4. ENERGY CONSERVATION IN PAPER AND PULP INDUSTRY

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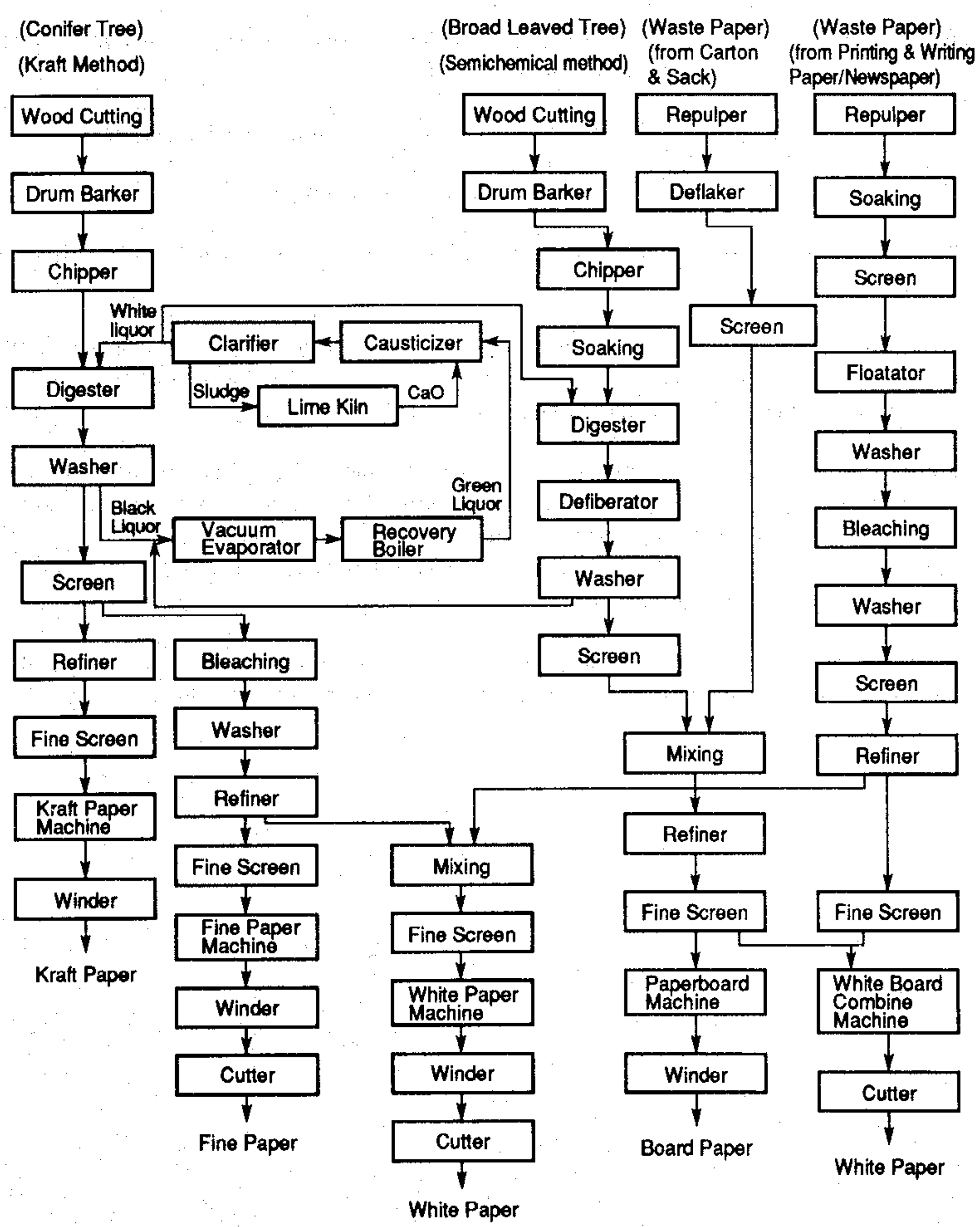
4.1 Paper Production Process

Figure 4.1 shows the flow of a paper production process in an integrated paper and pulp mill.

Figure 4.1 Production Process



The paper and pulp 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 and pulp production industry is referred to as an energy-intensive industry.

4.2 Stages of Actions for Energy Conservation

It is recommended that actions for energy conservation in a paper and pulp production factory be taken by following such stages as shown in Table 4.1.

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.

For the process industry, reducing energy consumption maximally to increase profits calls for continuously running the equipment without any stop at a load factor of nearly 100 %. This also applies to the paper and pulp production industry. The operation of facilities at the full production capacity without production being interrupted by faults such as paper breaking, etc. 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 4.1 Example of Stepwise Promotion Plans

Stage	Equipment	Others
First stage Effective utilization of and sufficient management of existing equipment Ensuring of continuous operation	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.	

4.3 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-leaved 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 4.2 shows an example of the batch type cooking digester and Figure 4.3 an example of the continuous type cooking digester

Figure 4.2 Batch Type Cooking Instruments

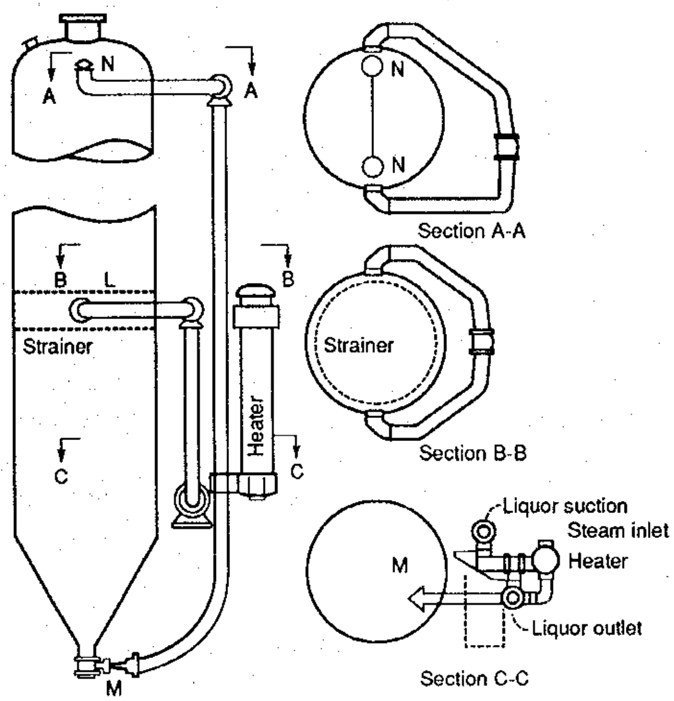
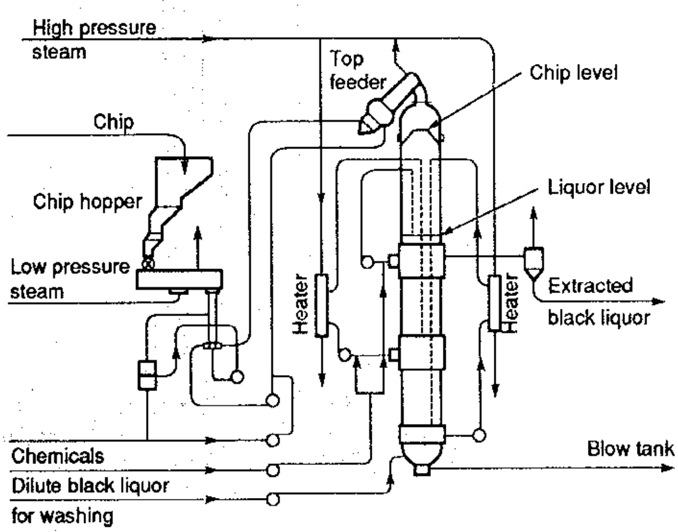


Figure 4.3 Continuous Type Cooking Instruments



(2) Heater

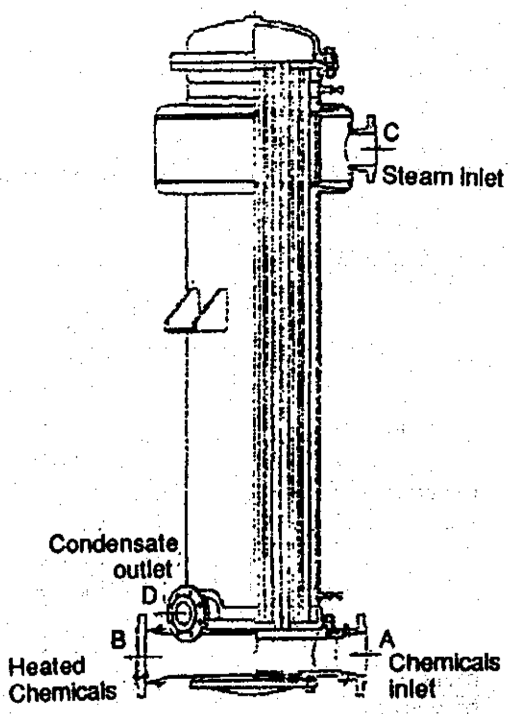
Indirect heating is accomplished by forcibly circulating chemicals and, thus, consumes much electric power energy. A tubular heater is used typically as the heater. Figure 4.4 shows its structure.

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 4.4 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, namely NaOH, Na_2S, Na_2CO_3 and Na_2SO_4. Figure 4.2 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 $(NaOH + \frac{1}{2} Na_2S) g/\ell$ as Na_2O, being 102 g/ℓ in the example of Table 4.2. 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.

The sulfidity is represented as $\frac{\text{sodium sulfide}}{\text{active alkali}} \times 100\ \%$. The approximate appropriate value of Na_2O is considered to be $\frac{Na_2S}{NaOH + Na_2S} \times 100\ \% = \frac{36}{84+36} \times 100\ \% = 30\ \%$.

The rate of added effective alkali is different depending on the conifer tree or the broad leaved 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 4.2 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
$Na_2S_2O_3$	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 4.3 shows data on H factor based relative speed at temperatures of 100 to 179 °C.

Figure 4.5 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 4.5 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 4.6 covers such cooking and plots the relation between the pulp yield and lignin contents with respect to the "H factor".

Table 4.3 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 4.5 Relative Reaction Velocity, Cooking Time or Temperature

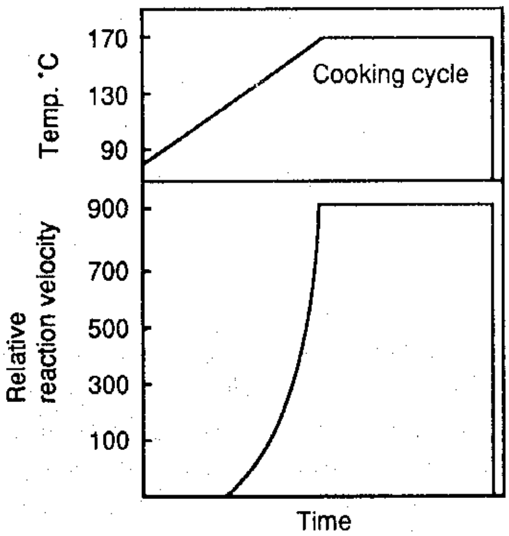
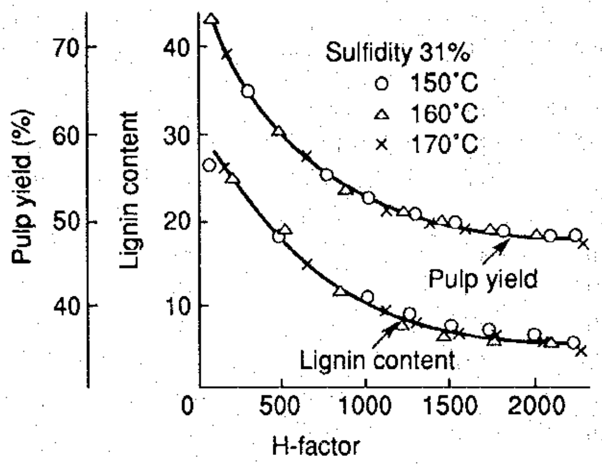


Figure 4.6 Relation of H-Factor, Pulp Yield and Lignin Content



(5) Cooking process and energy conservation

The cooking process consumes much steam and electric power for chemicals circulation. Table 4.4 shows the Japanese actual development of energy conservation for cooking based on the conifer tree and the broad leaved tree, and on the batch type digester and the continuous type digester.

Table 4.4 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 4.5.

Table 4.5 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.

4.4 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 washing water.

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

a. Counterflow type multi-stage washer (See Figure 4.7.)

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

1) The pulp consistency 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:

$$\frac{\text{warm water volume (t/h)} - \text{pulp washing water volume (t/h)}}{\text{air dry unbleached pulp (t/h)}} \text{ or}$$

$$\frac{\text{warm water volume (t/h)}}{\text{air dry unbleached pulp (t/h)}} - \frac{\text{moisture in washed pulp (\%)}}{\text{consistency of washed pulp (\%)}}$$

The dilution factor is fixed by the evaporator capacity, steam costs, the solid concentration in black liquor, the degree of pulp washing 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 permanganate number (PN)30 provides a dilution factor of 2.2 and a solid recovery rate of 96 to 97 %.

b. Diffusion washer (See Figure 4.8.)

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

It takes about 40 minutes for such brown stock to reach the outlet after its entry to the inlet. The brown stock 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 washing.

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

It is the object of washing to recover soluble material from brown stock completely as highly concentrated black liquor. By washing, the volume of steam used when black liquor is concentrated by the evaporator can be reduced and, thus, the volume of salt cake 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 4.7 Continuous Washer

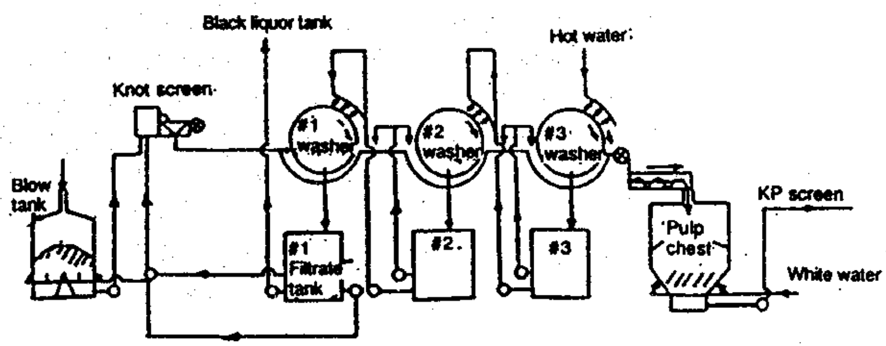
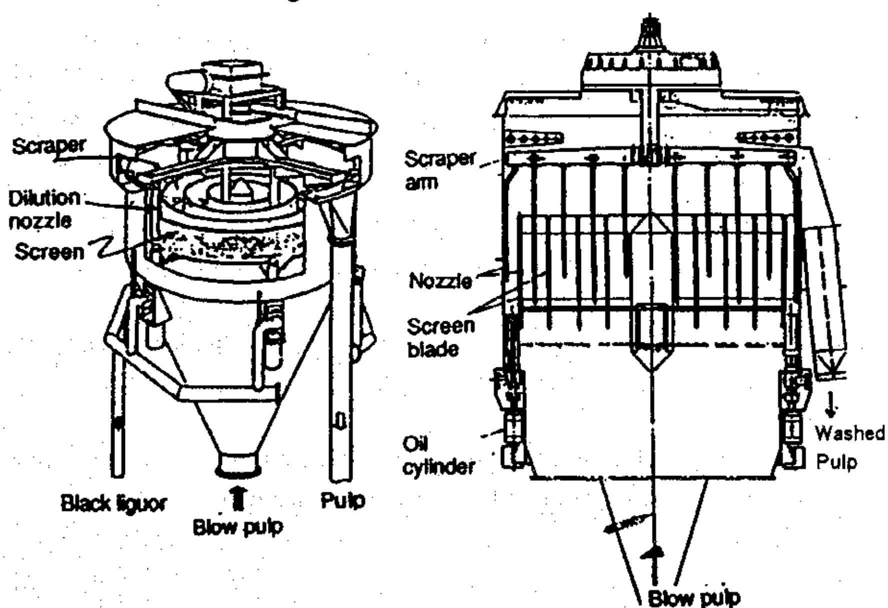


Figure 4.8 Diffusion Washer



4.5 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 rising of 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 heat conduction. What hinders heat conduction most considerably is inorganic scale and organic sludge adhering to the liquid side 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 the 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 washing process. An increase in the number of washing 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 4.6.

Table 4.6 Evaporation Ratio

Number of effect evaporators	4	5	6
Evaporation ratio $\left(\frac{\text{evaporated water (ton)}}{\text{steam (ton)}}\right)$	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 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 4.9 shows its structure, while Figure 4.10 compares the tube and the plate type evaporators with regard to structure. 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 4.7 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 leaved tree)	1.6	1.2	95	80

To prevent the heat 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 4.9 Falling Film Type Evaporator

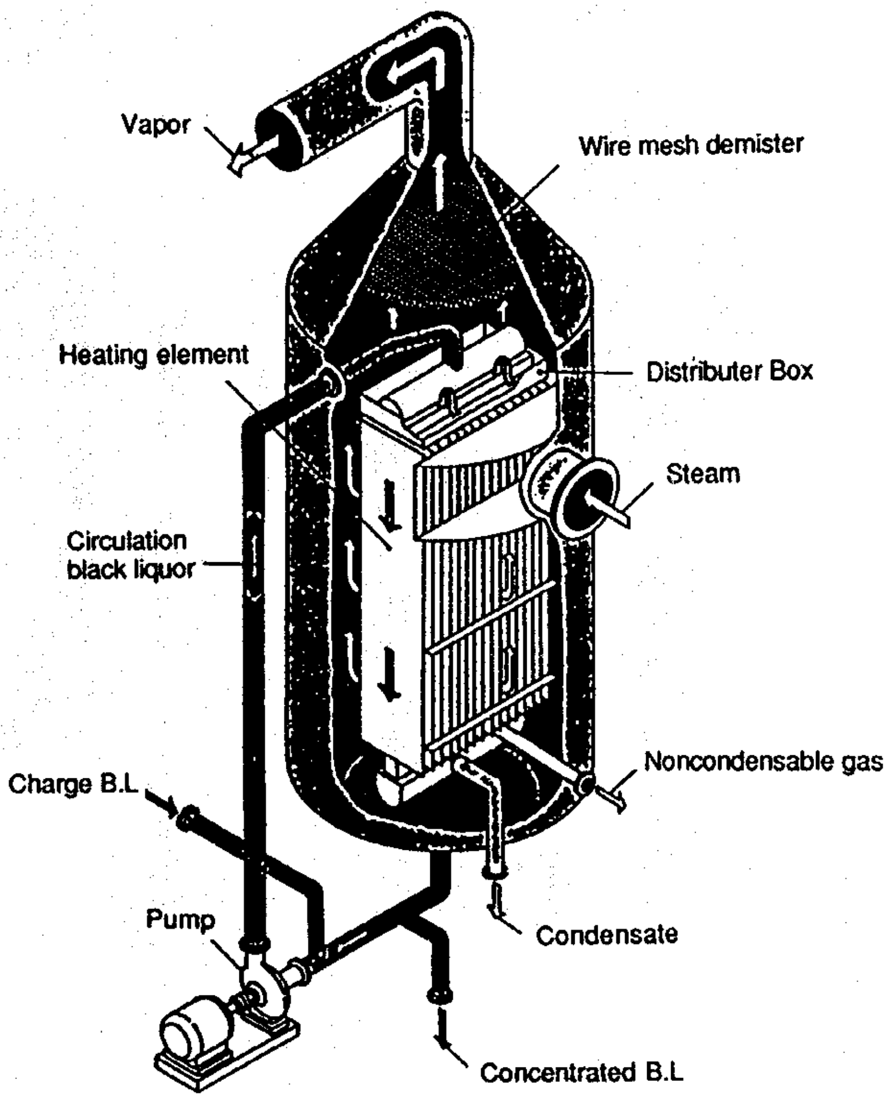
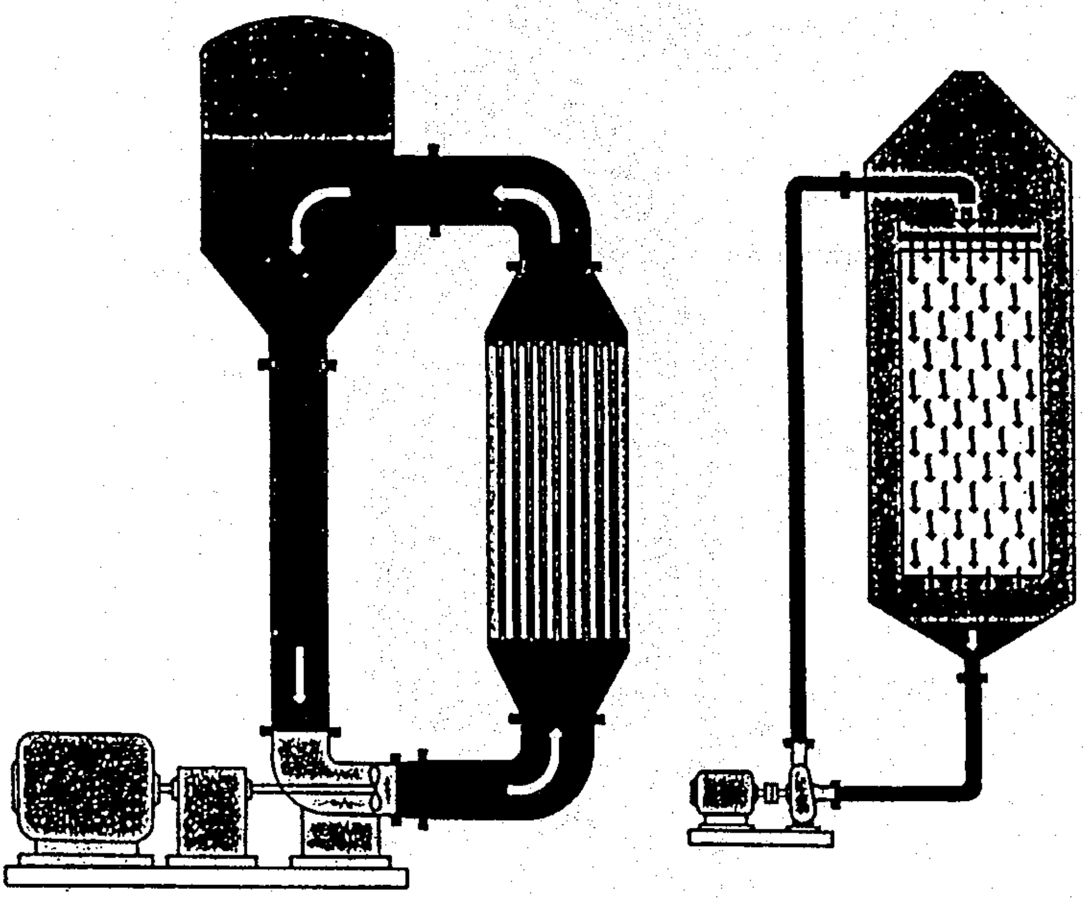


Figure 4.10 Comparison of Forced Circulation Evaporator and Falling Film Evaporator

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



(5) Oxidation of black liquor

Dilute black liquor, after having been oxidated in an 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.

4.6 Recovery Boiler

The recovery boiler is installed to:

① burn organic compounds to separate and recover soda elements;

② reduce soda cake (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 production plant. 80 to 90 % of power or steam is supplied by this burning in an integrated kraft pulp and paper mill.

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.

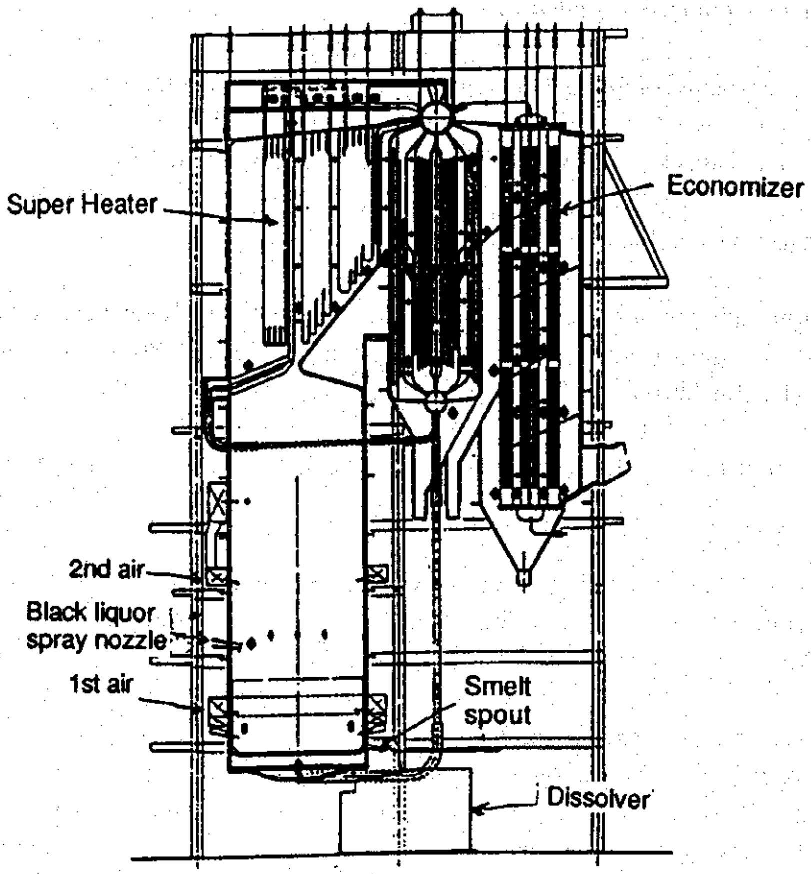
The present plate type evaporator allows concentration up to 70 %, eliminating the use of the cyclone or the cascade evaporator. As a result, the heat conductive surface of the economizer has been made to be twice to three times higher, with the boiler efficiency enhanced and odor decreased. Now, we 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. Blast-sprayed black liquor contains much moisture and is difficult to burn. The black liquor boiler requires twice or more operators for sweeping 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 blast-sprayed black liquor (70 to 75 %), the cleaning of the black liquor blast-spray nozzle and the primary and secondary air ports is automated. Further, facilities have been positively developed to regulate dust carry-over clogging the heat convection part, as well as control the char bed formation.

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

Figure 4.11 shows the outline of a typical recovery boiler.

Figure 4.11 Recovery Boiler



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 blast spray nozzle

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

4.7 Pulp from recovered waste paper

(1) Kinds of waste paper

To recover waste paper and reuse it as new paper is of an extreme significance from the standpoints of reduction of city garbage, protection of forest resources, and conservation of natural resources and energy as part of efforts to improve the global environment.

Waste paper includes newspapers, corrugated cardboards, magazines, wrapping paper, bags, leaflets, books, office paper, account books, etc. Including such secondary or incidental products as occur in a process of manufacture up to products which have finished serving their own purpose, waste paper will further be subdivided into much more kinds. Moreover, since many kinds of waste paper are found dispersing each in a small volume in a wide range of area, it is far from easy to collect them. This sort of matter cannot easily be encouraged unless people's moral is fostered through raising their concern for the beautification of their living environment, the protection of forest resources, the sound development of national economy and so forth.

To achieve this end, it is essential to provide drastic measures for the effective use of resources by means of administrative guidance through cooperation among governmental organs. These measures include the following:

1) Encouraging office people and general citizens to make it a practice to separate their garbage before putting it out

2) Support of garbage collectors in rational collecting methods

3) Setting up of quality standards for recycled paper from waste paper and promotion of quality improvement measures.

Japanese standard qualities of waste paper by Paper Recycling Promotion Center are listed in Table 4.8.

Table 4.8 The List of Japanese Standard Qualities of Waste Paper by Paper Recycling Promotion Center of Japan

Statistical Group	No.	Grade	Contents
A. Fine paper white shavings, white cards	1	White shavings	Shavings and sheets of white unprinted woodfree paper come from bookbinderies, printers and sheeting converteries.
	2	Cream shavings	Shavings and sheets of cream colored unprinted woodfree paper, come from bookbinderies, printers and sheeting converteries.
	3	Ruled lines shavings	Shavings and sheets of white or cream colored woodfree paper, having red or blue ruling or register mark, come from bookbinderies, printeries and sheeting converteries.
	4	Cards	Used tabulating cards made in Japan or imported.
B. White woody shavings, white manila	5	High grade white wood-containing shavings	Shavings and sheets of white unprinted high grade wood-containing paper, come from bookbinderies, printers and sheeting converteries.
	6	White wood-containing shavings	Shavings and sheets of white unprinted wood-containing paper, come from bookbinderies, printers and sheeting converteries.
	7	White manila	Cutting and sheets of uncolored and uncolored manila board come from carton makers.
C. Fine paper printed	8	Printed woodfree	White woodfree paper, black printed, computer printout.
	9	Color printed woodfree	White woodfree paper, printed with various colors, including coated papers.
	10	Woodfree shavings including some color printed	Shavings of white uncoated and coated woodfree paper, including some color printed, come from bookbinderies and printer.
	11	White coated shavings	Shavings and sheets of unprinted coated paper, woodfree come from bookbinderies and printers.

Statistical Group	No.	Grade	Contents
D. Quires, woody paper printed	12	High grade color printed wood-containing shavings	Shavings of high grade wood-containing white paper, printed with various colors, come from bookbinderies and priters.
	13	Color printed wood-containing shavings	Shavings of white wood-containing paper, printed with various colors, come from bookbinderies and printers.
	14	High grade wood-containing waste	Sheets of high grade wood-containing paper, come from bookbinderies and printers.
	15	Colored manila	Cutting of manila board, printed with various colors come from carton makers.
E. Old news	16	News	Old news.
F. Old magazines	17	Magazines	Old magazines
G. Kraft browns	18	New brown kraft cuttings	Cutting of unprinted brown kraft paper, come from kraft papr sack factories.
	19	Unprinted brown kraft	Waste sheets of unprinted brown kraft paper, come from kraft paper sack factories.
	20	Used brown kraft sacks	Brown kraft sacks, used for cements, chemicals, fertilizers, foods and others.
	21	Kraft lined corrugated waste	New kraft corrugated cuttings, old kraft corrugated containers, mainly imported.
H. Old corrugated containers	22	Corrugated container waste	Old corrugated containers.
I. Boxboard cuttings	23	Mill wrapper	Wrapping paper, used for newsprint rolls and other rolls.
	24	White paperboard cuttings	Cuttings of white paperboard, come from carton box makers.
	25	Chipboard cuttings	Cuttings of chipboard and colored chipboard, come from carton box makers.
	26	Carton box waste	Cuttings of straw board come from carton box makers, and used carton boxes of white paperboard, chipboard, colored chipboard.

(2) Waste paper pulping process

Recycled pulp from waste paper is always subject to fluctuations in its quality and great disparity due to differences in paper quality, processing etc, even with the closest attention paid to its collection and sorting. The papermaking process can hardly cover this quality disparity. Pulp from waste paper with great quality disparity is mixed for use within its allowable limit according to the characteristic required for each desired paper grade.

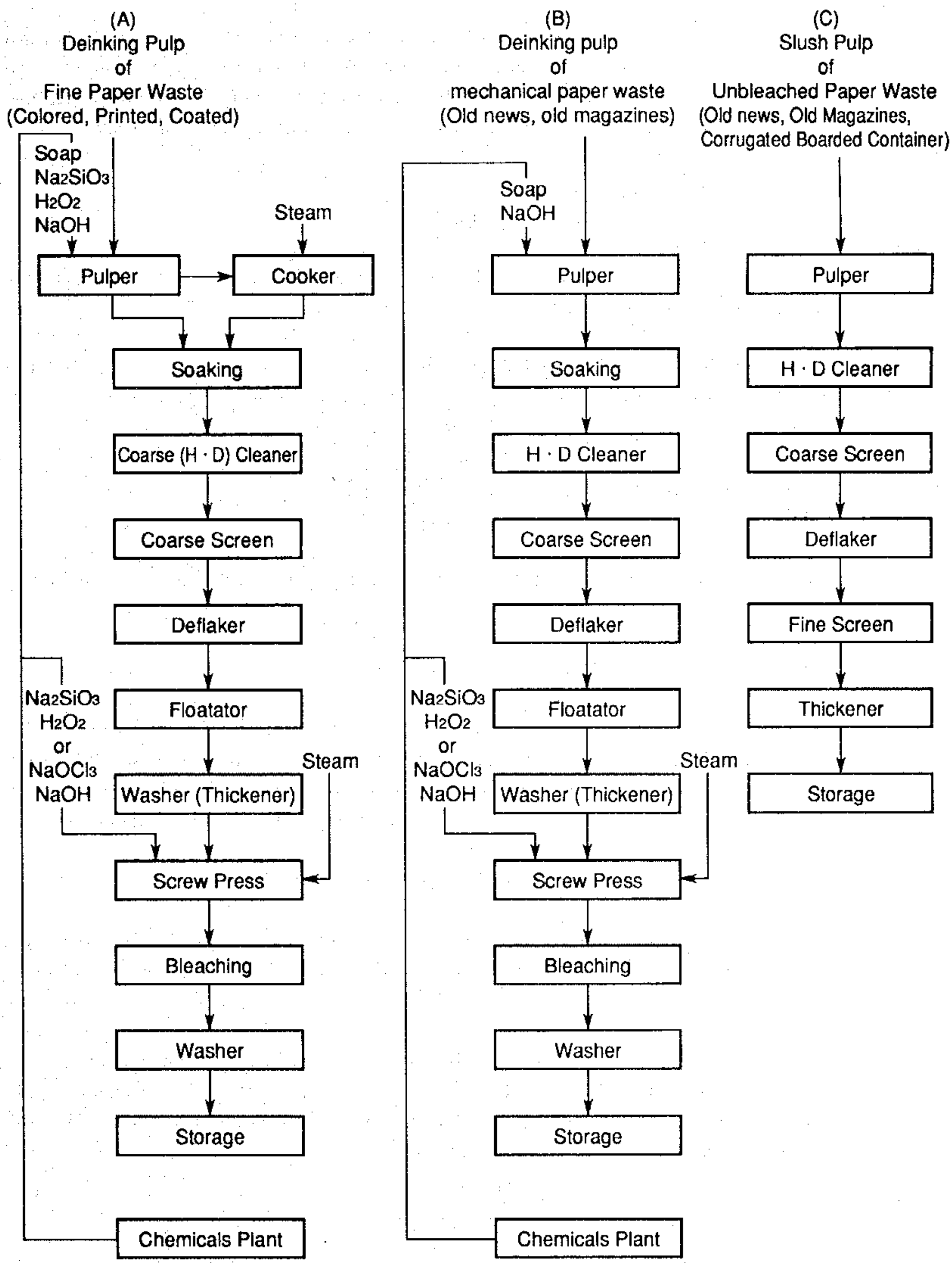
The pulping process was previously shown in Figure 4.1. The pulping process differs more or less depending on the kind of waste paper and the target pulp grade. A waste paper pulping flow sheet is shown in Figure 4.12,
where

A) is the flow for pulping waste paper to be mixed into medium-grade paper (white woody paper)

B) is the flow for pulping waste paper to be mixed into the paper for newspapers

C) is the flow for pulping waste paper to be used in fluting medium and paperboard base paper

Figure 4.12 Waste Paper Pulping Flow Sheet



(3) Waste paper and energy conservation

How much pulps from waste paper contribute to energy conservation is presented with reference to medium-grade printing paper as a model in the following example, where virgin pulp (mixture rate: BKP 50%, GP 50%) and waste paper deinking pulp are compared in terms of energy consumption rate. (Source: "Waste Paper Handbook, 1989)

BKP 50% + GP 50%: 2750 kcal/Pulp.kg
DIP : 1080 kcal/pulp. kg

This example shows that energy of only approx. one-third of that for virgin pulp is enough to make pulp from waste paper.

In addition, the energy consumption for each kind of pulp based on the recent data for 1992 from the Japan Paper and Pulp Technical Association is assumed to be as follows:

Bleached chemical pulp (BCP): 2450 kcal/pulp.kg
Mechanical pulp (GP) : 1850 kcal/pulp.kg
DIP : 675 kg/pulp.kg

A trial calculation in the same way for the above medium-grade printing paper is as follows:

Virgin pulp: 2150 kcal/pulp. kg $= \frac{(2450+1850)}{2}$
DIP : 675 kcal/pulp. kg

The concept of energy conservation is promoted for both virgin pulp production and DIP production. The energy consumption for the production of pulp from waste paper is, however, only one-third or less than that for the production of virgin pulp, which suggests that the production of recycled paper from waste paper should be further encouraged.

(4) Energy conservation measures for making pulp from waste paper

Setting the requirements for the maintenance of product quality should always take precedence over energy conservation measures. Product quality should not be adversely affected.

Quality characteristics of the pulp to be used for papermaking include pulp strength, viscosity, freeness, impurities, whiteness, etc. Surely, to improve the quality characteristics of pulp means to use much energy, but this also involves higher costs, and thus necessarily brings about stricter limitations in production.

The major factors affecting energy conservation in the papermaking process include the following:

a) Impurities
b) Freeness

(a) Removal of impurities

Among impurities in waste paper, the following synthetic resin-based adhesive materials affect energy conservation in papermaking.

- Laminated polyethylene film

- APP (Atactic polypropylene) used for pasting the back of the book

- Adhesive material of adhesive tapes (Synthetic rubber based)

- Ink vehicle (Synthetic rubber-based)

In addition, shives such as fibers not cooked, knots, etc., are included in the above impurities.

Synthetic resin-based impurities stick to wire meshes, blanket and canvas, cause pin hole and deforms the sheet formation, thus resulting in the production of unacceptable product, causing paper breaking and thereby lowering the production efficiency. Such paper as will contain these foreign matters and will be shipped out in form of roll may turn out to be a defective product, thus probably causing a claim.

When the wet paper with uncooked fibers or shives mixed into it is pressed by the press part, the pressure is applied on the protruding part. Hence, around the projecting part dehydration gets slower, thus causing a delay in the drying process by the dryer. In addition, when shives, etc. are located at the edge of the web, this may be an original point from which paper breaking starts.

To eliminate paper breaking is essential in terms of not merely production control but also energy conservation.

Removal of impurities is carried out by the screen, the centri-cleaner and so on, but the equipment and operation control of these dedusting devices tends to be neglected.

In this connection, at least the following should be executed from the points of quality and production control as well as energy conservation.

- To make the meshes of the screen to be used as small as possible.

- To know the appropriate consistency point at the inlet of the screen to carry out operation control

- To perform a proper operation control of the centri-cleaner with regard to the inlet consistency and the inlet and outlet pressures.

- To check periodically a dedusting rate or a rejection rate to confirm the normality/abnormality of the equipment.

- To carry out the maintenance and the periodical inspection of the equipment

Screen	:	Internal inspection for mesh breaking, etc. and adjustment of mesh cleaning shower condition Replacement or repair at occurrence of abnormality
Centri-cleaner	:	Inspection of the indication part of the pressure gauge, or repair. Checking for wearing of the internal part of the cleaner, and replacement Inspection of the reject part, and repair

4.8 Control of Freeness

Setting of freeness will, to some extent, allow sheet formation, paper quality, and strength to be determined.

It is the refiner that controls the freeness, and the electric power required for refining is so large as to amount to 20% or more of the total electric power consumption in the paper and pulp integrated production mill, as shown in Table 4.9.

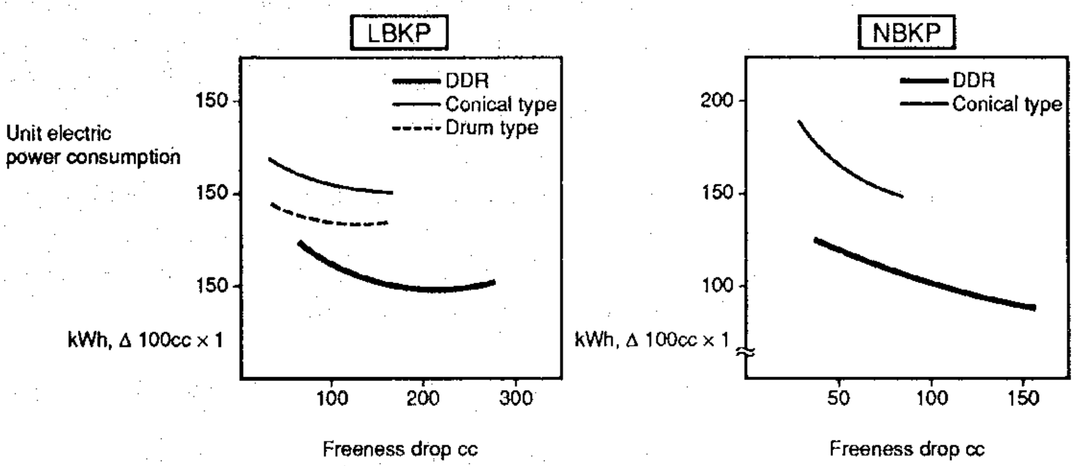
The refiner includes conical type, drum type and disk type, each of which differs in electric power consumption.

Figure 4.13 shows the electric power required for dropping freeness (Canadian Standard Freeness) by 100 cc in terms of unit consumption rate.

Table 4.9 Energy Consumption Pattern of Pulp and Paper Processes in an Integrated Fine Paper Mill

Energy	Process	Evaporator Causticizing	Cooking Washing	Bleaching	Paper Machine	Others
Steam	ton/paper ton	1.5	1.0	0.4	3.0	0.3
		5.9 (95%)				
		Cooking Washing	Bleaching	Refining	Paper Machine	Others
Electric Power	kWh/paper ton	140	150	240	600	220
		1,130 (84%)				

Figure 4.13 Comparison of Unit Electric Power Consumption



From this, it is known that regarding the double disk refiner (DDR) generally in use, the unit electric power consumption rate required for dropping freeness by 100 cc is

Approx. 50 kWH/pulp. ton/Δ100cc for LBKP
Approx. 100 kWH/pulp. ton/Δ100cc for NBKP

The electric power used for refining is converted into thermal energy, thus contributing to an increase in the temperature of the system.

The temperature in the system rises so much along with the electric power conversion heat generated from the pump and agitator as to promote the circulation of white water and decrease the amount of new water to be used. This rise in the system temperature brings about the following effects, leading to energy conservation.

Quickening of dehydration at the wire part
Quickening of dehydration at the press part

These effects decrease the moisture content at the wet end.

The subsequent section 4.11 describes the circulation of white water, while the next section describes dehydration by the press.

4.9 Enhancement of dehydration by the press

(1) Theory of water squeezing on the press

The cost for drying the wet paper in the drying process is generally estimated to be 5 or more times that for mechanical dehydration in the press part. This will lead to the estimation that hydration of moisture content in the press part for an extra 1% will allow the steam amount for drying to be saved by 4% in the dryer part.

Let us assume that the moisture content at the wet end is 61% when making paper with 7% moisture content at the dry end. Then, when the moisture content at the wet end is reduced to 60% by a 1% increase of the nip pressure of the press, the decrease rate of the steam amount used for the dryer will be obtained as follows.

The amount of evaporated water amount at the dryer per 1kg of paper (W kg)

1) $W_{61} = \frac{61-7}{100-61} = 1.384$ kg for 61% moisture content at the wet part

2) $W_{60} = \frac{60-7}{100-60} = 1.325$ kg for 60% moisture content at the wet part

A 1% increase of dehydration by press will make it possible to decrease steam consumption by 4.3%, as shown in the following expression.

$$\left(\frac{1.384-1.325}{1.384}\right)\times 100 = 4.3\%$$

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.

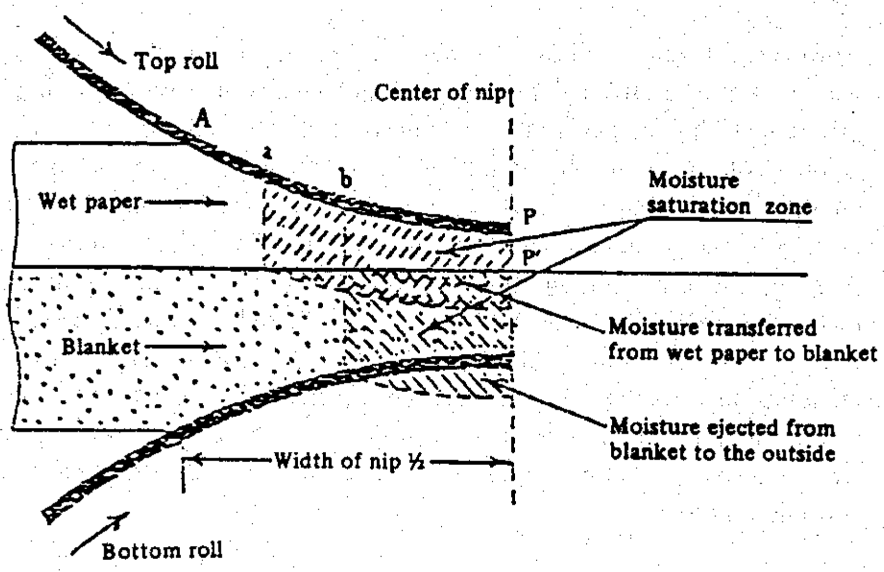
However, in order to make sure that the pressing in the press part is carried out, it is necessary to take sufficient pre-treatment procedures such as dusting and beating (refining) prior to entering the paper machine and sheet formation in the wire part. If there are large amounts of shives and foreign 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, shives 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 4.14 was advocated.

Figure 4.14 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 to energy conservation.

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

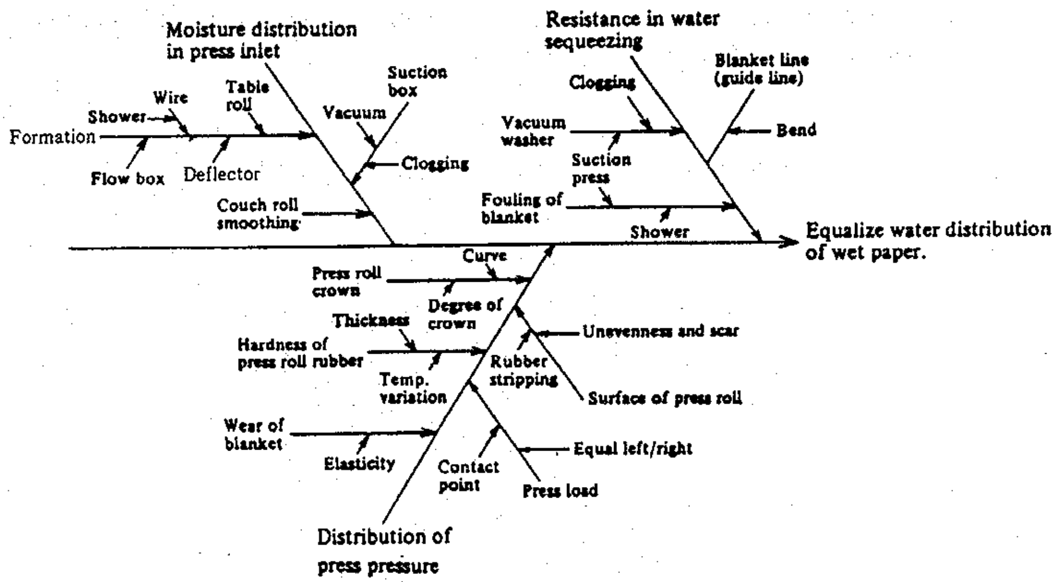
Even if the moisture content after pressing could be decreased, it would be quite useless, unless an uneven moisture distribution in the width direction is improved. The factors for adjusting the moisture distribution in the width direction is graphically described as shown in Figure 4.15.

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 4.15 Chart for Characteristic Factors of Moisture Distribution in Wet Sheet



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 4.16. Accordingly, the change of the linear pressure on the same conditions signifies the change of the average nip pressure as follows:

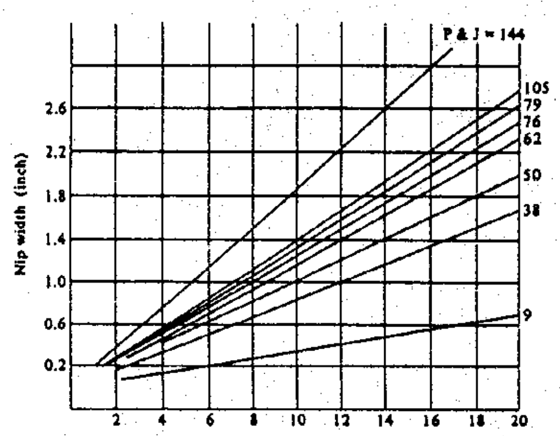
$$\overline{P} = \frac{P_L}{k \cdot \sqrt{P_L}} = k' \sqrt{P_L}$$

$\overline{P}$: 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.

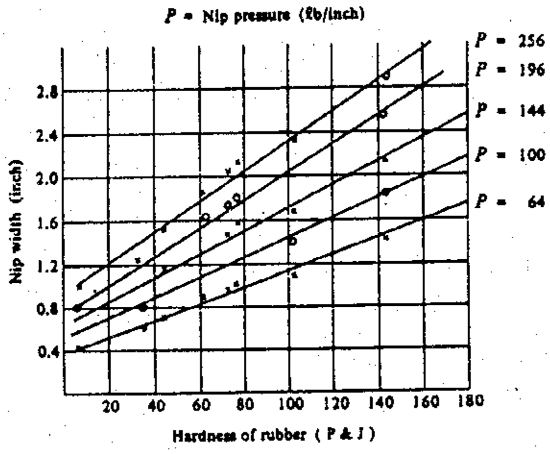
Under a constant linear pressure, the nip width is increased or decreased in proportion to the rubber hardness indicated by the P & J hardness (refer to Figure 4.17).

Figure 4.16 Nip Pressure and Nip Width



P & J (Pusey & Jones Plastometer)

Figure 4.17 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 4.10.

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 4.10 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

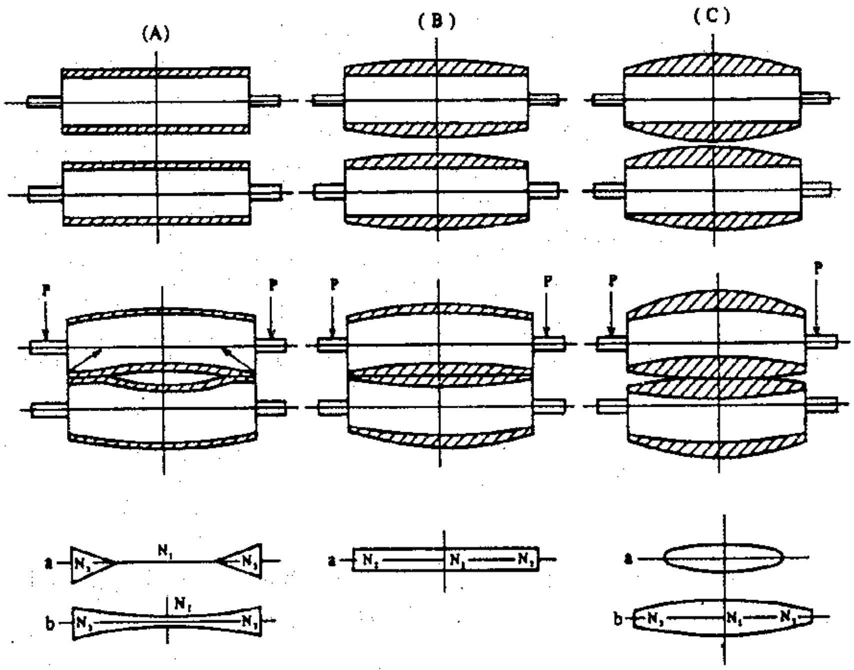
Quoted literature: Voith Tech. Bellage 1966 S. 45

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 4.18).

Figure 4.18 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 thin 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.

4.10 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.

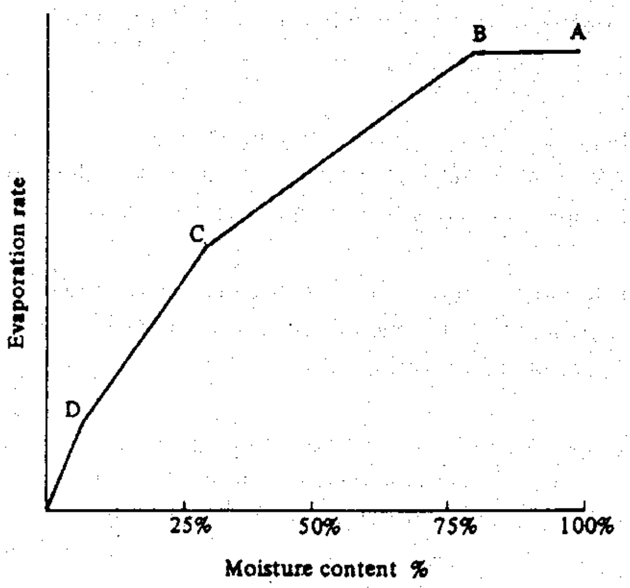
h. If the condensate inside the cylinder is resident or formed into a water film ring, the thermal efficiency drops so that the condensate should be discharged effectively.

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 4.19.

Figure 4.19 Drying Curve of Paper



A → B: The evaporation velocity 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 velocity 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 velocity 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

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

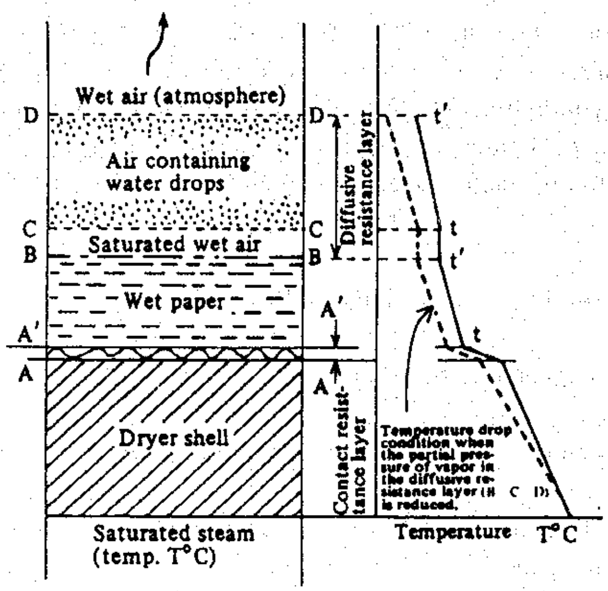
B) Character and velocity of air contacting the surface of paper

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 4.20.

Figure 4.20 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 velocity between two points is proportional to the temperature difference between the two points. Accordingly, in order to quicken the heat transfer velocity, 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 4.20 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 velocity 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 velocity. Thus, the environmental conditions around the wet paper (temperature, humidity, and wind speed) 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) Condensate 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 uncertainty and sensitivity beyond expectation.

For the elimination of wrinkles and air held, the leading dryer is sometimes installed. Figure 4.21 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.

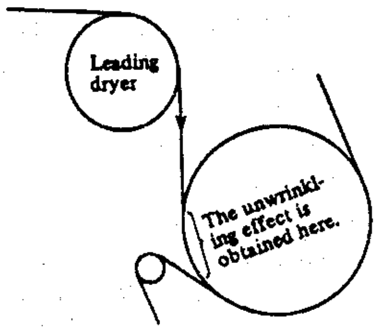
Regarding the routine operation, attention needs to be given to simple work, namely,

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 4.21 Leading Dryer

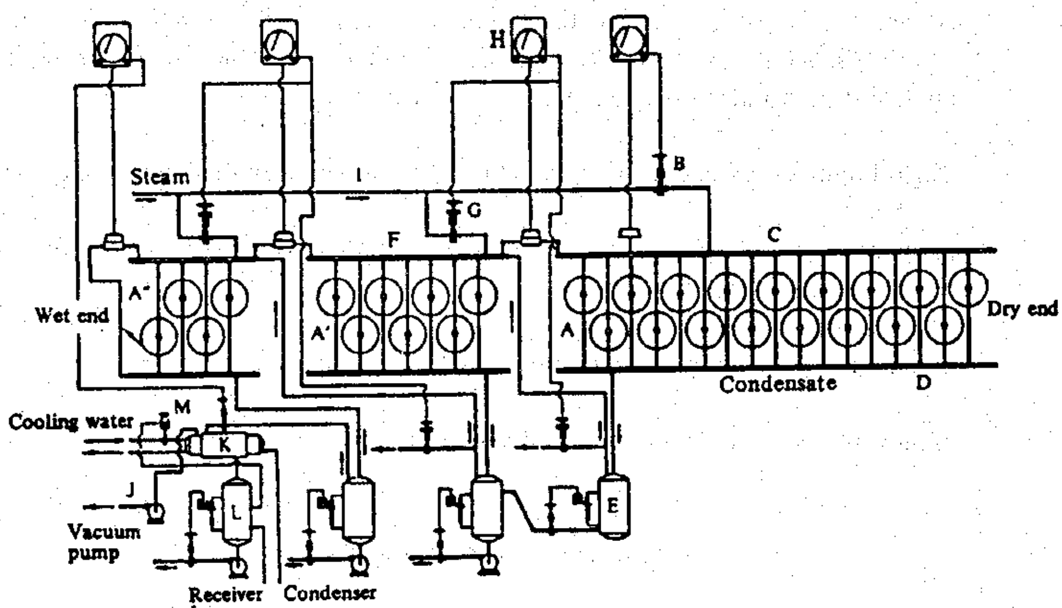


(4) Steam supply and exhaust system

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 4.22 shows the typical drainage system of 3 groups called "below through systems."

Figure 4.22 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 4.22)

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 size of the receiver tank (flash tank) can be obtained as shown in Table 4.11 and Table 4.12.

Table 4.11 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 4.12 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.

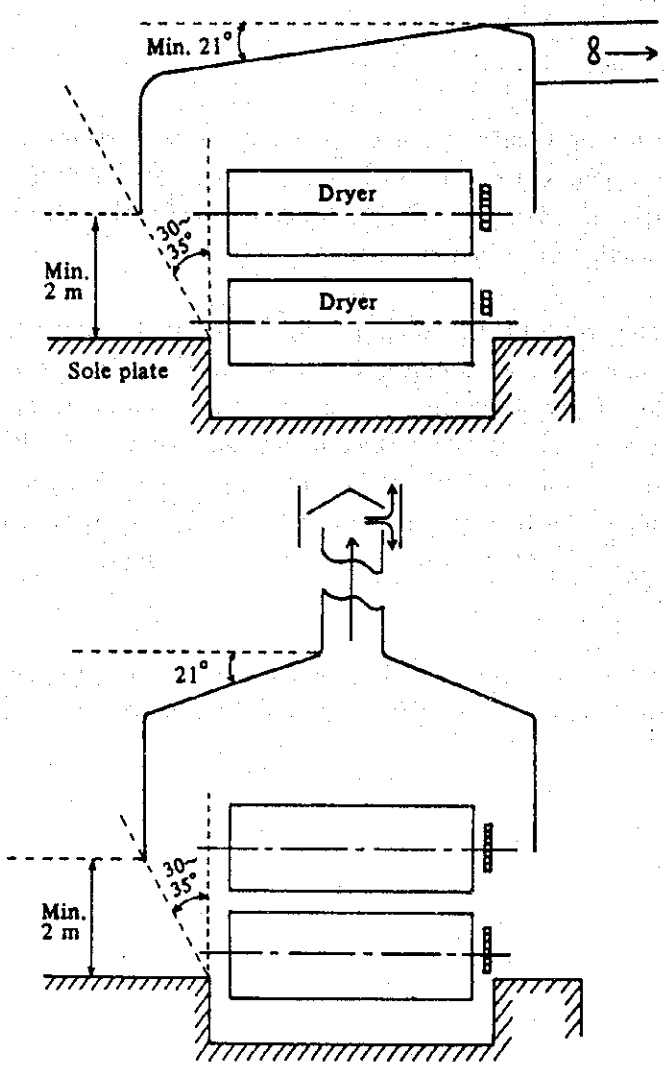
A) Dryer hood

In the ordinary paper machine, approx. 2 tons of moisture is evaporated for drying one ton 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 4.23). 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 4.23 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 waterproof, fireproof and anticorrosive.

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.

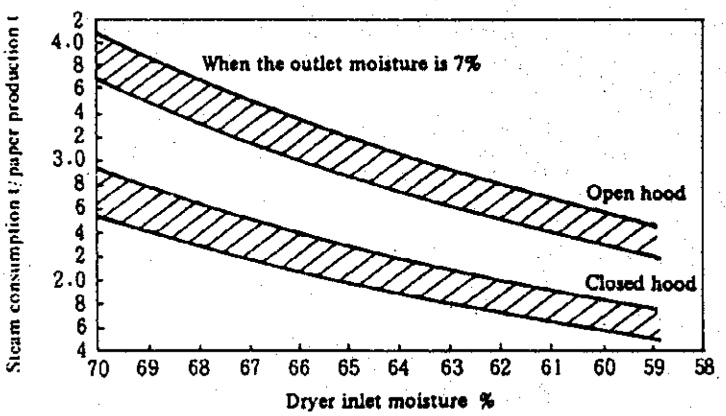
The air volume normally required per 1 ton of paper is as follows:

- 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 4.24 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 4.24 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 4.25. The waste heat recycling flow and the ventilation control system are shown in Figure 4.26.

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 4.25 An Example of "Closed Hood Ventilation System"

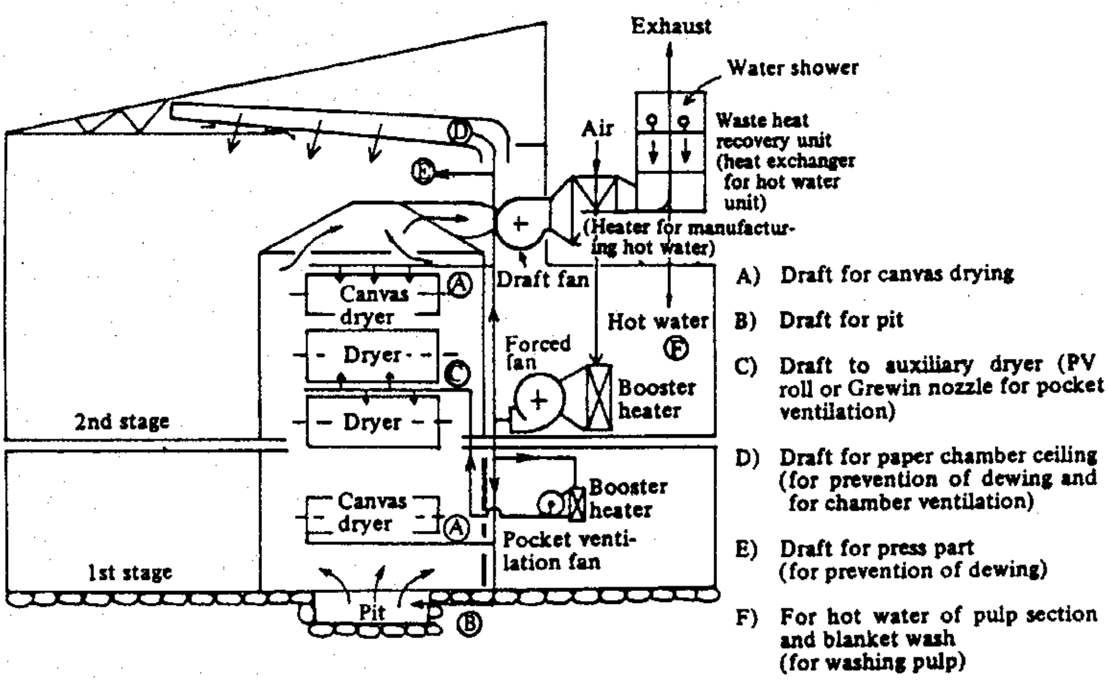
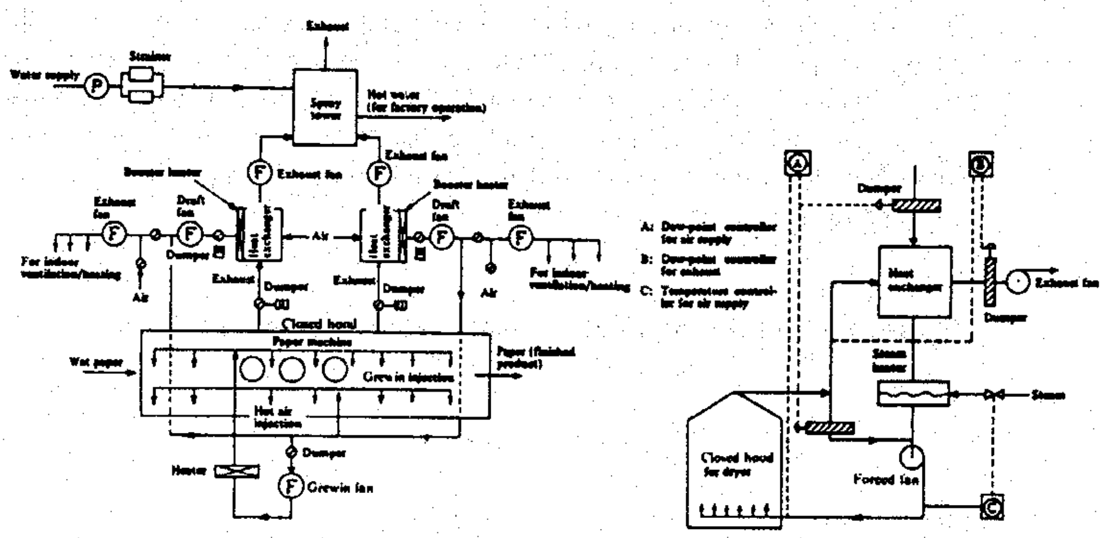


Figure 4.26 Waste Heat Recovery Flow for Closed Hood Ventilation System and Control System



4.11 Effective use of white water

The paper and pulp industry consumes a great amount of energy and water. To reduce the amount of water to be used, that is, to recirculate white water for its reuse will not merely prevent the loss of raw materials and constitute a countermeasure for pollution, but also prevent the loss of energy, thus leading to improvement in yield and energy conservation, as well as contributing to an increase in profits.

Table 4.13 shows a decline in the amount of new water used in the paper mill in Japan in terms of unit water consumption rate.

Table 4.13 Transition of the Unit Water Consumption of the Paper Mill in Japan

Kind of paper \ Year	1970	1980	1990
General paper (ton/paper ton)	150	95	85
Paperboard (ton/paper ton)	100	50	45
Tissue paper (ton/paper ton)	200	150	120

A decrease in the amount of new water increases the temperature in the system. Table 4.14 shows the transition of the unit water consumption, head box temperature, and the unit steam consumption in an integrated paper and pulp mill where about 150,000 tons of fine paper are produced per year.

Table 4.14 Transition of the Unit Water Consumption and Head Box Temperature

	1960	1990
Unit water consumption (ton/paper ton)	175	87
Head box temperature (°C)	20	45
Paper machine unit steam consumption (ton/paper ton)	3.6	2.8

A reduction of water caused a rise in the temperature in the process, and also decreased the unit steam consumption. However, the decrease in the unit steam consumption is considered to result not only from the decrease in the amount of water consumption but also presumably from the modification effect of the press. Therefore we should not draw hasty conclusions but surely the rise in the temperature at the wire part and in the temperature of the wet paper at pressing has increased the hydrating effects.

As a measure for decreasing the white water, it is necessary to make a detailed measurement of the density and consistency of stuff and white water passing through each equipment. Particularly regarding the washer and concentrator, the temperature and consistency at the white water side should be noted, and also the water quality after processing and its application must be taken into due consideration before planning the introduction of a white water recovery device. Use of a white water recovery device may be one of the measures to promote the reuse of white water.

4.12 Operation efficiency and energy conservation

Since the paper and pulp industry is the process industry (one production train) it is recommendable that all equipment should be continuously operated with their full capacity without any long interruption. In other words, high operation efficiency is most economical, bringing about a great energy conservation effect. Especially the paper-making process requires the most energy consumption in the paper and pulp integrated mill, where steam accounts for more than 40% of the entire amount used and electric power amounts to more than 50% as previously shown in Table 4.9.

To take a drastic policy for enhancing the operation efficiency of the paper machine will serve as an energy conservation measure as well as a cost reduction method.
To this end, the following should be carried out.

1) To eliminate paper breaking

2) To eliminate the stop due to an accident to the paper machine

3) To eliminate the stop due to wire repairs, blanket washing, repairs, etc.

4) To eliminate the stop due to faults caused by poor maintenance of facilities and electric equipment, etc.

5) To eliminate the stop by faults due to such related sections as pulp, boiler, finishing and other sections

6) To eliminate faults due to power failures attributable to electric power companies. To submit as a customer a claim against power failures to the company in charge and to make them responsible for its compensation and prevention of the recurrence of such failure

7) To eliminate operation troubles due to quality disparity in purchased materials, minor materials, devices and equipment, delay in delivery date, etc.

These can be attained through accumulation of efforts to establish the management system of the entire factory, analyze causes for the downtime and prevent the recurrence.

Out of the troubles with the paper machine, this section picks up and describes paper breaking and the measures for decreasing such trouble.

(1) In order to eliminate paper breaking, the following steps should be preferably taken.

1) To create a cause and effect diagram such as Figure 4.27 to analyze the causes for the occurrence of paper breaking.

2) To identify the location of occurrence as shown in Table 4.15 to find out the causes and then the countermeasures on the basis of the position, the face, and the way of paper breaking.

(2) Introduction of operation efficiency control of the paper machine

Elimination of paper breaking and faults cannot be accomplished unless not merely the operation efficiency of the paper machine but also PM efficiency of the maintenance division and the efficiency of each related division are all controlled concurrently. However, the paper machine division should identify its own scope of responsibility, work out a policy to fully cover that scope of responsibility and file a strict claim against failures due to other divisions in order to encourage and promote the trend for the establishment of the control system for the entire mill.

Figure 4.27 Cause and Effect Diagram of Paper Breaking

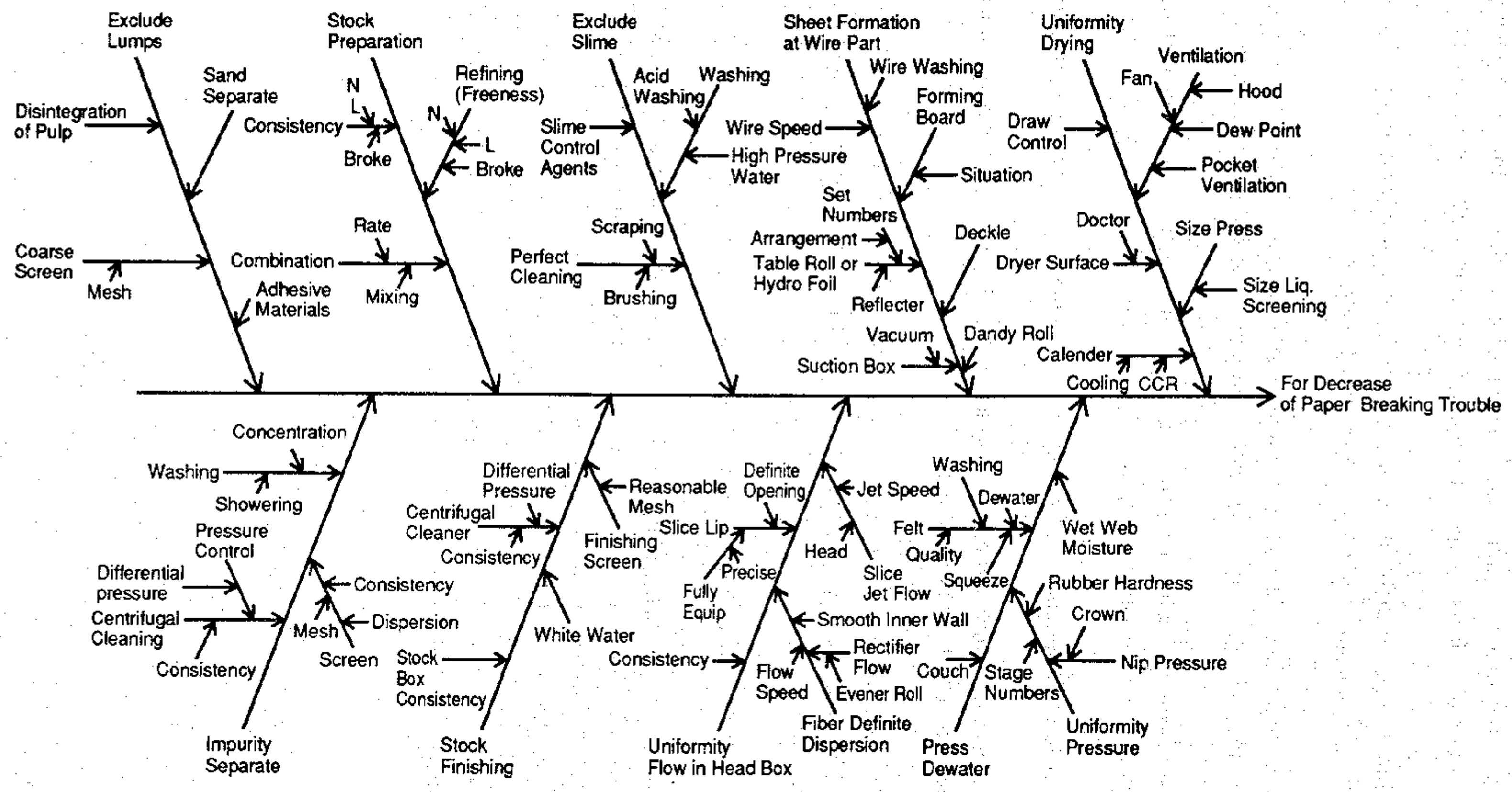


Table 4.15 Causes for Paper Breaking and Remedies

Places for paper breaking	Classifications	Causes	Measures	Equipment factors
1. Wet part				
(1) Couch	Fall from couch	Excess Moisture (Wet Insufficient strength) Trimming water cutting fault	Promotion of dewatering on wire	Dewater rectify on Wire Part Setup of Pick up roll High pressure of water jet
(2) Press	Breaking by press	Crushing Roughened surface on plain roll Mixing of slime Mixing of adhesive substances	Promotion of dewatering Roll surface repair Removing the slime Separation, removal and dispersion	Line pressure up Grinding
	Uneven dewatering	Faulty formation Dirty blanket Uneven line pressure	Formation correction Promotion of blanket washing Roll crown correction	Flow rectify in Head Box & Wire Part Washing by showering, squeeze and dewatering Grinding
(3) Wet end	Fall in wet end	Faulty drawing Excessive moisture Mixing of shives	Drawing adjustment Line pressure increase (Promotion of dewatering) Promotion of screening	Setup of high pressure
2. Dryer part				
(1) Yankee Dryer	Breaking due to faulty separation	Paper power attached Damage on dryer surface	Effective use of the doctor Polishing the surface	Dryer cleaner Bronze doctor, Dryer grinding
	Breaking due to intrusion of foreign substances	Mixing of shives and impurities	Promotion of screening	Strengthening of dedusting equipment of centricleaner, etc.
	Breaking by tension	Faulty drawing Faulty formation	Drawing adjustment Correcting the formation	Flow rectify in Head Box & Wire Part
(2) Multi-dryer	Breaking by tension	Faulty drawing between groups	Drawing adjustment	
	Edge breaking	Edge too dry Mixing of shives and impurities Trimming water cutting fault	Improvement of dryer pocket Promotion of screening Water pressure increase	Pocket Ventilation Centricleaner, Fine Screen
3. Calender part	Crushing	Faulty formation Incorrect roll crowing	Correcting the formation Correct the roll crowing	Flow rectify in Head Box and Wire Part Grinding
	Breaking by foreign materials	Mixing of shives and impurities	Promotion of screening	Centricleaner, Fine Screen
	Breaking by tension	Faulty drawing Faulty formation	Drawing adjustment Correcting the formation	Flow rectify in Head-Box and Wire Part
	Breaking in machine direction	Faulty formation and wrinkling Unevey drying and wrinkling	Improvement of dryer ventilation Correcting the formation Removing the dryer pressure	

The operation efficiency of the paper machine can be considered as follows.

$$\text{Operation efficiency of the paper machine } (\zeta_1) = \frac{\text{Actual operation time (min.)}}{\text{Operation time (min.)}} \times 100\ (\%)$$

$$= 1 - \frac{D}{A - B - C} = \frac{A - B - C - D}{A - B - C} \times 100\ (\%)$$

A: Paper machine operation time determined by the production program (min./day)
B: Downtime due to external factors including power failures, etc., imputable to electric power companies (min.)
C: Downtime due to internal factors such as mechanical and electrical faults etc.(min.)
D: Downtime due to paper machine division failures (min.)

A is the operation time based on to the annual or monthly production plan, which is determined by the budget.

B is caused by failures imputable to electric power companies to which a claim for damage compensation can be submitted.

C is caused by faults due to the equipment maintenance division, the material procurement division, etc.

D is caused by faults due to the paper machine division; Suspension time required for repairs of paper breaking arising from mis-adjustment of drawing, poor sheet formation or from scratches on the wire part due to foreign matters on the guide rolls.

D can be further sub-divided into detailed factors, that is, x for paper breaking, y for wire repair and z for blanket repair, which may be a better control method.

To eliminate the downtime due to mechanical and electrical faults, preventive maintenance efficiency can be set for controlling the availability of the facilities. This can be expressed as follows:

$$\text{Preventive maintenance efficiency } (\zeta_2) = \frac{\text{Operation time (min.)}}{\text{Actual production plan time (min.)}} \times 100\ (\%)$$

$$= 1 - \frac{C}{A - B - D} = \frac{A - B - C - D}{A - B - D} \times 100\ (\%)$$

When each division rearranges the efficiency control system to make every effort to achieve an efficiency index 100%, then the overall efficiency (ζ), which is expressed as

$$\zeta\ (\%) = (\zeta_1 \times \zeta_2 \times \zeta_3 \times \cdots\cdots)\ (\%)$$

will be demonstrated up to the utmost point, thus further promoting energy conservation.

APPENDED MATERIALS

5. WORKSHOP TEXT

Contents