuously replenished through comparatively large capillaries or fibrous clearances in the inner paper layer. If this evaporation status proceeds further, the paper reaches the stage where it is impossible to retain sufficient moisture in the surface of the paper "B" point.

This phenomenon is considered attributable to the increasing flow resistance resulting from the gradual shift mainly to the movement of water from tiny capillaries.

B → C: Under this process, the resistance of moisture moving from the internal clearance, onto the surface of the paper layer, becomes gradually stronger and the evaporation rate becomes gradually lower following the decrease of moisture. Various factors of the resistance are conceivable. However, the size distribution of capillaries affected by the beaten condition of fiber should be estimated as a most important factor.

C → D: The "C" point represents a turning point indicating the initiation of evaporation of moisture absorbed in microcapillaries or fibers. The evaporation rate is lower in the C - D. It is said that the quantity of moisture absorbed into the fiber should have to do with the content of hemicellulose and the degree of beating.

D → E: A the "D" point, moisture hydrated into the fiber begins to evaporate. In this process, the resistance is higher. The hydrated moisture is restrained by cellulose or hemicellulose particles, or is absorbed in them as a particle layer.

(3) Conditions controlling the drying speed of paper

It is considered that the mechanism of moisture evaporation from wet paper and the process of evaporation in dryer should already be well understood. Yet, important in the actual operation is uniform drying in the width direction. The essential points of drying are that the sheet formation should be uniform in thickness and density and the wet paper be free from admixtures such as shives and foreign matter. General conditions controlling the drying speed are described below.

The three controlling elements are as follows:

A) Surfacial temperature of dryer

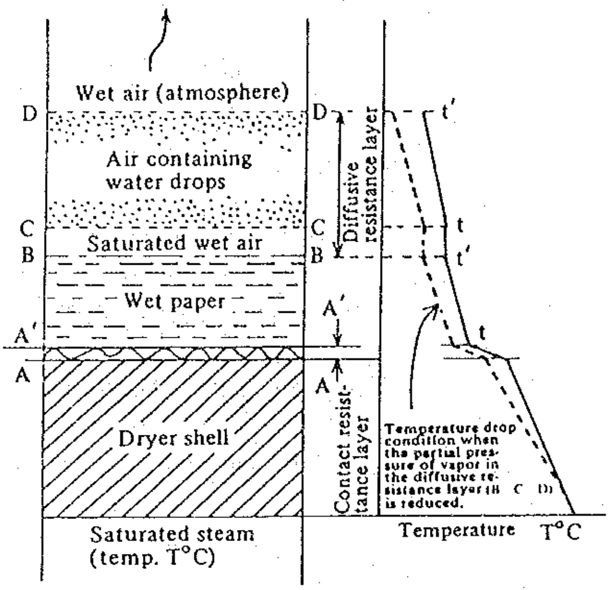
B) Character and velocity of air contacting the surface of paper

C) Heat transfer resistance (contact resistance) on the contact surface between the surface of dryer and paper

With regard to Item A) if the discharge of condensate is normal, it would not be a cause for uneven drying. However, cases where a siphon is missing inside the cylinder, causing uneven drying were often experienced. As regards Item B) the air between paper and the cylinder is often a problem. Explanation is made of the relationship between air conditions and drying speed in Figure 6.17.

Figure 6.17 shows the state of air contacting the wet paper. The essential point is how rapidly heat required for the evaporation of moisture in the wet paper should be supplied to the wet paper. And there is a principle that heat transfer speed between two points is proportional to the temperature difference between the two points. Accordingly, in order to quicken the heat transfer speed, the difference between the cylinder's surfacial temperature and the wet paper's temperature must be large. In order to obtain such a difference, a) the surfacial temperature T of the cylinder shall be increased or b) the temperature t of wet paper shall be decreased.

Figure 6.17 The Relationship between Air Conditions and Drying Speed



a. In order to maintain the cylinder at high surfacial temperatures, the steam adjusting valve has only to be opened. However, the problem is the decrease in temperature of wet paper and its effect. The moisture is vaporized by the heat of vaporization and then is released into the atmosphere from the surface of wet paper through the saturated wet air layer B-C (layer saturated with vapor evaporated from wet paper at high temp.) and the layer of saturated wet air containing water drops C-D (layer of water drops condensed from part of the vapor at lower temperatures than the B-C layer). However, the lower the partial pressure of vapor in the C-D layer, the more extensively the vapor of the B-C layer is diffused. Consequently, the evaporation rate of vapor from the wet paper increases and, as a result, the wet paper loses its heat of vaporization and is at low temperature levels. Consequently, the temperature difference between the wet paper and steam becomes large, increasing the heat transfer rate. Thus, the environmental conditions around the wet paper (temperature, humidity, and wind velocity) are important factors for affecting the drying speed and for the evenness in drying in the width direction.

Next, as regards Item C), if each factor of heat transfer resistance in the contact surface between the dryer's surface and paper is normal, the possibilities that the drying speed might be uneven are small.

a) Film resistance on the internal surface of the cylinder

b) Resistance of cylinder wall

c) Air film resistance between the cylinder surface and paper

d) Resistance of the paper layer itself

With regard to the above, the item to which attention must be given is c), because of the uncartainty and sensitive beyond expectation.

For the elimination of wrinkles and air held, the leading dryer is sometimes installed. Figure 6.18 shows its operating procedures. The leading dryer is slightly smaller in diameter than the dryer cylinder and heated at approx. 50 °C.

As described above, it is essential to check, maintain, service and improve equipment, auxiliary machines, and tools in accordance with the drying function of the dryer part and operate them satisfactorily to meet the circumstances.

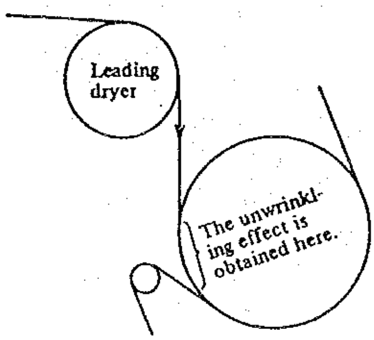
Regarding the routine operation, attention needs to be given to simple work, namely,

a) maintenance and check of the doctor, and removal of refuse to keep the cylinder's surface always clean,

b) removal of clogging and humidity in the canvas, and

c) prevention of the flow of cold and wet air to the dryer.

Figure 6.18 Leading Dryer

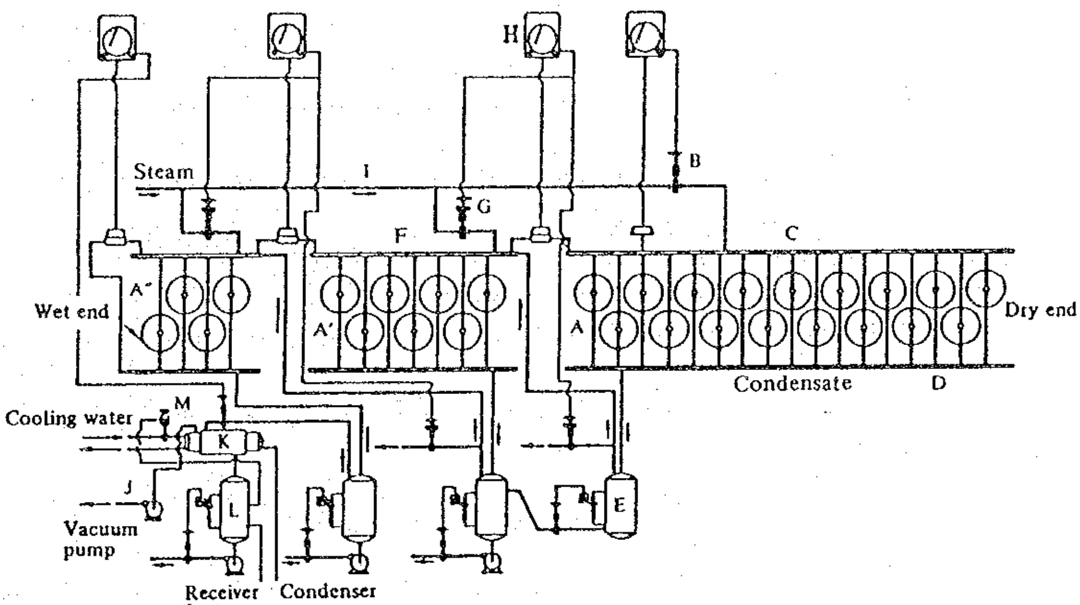


(4) Steam supply and exhaust system

In the case of paper drying, it is necessary to consider the qualitative problem according to the kind of paper. However, it is generally required that the surfacial temperature of the dryer is gradually increased from the wet and to the dry end. This requirement agrees with a condition that the drying resistance increases in accordance with decreases in the moisture of paper and, at the same time, the heat transfer rate of the cylinder decreases. Accordingly, the dryer part should be divided into 2 to 3 dryer groups to change the steam pressure. In other words, it should be arranged so that steam consumption can be increased for the dryer groups of the dry end, and steam consumption can be decreased for the dryer groups of the wet end.

As the standard for the grouping of cylinders, the ratio of the number of cylinders should be 1:2:4 from the wet end, for instance, in the case of 3 groups. Figure 6.19 shows the typical drainage system of 3 groups called "below through systems."

Figure 6.19 Typical Third Group Drainage System (Blow Through System)



A : First group dryer (A': second group dryer, A": third group dryer)
B : First group control valve
C : First group steam header
D : First group condensate header
E : First group condensate receiver tank
F : Second group steam header
G : Second group control valve
H : First group and second group differential pressure controller
I : Main steam pipe
J : Non-condensive gas ejection vacuum pump
K : Condenser
L : Receiver tank
M: Cooling water control valve

(Explanation of Figure 6.19)

Steam flowing into the header (C) for the first dryer groups (A) from the control valve (B), enters the drain header (D) as drain and then the receiver tank (E). In this receiver tank where the pressure is lower than (A), the steam is revaporized, resulting in the separation of steam from drain. This revaporized steam enters the steam header (F) of the following intermediate dryer section (A'). Between the steam headers of (A) and (A'), the control valve (G) and the controller (H) are provided for keeping constant differential pressure. This differential pressure is set so that the condensate flow for (A) can be in the most ideal state. However, if the differential pressure is higher than the set value, the control valve (G) will be opened, causing the steam to flow from the main steam pipe (I) to the steam header (F) of (A') until the differential pressure reaches the fixed pressure level.

In case the sum of the revaporized steam volume and the siphon's blow-through steam volume is larger than the steam consumption of the following dryer group, the steam should be partially released into the atmosphere. Otherwise the differential pressure cannot be controlled, and subsequently, the system will be further complicated. For this reason, it is also necessary to make negative the pressure of the drain header for the final stage's wet end dryer section (A").

At the same time, a vacuum pump (J) is provided for the purpose of ejecting non-condensive gas forcibly. In normal cases, a condenser (K) is also installed along with the vacuum pump for assisting the latter. The cooling water volume for the condenser is adjusted by means of a control valve (M) according to the temperature of the receiver tank (L).

Each receiver tank is equipped with a level controller so that the liquid level can always be kept at a constant level.

The drain is collected into the collection tank and returned to the boiler.

Table 6.10 Flash Tank Capacity Index

Diameter (mm)	Diameter (inch)	Maximum drain volume (kg/hr)
150	6	900
200	8	2,250
300	12	4,500
380	15	9,000
460	18	13,000
500	20	16,000
600	24	20,000
760	30	34,000
920	36	50,000

Table 6.11 Flash Tank Height Index

Diameter (mm)	Diameter (inch)	Height (mm)
150	6	940
200	8	940
300	12	1,000
380	15	1,100
400	18	1,200
500	20	1,400
600	24	1,400
760	30	1,400
920	36	1,500

(5) Supply and exhaust of air in the dryer part

If the best dried and high-temperature air is supplied into the surroundings of the dryer cylinder, and the high-humidity exhaust is rapidly ejected into the atmosphere, the drying efficiency will be improved.

The air discharged from the dryer part is at high humidity and, at the same time, is at high temperatures (60 to 80 °C). Therefore, if the heat is recovered in some way, the heat balance will be improved.

In order to achieve the above mentioned purposes, the hood covering the dryer cylinder group plays an important role.

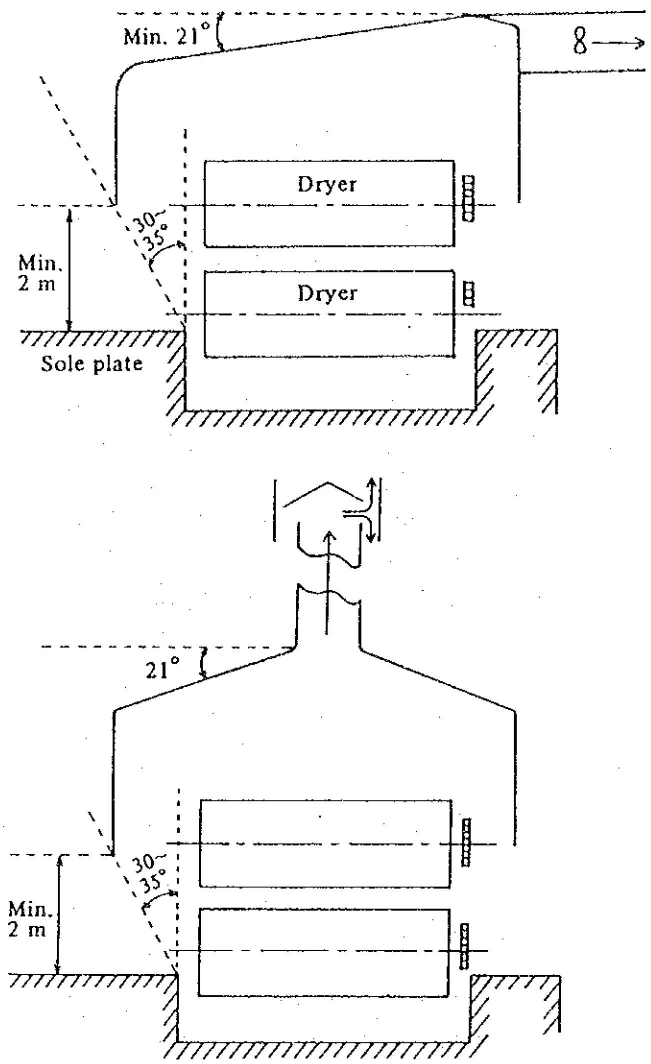
A) Dryer hood

In the ordinary paper machine, approx. 2 tons of moisture is evaporated for drying one tone of paper. For ejecting this vapor, 50 to 60 tons of air is required. Therefore, from the structural point of view, the following design considerations must be given to the construction of the dryer hood.

a. The width of the hood and the height of the side wall should have sufficient dimensions for capturing wet air. In the case of the open hood, it is necessary that the height of the side wall is at least 2 m and the location is almost at 30 to 35° against the internal surface of the sole plate as the distance from the machine frame (refer to Figure 6.20). This must be done from the operational point of view and to sufficiently treat the blowout of vapor from the dryer pocket or the expansion of an ascending air current passing on the internal surface of the sole plate.

The upper inclination is designed to prevent the dropping of condensed water in the interior. The upper space capacity should also be large enough.

Figure 6.20 Design of Open Hood



b. The location, size and shape of the exhaust port should be provided so that they can fully eject wet air without fail. At the same time, the exhaust port should not make deflected air current which would be the cause for uneven drying in the paper width direction.

In case the exhaust port is directly mounted to the hood ceiling, it should be provided at the portion equivalent to 3/4 of the wet end of the dryer part. This is because most of the vapor is generated in the so-called constant rate drying zone where the paper moisture is kept at about 15 %.

c. The dryer hood should have such a structure that it does not disturb paper feed operation.

d. The hood should also be so designed as it allows easy access to the operator for the maintenance, repair and cleaning of the dryer.

e. Material for the hood should be strong enough for the passage of the operator.

f. The hood ceiling should be strong enough for the passage of the operator.

In the conventional paper machine, a roof-shaped hood was provided on the group of dryer cylinders and the hood was equipped with 3 to 4 pieces of large exhaust ducts for exhaust by natural ventilation.

For developing the high-speed paper machine of high productivity the drying performance was reevaluated. And the machine was improved by the procedures such as the adoption of forced exhaust, introduction of hot blast supply equipment, complete sealing of hood and building-in of waste heat recycling device. In case of the totally sealed hood, it is possible to make a theoretical design and to calculate the heat balance easily. However, in case of the open-type hood, it is possible to sequentially modify and improve it to meet the production requirements in the actual operation.

The relationship between the dryer's steam evaporation amount and the exhaust amount is expressed by the following equations.

$$E = P \times \frac{W_1 - W_2}{100 - W_1} \qquad (1)$$

$$G = \frac{E}{X_2 - X_1} \qquad (2)$$

E : Evaporation amount kg/h
P : Paper feed amount kg/h
W_1: Moisture at inlet
W_2: Moisture at outlet
G : Air exhaust amount kg/h
X_2 : Absolute humidity against dew point at the hood output kg/kg
X_1 : Absolute humidity of fresh air to be supplied to the hood kg/kg

X_1 changes according to season and location and X_2 can be changed by operation. The higher the value of X_2, the less the value of G. Namely, the maintenance of the dew point of exhaust at high level contributes toward the decreasing of the unit steam consumption rate. Therefore, it is important to study various factors involved in such a contribution and work out plans carefully to deal with these factors.

It is reasonable and effective to hang a transparent film curtain from the side wall end of the open-type hood. The measure will also improve the operating environment.

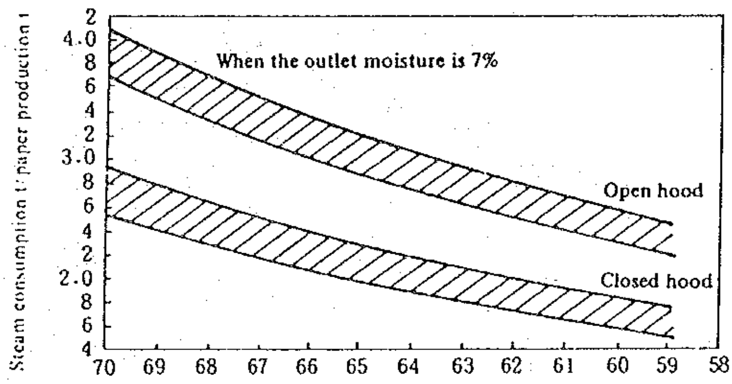
The air volume normally required per 1 ton of paper is as follows:

- Hoodless paper machine 75 - 80 tons
- Paper machine with open-type hood 50 - 60 tons
- Paper machine with closed-type hood 25 - 30 tons

If the hood device is improved, less air consumption is required, and subsequently, the unit steam consumption rate is reduced. Figure 6.21 shows the difference between the open-type hood and the closed-type hood.

When the dryer is at a marginal capacity, an approx. 20 % increase of the capacity is expected, if the closed-type hood is adopted.

Figure 6.21 Unit Steam Consumption Rate for Open Hood and Closed Hood



B) Improvement of dryer ventilation

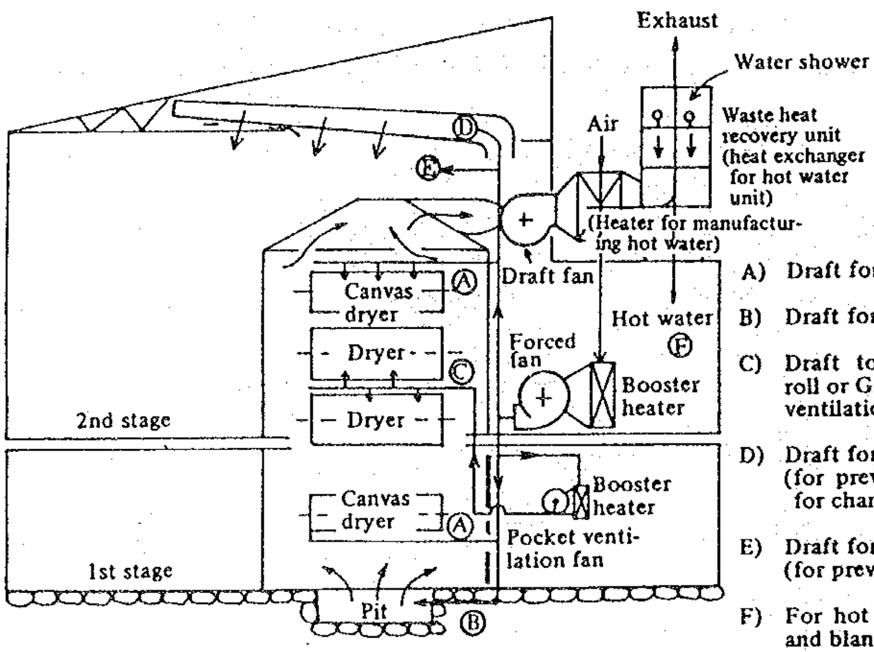
In the case of the closed hood, it is suggested that the ventilation system be built into the paper machine with the dryer. Otherwise, the drying effect would be reduced. The well-balanced air supply and exhaust, and appropriate temperature will be contributing factors toward the effective consumption of thermal and electric energies and the stabilization of paper quality.

Water vaporized from the dryer part is released as an exhaust of high dew point. It is suggested that air or water at high temperature be obtained by heat exchange in the process of the said release, and that hot air be used as an air supply to the dryer and hot water for blanket washing and pulp washing process.

The dryer ventilation system is a system where high-efficiency vaporization and waste heat recycling are carried out by means of ventilation control. One example of this system is shown in Figure 6.22. The waste heat recycling flow and the ventilation control system are shown in Figure 6.23.

The pocket ventilation system is effective for equalizing moisture distribution across the entire width of wet paper and thus economizing steam consumption. In addition, this system prevents overdrying at both ends of the paper and also prevents paper break. Therefore, its effects are remarkable. In case of the open hood, the stagnation of vapor is a problem remaining to be solved. The devices such as PV roll and Grevin nozzle incorporated in the canvas roll are also available. In some cases, air is injected into a part where vapor is stagnant.

Figure 6.22 An Example of "Closed Hood Ventilation System"



A) Draft for canvas drying

B) Draft for pit

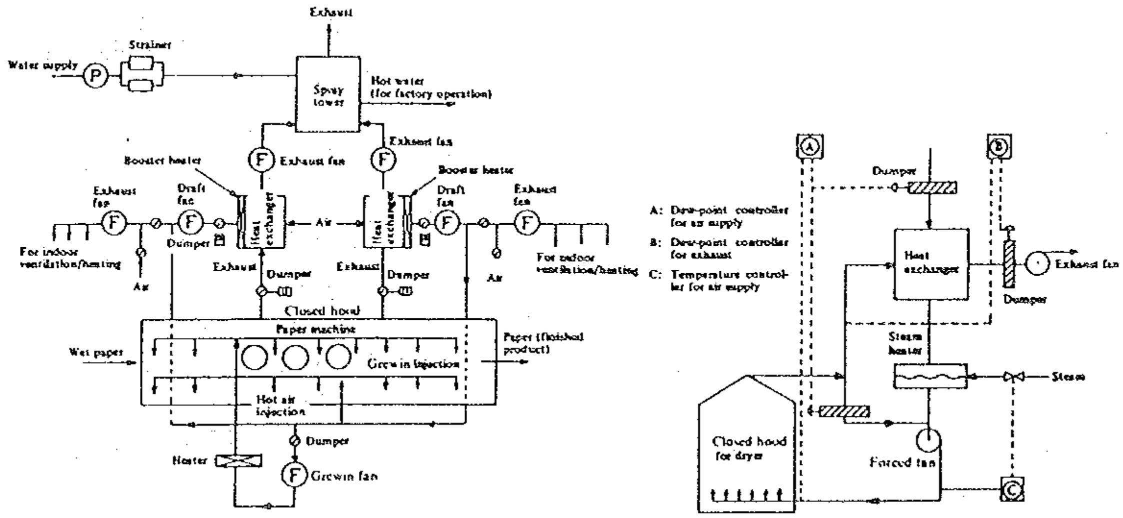
C) Draft to auxiliary dryer (PV roll or Grewin nozzle for pocket ventilation)

D) Draft for paper chamber ceiling (for prevention of dewing and for chamber ventilation)

E) Draft for press part (for prevention of dewing)

F) For hot water of pulp section and blanket wash (for washing pulp)

Figure 6.23 Waste Heat Recovery Flow for Closed Hood Ventilation System and Control System



7. Energy Conservation in Textile Industry

7. TEXTILE

7.1 Characteristics of Energy Use

7.7.1 Energy unit consumption

Unit consumption 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 unit consumption is checked in comparison with that of competitors, and the other is that the trend of unit consumption is checked, that is, it is checked whether it is improving or on the downgrade.

If it is unknown whether energy unit consumption 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 fuel unit consumption in the industry over a time span of several years or more.

Figure 7.1 Trend of Energy Consumption in Dyeing Industry

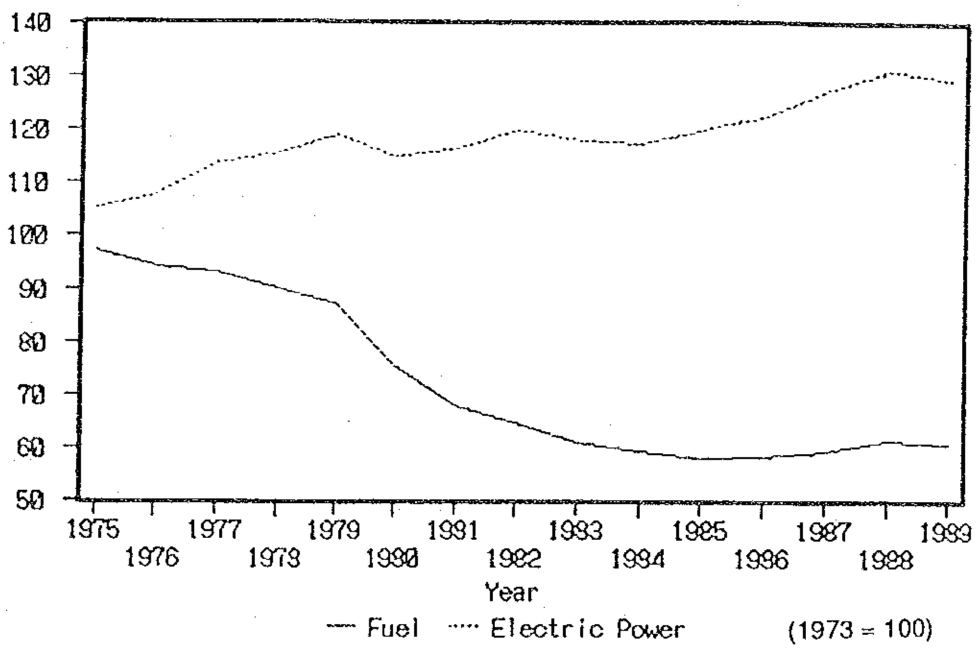


Figure 7.1 shows the transition of the energy unit consumption in the dyeing industry in Japan. As for fuel, remarkable energy conservation has been achieved; for electric power, the energy unit consumption has been degraded due to some factors mentioned below.

(1) Fuel Unit Consumption

Table 7.1 shows the unit consumption for each energy source.

The fuel unit consumption of the dyeing industry is much larger than that of other industries.

For the textile industry, the unit consumption of wool fabric is twice those of the other industries or more. This is because, unlike processes for cotton, chemical fiber, and synthetic fiber fabrics, processes for wool fabric, such as crabbing, washing and decatizing, are specific, and any of these requires a large quantity of hot water and steam.

In addition, the multikind small quantity production system for higher grade wool fabrics is another cause of the degradation of the energy utilization efficiency.

(2) Electric Power Unit Consumption

The power consumption of the dyeing industry occupies half of that of the Japanese textile industry or more. The power unit consumption of the dyeing industry tends to increase in general. Though measures to save electric power have been probably taken, the increase in power consumption has overtaken the effect of power saving.

In many cases electric power is used as an alternative energy for energy conservation, water saving and the improvement of environment. For example, liquor feed pumps or air feed fans are operated for waste heat recovery; circulation pumps are operated for saving water; and power for coolers is additionally used for the improvement of workshop environment.

As shown in Table 7.1, the industries for silk and rayon fabric have the largest power unit consumption, followed by the industries for flaxen fiber fabrics, wool fabric dyeing, cotton and staple fiber fabrics. These industries are provided with longer manufacturing processes, and almost all of them are natural fiber processing industries. In addition there is a continuous trend toward a larger energy consumption: Higher values added, multikind small quantity production and shortened delivery periods.

Challenges for electric power saving are how these long processes are integrated or omitted; how heating electric power as a heat source is converted into other energy sources; and how the production system is restructured into one suitable for multikind small quantity production.

Table 7.1 Unit Energy Consumption of Energy-Intensive Categories of the Textile Industry (Average for the three Years Up to 1990)

Type of Industry: Category / Subcategory	Fuel Unit Consumption (ℓ/ton)	Power Unit Consumption (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	1046.2	3.82	Scouring, bleaching and dyeing for cotton, flaxen 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	2187.2	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	1145.3	1.48	
Miscellaneous textile goods dyeing	1917.3	2.16	Including raising

1) Fuel unit consumption = Annual fuel consumption by items (kℓ) ÷ [Quantity of processing by items (m^2) × Specific weight (kg/m^2)]

2) Power unit consumption = Power consumption by items (kwh) ÷ [Quantity of processing by items (m^2) × Specific weight kg/m^2)]

[Source: Industrial Statistics (Item)]

7.2 General Description of 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 produced depending on types 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.

In this paper, the general description of the relation between common manufacturing processes and utilities is given.

7.2.1 Chemical and synthetic fibers

Figure 7.2 is a flowchart of polyester fiber manufacture, the main stream of synthetic fiber production.

A single fiber extruded is divided into two streams: Filaments and staples. The staple is processed in short fiber spinning processes.

Figure 7.2 Process Flow Chart of Polyester Fiber

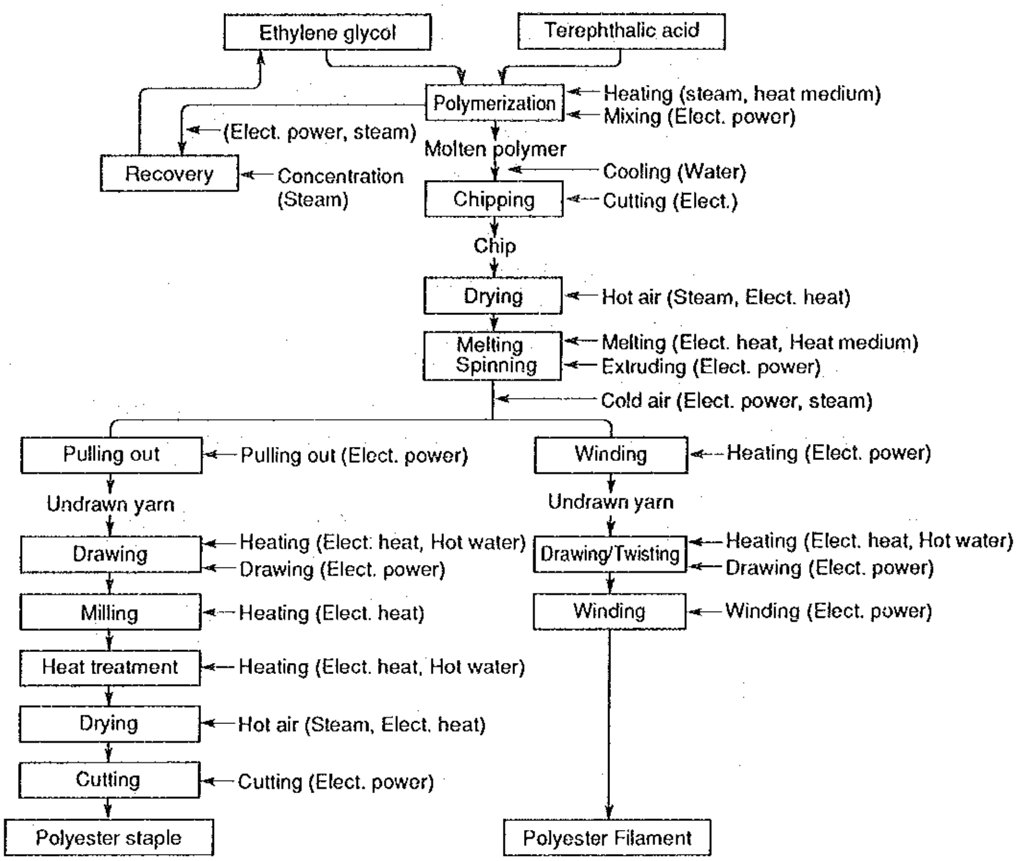
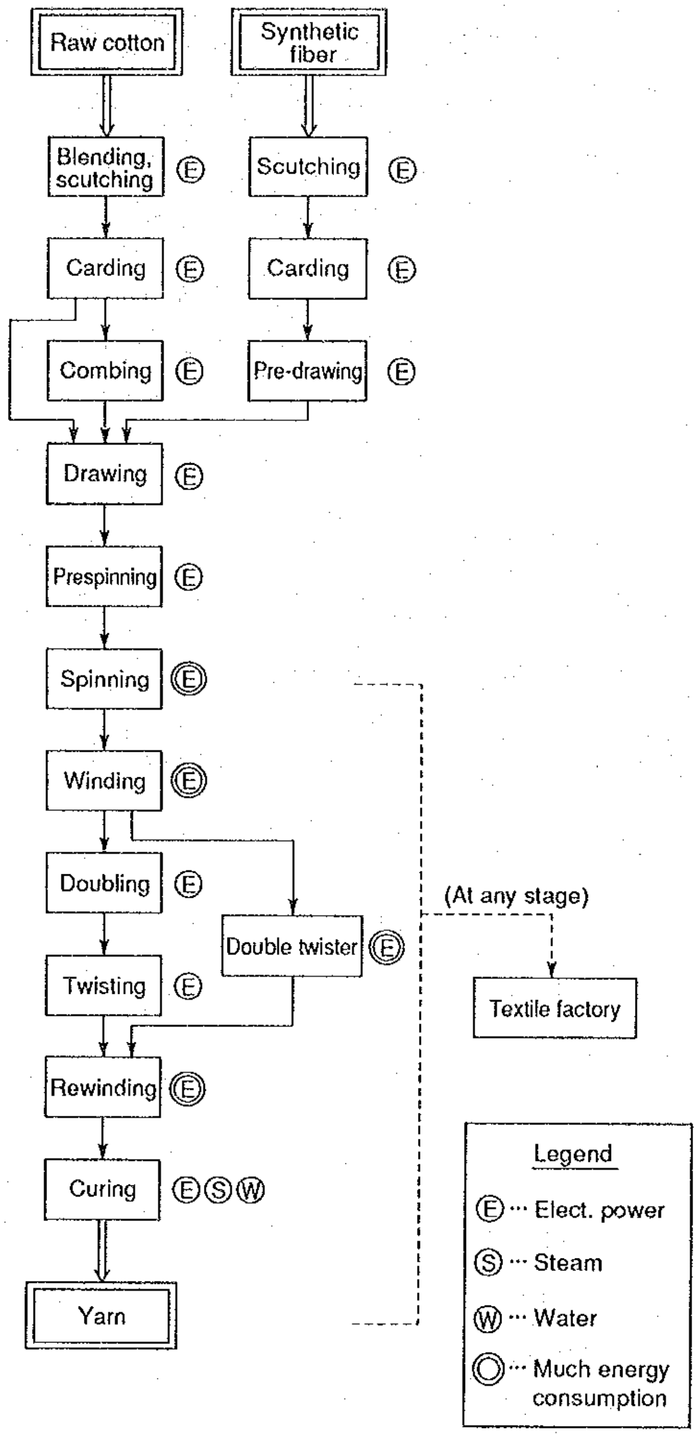


Figure 7.3 Process Flowchart of Cotton Spinning



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.

7.2.2 Cotton spinning

a. 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 7.3. This process is common to mixed spinning with synthetic fibers and single and mixed spinning of man-made fibers, such as rayon and acetate.

The features of the manufacturing process are as follows:

- The drawing processes from scutching to prespinning 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 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.

b. Wool Spinning

(1) Classification of Wool Yarn by Spinning Method

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

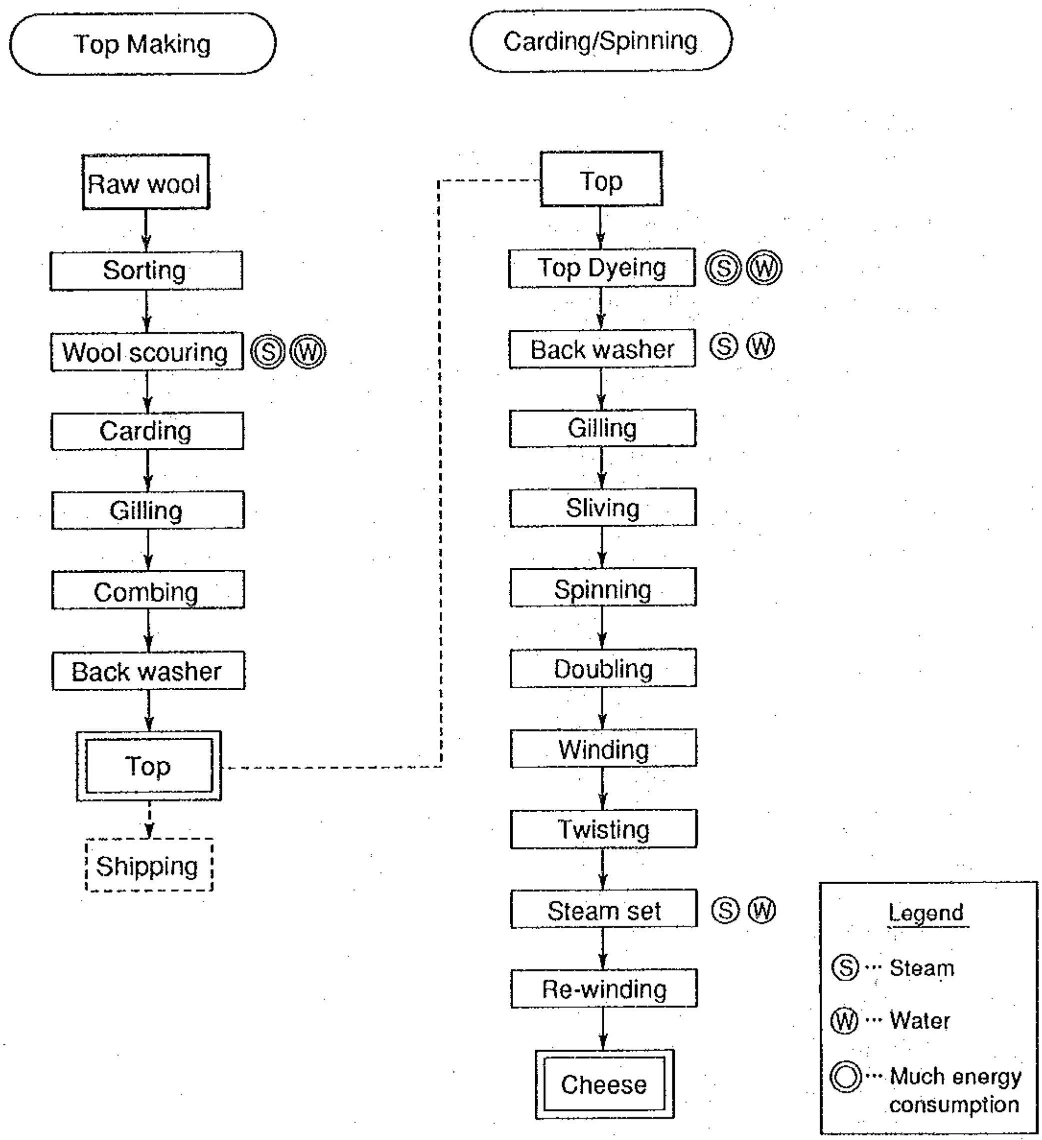
Worsted yarn is a wool yarn with relatively smooth surface, and is obtained by combing wool yarn to remove short fibers and performing spinning such that long fibers are arranged in parallel. Woolen yarn is, on the contrary, a wool yarn spun such that fibers are twined around each other and maintains 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.

(2) 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 7.4 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 7.4 Process Flowchart of Worsted Spinning



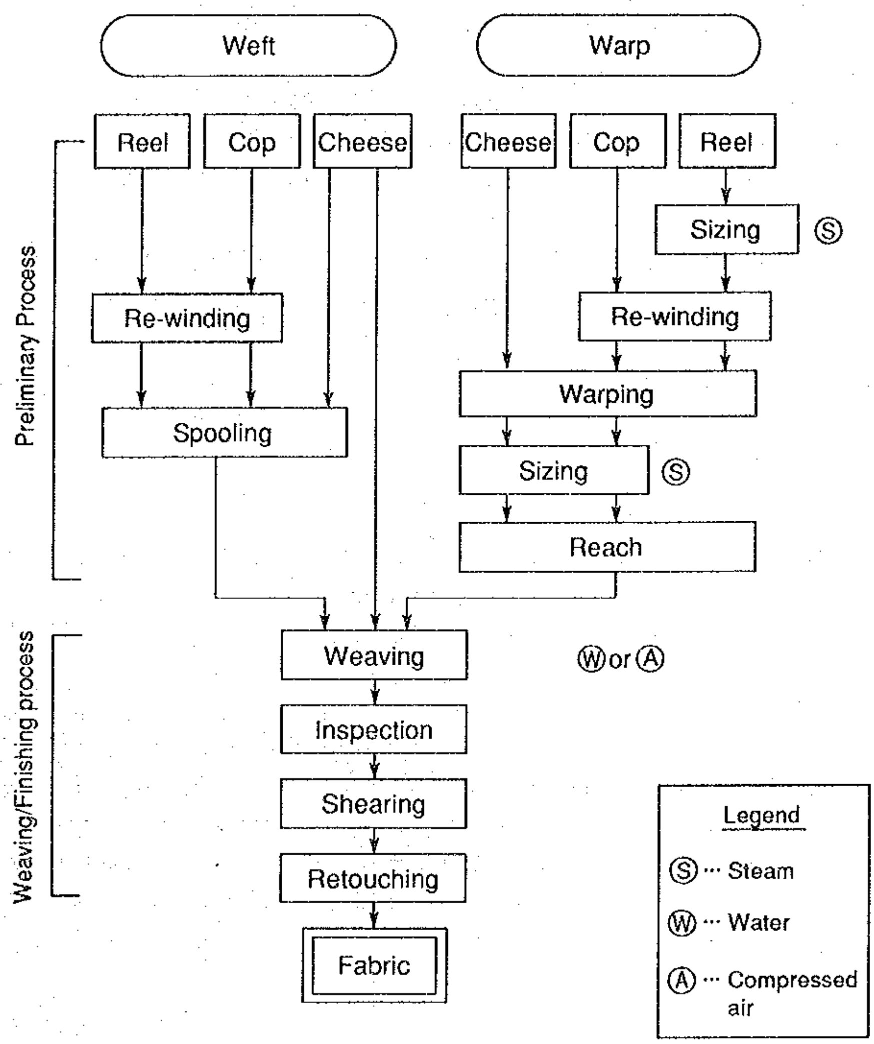
① Wool dyeing : Scoured raw material is dyed before spinning. This is often used for woolen yarn.

② Top dyeing : Top, an intermediate product from raw wool, undergoes dip (batch) dyeing before spinning. This is usually used in ordinary cases.

7.2.3 Weaving

The weaving process is roughly divided into the preparation process and the weaving process. Figure 7.5 shows a standard weaving process.

Figure 7.5 Weaving Process



a. 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.

b. Weaving Process

A fabric is made by crossing the weft and the warp at a right angle. The mechanism is based on the motion of passing the warp through two groups of the weft, 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.

7.2.4 Dyeing

a. 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.

(1) Basic Operation in Dyeing

The basic operations in dyeing are the following five as shown in Table 7.2: "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 7.2 Outline of Dyeing and Finishing

Item	Operation
Washing	A fabric is cleaned using cold water or hot water to remove impurities, unfavorable content, and extra additives and auxiliaries.
Adding	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.

b. Short Fiber Fabric

Figure 7.6 shows a standard dyeing process for short fiber fabrics using cotton and chemical and synthetic fibers.

(1) 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.

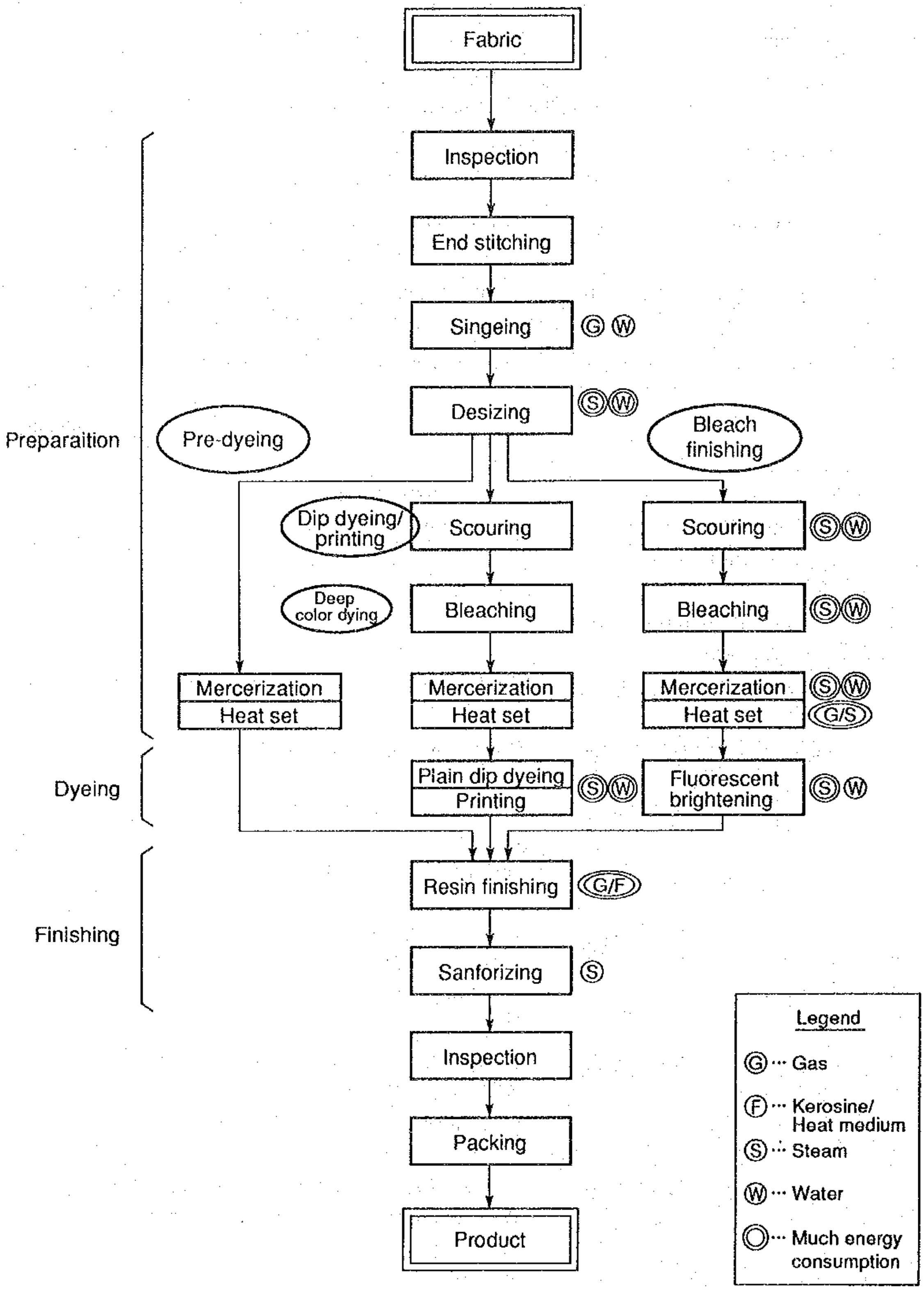
③ Scouring : Process to remove fat, pectin and coloring matter a large quantity of which is contained in natural fibers using alkali and surface-active agent.

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 taut cotton fabric in concentrated caustic soda solution to provide 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.

Figure 7.6 Dyeing and Finishing Process (Short-Fiber Textiles)



(2) 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 to 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 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 the sharp printing effect.

② Color development and setting: Process to heat printed ground fabric using steam. Steamers and agers are used for this purposes.

③ Posttreatment: To sufficiently clean color-developed and dye-set ground fabric and then dehydrate and dry it to provide more excellent texture.

(3) 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 calendering (glazing).

Figure 7.7 illustrates the outline of the structure of major continuous type equipment; Figure 7.8 shows the outline of the structure of major batch type equipment.

c. Synthetic Long Fiber Fabric

Figure 7.9 shows a standard process for polyester fiber finished yarn fabrics.

Operations specific to long fiber fabric manufacture are described below.

(1) 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 purposes is called relaxer.

② Scouring: Process to remove fat, size and any other impurities applied to ground fabric.

③ Drying

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.

(2) Dyeing Process

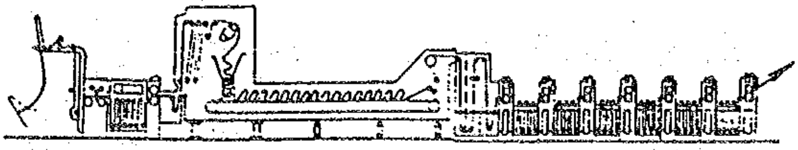
The dyeing process has two types: High pressure dyeing and normal pressure dyeing. The high pressure dyeing activates molecules of dye and fiber using high temperature high pressure thermal energy to make the dye penetrate into the fiber.

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

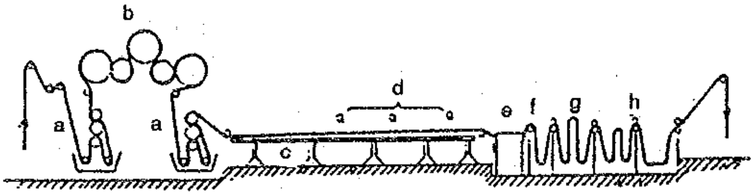
d. Wool Fabric Finishing

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 7.10 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 7.7 Continuous Dyeing Machine

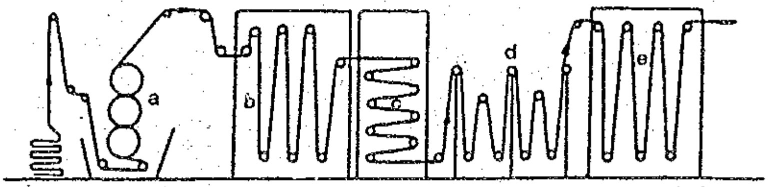


Conveyer Steamer Type Continuous Bleacher



a: Caustic soda dipping device b: Steel cylinder c: Tentering d: Shower washing
e: Hot water washing f: 1st washing tank g: Neutralizing tank h: 2nd washing tank

Mercerization Unit Process Chart

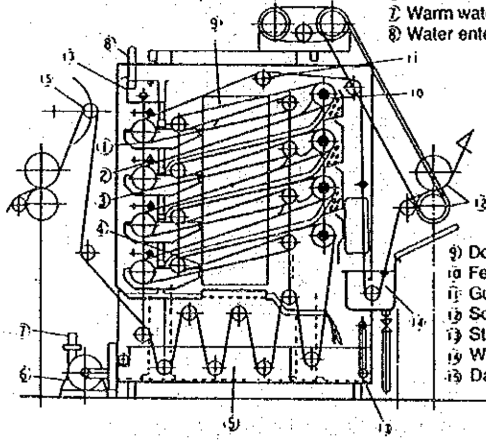


a: High pressure mangle b: Dryer c: High heat treatment device
d: Washer e: Dryer

Resin Treatment Equipment

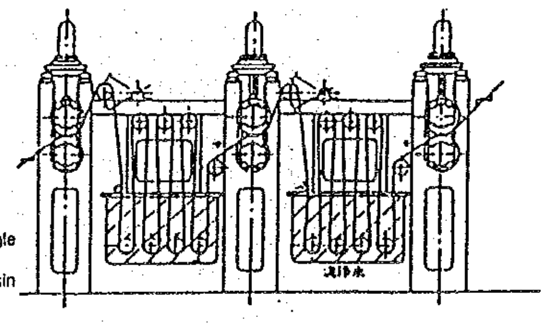
1 Water bag(small bag)
2 Pinch bar
3 Touch bar
4 Water drain bar (removable)

5 Small basin
6 Warm water counter flow pump
7 Warm water supply pipe
8 Water enters the front washer



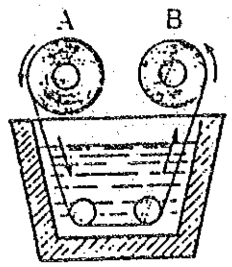
9 Door
10 Feed roll
11 Guide roll
12 Squeeze mangle
13 Steam heater
14 Water seal basin
15 Dancer roll

Counter Current Type Water Saving Washer

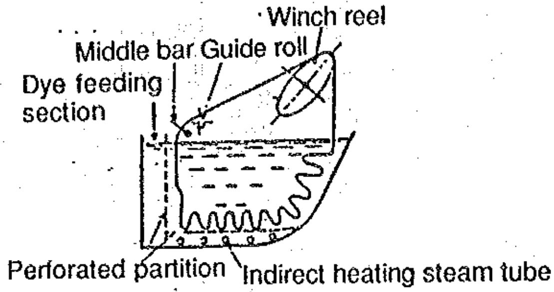


Conventional Washer

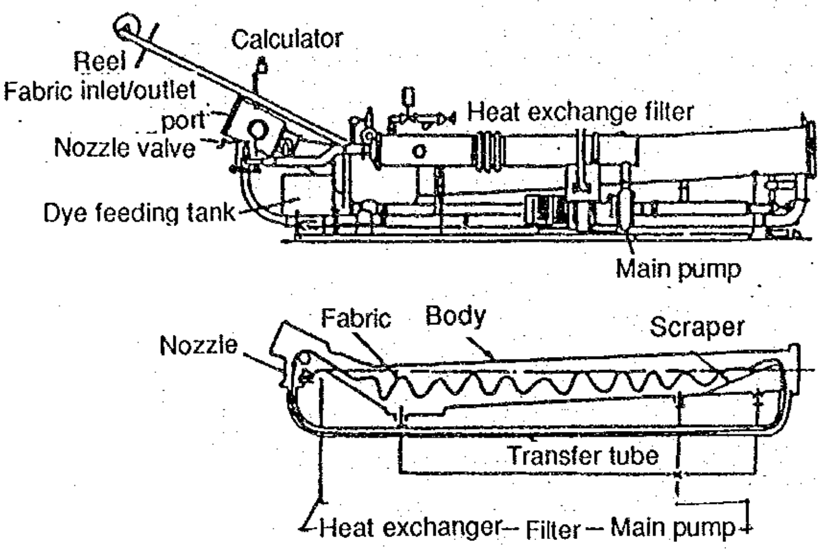
Figure 7.8 Batch Type Dyeing Machine



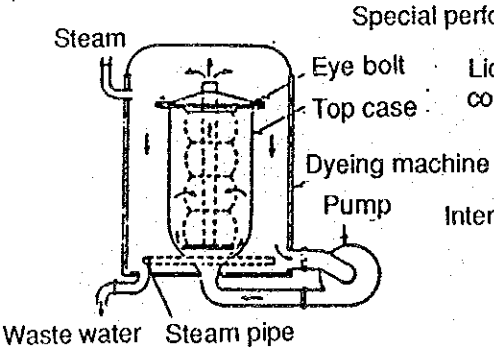
Jigger Dyeing Machine



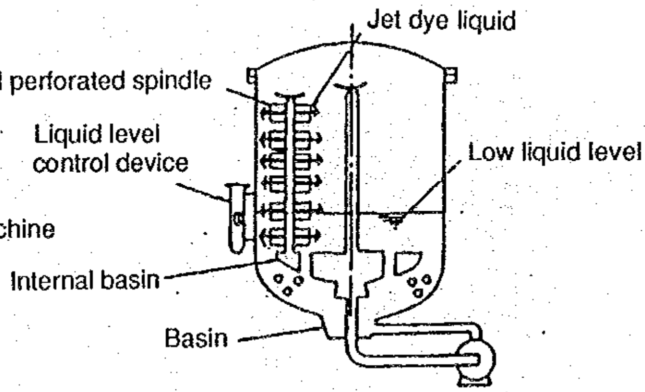
Wince Dyeing Machine



Liquid flow dyeing machine



Woolen Top Dyeing Machine



Jet Type Yarn Dyeing Machine

Figure 7.9 Dyeing Process for Long-fiber Fabric (Example of Polyester)

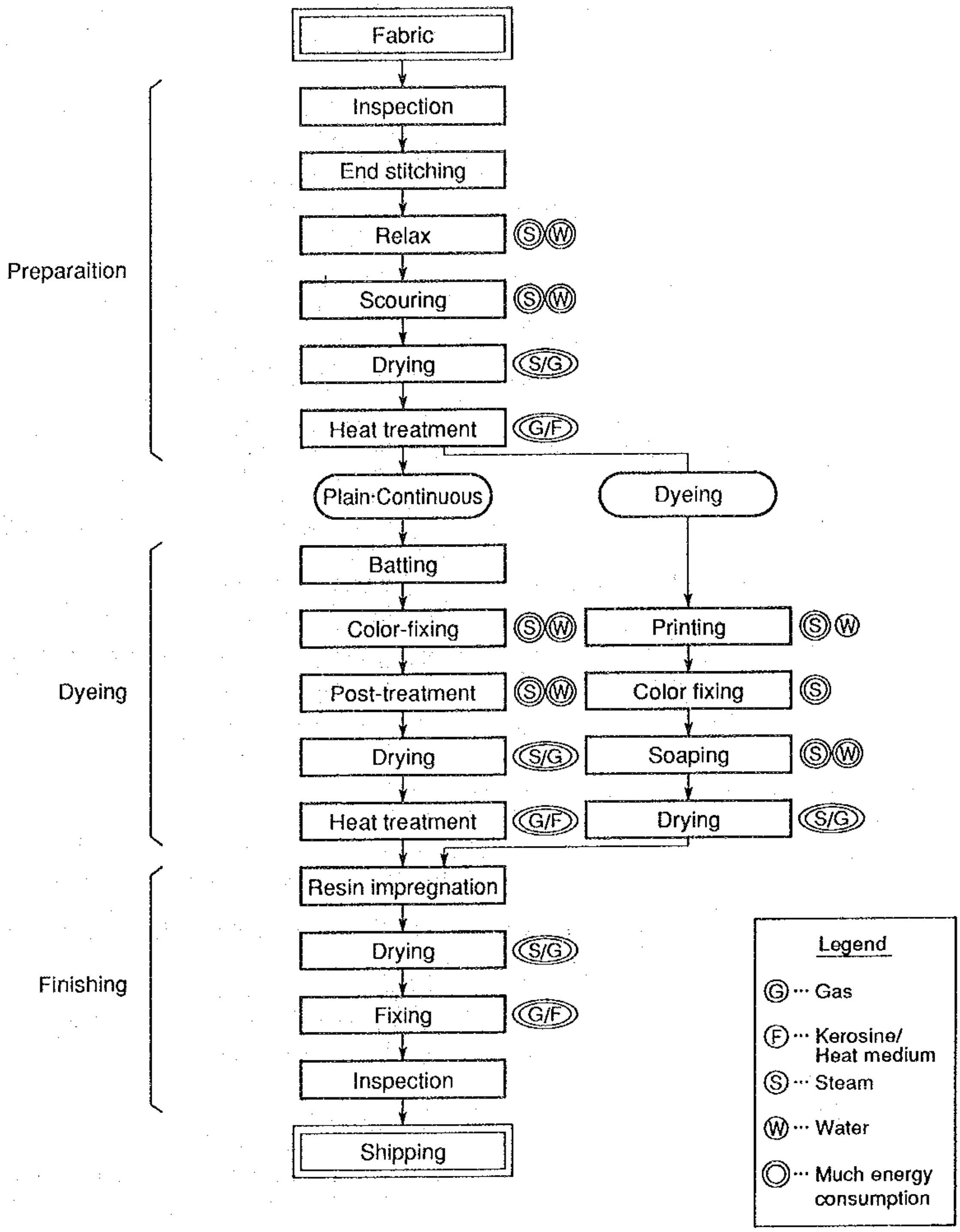
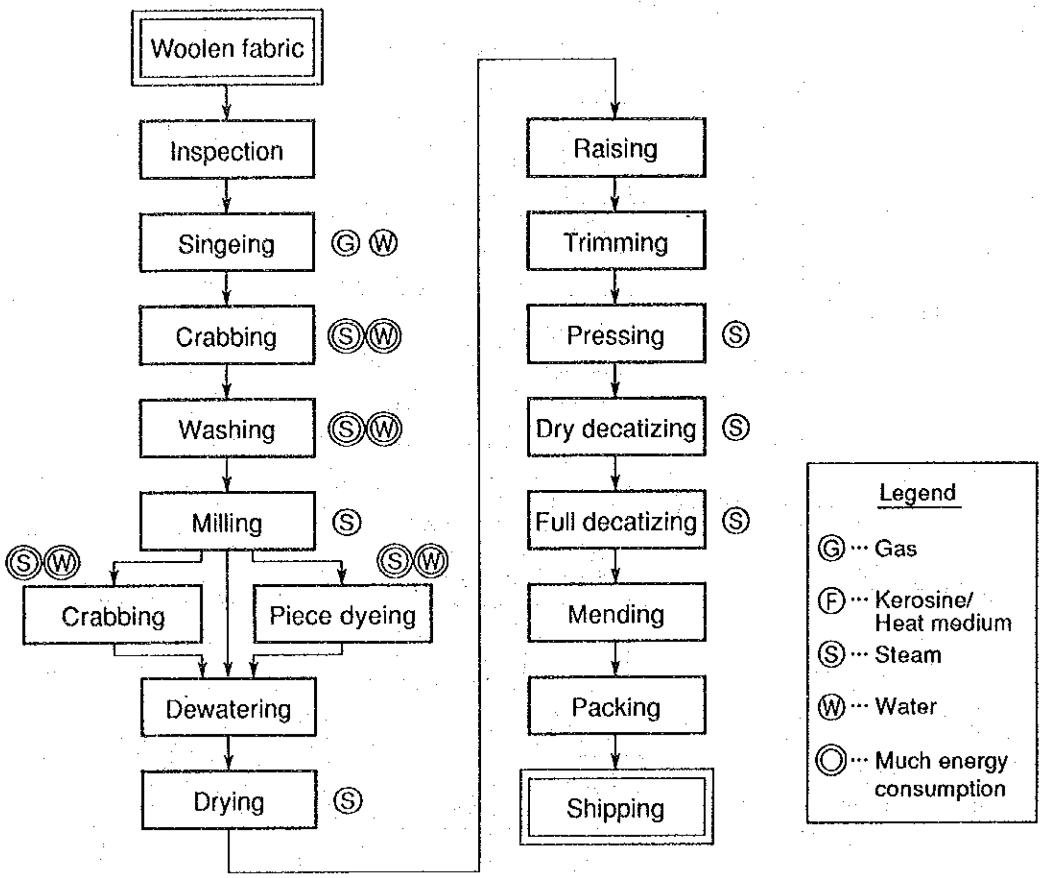


Figure 7.10 Worsted Finishing Process



(1) 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.

(2) Dyeing Process

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

(3) Finishing and Touching Processes

Excessive distortion in wool fabric is eliminated through dry decatizing 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.

7.3 Rationalization of Energy Utilization

7.3.1 Spinning (Including worsted spinning)

(1) Basic Measures

Before implementing quality control, labor saving measures or energy conservation measures in a factory, it should be reviewed whether the entire factory is well-controlled. If the factory is not controlled well, any new measures taken will not have sufficient effect. Moreover, it often makes the operation of the factory more complicated, resulting in half effect.

Figure 7.11 shows the points to be checked before taking various hinds of energy conservation measurer.

Figure 7.11 Check Points in First Step

- Motor performance check
  - Measure motor power, and adjust or replace defective motors.
  - Reduce the differences among the motors.
- Reducing the motor base load
  - Adjust belt and tape tensions.
  - Correct the engagement of gearwheels and center the motor bases.
  - Optimize cleaning, oiling, and maintenance intervals, and perform them thoroughly.
- Study of economical speed

① Motor performance check: The power of the motor of each machine should be measured, and troubles should be checked for. If any faulty machine is found, it should be re-adjusted or replaced depending on the fault. Thus consideration should be given to minimize the unevenness of the performance of each machine. In replacing a motor, the introduction of a high efficiency motor should be taken into account.

② Reducing the motor load: Each motor should be surely centered through proper maintenance. Further, the tension of belts and tapes, means for driving each part, should be correctly adjusted and the engagement of gearwheels should be corrected. Moreover, the intervals of periodical cleaning, lubricating and maintenance should be optimized and thoroughly performed. Try to keep the motor under control through the practices mentioned above. On the other hand, it is also important to introduce bearings into the driving parts and smooth their rotation.

③ Study of Economical Speed

The increase of the production machine speed will exponentially increase the energy consumption. It is advisable to find the number of units in operation and revolution most economical based on a production, and establish them as operation standards.

(2) Energy Conservation Measures for Individual Processes

① Blowing

The blowing process is composed of a linkage of many machines having different purposes. In many cases, individual machines are provided with a fan for collecting dust and use air to transport material fiber. The power consumption of the blower systems is measured, and, when air is throttled by dampers, the number of revolution of the blowers is decreased to control the discharge pressure and the air flow of each system.

For the prevention of troubles during operation, it is advisable to reduce the number of revolution of the blowers by approx. 10%, then observe the condition of operation, and further, reduce the number of revolution by stages with an increment of 5%.

② Carding

An energy conservation measure must cover carding machines because of their large number. The rotary body of a carding machine is heavier than that of other production machines.

Introducing bearings will reduce the power consumption of the old type carding machines. The new type machines are provided with a separate dust collector, and the automation of dust collection contributes to the saving of labor, and the improvement of quality and working environment.

However, the blowers for dust collection do not deliver their full power yet, and the efficiency of the blowers is low in general.

Grouping or centralizing the separate dust collectors will conserve energy.

(3) Drawing and Roving

The new type drawing machines and roving machines are provided with a large pneumatic dust collector. Reducing the outside diameter of the impellers of blower (impeller cut) is one of the common energy conservation measures.

The configuration of the roving machines is similar to that of the ring frames mentioned below. The energy conservation measures for the machines can be considered to be in accordance with that for the ring frames.

(4) Energy Conservation Measures for Ring Frame

① Introducing Bearings into Draft Part

With the shift from the conventional roller weight to the top arm, the power consumption is reduced by introducing bearings.

② Retrofitting Spindle Part

The width of the spindle tape is reduced and the material is replaced with elastic one. The friction loss with air is thereby reduced. Slipping is prevented by the employment of elastic material.

The routine control is tightened: For example, the amount of lubricant to the spindle supports is reduced.

The diameter of the spindle wheel has a tendency to be smaller; however, this increases the cost of retrofitting. Therefore, this should be considered together with increasing the number of revolution.

③ The pneumatic apparatus associated with the ring frame has been made larger in capacity with the improvement of productivity. However, there is a trend that the capacity of the pneumatic blower is reduced by reviewing the economical operation speed of ring frames and tightening the routine control against duct clogging.

For the existing blowers, cutting the outside diameter of the impellers aids the energy conservation. The centralized system, mentioned in the section of carding, is also introduced.

④ It may be another energy conservation measure to make intermittent the operation of the ring frame traveling cleaners for removing flies, or to increase the coverage of the traveling cleaners.

⑤ When an aged main motor is replaced, a high efficiency motor is introduced.

(5) Winder

Winders were modernized earlier than machines of any other processes, and many high performance winders have been introduced.

For these high performance winders, however, their blowers for yarn collectors consume a considerably large quantity of power.

For an energy conservation measure, a system is widely employed which groups five to ten units of yarn collectors and centralizes their suction lines.

In this case the specifications of a blower selected will determine the effect of energy conservation.

(6) Air Conditioning (Refer to the volume of electricity.)

A) Reviewing Air Conditioning Load

Approx. 30 % of power for direct production is consumed for air conditioning.

The air condition in a spinning process influences the quality of yarn and the productivity, and individual factories has established their own conditions. However, it is necessary to review these conditions as required with the advance in technology.

Table 7.3 shows an example of temperature and humidity standards.

Table 7.3 Standard Humidity by Fiber Materials and Processes

Process	Cotton	Worsted	Synthetic Fiber
Blending and scutching	40 ~ 60 %	— %	— %
Carding	45 ~ 55	65 ~ 70	
Combing and Gilling	55 ~ 65	60 ~ 70	55 ~ 65
Drawing	50 ~ 65	50 ~ 60	
Prespinning	50 ~ 60	50 ~ 60	
Spinning	50 ~ 65	50 ~ 55	60 ~ 65
Winding	60 ~ 70	50 ~ 60	60 ~ 70
Twisting	60 ~ 70		
Warping and Reaching	60 ~ 70		
Weaving	70 ~ 85	50 ~ 60	

Note 1: Temperature: 24 - 29°C
2: The conditions of the carding process is as per the Bradford system.
[Source: Text. World]

In a factory in Japan they varied the temperature and humidity by stages and checked the quality of yarn wisps and the working environment each time, and thereby found the limit within which no problem will be caused. They, who used to apply consistent conditions throughout all seasons, established new conditions for each season based on the findings, and achieved the reduction of 14% of refrigerating load and 16% of humidifying heating steam.

Enhancing the thermal insulation of the building and heating equipment leads to the reduction of load.

Moreover, it reduces the load of cooling and heating load by efficiently utilizing fresh air in mild seasons.

B) Changing Spray Nozzle

When directly cooling air using cold water sprays, enlarging the spray nozzles and reducing the number of them will reduce the original pressure. This reduces the power of pumps and may reduce the number of pumps as well in some cases.

In a factory in Japan, for example, they used to use 15,400 nozzles of 4 mm in diameter and replaced them with 212 nozzles of 44 mm in diameter. This reduced the spray pressure of 3 kg/cm^3 to 2 kg/cm^3, saving approx. 470,000 kWh of electric power per year.

The air conditioning systems called a carrier in spinning and weaving mills, directly sprays cold water (L) in air (G), and transports the resultant cooled air into the building as supply air. In many cases the operation is controlled, as the ratio of the weigh of L to that of G is 1:1. In this case, properly maintaining spray water nozzles may reduce the weight ratio of L/G down to 0.7 or so; in outdoor air using seasons, that is, mild seasons and winter, L/G may be further reduced to 0.3 or so.

C) Introducing High Efficiency Refrigerating Machine

An aged refrigerating machine does not deliver its full performance.

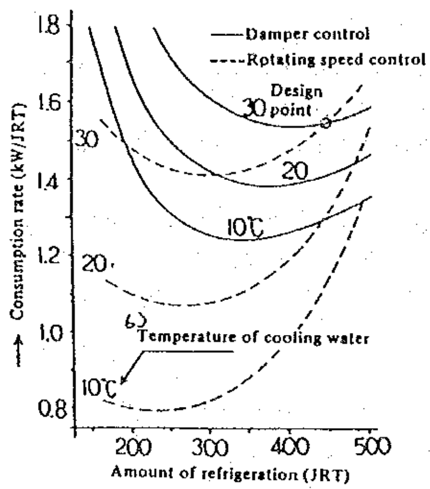
In a factory in Japan, refrigerating machines of a design unit consumption of 1.28 kW/JRT (Note: 1 JRT=79,690 Kcal/d) had been degraded and the unit consumption fell to 1.41 kW/JRT; so, they replaced them with high efficiency refrigerating machines of a unit consumption of 0.91 kW/JRT, saving 750 kW.

D) Controlling Number of Revolutions of Refrigerating Machine

In case the load is largely fluctuated in a factory using turbocompressors, the control of the number of units or revolution is effective. Figure 7.12 shows an example of the reduction of the power consumption.

Table 7.4 lists examples of energy conservation measures for individual processes. Incorporation of organizational energy conservation activities into the routine control will produce a remarkable result.

Figure 7.12 Characterstic Comparison of Capacity Adjustment



E) Saving the fluid conveyance power

Measures for saving the fluid conveyance power includes the control of the rotation number of fan · pump, change of pulley diameter, reduction in the impeller diameter, exchange to small-sized high-efficient fan · pump, etc.

Table 7.4 (1) Example of Energy Conservation Measures for Individual Processes

Process	Measure	Description (Example)	Remarks
Scutching	1. Optimizing condenser fan speed	• 1,200rpm → 1,000rpm	• Be careful of blow of fibers to cage surface and duct blocking.
	2. Reducing operating speed of dust collector fan.	• Down about 10%	• Abut 10% seems to be the limit, considering the effects on dust collection, etc.
	3. Stopping scutching fans	• Fans that can be substituted by duct collector fans are stopped.	• This means cannot be taken if indoor environment changes due to fan stoppage. • This measure may be taken if other fans have extra capacity to compensate for suction fan stoppage.
	4. Total stoppage of scutching machines	• Scutching machines are totally stopped only in emergencies. Instead of this conventional practice, stop all scutching machines in ordinary cases where their stoppage is necessary.	• Reduce the number of processes if possible.
Carding	5. Reducing operating speed of cylinder	• Use driving pulley of smaller diameter.	• Consider effects on quality.
	2. Use of ball bearing in place of doffer metal	• Use ball bearings in place of plain bearings	• Effective for not only power saving but also oil saving and labor saving
	3. Intermittent operation of cotton and dust collectors	• Change constant suction of flat strips to intermittent suction.	• Power can be saved by stopping constant suction equipment. • Power can be saved by reduced carrier air rate incidental to reduced volume of return.
	4. Intermittent operation of blow cleaners	• Operate suction blow cleaners intermittently.	
	5. Reducing operating speed of main blower for dust collector	• Stop dust suction at taker-in.	• Indoor cleanliness remains hardly changed.
Combing	1. Stopping creels of predrawing machine	• Stopping creel rollers	• Power saving effect is not so much, but creels no longer need maintenance.
	2. Reducing operating speed of pneumatic fan for lap former	• 2,240rpm → 1,640rpm	• Static pneumatic pressure above a certain level is unnecessary depending on the cleanliness of roller parts.
	3. Reducing pressure of compressor for auto lap changer	• Auto lap changer's pressure is 6.5 kg/cm^2. Compressor (primary) pressure is reduced from 9 kg/cm^2 to 7 kg/cm^2.	• Reduce required air volume by enforcing proper maintenance of auto lap changer (preventing air leaks; centering various parts).

Table 7.4 (2) Example of Energy Conservation Measures for Individual Processes

Process	Measure	Description (Example)	Remarks
	4. Reducing operating speed of comber cylinder brush	• 1,240rpm → 780rpm	• Cylinder needles are hardly blocked in uni-combing. Brush operating speed (rpm) should be about 5 times that of cylinder.
	5. Interlocking operation of comber fans	• Interlock machine motors and fan motors so that fans stop when machines are stopped.	• Interlocked operation will not cause sliver trouble at start/stop of machines.
	6. Reducing operating speed of comber suction fan	• 1,970rpm → 1,600rpm • 40mmAq → 32mmAq	• Because of sliver joining, static pressure of 25 to 30 mm. Aq. is sufficient for perforated roller. Determine operating speed of suction fan depending on cleanliness of draw part.
	7. Reducing operating speed of comber exhaust fan	• Down 20% to 40%	• Underground duct suction has excess capacity because of dust collection and recovery equipment. • Spinning is hardly affected even though individual machines air flow rate is reduced.
Roving	1. Driving upper and lower Ermen's clearers with back roller	• Upper and lower Ermen's clearers are driven with chain from back roller.	• No problem arises from driving clearers with back roller.
	2. Interlocking pneumatic motors with machine motors	• Interlock pneumatic motors with machine motors so that pneumatic motors stop when machine motors are stopped.	• It is not necessary to keep pneumatic motors operating at all times.
Spinning	1. Using bearings for draft rollers	• Use bearings for bottom and top rollers.	• Consider this measure for not only saving power but also quality and maintenance.
	2. Changing spindle tape	• Replace with elastic spindle tape.	• Tape slip will decrease by half, and variation rate will also sharply improve to make thread quality more constant. Power saving effect is great.
	3. Using narrowing spindle tape	• Elastic tape: 13mm → 11mm	• Take slip ratio into consideration.
	4. Reducing spindle tape tension	• 1.9 → 1.5lb/4sp	• Take slip ratio into consideration.
	5. Using spindle wrap of smaller diameter	• 23.8 → 20.2mm	• Take this measure when spindle insert is renewed.
	6. Using tin pulley of lighter weight	• Tin roller → Lightweight tin pulley or bakelite tin pulley	• Take this measure when old tin roller must be replaced.
	7. Pneumatic impeller cut	• Cut impeller for pneumatic fan.	• After cutting impeller to smaller diameter, adjust balance. Otherwise, vibration occurs.

Table 7.4 (3) Example of Energy Conservation Measures for Individual Processes

Process	Measure	Description (Example)	Remarks
	8. Interlocking pneumatic with main body		• Effective also for reducing thread breakage at start.
	9. Intermittent operation of overhead cleaner	• Operate at half-hour interval instead of continuous operation.	
	10. Changing drive belt	• V-belt → Cog belt	
	11. Removing Auto doffer clip		
	12. Changing Open End rotor drive belt		
	13. Improving power factor	• Use low-voltage condenser.	
	14. Using high-efficiency motors	• Replace existing motors with high-efficiency motor for energy conservation.	
Winding	1. Changing drive belt	• V-belt → Plain belt (elastic spindle tape)	
	2. Reducing area of blower opening	• Reduce blower suction port to lower static pressure.	• Pulley down not possible because motors and fans are directly connected.
	3. Integrating blowers	• Auto corner: Integrate 6 blowers. • Couple to Automatic Cop feeder blower motors. • Use centralized exhaust system, and newly employ motors specially designed for low-pressure fans. • Individual blowers → Large blower.	• If exhaust air from each blower flows into room, room temperature rises. This measure is taken to prevent it.
Air conditioning	1. Reducing operating speed of air conditioning fans		• Drill shaft hole in motor pulleys on hand.
	2. Reducing operating speed of prespinning carrier fan	• 2,590 → 1,735m²/min	
	3. Reducing operating speed of spinning carrier fan	• 360 → 325mmø	• Use pulleys on hand.
	4. Reducing size of finish spray blower		

(3) Case Study of Energy Conservation Measures for Spinning Process

Assumption:

Assuming that the process conditions are constant for all the individual processes, the energy conservation effect in each process was calculated.

Figure 7.13 shows an energy conservation measure taken for each process and the effects.

Figure 7.13 Example of Energy Conservation Measures under Constant Process Conditions (Power consumption for direct production: 520 kwh/400 lbs)

- Prespinning
  - Replacing bale opener and hopper bale breaker .... Δ 1.78 kWh/400 lbs
  - Reducing operating speed of dust collector fans .... Δ 0.86 kWh/400 lbs
  - Interlocking comber fans .... Δ 1.41 kWh/400 lbs
  - Subtotal: Δ 4.05 kwh/400 lbs (0.8%)
- Spinning
  - Using smaller-diameter spindle wharve .... Δ 13.28 kWh/400 lbs
  - Using elastic tape .... Δ 13.28 kWh/400 lbs
  - Tin pulley (bakelite) .... Δ 9.83 kWh/400 lbs
  - Cutting pneumafil impeller .... Δ 3.47 kWh/400 lbs
  - Intermittent operation of overhead cleaners or arranging them in series .... Δ 10.35 kWh/400 lbs
  - Using high-efficiency motors .... Δ 10.09 kWh/400 lbs
  - Subtotal: Δ 60.30 kWh/400 lbs (11.6%)
- Winding
  - Intergrating blowers .... Δ 18.25 kWh/400 lbs (3.5%)

Total: Δ 82.60 kWh/400 lbs (15.9%)

It turns out from this case study that the energy conservation measures had the greatest effect in the winding and spinning processes. Figure 7.14 shows the power consumption per bale (400 Lbs) for each process; Figure 7.15 is the Pareto's diagram of the required power for each process.

Figure 7.14 Required Power per Bale

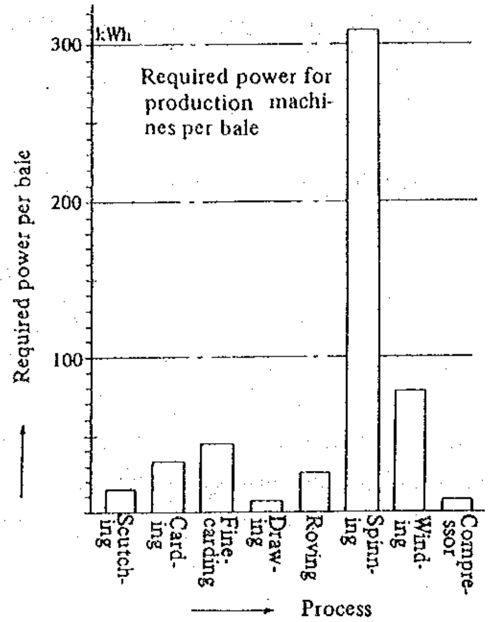
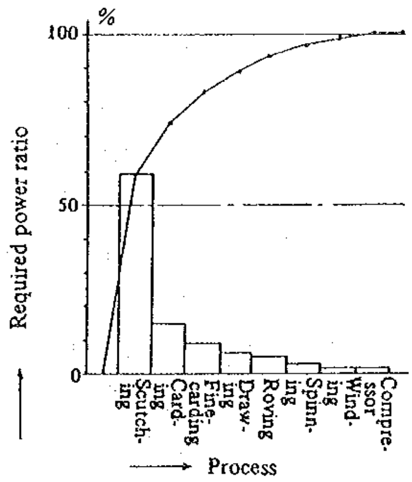


Figure 7.15 Pareto's Diagram of Required Power (%)



(4) Challenges in Energy Conservation

Listed below are considerations for future energy conservation in the spinning process:

① Review the process design conditions (e.g. number of revolutions).

② Review the size and unit quantity of individual packages.

③ Consider the flat belt material and replace the V-belts with cog belts.

④ Develop an energy conservation rubber roller.

⑤ Introduce ball bearings into the skewer metal.

⑥ Make the shafts lubrication-free.

⑦ Thoroughly control idle spindles (using computers).

⑧ Improve the operation efficiency to shorten the operation time.

⑨ Reduce the diameter of the pneumatic fan impellers.

⑩ Centralize the air compressors.

⑪ Centralize the machine fans.

⑫ Change the use of compressed air for cleaning.

⑬ Shorten the time of the dust and cotton collector intermittent operation.

⑭ Recover and reuse the waste heat from the spinning machines.

⑮ Introduce high efficiency spinning machines (winders and twisting machines).

7.3.2 Weaving (Including wool fabric)

(1) Works before Implementing Energy Conservation Measures

A larger number of production machines with a smaller motor capacity per unit are installed in the weaving process than in the spinning process. Accordingly, the weaving process is characterized by the difficulty of implementation of efficient energy conservation measures.

It is necessary to thoroughly implement basic measures as in the spinning process.

(2) Energy Conservation Measures for Individual Processes

A) Preparation Process

The preparation process consists of the rewinding, weft winding, warping, sizing, and reaching. The utilities supplied to the process include electric power, water, and compressed air.

(a) The electric energy is used as power for driving production machines. The energy is also consumed by the following:

I) Dust collector suction blowers for collecting dust and cotton

II) Compressed air for removing yarn waste and flies

- The power consumption of a blower for collecting dust is in proportion with the third power of the number of revolutions of the blower. If you can manage to reduce the required air quantity and the number of revolutions of a blower by 10% by reducing the area of its suction opening and reviewing the interval of cleaning its filter, it saves electric power by 23 %.

- Reducing Compressed Air Pressure for Cleaning

  Reducing the discharge pressure of the air compressors will save electric power.

If you reduce the air pressure of 7 kg/cm^2G to 5 kg/cm^2G, it saves electric power by approx. 14%.

If the existing nozzles for cleaning, many of which are self-made, are replaced with ones of gun type that can be opened/closed with a lever, it will have a great sufficiency of saving.

(b) Sizing Machine

A Enhancing thermal insulation

Provide the tanks, headers and piping with complete thermal insulation.

B Mounting Hood

A hood helps to maintain temperature around the cylinders and promptly remove vaporized moisture.

C Squeezing at High Pressure

There is a case where increasing the squeeze pressure after sizing from 350 kg to 1,500 kg reduced the amount of moisture to be vaporized by 33%.

D Changing Type of Size

Changing the type of size enables preparing the size and sizing at low temperature. There is a case where reducing the preparation temperature from 130 °C to 80 °C saved steam by 13%.

E Increasing Number of Yarn Sized at a Time

Increasing the number of yarn sized at a time reduces the speed but contributes to energy conservation after all.

F Improving Heat Transfer Property of Cylinder

Adjust the siphons and locate the traps so that condensate in the cylinders will be smoothly removed.

G Recovering Condensate

Refer to the volume of boiler steam.

H Controlling Exhaust from Hot Air Drier

The thermal efficiency of the hot air drier is lower than that of the cylinder drier. Therefore, the amount of exhaust air and the drying temperature are controlled to prevent overdrying.

B) Weaving

(a) Almost all of the weaving machines are shuttle driving type machines called loom, and a large number of them are installed.

Electric energy is consumed for the rotation and reciprocation of looms, and this is different from cases of the other production machines.

The basis of energy conservation measures for the weaving process is proper maintenance.

(b) Energy Conservation Measures for Weaving Process

① Reduce the suction area of the yarn waste suction blowers and prevent yarn waste clogging.

② Employ energy conservation drive belts for power transmission.

The shift to the cog belt will reduce the power consumption by 4%.

③ Correct the belt tension.

④ Control the lubrication to individual parts of the machines (proper amount of lubricant, early repair of leakage)

⑤ When renewing a drive motor, employ a high efficiency one (It is estimated that the difference in price between a standard type and a high efficiency type will be paid in one or two years).

⑥ Control the compressed air for cleaning in accordance with the description in the section of "Preparation Process".

⑦ Air Conditioning Equipment

Some types of weaving yarn require a high humidity of 70 - 80 %RH. The air washing system together with indoor direct humidifying system is in common use. Increasing the rate of indoor direct humidification enables the reduction of the air feed amount, and the reduction of the number of revolutions of blowers reduces the power consumption.

⑧ New Type Loom

Compared with the shuttle type loom, the air jet loom and the water jet loom are of energy conservation type. However, these new type looms require compressed air, pressure water, electric heating cutters and driers in addition to fundamental driving power. Accordingly, energy conservation measures for these peripheral devices are required. For the air jet loom, it is required to set a driving air pressure according to types of products; for the water jet loom, it is necessary to efficiently vaporize the moisture content in ground fabric.

⑨ Introducing Production Monitoring System

This is to reduce the machine interruption loss due to end breakage and thereby improve the working ratio. There is a case where the working ratio was improved by 10% or more.

⑩ Maintain Machinery

- Prevent the idle running of the motors.
- Correct the belt tension.
- Correct the amount of lubrication.

The implementation of these basic items is indispensable.

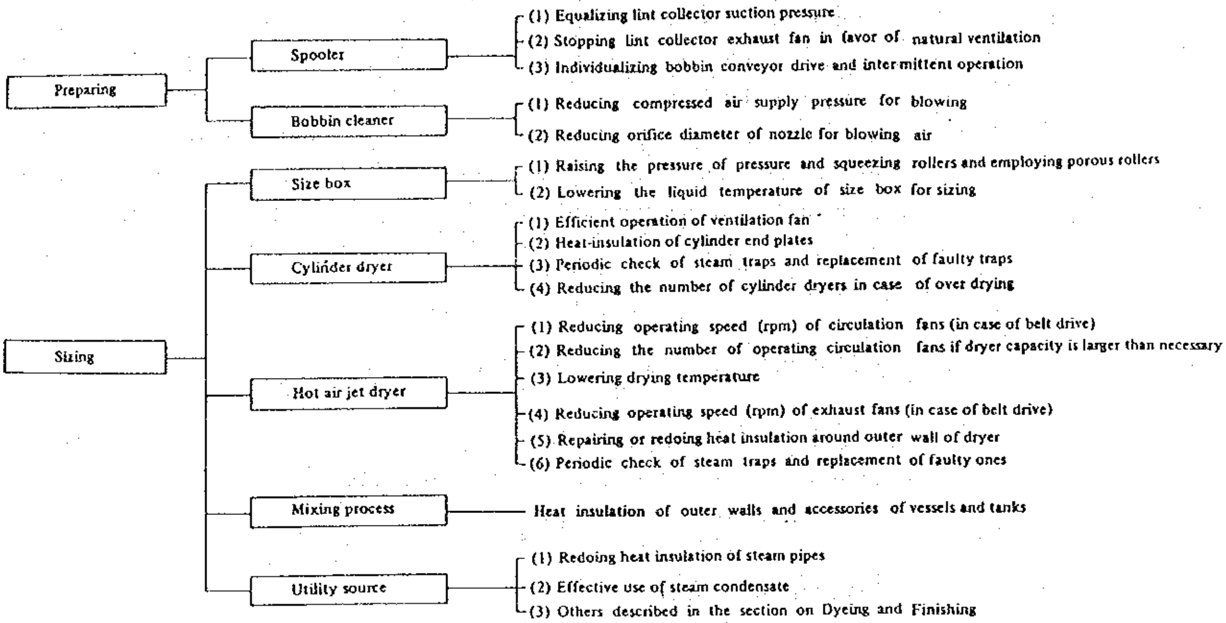
C) Finishing

Shearing is one of the finishing processes in which a large quantity of electric power is consumed. Especially, the dust collectors occupy a large portion of the power consumption.

This process is the final one in the manufacture, and care should be taken to prevent troubles from occurring in quality.

Figure 7.16 shows the energy conservation measures for individual processes.

Figure 7.16 Items of Study for Energy Conservation in Individual Processes



7.3.3 Dyeing and finishing

(1) Reducing Bath Ratio

The dyeing industry consumes a large quantity of water, and hot water is often used. Therefore, saving water leads to saving thermal energy.

The quantity (ℓ) of water used to dye 1 kg of fabric is called bath ratio, which largely varies depending on dyeing methods and types of dyeing machines.

The following measures are taken in the dyeing process:

A) The bath ratio is lower in hank dyeing than in cheese dyeing; that of the former is 25 - 35, and that of the latter is 8 - 15.

B) Even in cheese dyeing, changing the winding density and the spindle arrangement reduces the bath ratio.

C) If dye is distributed in the form of foam or mist, the bath ratio is reduced to 3 or below. The foam dyeing applies to plain dyeing: Dye is bubbled using air into fine uniform foam, and applied to fabrics.

D) For blended yarn fabric, changing the two bath dyeing to the one bath dyeing is effective in the reduction of the bath ratio and the shortening of the dyeing time. A variety of low bath ratio dyeing machines has been developed.

The low bath ratio type dyeing machine rotates a fabric at a high speed of 200 m/min or above or vibrates it, and thus ensures the sufficient contact between them. This method achieves a bath ratio of 1:11, whereas the bath ratio of ordinary type dyeing machines is 1:20 - 30. Table 7.5 and 7.6 show the performance of the low bath ratio type dyeing machine and that of conventional ones.

Table 7.5 Example of Performance Comparison

	Length of work	Amount of liquid	Weight of fabric	Amount of steam	Amount of steam per m	Amount of steam per kg of fabric
Conventional	300 m	4,000 ℓ	514 g/m²	1,473 kg	4.91 kg/m	9.54 (100)
Low bath ratio type	500 m	2,000 ℓ	409 g/m²	440 kg	0.88 kg/m	2.15 (23)

Figure 7.6 Example of Power Consumption Comparison

	Electric power		Load factor		Dyeing time each time		Electric energy each time		Length of work	Electric energy per m
Conventional	24 kw	×	0.8	×	2.5	=	48	÷	300 m	= 0.16 kwh/m (100)
Low bath ratio type	16.5 kw	×	0.8	×	2.5	=	33	÷	500 m	= 0.066kwh/m (41)

Moreover, a system has been developed which reduces the required energy to 1/10 using rapid heating by microwaves.

(2) Reducing Amount of Cleaning Water

Various efficient cleaning machines have been developed. The principles of these machines are as follows:

① Increase the number of times of contact between fabrics and water.

② Feed water in a flow counter to that of fabrics.

③ Provide fabrics and water with vibration.

The efficient cleaning machine uses these principles to enhance the cleaning effect. There is a case where the amount of water and steam was reduced to 1/10 and the power consumption was reduced to 1/4 compared with those of conventional machines.

(3) Shortening Dyeing Time

For polyester dyeing, a technique has been developed which maximizes the temperature rise to the extent that dyeing is not influenced and makes level dyeing unnecessary.

(4) Reducing Processing Temperature

Try to reduce the bleaching and dyeing temperature by changing liquor. For water washing, it should be considered whether the temperature can be further reduced.

(5) Saving Drying Energy

A) Dyeing is a process which repeats dipping into liquor and drying many times. For some types of fabric, the drying process is omitted; fabrics are only squeezed and forwarded to the next process (Wet on Wet method). In some cases, for example, a technique to uniformly apply finishing agent to a wet cloth was developed, and the drying process after the dyeing process was omitted. It has been reported that this achieved the energy conservation of 8% or more. Refer to <Case 1>.

B) Before drying, sufficient dehydration is performed using a mangle to save thermal energy. Rubber coated rolls of an appropriate hardness are used; the rolls are so adjusted that the linear pressure will be even in the direction of width. More efficient equipment include ones using a non woven fabric roll and vacuum type which sucks through slits. The hydration by blowing air at a high speed is also effective.

25 - 50 % of moisture content is removed. Therefore, there is a case where the drying speed was doubled and the drying cost was reduced by 17 %.

C) When dried too much, fibers, when left in air, absorb moisture to the equilibrium moisture content. Therefore, overdrying, specified in Table 7.6, will result in the loss of energy.

Table 7.6 Norms for Exit Moisture Percentage (20 °C/65 % RH)

Material	Exit moisture percentage (%)
Cotton	7.0
Polyester	0.4
Nylon	4.5
Viscose	12.5
Wool	16.0
Polyester-cotton blend (2:1)	2.5
Polyester-wool blend (2:1)	5.5

D) The hot air drier circulates hot air, and accordingly, rises the drying temperature, conserving energy. Periodically measure the moisture content in exhaust air, and adjust the relieving amount based on the measurement result. In case flammable solvent is contained, care should be taken for the prevention of explosion.

For the drying of wool fabrics, consideration should be given to the introduction of automatic control of the drying temperature and the exhaust air humidity for the prevention of overdrying as well as for the purpose of quality control.

E) With respect to thermal efficiency, the cylinder (slasher type) drier is more advantageous than the hot air drier. For efficiently utilizing cylinder driers, it is important to inspect and maintain the internal siphon pipe and the steam trap for extracting condensate from inside cylinders.

F) In applying liquor, such as waterproofing agent, to a fabric, minimizing the amount of application using a mesh roll will save drying energy.

(6) Preventing Loss of Heat

A) Many dyeing machines and washing machines are provided with no thermal insulation. This is because the conventional fiber or porous thermal insulation materials absorb moisture easily and to use them in a high humidity atmosphere, such as a dyeing factory, a larger cost is required. However, a closed cell type water repellent plastic foam was recently developed, and it has been used together with chloroprene adhesive. Polypropylene and hard urethane can be used at a temperature of up to 120 °C; intermediate pressure polyethylene foam is applicable at 100 °C or below.

Simpler methods have been implemented. For example, there is a case where thermal insulation material was just wrapped with vinyl sheets attached like skirts for preventing water and steam was thereby saved by 20% or so.

B) Hot Water Storage Tank

Provide the hot water storage tanks with thermal insulation as well, and place a cover or a floating cover to prevent the loss of heat from the surface.

C) Provide the outer wall of the driers with thermal insulation, and lessen the openings as much as possible.

(7) Recovering Waste Heat

Table 7.7 shows an example of analyses of the thermal energy consumption in dyeing factories. It turns out from the table that large part of heat is lost through waste liquor. For this reason there are a lot of cases where heat of dyeing waste liquor is transferred to supply water or cooling water used is used for the next water supply.

Table 7.7 Thermal Energy Consumption State (Intermediate Scale Dyeing Factory)

Item	Percentage (%)
Product heating	16.6
Product drying	17.2
Waste liquor loss	24.9
Heat release from equipment	12.3
Exhaus loss	9.3
Idling	3.7
Evaporation from liquid surface	4.7
Unrecovered condensate	4.1
Loss during condensate recovery	0.6
Others	6.6
Total	100.0

<Case 1>

Employment of Wet on Wet Finishing for Knitted Fabric Dyeing

(1) General Description of Factory

- Products: Dyeing of circular knitted fabric of polyester/cotton (blended yarn fabric, union cloth), cotton and so on.

- Number of employees: 205

- Energy consumption: 11,025 kℓ calculated in terms of crude petroleum

(2) Selection of Energy Conservation Measure

Among the dyeing processes (refer to Figure 7.17) for knitted fabric, the drying process, which used the largest quantity(13.7 %) of energy among all the processes, was omitted to reduce the energy consumption and the time when work is in process for the improvement of the productivity. Since wet fabrics soaked with dye are processed in the finishing process, the technique is called wet on wet.

Figure 7.17 Finishing of Knit

Process / Feeder	⇨ Mercerizing • Scouring	⇨ Coloring	⇨ Drying	⇨ Finishing	⇨ Inspection • Shipping
Processing capacity (m/min)	30~60	(100,000m/day)	50	40	
Energy consumption rate	12.0	59.7	13.7	14.0	100%

(3) Problems and Energy Conservation Measures Taken

(3.1) Problems in Directly Feeding Wet Fabric to Finishing Process

① For fabrics soaked with dye, difference is produced in moisture content between upper and lower fabrics with the passage of time, and this results in the uneven fixation of finishing agent in the finishing process.

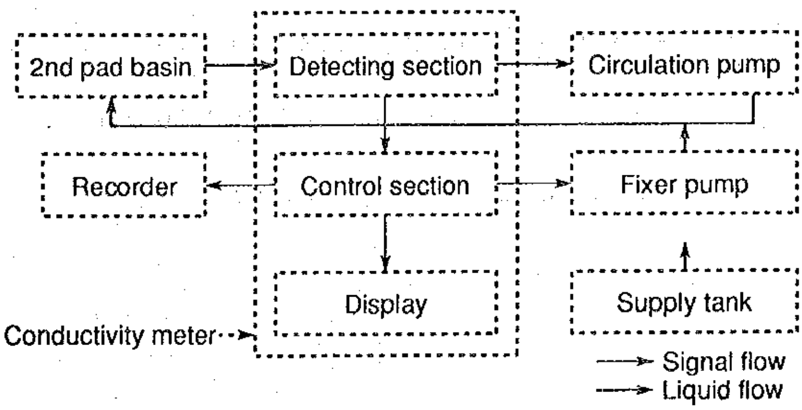
② Finishing agent in the liquor baths is diluted with the passage of time by moisture carried by fabrics.

(3.2) Countermeasures

① Uneven fixation of finishing agent: Two stage padding system

② Variation in concentration of solution in liquor baths: Automatic control of concentration of solution in liquor baths (Refer to Figure 7.18.)

Figure 7.18 Agent Concentration Control



③ Measurement of finishing agent concentration ⇨ The alternative characteristic of inorganic electrolyte solution concentration is used.

It was verified through measurement that the following relations are both proportional:

i) Relation between the concentration of inorganic electrolyte solution (Na_2SO_4, NaCℓ) and the conductivity

ii) Relation between the concentration of finishing agent added to 10 % inorganic electrolyte and the conductivity

(4) Effects of Measures (Assuming that the wet on wet method is applied to 1/2 of the whole facility)

① Saved energy (Comparison of the energy consumption before and after the implementation of the wet on wet method)

Fuel: 28560 ℓ /month (3.8 % reduced), Electric power: 30167 kWh/month (3.6 % reduced)

② Improvement of overall process capability by the reduction of time when work is in process

357 hrs per month was saved and the productivity was improved.

③ Drier operation

Before implementation: 24 hrs × 2 units

After implementation : 18 hrs × 1 unit

④ Effect of investment (investment pay back year)

Cost of improvement : U.S.$200,000

Energy conservation effect: U.S.$250,000/year

Investment pay back : 0.8 year

<Case 2>

In a knit dyeing factory, waste water from the dyeing machines at 60 °C or above is passed through two spiral heat exchangers to obtain hot water at 50 - 60 °C, which is used for the next dyeing cycle.

Heat was recovered from waste water of 100 m^3/d out of 200 m^3/d, and the quantity of hot water obtained was also 100 m^3/d.

Cost of installation : U.S.$100,000

Ratio of fuel oil saved: 25 %

Investment pay back : 2.2 years

<Case 3>

The following measures were implemented in a polyester and rayon yarn dyeing factory with 40 employees.

a. Condensate in the dyeing machines and the driers was recovered for boiler water supply, and the supply water temperature was raised to 80 °C.

b. Cooling water for the high pressure dyeing machines was recovered into the hot water baths.

c. Dyeing waste water at 57 °C or above was detected with temperature sensors, separated, and passed through heat exchangers; hot water of 170 m^3/d at 60 °C on average was recovered.

   In addition, dyes, auxiliaries and dyeing methods were improved so that dyeing could be performed at least 60 °C.

   Cost of installation: U.S.$210,000 in total

   (Breakdown: U.S.$180,000 for the relocation, piping, and thermal insulation of dyeing machines, condensate recovery pumps, hot water tanks, U.S.$30,000 for heat exchangers and pumps)

   Improvement of fuel oil unit consumption: 45 % (from 0.85 ℓ/kg to 0.47 ℓ/kg)

   Reduction of fuel cost : U.S.$270,000/year

   Investment pay back : 1 year or less

<Case 4>

A factory dedicated to yarn dyeing with 12 employees. For energy conservation, condensate was recovered, and heat was recovered from dyeing waste liquor. Condensate is produced from dyeing machines and driers, but there is a fear that dye solution may be contained therein. So condensate is not mixed directly into boiler supply water, but heat is transferred to boiler supply water through heat exchangers. For heat exchangers, the plate type which is easy to clean was employed, and stainless steel (304) material was used in case of acid liquor mixing in (Refer to Figure 7.19).

Dyeing waste liquor of 10 - 15 t/h is produced at 50 - 100 °C. The waster liquor is passed through vortex type filters to remove cellulose sludge, and subsequently, used in the plate type heat exchangers (stainless steel) for preheating water from 30 °C to 48 °C. The heat exchangers are provided with piping capable of back wash, and automatic operation is possible by setting the temperature and flow rate.

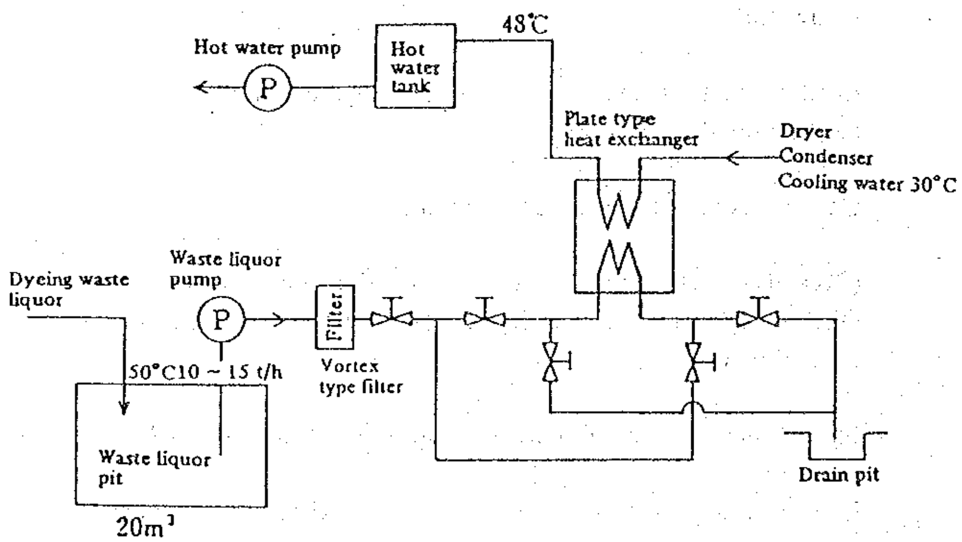
Cost of installation: Approx. U.S.$120,000 for two heat exchangers, pumps, tanks and piping.

Reduction of fuel consumption: 22 %

Saved cost : U.S.$38,000/year

Investment pay back : Approx. 3 years.

Figure 7.19 Dyeing Waste Liquor Recovery Equipment



<Case 5>

Heat recovery from hot waste water discharged from the dyeing and the bleaching processes to service water by heat exchangers had been executed. It was found that the introduction of the absorption type heat pump would enable heat recovery from lower temperature waste water. In addition, waste heat from coolers, which used to be emitted outdoor through refrigerating machines and cooling towers, was recovered and utilized as hot water.

Figure 7.20 is the flow sheet.

Cost of installation : Approx. U.S.$250,000

Energy conservation effect: As per Table 7.9

Figure 7.20 Flow Sheet of Heat Pump System

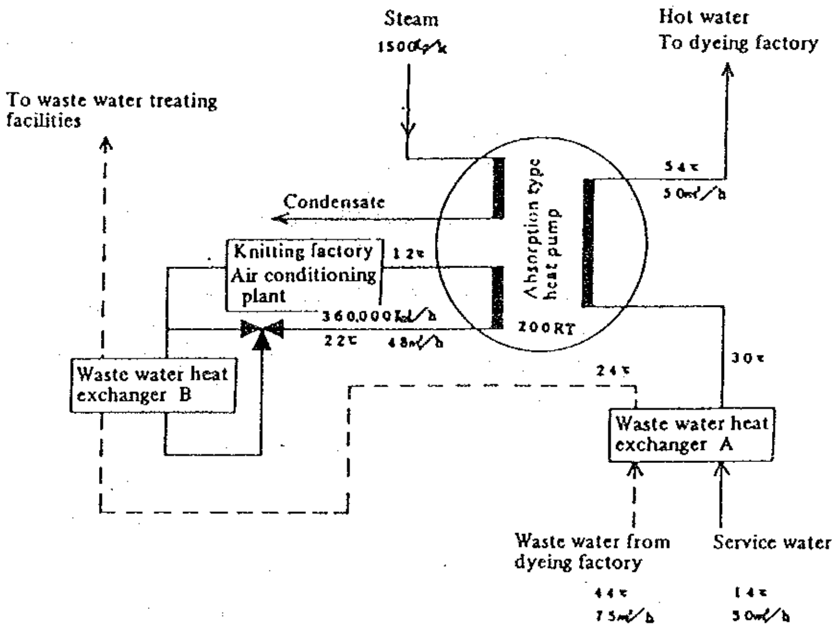


Table 7.9 Energy Conservation Effect

Fuel oil saving	170 kℓ/Year	About 70,000 U$S/Year
Reduction in contract demand by stop of refrigerator	170 kW	About 30,000 U$S/Year
Reduction in refrigeration electric energy	200 thousand kWh	About 20,000 U$S/Year
Total		12,000 U$S/Year

There is a case where heat of exhausted air from hot air driers is recovered and used for air supply using rotary heat exchangers.