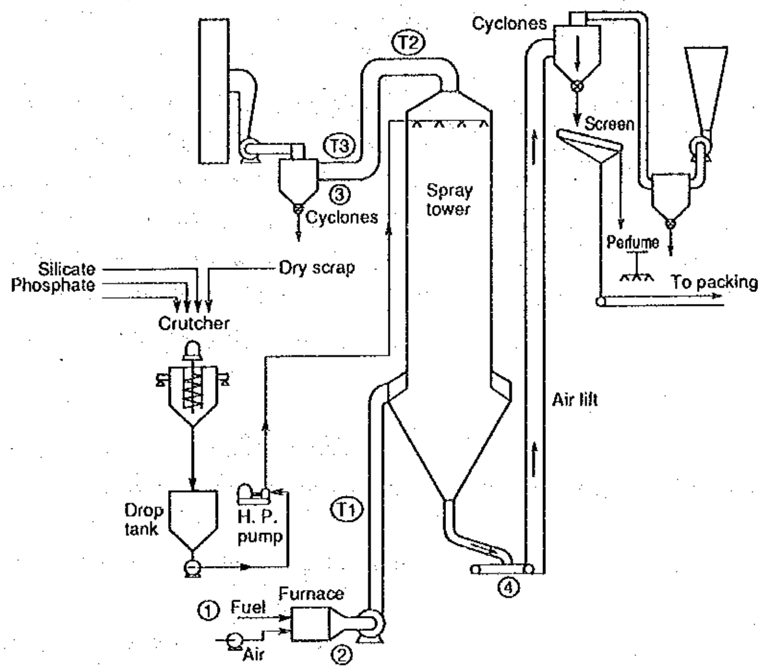
(2) Synthetic detergent dryer

A) Equipment specifications

a. Flow sheet

Figure. 5.1.5 shows the equipment flow sheet.

Fig. 5.1.5 Flow sheet of dryer



Natural gas is burnt in the combustion furnace, and combustion gas is adjusted to the temperature of about 500 °C by mixing with air which flows through the outer sleeve of the combustion furnace. Then, as hot air for drying, it is fed to the lower part of the dryer tower by the blower.

The slurry mixed with such additives as sodium alkyl benzene sulfonate paste and sodium tripolyphosphate as main materials is sprayed from the top of the dryer tower by the high pressure pump.

While it goes upward within the dryer tower, the hot air deprives moisture of the material slurry, and goes out of the tower in an almost moisture-saturated condition. After it is collected by the multi-cyclone, it is discharged by the outlet blower. The material slurry, on the other hand, is dried while it goes downward within the tower, and is discharged from the lower outlet. While the dried object is transported to the top of the building by the air lift, heat generated by crystallization of sodium tripolyphosphate is removed by air. It then passes through the screen, and coarse grains are fed back to the material slurry. Components are added to the graded material, which is made into the product --- granular synthetic detergent.

T1, T2 and T3 in Figure 5.1.5 denote the positions where thermocouples are inserted for temperature measurement, and temperature is indicated by the temperature indicator located in the control room. The flow rate of natural gas as fuel is controlled by the high-low valve position according to the temperature set on the T1. Additives such as sodium alkyl benzene sulfonate paste and sodium tripolyphosphate as main materials are measured by the measuring instrument and are added. The added values are recorded on the recorder located in the control room. However, the volume of the added water is not recorded.

①, ② , ③ and ④ in Figure 5.15 show positions used for the present measurement. The following give measurement items for each position:

① Natural gas: Flow rate, temperature and pressure

② Hot air at the inlet: Flow rate, temperature and oxygen concentration

③ Hot air at the outlet: Flow rate, temperature and oxygen concentration (However, the flow rates were measured intermittently due to dust troubles).

④ Dried output: moisture

b. Combustion furnace and dryer structure

Figures 5.1.6 and 5.1.7 illustrate the combustion furnace and dryer tower structure.

c. Equipment specifications

Table 5.1.6 shows the equipment specifications:

Figure 5.1.6 Structure of Furnace

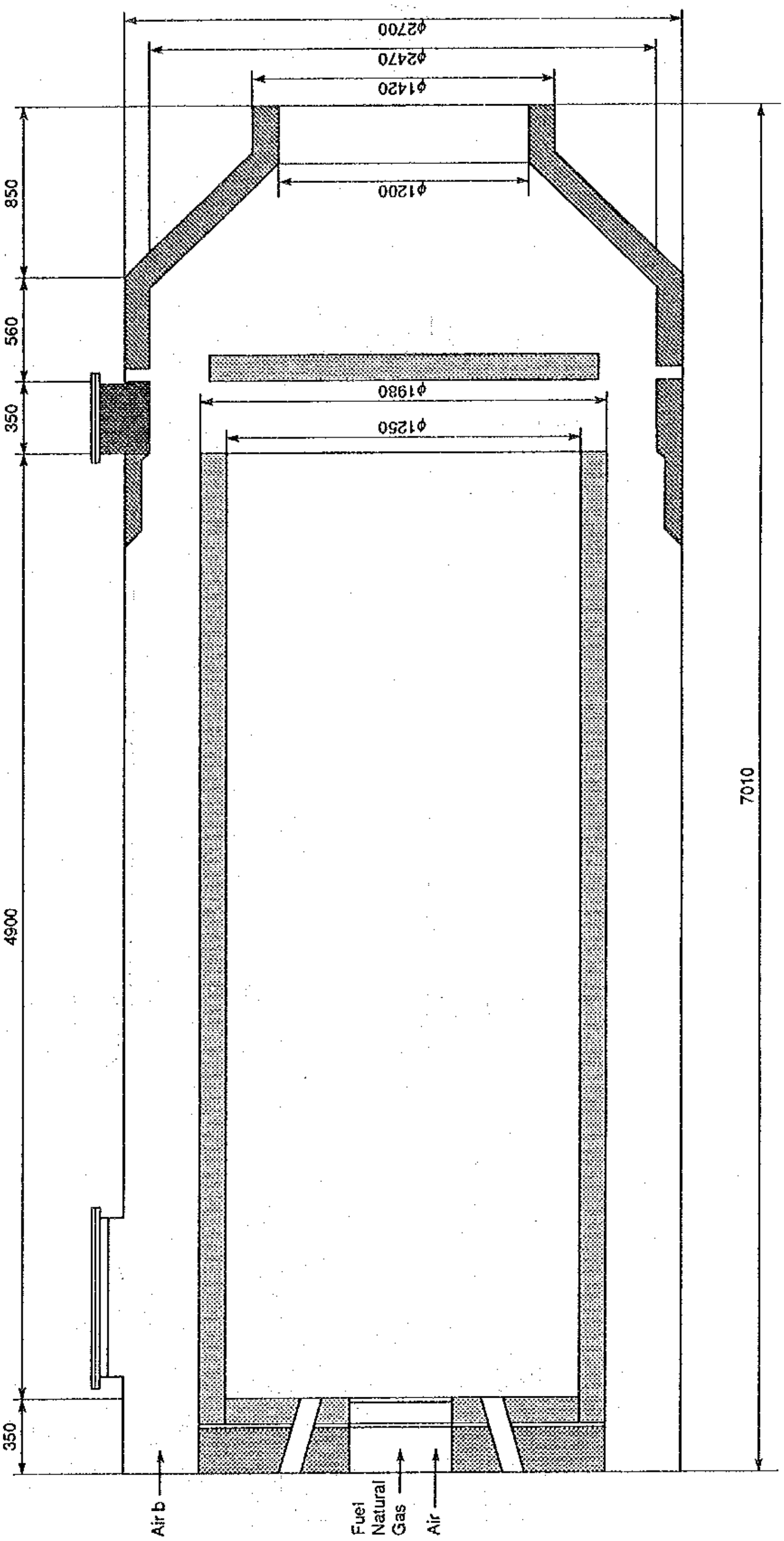


Figure 5.1.7 Structure of Dryer

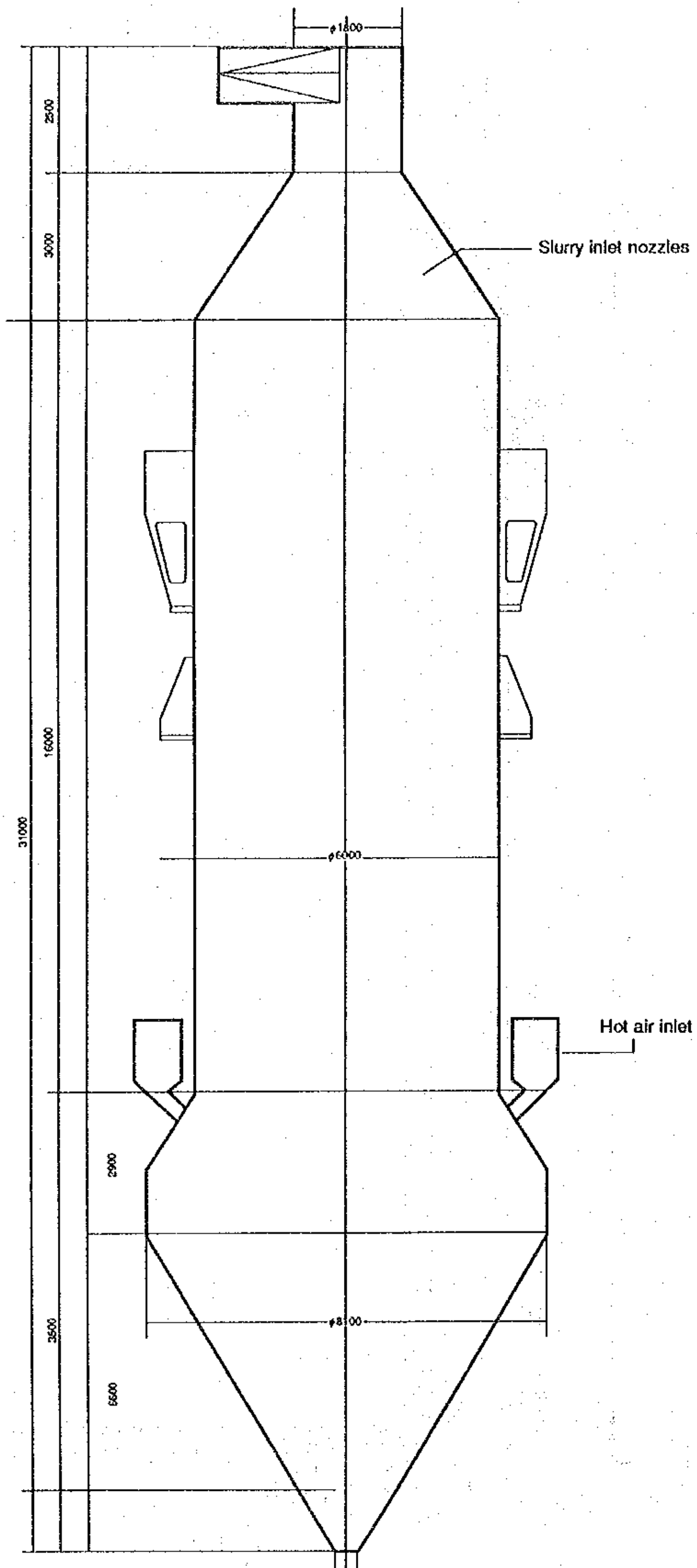


Table 5.1.6 Specification of Dryer

Item		Specification
Furnace	Combustion Chamber	4,900mm L × 1,750mm φ 11.8m³
	Air Mixing Chamber	3.7m³
	Refractory	110～115mm t
	Bridge Wall	110mm t
Spray Tower	Drying Chamber	16,000mm L × 6,000mm φ 453m³
	Insulator	Drying Chamber 40mm t (300℃ type)
		Hot Air Chamber 50mm t (400℃ type)
	Surface Area	480㎡
Hot Air Inlet Duct		20,000mm L × 1,200mm φ
	Insulator	50mm t (400℃ type)
	Surface Area	100㎡
Hot Air Outlet Duct		20,000mm L × 1.100mm φ
	Insulator	40mm t (300℃ type)
	Surface Area	70㎡
Blower	Combustion Air	6,000 Nm³/h
	Inlet Hot Air	90,000 Nm³/h
	Insulator	50mm t (400℃ type)
	Motor	18.5 kW
	Outlet Hot Air	75,000 Nm³/h
Material Preparation	Ponderal Dosing Group on Strain Gages	6 Sets
	Dosing Cycles	120 times/h
Material Feed	High Pressure Pump	2 Step Reciprocating type
		1 st. Step 6～8 bar.
		2 nd. Step 20～60 bar.
		800～1,500 rpm
		Steam Tracing & Insulation
		Feed Temparature 50℃
	Spray Nozzles	12 Nozzles (6 Spare)
		Dia.3.5mm φ
Auxiliary Components	Exhaust Air Cyclones	3 × 2 Lines
	Air Lift	
	Cyclone for Air Lift	2 × 1 Lines
	Vibrator	
	Rotating Mixer	

B) Heat balance

a. Measuring time

Measuring instruments were set to the required positions on the morning of March 10, 1993 to start the measurement of the operating conditions of the drying tower. The following shows how the operation was performed:

12:00 Start of combustion
12:30 Start of material feed, start of measurement
15:05 Material feed stop
(due to the failure of the snake pump to feed sodium alkylbenzene sulfonate paste)
16:00 End of measurement

After studying the reliability of the measurement record, measurements in the following time zone shall be analyzed.

Flow rate, temperature, pressure and oxygen concentration	14:10 to 15:10
Material slurry feed	13:00 to 15:00
Water content in dried output	14:00 to 15:00

b. Material balance of the raw materials

Table 5.1.7 shows the cumulative volume of the materials to be fed and analyzed value of the water content in the dried output. Components and composition of each material are also shown. This cumulative volume is given in Figure 5.1.8. The figure also shows the volume of each component fed per unit time obtained from the gradient of each straight line.

Table 5.1.7 Raw Material Cumulative Feed

Time\Component	①	②	③	④	⑤	⑥	Moisture
13:00	284	294	166	327	283	216	
13:20	586	672	336	667	575	437	
14:00	1212	1474	707	1194	824	913	4.0%
14:30	—	—	—	—	—	—	3.7%
15:00	2204	2763	1285	1998	1797	1655	2.03%

Note 1: ① Sodium tripolyphosphate $Na_5P_3O_{10}$ MW = 368
② Sodium sulfate $Na_2SO_4 \cdot 1H_2O$ MW = 142 + 18
③ Sodium carbonate Na_2CO_3
④ ABS 47 % Paste

⑤	CMC	6.0 %	
	VEROL-C15	8.3 %	Nonion Surfactant
	Additives	1.0 %	Bleaching Agent
	Water	84.7 %	
⑥	Sodium silicate	40 %	

Note 2: Slurry Water Content Target 40 %

Note 3: Product Water Content 4 % (105 °C × 1 h)

Table 5.1.8 shows the material balance of the raw materials.

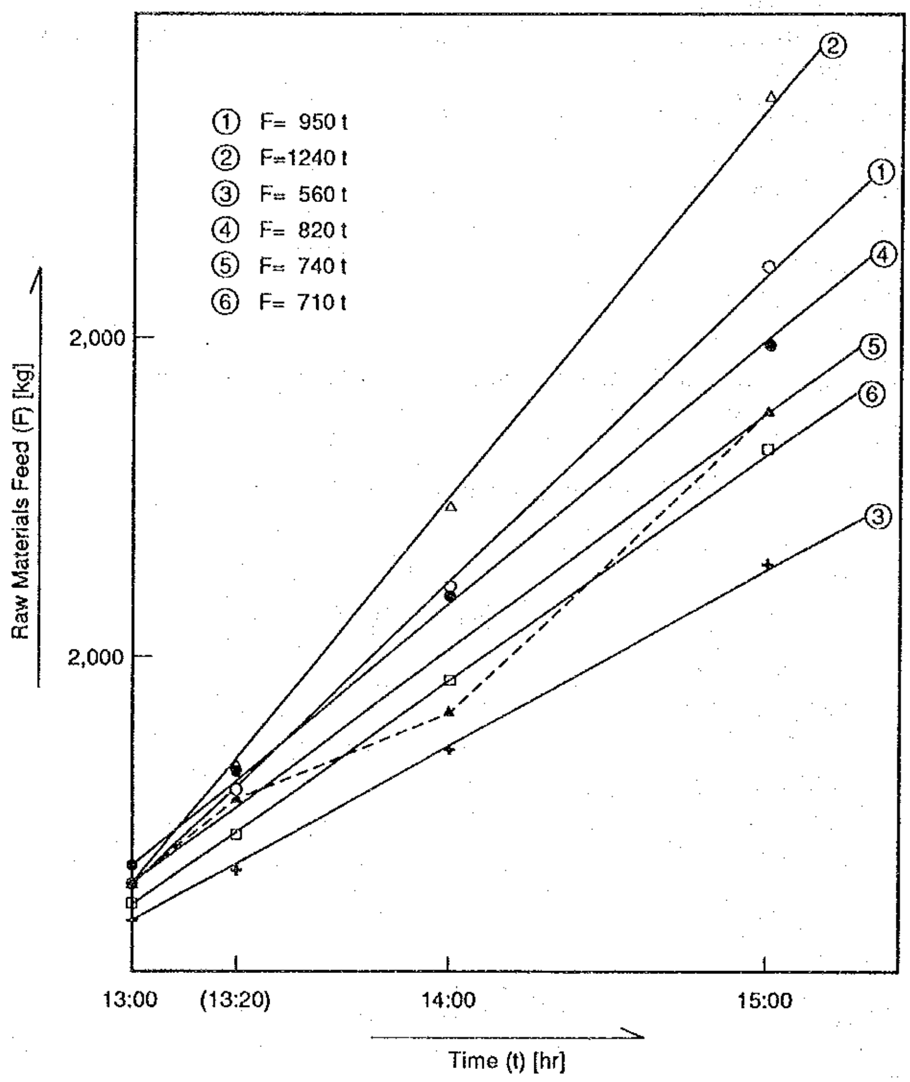
Table 5.1.8 Material Balance

No.	Materials		Wet kg/h	Dry kg/h	H_2O kg/h	Note
①	$Na_5P_3O_{10}$		950	950	0	
②	$Na_2SO_4 \cdot 1H_2O$		1240	1100.5	139.5	1240×142／1 6 0 =1100.5
③	Na_2CO_3		560	560	0	
④	ABS Paste	47%	820	385.5	434.5	820×0.47=385.5
⑤	CMC & Aditives	15.3%	740	113	627	740×0.153=113
⑥	Sodium silicate	40%	710	284	426	710×0.4=284
	subtotal		5020	3393	1627	
Additive H_2O					635	
Feed Slurry		H_2O=40%	5655	3393	2262	3393／0.6=5655
Product		96%	3534	3393	141	3393／0.96=3534.4
Out put H_2O					2121	

The following shows the volume of feed to and from the dryer based on the Table 5.1.8:

Material slurry (40 %) feed	5, 655 kg/h
Discharge of dried output (4 %)	3, 534 kg/h
Discharged water	2, 121 kg/h

Figure 5.1.8 Raw Material Cumulative Feed



c. Material balance of hot air

Table 5.1.9 shows the composition and physical properties of the natural gas, while Table 5.1.10 gives measurements of the hot air.

Table 5.1.9 Composition of Natural Gas

Component	CH_4	C_2H_6	nC_4H_{10}	N_2	CO_2	RSH
Vol.%	98.66	0.33	0.02	0.96	0.03	25mg

Density	0.726	kg/Nm³
Calorific Value	8,507	kcal/Nm³
Viscosity	1.088×10^{-5}	kg/(ms)

Table 5.1.10 Result of Measurement

Time		March 10, 1993 (14 : 10~15 : 10)		
Room Temperature		Average	Max.	Min.
℃		9.67	10.9	7.8
Fuel		Pipe Inner Dia.=76mm φ		
		Average	Max.	Min.
Flow	m^3/h	333.0	581.4	0
Pressure	kg/cm^2G	0.100	0.118	0.079
Temperature	℃	7.17	7.9	6.5
Hot Air Inlet		Pipe Inner Dia.=1,200mm φ		
		Average	Max.	Min.
Flow	m/s	16.89	21.57	12.76
	Nm^3/h	16,936	42,189	0
Pressure	kg/cm^2G	0		
Temperature	℃	506.79	576.9	431.4
O_2	%	17.20	18.64	15.57%
Hot Air Outlet		Pipe Inner Dia.=1,100mm φ		
		Average	Max.	Min.
Flow	m/s	12.88	15.0	11.5
Pressure	kg/cm^2G	0		
Temperature	℃	100.93	110.7	90.5
O_2	%	178	18.57	17.23

The above physical properties and measurements are used for tentative calculation of the volume of hot air according to the following procedures given in (1) and (2), and heat balance is carried out using the value which is evaluated to have a higher reliability.

(1) Calculation based on the natural gas flow and hot air oxygen concentration

Equations (1.1) and (1.2) show theoretical air volume for 1 N m^3 of natural gas and theoretical wet combustion gas volume.

$$A_o = (2CH_4 + 3.5C_2H_6 + 6.5C_4H_{10}) / 0.21 = 9.46 \quad (1.1)$$

$$G_o = 1 + A_o + 0.5 \times (C_2H_6 + 3C_4H_{10}) = 10.46 \quad (1.2)$$

where,

A_o : Theoretical air volume — Nm^3/Nm^3-Fuel

G_o : Theoretical wet combustion gas volume — Nm^3/Nm^3-Fuel

The volumes of the components in the combustion gas are given by equations (1.3), (1.4), (1.5) and (1.6).

$V_{O2} = 0.21\ (m-1)\ Ao = 1.986\ m - 1.986$ .... (1.3)

$V_{N2} = 0.79 \times m \times Ao + N_2 = 7.473\ m + 0.0096$ .... (1.4)

$V_{CO2} = CH_4 + 2C_2H_6 + 4C_4H_{10} + CO_2 = 0.994$ .... (1.5)

$V_{H2O} = 2CH_4 + 3C_2H_6 + 5C_4H_{10} = 1.984$ .... (1.6)

where,

m	: Air ratio	
V_{O2}	: Oxygen volume	Nm^3/Nm^3-Fuel
V_{N2}	: Nitrogen volume	Nm^3/Nm^3-Fuel
V_{CO2}	: Carbon dioxide gas volume	Nm^3/Nm^3-Fuel
V_{H2O}	: Water vapor volume	Nm^3/Nm^3-Fuel

Since the oxygen concentration in the combustion gas (O_2) is 17.20 %;

$(O_2) = V_{O2} / (V_{O2} + V_{N2} + V_{CO2} + V_{H2O}) = 17.20/100$ .... (1.7)

Solving equation (1.7), we get the air ratio of m = 6.0.

Actual volume of wet combustion gas G is given by equation (1.8).

$G = Go + (m-1)\ Ao = 10.46 + 5.0 \times 9.46 = 57.75$ Nm^3/Nm^3-Fuel .... (1.8)

The volume of burnt natural gas is obtained by multiplying the center flow rate in the fuel pipe measured with the Pitot tube by the correction coefficient (Vav/Vmax = 0.85) according to the Reynolds number, and the result is converted into the value under standard conditions. The following shows the result of the calculation: 333.0 Nm^3/h

Thus, the volume of inlet hot air is given by the following:

$57.75 \times 333.0 = 19.229$ Nm^3/h

(2) Calculation based on the inlet hot air velocity

The volume of inlet hot air is obtained by multiplying the center flow rate measured by the hot wire anemometer at the combustion gas duct of the combustion furnace outlet by the correction coefficient (Vav/Vmax = 0.85) according to the Reynolds number, and the result is converted into the value under standard conditions. The following shows the result of the calculation:

20, 394 Nm^3/h

Comparison of the calculation results (1) and (2) reveals that the volume of the hot air obtained from combustion gas velocity is about 1.06 times the volume of hot air calculated from the volume of burnt natural gas. Since the hot air duct has a large diameter (1,200 mm) with a short straight tube section, the calculation from the volume of burnt natural gas is considered to be more reliable. So this value will be used for calculation of heat balance.

d. Heat release

Heat transfer coefficient from the perpendicular wall surface to the ambient air in the absence of wind blowing is obtained from equations (1.9) to (1.11)

Natural convection heat transfer coefficient

$$h_c = \alpha \times (t_a - t_o)^{1/4} \text{ kcal} / (m^2 \cdot h \cdot {}^\circ C) \quad \text{(1.9)}$$

Radiation heat transfer coefficient

$$h_r = 4.88 \times \varepsilon \times \{(273 + t_a)^4 - (273 + t_o)^4\} / 10^8 / (t_a - t_o) \text{ kcal} / (m^2 \cdot h \cdot {}^\circ C) \quad \text{(1.10)}$$

Heat release per unit area

$$h = (h_c + h_r) \times (t_a - t_o) \text{ kcal} / (m^2 \cdot h \cdot {}^\circ C) \quad \text{(1.11)}$$

where,

- t_a : Wall surface temperature
- t_o : Ambient temperature (10°C)
- ε : Emissivity $\varepsilon = 0.8$
- α : Coefficient related to the sense of the surface of natural convection heat transfer
  - Horizontal upward surface $\alpha = 2.8$
  - Horizontal downward surface $\alpha = 1.5$
  - Perpendicular surface $\alpha = 2.2$

According to the measurement of the wall temperature of the completely heat-insulated area, the temperature was about 65 °C in the area of about 200 m² on the inlet hot air duct and the dryer bottom, and was about 35 °C in the area of about 450 m² on the outlet hot air duct and the dryer top.

Thus, the heat release on the heat insulated area is given as follows:

$$11.3 \times 200 \times (65 - 10) + 9.5 \times 450 \times (35 - 10) = 124.200 + 106.400 = 230.600 \text{ kcal/h}$$

For the area where the insulation is damaged, the temperature was about 300 °C in the area of about 10 m² on the inlet hot air duct and dryer bottom, and was about 100 °C in the area of about 10 m² on the outlet hot air duct and dryer top.

Thus, heat release on the non-insulated area (insulation damaged) is as follows:

$$24.4 \times 10 \times (300 - 10) + 13.1 \times 10 \times (100 - 10) = 70,900 + 11,800 = 82,700 \text{ kcal/h}$$

The total heat release is : 230,600 + 82,700 = 313,300 kcal/h

e. Heat balance

Assume that the reference temperature is equal to the room temperature (10 °C).

[Heat input]

(1) Natural gas combustion heat $8{,}507 \times 333 = 2{,}832{,}800$ kcal/h

(2) Natural gas sensible heat 0 kcal/h

(3) Combustion air sensible heat 0 kcal/h

(4) Material slurry (50°C) sensible heat

Assume that the average specific heat of the solid content is 0.22 kcal/(kg · °C) and the specific heat of water content is 1 kcal/(kg · °C).

$$(0.22 \times 3{,}393 + 1 \times 2{,}262) \times (50 - 10) = 120{,}300 \text{ kcal/h}$$

(5) Feed blower

Eighty five percent of average input measurement of 16 kW is assumed as work heat.

$$16 \times 860 \times 0.85 = 11{,}700 \text{ kcal/h}$$

[Heat output]

(1) Exhaust hot air

Oxygen concentration of the outlet hot air is 17.88 %, and that of the inlet hot air is 17.20 %; they are very similar to each other. The outlet hot air is assumed to be composed of inlet hot air and the water content derived from material, and the dust corresponding to 5 % of the dried substance.

The components of inlet hot air are given by equations (1.3) to (1.6) as follows:

V_{O2} = 9.930 Nm³/Nm³-Fuel

V_{N2} = 44.838 Nm³/Nm³-Fuel

V_{CO2} = 0.994 Nm³/Nm³-Fuel

V_{H2O} = 1.984 Nm³/Nm³-Fuel = $1.9841 \times 18/22.4 = 1.594$ kg/Nm³

The following shows the specific heat (100 °C):

O_2	0.315	kcal/(Nm³ · °C)
N_2	0.311	kcal/(Nm³ · °C)
CO_2	0.412	kcal/(Nm³ · °C)
H_2O	0.45	kcal/(Nm³ · °C)

Thus, heat retained in exhaust gas (except for the dust) is as follows:

Heat content of the dry exhaust gas

$$333 \times (9.930 \times 0.315 + 44.838 \times 0.311 + 0.994 \times 0.412) \times (100 - 10)$$
$$= 523{,}900 \text{ kcal/h}$$

Heat content of water vapor in the exhaust gas

$$1.594 \times 333 \times 0.45 \times (100 - 10) + ((100 - 10) + 539.1) \times 2.121$$
$$= 1{,}355{,}000 \text{ kcal/h}$$

(2) Dried output

Assuming that the temperature of the dried output is 50 °C and that of dust is 100 °C.

$$(0.22 \times 3{,}393 + 1 \times 141.4) \{(50 - 10) \times 0.95 + (100 - 10) \times 0.05\}$$
$$= 37{,}700 \text{ kcal/h}$$

Table 5.1.11 shows the result of heat balance.

Table 5.1.11 Heat Balance Chart of Dryer

Item	kcal/h	%
Heat Input		
(1) Combustion heat of fuel	2,832,800	95.5
(2) Sensible heat of fuel	0	0
(3) Sensible heat of air	0	0
(4) Sensible heat of slurry	120,300	4.1
(5) Work done by blower	11,700	0.4
Total	2,964,800	100.0
Heat Output		
(1) Heat of dry exhaust gas	523,900	17.7
(2) Heat of water vapor	1,355,600	45.7
(3) Heat of product	37,700	1.3
Subtotal	1,917,200	64.7
(4) Heat emission from insulated zone	230,600	7.8
(5) Heat emission from noninsulated zone	82,700	2.8
Subtotal	313,300	10.6
(6) Other heat losses	734,300	24.8
Total	2,964,800	100.0

f. Study of heat balance

(1) Unit consumption rate

The following shows the unit thermal consumption rate for one ton of the products of this factory:

2,964,800/3.534 = 839,000 kcal/t-product

The following gives comparison with the values disclosed in Japan:

Example A (Note 1):

Water content of material about 40 %

Unit thermal consumption rate 500,000 to 1,500,000 kcal/t-product

Example B (Note 2):

Treated volume	2,500	kg-product/h
Material temperature	50	°C
Water content per dry material	65	%
Water content per dry product	7	%
Hot air flow rate	870	m^3/min
Hot air inlet temperature	230	°C
Hot air outlet temperature	90	°C

Unit thermal consumption rate

Assume that the specific heat of air is 0.3 kcal/(Nm^3 · °C).

$0.3 \times \{870 \times 273/(273 + 230)\} \times (230 - 20) \times 60/2{,}500$

=714,000 kcal/t-product

Simple comparison is difficult since the result depends on the size of the equipment. The unit consumption rate of this factory is on the same level as that introduced above.

(2) Impact of water content

The heat balance of Table 5.1.11 reveals that there are "other heat losses" amounting to about 734 Mcal/h., which corresponds to about 25 % of heat input, a considerable figure. The following discusses the water content of the slurry as material, which is considered to be a major cause for such losses.

In the heat output in the heat balance, heat content of water vapor in the exhaust gas is dominant. According the survey by hearing, water content of the material slurry changes within the range of 40 to 50 %. We could not get measurement data on the water content of the slurry in the present study. For our calculation we assumed 40%, which is the value set for that day.

As discussed in (2) B) e., the sensible heat provided by water content of the slurry is given by equation (1.10):

$$1 \times 2{,}262 \times (50 - 10) = 90{,}500 \text{ kcal/h} \quad \cdots\cdots (1.10)$$

Of the heat content of water vapor in the exhaust gas, the heat derived from the evaporation of slurry water is given by equation (1.11):

$$629.1 \times 2{,}121 = 1{,}334{,}100 \text{ kcal/h} \quad \cdots\cdots (1.11)$$

where 2,262 and 2,121 denote water content in the material and water content evaporated when the slurry water content is 40%, respectively.
The volume of water vapor generated from the slurry is given by (1.12):

$$Y = aX/\ (1-X) - b \quad \cdots\cdots (1.12)$$

where,	Y :	Water vapor from material	kg/h
	X :	Water content of material	%
	a :	Solid matter of the dried product	3,393 kg/h
	b :	Water content of the dried product	141.4 kg/h

Therefore, Table 5.1.12 shows the change of heat input and output due to the change in water content of the material. In this case, however, it is assumed that the conditions except for water content remain unchanged.

Note 1 : TOYODA Sadao, Petrochemical Vol.12 (1963), P.383
Note 2 : Courtesy of Chemical Industry Co.

Table 5.1.12 Change of Heat Balance by Water Content of Slurry

Water content of material	Slurry water		Vapor generated		Heat input	Heat output	Other losses	
	Volume	Latent heat	Volume	Potential heat				
(%)	kg/h	Mcal/h	kg/h	Mcal/h	Mcal/h	Mcal/h	Mcal/h	%
35	1,827	73	1,686	1,061	2,947	1,957	991	34
40	2,262	90	2,121	1,334	2,965	2,231	734	25
45	2,776	111	2,635	1,658	2,985	2,554	431	14
50	3,393	136	3,252	2,046	3,010	2,942	68	2

This table shows that impact of change in the water content on the heat balance is great; calculation of the water content on the basis of an estimated value is considered to be the cause for unidentified heat.

If the change in heat output with the water content in the range of 35 to 50% is assumed as a straight line, it corresponds to about 2.2 percent of the heat input for one percent of the water content. This suggests that adjustment in the volume of the water content is a very important task for energy conservation.

C) Problems of equipment and operation and their countermeasures

a. Inlet hot air flow rate

Figure 5.1.9 shows the flow of natural gas, Figure 5.1.10 the inlet hot air flow rate, Figure 5.1.11 the inlet hot air temperature and Figure 5.1.12 the outlet air temperature. Measuring points are given by ①, ② and ③ in Figure 5.1.5.

Figure 5.1.9 Fuel Gas Flow

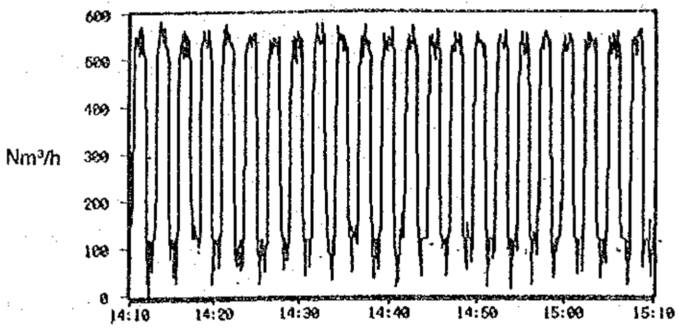


Figure 5.1.10 Inlet Hot Air Flow Rate

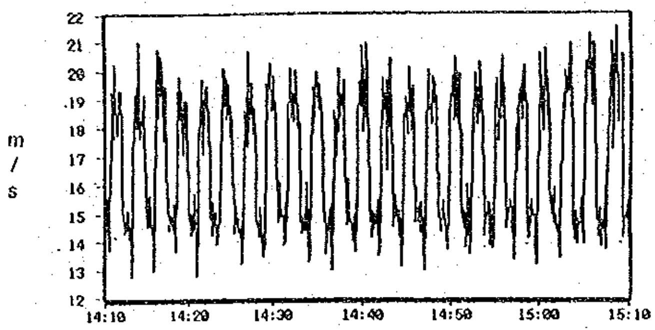


Figure 5.1.11 Inlet Hot Air Temperature

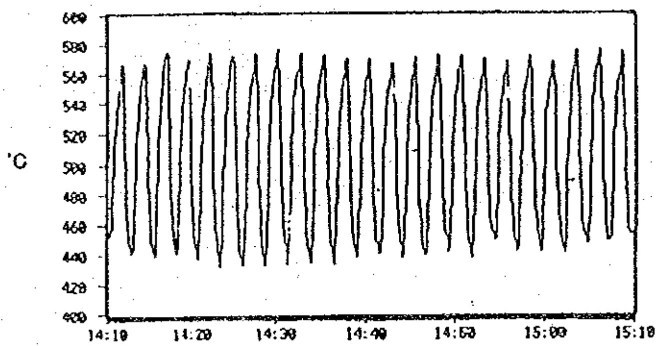


Figure 5.1.12 Outlet Air Temperature

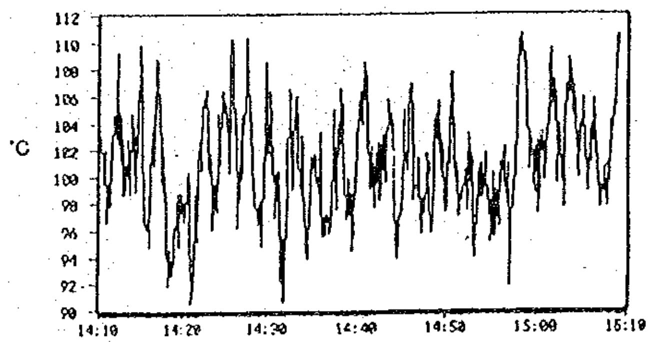


Figure 5.1.9 shows that the fuel gas flow changes from 0 to 580 Nm^3/h, Figure 5.1.10 indicates that the inlet hot air flow velocity changes from 13 to 22 m/s, and Figure 5.1.11 shows that the inlet hot air temperature changes from 430 to 570 °C, regularly at intervals of about 2 minutes. Outlet air temperature shown in Figure 5.1.12 changes irregularly from 90 to 110 °C, even though the variation of the changes is reduced by evaporation of a great amount of water.

The pulsation of the inlet hot air conditions is caused by the natural gas flow control method. The volume of inlet natural gas is controlled by the method where the opening of the natural gas control valve is set to a high or low position by the signal issued from thermometer T1. Judging from the measurements, it is considered to be working under the condition similar to on-off control condition. Therefore, both inlet hot air flow rate and temperature are pulsating. Affected by the fluctuation in the spray condition of the slurry, pulsation width of the outlet hot air temperature is made irregular. This suggests that the fluidized bed is very unstable.

Such a great pulsation of hot air conditions is not appropriate in the drying process. Especially in such a process of spray drying as the present process where the slurry forms the fluidized bed while being dried, it is necessary to stabilize the conditions for hot air as fluidized gas in order to maintain the stable fluidized bed. This is important for the quality control in maintaining the water content of the product within the set range and preventing the product from being overheated. Such a situation not only causes energy loss but also accelerates the combustion furnace and inlet hot air blower to be damaged, thereby reducing the service life of the equipment.

The problem can be solved by expanding the range of the proportional band of the controller for inlet natural gas or by changing the variation range from the current 0 ~ 580 Nm^3/h to 330 ± 30 Nm^3/h by supressing the maximum flow rate with the gas inlet valve, even in the case of two-position operation.

Regarding the variation of the slurry spraying condition which is another cause for lack of stability, it is necessary to maintain the spraying conditions stable by repairing the faulty rotation speed controller for high pressure slurry pump. It should also be noted that power consumption will be increased by using the bypass for the flow control of the high pressure slurry pump, without using the speed control.

If the fluid state within the dryer is made stable by the above mentioned measures, control of the quality including the water content of the product and apparent density will be facilitated.

b. Water content control

The following discusses how the production is affected by the water content of the slurry and product. Table 5.1.13 shows the calculation results for the cases where the water content of the slurry becomes 50 or that of the product becomes 10 %, compared with the case where the water content of the slurry is 40 % and that of the product is 5 %, and the volume of evaporated water content kept constant as the standard.

Table 5.1.13 Productivity Change by Water Content

Case		A	B	C
Water content of slurry	%	40	50	40
Water content of product	%	5	5	10
Dry matter in slurry	t	1.000	0.648	1.105
Water in slurry	t	0.667	0.648	0.737
Evaporated water	t	0.614	0.614	0.614
Water in product	t	0.053	0.034	0.123
Output of product	t	1.053	0.682	1.228

Increase of the water content in the slurry by 10 % causes the production to be reduced by 35 %, and increase of the water content in the product by 5 % causes the production to be increased by about 15 %.

To improve present situation, it is necessary to implement automatic adjustment of the water content in the slurry, to configure a water content analysis system, and to introduce an automatic recording system. At the same time, it is preferred to minimize the water content of the slurry by stabilizing the high pressure slurry temperature.

If the water content of the slurry can be reduced by 3 % in conformity to the above mentioned measures, the amount of natural gas used for one ton of the product can be reduced by about 7%.

c. Reduction of heat release from equipment surfaces

(1) Dryer

The hot air ducts on the upper and lower parts of the dryer were observed to have a total area of about 20 m^3 where insulations were damaged. Repairing of these insulations will reduce the heat release as follows:

Heat release before repair See the description in B) d.

$24.4 \times 10 \times (300 - 10) + 13.1 \times 10 \times (100 - 10) = 70{,}900 + 11{,}800$

$= 82{,}700$ kcal/h

Heat release after repair

$11.3 \times 10 \times (65 - 10) + 9.5 \times 10 \times (35 - 10) = 13,400 + 3,300$
$= 16,700$ kcal/h

Reduced heat release $82,700 - 16,700 = 66,000$ kcal/h

(2) High pressure slurry pipe

The slurry contains solid matters and has a high viscosity, so temperature control is crucial to ensure stable spray conditions. However, about 40 % of the slurry pipe subjected to the steam tracing has its heat insulations damaged, and steam was observed to be leaking from a few positions. This situation not only results in heat loss, but also hinders a stable supply of the slurry. An immediate action must be taken to repair such damages.

d. Equipment maintenance

The operation is mainly performed in the control room. The high pressure slurry pump, additive adjusting stage, additive measuring instrument and screen and spray nozzle are adjusted by the operator relatively frequently. The positions to be subjected to failure are limited to some extent, so it is necessary to check the cause of the failure and to take appropriate measures.

(1) Spray nozzle

The spray nozzle in particular has its heat insulation damaged seriously. This is because, when the operator is engaged in the adjustment work, his feet are placed on the heat insulation of the cone section of the dryer top. It is necessary to repair the heat insulation around the spray nozzle and to provide a scaffold for maintenance. This will considerably prevent the nozzle from being clogged and will ensure safe and easy adjustment works.

The nozzle maintenance procedures should be summarized in the form of a maintenance manual, and maintenance should be done on a periodic basis, rather than mere adjustment of the failure which has already taken place.

(2) Maintenance of standby equipment

The major equipment for the manufacturing process are provided with standby equipment. This process includes the snake pump for paste, slurry pump and spray nozzle. The standby equipment must be maintained according to the specified manual at all times.

Regarding the paste pump which caused the shutdown of the system in the course of the present study, the standby pump was not repaired. In order to ensure continuous operation, it is necessary to keep the standby equipment maintained and adjusted.

e. Pollution control measures

Much synthetic detergent powder is settled in each stage especially around the screen, dryer outlet and air lift outlet. The outlet of exhaust gas is located outdoors, and powder dissolves in rain water to enter the sewage, giving much load to the waste water treatment facilities.

Since the synthetic detergent powder which is settled in each stage is a product, some appropriate means must be considered to collect it. It would be effective to remove such powder by a cleaning flexible hose connected to the air lift pipe.

It is difficult at present to collect powder coming out of the exhaust gas outlet, but a dry or wet dust collector should be installed to form a closed cycle in future. Incidentally, powder is collected in Japan by a combined use of the bag filter and cleaning method.

(3) Boiler

This plant has four boilers, of which three are normally used for operation. Steam is supplied by two steam piping systems; 6-bar and 3-bar systems, and boilers play a major role as energy source for each process.

Fuel was converted from heavy oil to natural gas at the end of 1991. The fuel piping system is provided with safety measures against air shortage, gas fire extinction and pressure reducing valve failure.

To get feed water of the boiler, the well water is provided with ion exchange softening treatment.

However, the boiler is not provided with the feed water flow meter or fuel flow meter, raising problems of operation control. No problem was found in the boiler operation procedure.

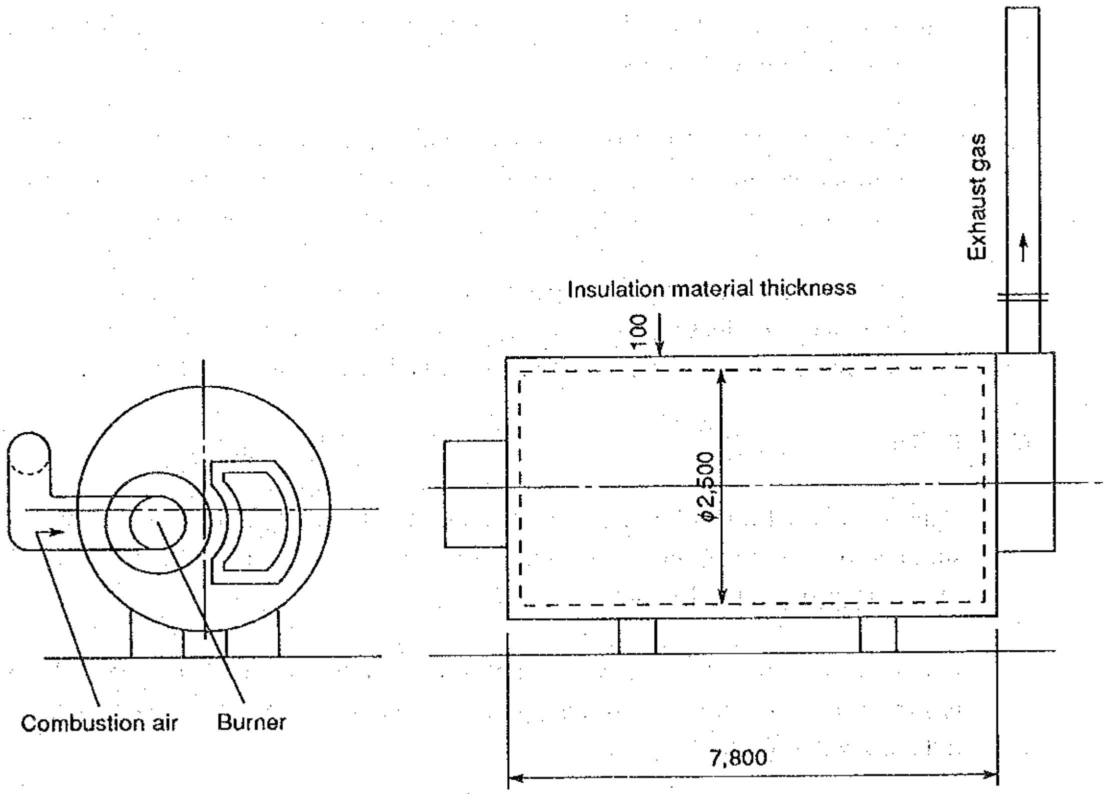
The boiler No. 1 was subjected to the performance test this time.

A) Boiler specifications

Type	: 3-pass flue and smoke tube boiler
Steam amount	: 12 tons per hour

Steam pressure : 12 bars (rated)
Fuel : Natural gas (HI 8,507 kcal/Nm³)
Composition : CH_4 = 98.66 % C_2H_6 = 0.33 % n-C_4H_{10} = 0.02 %
N_2 = 0.96 % CO_2 = 0.03 % RSH = 25 mg/Nm³
Year of manufacture : 1972
Structure : See Figure 5.1.13 Boiler Structure.

Figure 5.1.13 Boiler Structure



B) Heat balance

a) The heat balance of the boiler is based on the data measured on March 9, 1993 (from 14:20 to 15:20). The following shows the data:

1) Fuel type : Natural gas
2) Fuel consumption (See (b).) : 713.9 Nm³/h
3) Calorific value of fuel : 8,507 kcal/Nm³
4) Fuel temperature : 12.5 °C
5) Ambient temperature : 3.0 °C
6) Combustion air temperature : 16.0 °C
7) Oxygen (%) in dry exhaust gas : 6.2 %
8) Carbon dioxide (%) in dry exhaust gas : 8.68 %
9) Carbon monoxide (%) in dry exhaust gas : 0.045 %

10) Exhaust gas temperature : 177.1 °C
11) Feed water : 8.56 t/h
12) Feed water temperature : 14.5 °C
13) Steam pressure : 4.6 kg/cm²
14) Boiler surface temperatures
    Front plate 49.2 °C
    Shell plate 40.9 °C
    Rear plate 37.2 °C

The instantaneous variation in the amount of feed water during the measuring period was recorded to be in the range from 9.32 m³/h (maximum) to 7.98 m³/h (minimum), and the variation range of the exhaust gas temperature was also within ±2 °C. This indicates small load variations and stable operation.

b) Calculation of heat balance

Heat balance is calculated per Nm³ of fuel. The fuel flow rate shows a variation of ±30 %. The variation range went over the measuring range of the measuring instrument, and accurate measurements could not be obtained. So the heat loss method was used for heat balance calculation.

[Heat input]

① Fuel low-level calorific value H1 8,507 kcal/Nm³-Fuel

② Fuel sensible heat Q_1

$Q_1 = C_f \times (t_f - t_0)$ kcal/Nm³-Fuel

$= 0.37 \times (12.5 - 3.0)$

$= 3.56$ kcal/Nm³-Fuel

where,

C_f : Average fuel specific heat kcal/(Nm³ · °C)

t_f : Fuel temperature °C

t_0 : Ambient air temperature °C

③ Air sensible heat Q_2

$Q_2 = A \times C_a \times (t_a - t_0)$ kcal/Nm³-Fuel

$A = m \times A_0$ Nm³/Nm³-Fuel

$A_0 = (2CH_4 + 3.5C_2H_6 + 6.5C_4H_{10}) / 21$ Nm³/Nm³-Fuel

$= (2 \times 98.66 + 3.5 \times 0.33 + 6.5 \times 0.02) / 21$

$= 9.46$ Nm³/Nm³-Fuel

$$m = \frac{21}{21 - 79 \times \frac{(O_2) - 0.5 \times (CO)}{(N_2)}} \times [1 + \{(O_2)/(N_2)\} \times \{n_2/(21A_0)\}]$$

$$= \frac{21}{21 - 79 \times \frac{(6.2) - 0.5 \times 0.045}{85.08}} \times [1 + \{6.2/85.08\} \times \{0.96/(21 \times 9.46)\}]$$

$= 1.39$

$A = 1.39 \times 9.46$

$= 13.11$ Nm^3/Nm^3-Fuel

$Q_2 = 13.11 \times 0.31 \times (16.0 - 3.0) = 52.82$ kcal/($Nm^3 \cdot$ °C)

where,

A	: Amount of air per Nm^3 of fuel	Nm^3/Nm^3-Fuel
C_a	: Average air specific heat	kcal/($Nm^3 \cdot$ °C)
t_a	: Combustion air temperature	°C
m	: Air ratio	
A_0	: Theoretical air amount	Nm^3/Nm^3-Fuel
(CO_2)	: Carbon dioxide (%) in dry exhaust gas	%
(O_2)	: Oxygen (%) in dry exhaust gas	%
(CO)	: Carbon monoxide (%) in dry exhaust gas	%
(N_2)	: Nitrogen (%) in dry exhaust gas	%
	$= 100 - \{(CO_2) + (O_2) + (CO)\}$	
	$= 85.08$	
n_2	: Nitrogen content (%) in fuel gas	%

④ Total heat input Q_i

$Q_i = H\ell + Q_1 + Q_2 = 8{,}507 + 3.55 + 52.82 = 8{,}563.37$ kcal/Nm^3-Fuel

[Heat output]

① Heat absorbed by generated steam (effective heat output) Q_s

$Q_s = W_1 \times (h_2 - h_1)$

$= 11.99 \times (647.10 - 14.5) = 7585.47$ kcal/Nm^3-Fuel

$W_1 = W/F = 8{,}560/713.93 = 11.99$ kg/Nm^3-Fuel

$h_2 = h_3 - (1.00 - x) \times r$

$= 657.14 - (1.00 - 0.98) \times 501.78 = 647.10$ kcal/kg

where,

W_1	: Amount of feed water per Nm^3 of fuel	kg/Nm^3-Fuel
W	: Amount of feed water per hour	kg/h
F	: Amount of fuel gas per hour	Nm^3-Fuel/h
h_1	: Feed water enthalpy	kcal/kg
h_2	: Generated steam enthalpy	kcal/kg

h_3 : Saturated steam enthalpy kcal/kg

x : Generated steam dryness

r : Latent heat of evaporation kcal/kg

② Retention heat loss of exhaust gas (including water vapor) L_1

$L_1 = G \times C_g \times (t_g - t_0)$ kcal/Nm³-Fuel

$G = G_0 + G_w + (m - 1) \times A_0$ Nm³/Nm³-Fuel

$G_0 = [\,(4.76 \times 1 + 0.94 \times 4) \times 98.66$

$+ (4.76 \times 2 + 0.94 \times 6) \times 0.33$

$+ (4.76 \times 4 + 0.94 \times 10) \times 0.02 + 0.96 + 0.03]/100$

$= 8.75$ Nm³/Nm³-Fuel

$G_w = (4CH_4 + 6C_2H_6 + 10C_4H_{10})\ /200$

$= (4 \times 98.66 + 6 \times 0.33 + 10 \times 0.02)\ /200$

$= 1.98$ Nm³/Nm³-Fuel

$G = 8.75 + 1.98 + (1.39 - 1) \times 9.46$

$= 14.30$ Nm³/Nm³-Fuel

$L1 = 14.30 \times 0.33 \times (177.1 - 3.0)$

$= 821.77$ kcal/Nm³-Fuel

where,

G : Actual amount of exhaust gas per Nm³ of fuel (including water vapor) Nm³/Nm³-Fuel

G_0 : Theoretical amount of dry exhaust gas Nm³/Nm³-Fuel

G_w : Amount of water vapor generated by combustion Nm³/Nm³-Fuel

C_g : Average specific heat of exhaust gas (Generally, 0.33 kcal/(Nm³. °C)) kcal/(Nm³. °C)

t_g : Exhaust gas temperature °C

t_0 : Ambient air temperature °C

m : Air ratio

A_0 : Theoretical air amount Nm³/Nm³-Fuel

③ Dissipated heat loss L_2

$L_2 = 29.44$ kcal/Nm³-Fuel

Table 5.1.14 Heat Loss from Boiler Surface

Part	Temperature (°C)	Surface area (m^2)	Heat loss [kcal/(m^2·h)]	Heat loss (kcal/Nm^3-Fuel)
Front plate	49.2	5.70	321.65	2.57
Shell plate	40.9	79.71	225.23	25.20
Rear plate	37.2	5.70	208.61	1.67
Total				29.44

Note: For the shell plate, 1/4 of the surface area was assumed as the top area, and 1/2 of it as the side wall, and 1/4 of it as the bottom. Furthermore, the heat loss was calculated from equations (1.9) to (1.11), assuming $\varepsilon = 0.8$.

④ Other heat losses L_3

$$L_3 = Q_i - (Q_s + L_1 + L_2)$$
$$= 8{,}563.37 - (7{,}585.47 + 821.77 + 29.44)$$
$$= 126.69 \quad \text{kcal/Nm}^2\text{-Fuel}$$

Note : According to the boiler heat balance method specified in the Japanese Industrial Standards (JIS), 1.4 % is indicated as a reference value for other losses of the about 10 tons per hour-capacity boiler. We used this value to calculate back the heat input amount.

⑤ Total heat output Q_0

$$Q_0 = Q_s + L_1 + L_2 + L_3$$
$$= 7{,}585.47 + 821{,}77 + 29.44 + 126.69$$
$$= 8{,}563.37 \quad \text{kcal/Nm}^2\text{-Fuel}$$

c) Heat balance chart

The above can be summarized as given in Table 5.1.15.

Table 5.1.15 Heat Balance Chart of Boiler

Item		kcal/Nm³	%
Heat Input			
(1) Calorific value of fuel	Hl	8,507.00	99.34
(2) Sensible heat of fuel	Q_1	3.55	0.04
(3) Sensible heat of air	Q_2	52.82	0.62
Total	Q_i	8,563.37	100.00
Heat Output			
(1) Heat absorbed by generated steam(Effective heat output)	Q_s	7,585.47	88.58
(2) Exhaust gas retention heat	L_1	821.77	9.60
(3) Radiated heat loss from surface	L_2	29.44	0.34
(4) Other heat losses	L_3	126.69	1.48
Total	Q_o	8,563.37	100.00

C) Boiler water quality control

The feed water and boiler water quality was as shown in Table 5.1.16.

The raw water quality in this plant has been found to be excellent; both the pH value and electric conductivity of feed water and boiler water indicated favorable values.

Table 5.1.16 Quality of Feed Water and Boiler Water

	Raw water		Soft water		boiler water	
	pH	Electric conductivity μS/cm	pH	Electric conductivity μS/cm	pH	Electric conductivity μS/cm
Measurement	7.72	0.48	8.10	0.53	11.5	3.00
	7.28	0.50	7.46	0.53	11.2	2.92
	7.34	0.51	7.38	0.52	10.4	3.23
Standard			7.0−9.0		11.0−11.8	4.5

Note: The standard value is based on JIS B 8223-1989 "Boiler feed water and boiler water quality".

D) Operation control

a) No boiler was provided with a feed water flow meter and fuel flow meter. At least these meters must be installed for boiler operation control. Their installation will give correct information on the relationship between the amount of generated steam (amount of feed water) and the amount of fuel, namely, the evaporation multiple (amount of feed water/amount of fuel).

   This evaporation multiple serves as a substitute index to represent heat efficiency. It should be made into a control chart for easy reading of the long-term trend, and should be checked at all times. If any reduction is observed in the graph, corrective actions such as cleaning of the heat transfer pipe should be taken.

   Furthermore, a steam pressure gauge should be installed on each collector.

b) Hourly amount of feed water, used fuel, blow-off time point and time duration, and evaporation multiple should be described in the boiler operation journal. These data must be used to arouse the interest of the boiler operators in more effective operation.

E) Air ratio improvement

Heat loss due to exhaust gas is the greatest of all boiler heat losses. To reduce heat loss due to exhaust gas, the amount of exhaust gas must be reduced. This can be achieved by adjusting the amount of combustion air.

The current oxygen concentration in the exhaust gas is 6.20 % and air ratio is 1.39. The amount of air is not very great. However, the standard air ratio in Japan is considered as 1.2 to 1.3 when gas fuel is used for combustion in the boiler where the hourly amount of evaporation is over 10 tons up to 30 tons.

Furthermore, it is not difficult to reduce oxygen concentration down to 4.2 % by careful adjustment of the air ratio. As a result, the air ratio will be 1.25, and the amount of exhaust gas can be reduced about 8.4 %, as given in Table 5.1.17.

Table 5.1.17 Reduction of Exhaust Waste Heat by Improving Air Ratio

Item	Unit	Present	Improved
Amount of oxygen in exhaust gas	%	6.20	4.20
Air ratio		1.39	1.25
Theoretical amount of air	Nm^3/Nm^3	9.46	9.46
Theoretical amount of dry exhaust gas	Nm^3/Nm^3	8.75	8.75
Actual amount of air	Nm^3/Nm^3	13.11	11.821
Actual amount of exhaust gas	Nm^3/Nm^3	14.30	13.098
Exhaust gas temperature	℃	177.1	177.1
Amount of exhaust retention heat	$kcal/Nm^3$	821.77	752.69

The ratio of amount of fuel to the amount of air is currently controlled by the link mechanism. The amount of air can be reduced by changing the set values. This action does not require investment for equipment installation.

The fuel saving ratio (S) by this efforts for reduction in air ratio can be calculated according to the following equation and Table 5.1.17.

$$S = 1 - \frac{Q_i - L_1}{Q_i - L_{1i}} = 1 - \frac{8{,}563.37 - 821.77}{8{,}563.37 - 752.69} = 0.0089 = 0.89\ \%$$

where,

Q_i : Heat input per Nm^3 of fuel — $kcal/Nm^3$-Fuel

L_1 : Amount of exhaust retention heat — $kcal/Nm^3$-Fuel

L_{1i} : Amount of exhaust retention heat after improvement — $kcal/Nm^3$-Fuel

Assuming that other boilers are also under the same conditions, and that the annual amount of the fuel used for boilers is 5,000,000 Nm^3, the amount conserved can be calculated as follows:

5,000,000 $Nm^3/y \times 0.0089 = 44{,}500\ Nm^3/y$

F) Reinforcement of heat insulation

The surface temperature of the boiler proper is low, and the heat insulation can be said to be sufficient. Actually, however, heat released from the lever type safety valve, steam valve, etc. is added to the measured value, thereby increasing the dissipated heat loss.

Heat insulation is not provided at the connecting pipes between steam collectors in the boiler room and steam pipe, and the valve. Immediate actions must be taken to provide heat insulation.

Heat insulation of the valve is expected to provide a substantial reduction in the loss of heat from surface. Table 5.1.18 shows the current area for loss of heat from surface.

Table 5.1.18 Heat Radiation from Steam Valve

Size inch	Equivalent length m	Number	Heat Radiation kcal/h Present	after Insulated	Decrease
10	1.68	4	14,940	4,370	10,600
6	1.50	12	24,720	7,230	17,500
4	1.27	4	4,830	1,410	3,400
3	1.25	2	1,850	540	1,300
$2\frac{1}{2}$	1.23	1	780	230	600
2	1.11	2	1.120	330	800
		Total	48,230	14,110	34,200

The following equation has been used to calculate the heat release from surface:

$Q = \pi \times d \times \alpha \, (t_1 - t_2)$

where,

Q	: Heat release from surface	kcal/ (m · h)
d	: Pipe diameter	m
α	: Heat transfer coefficient	18 kcal/ (m² · h · °C)
t_1	: Pipe surface temperature	164 °C (where steam pressure is assumed to be 6 kg/cm²)
	After heat insulation	60 °C
t_2	: Temperature in the room	17 °C

The reduction of the heat release from surface amounts to 34,200 kcal/h. When this is converted into the loss of steam and natural gas, the following result is given:

If the latent heat of evaporation of 6 kg/cm³ (G) is assumed to be 493.8 kcal/kg;

34,200 kcal/h × 24 h/d × 200 d/y × 1/493.8 kg/kcal
= 332 t-steam/y

The fuel required to generate one ton of steam is 83.4 Nm³/t, so;

332 × 83.4 = 27,730 Nm³/y

The value of reduced fuel cost is;

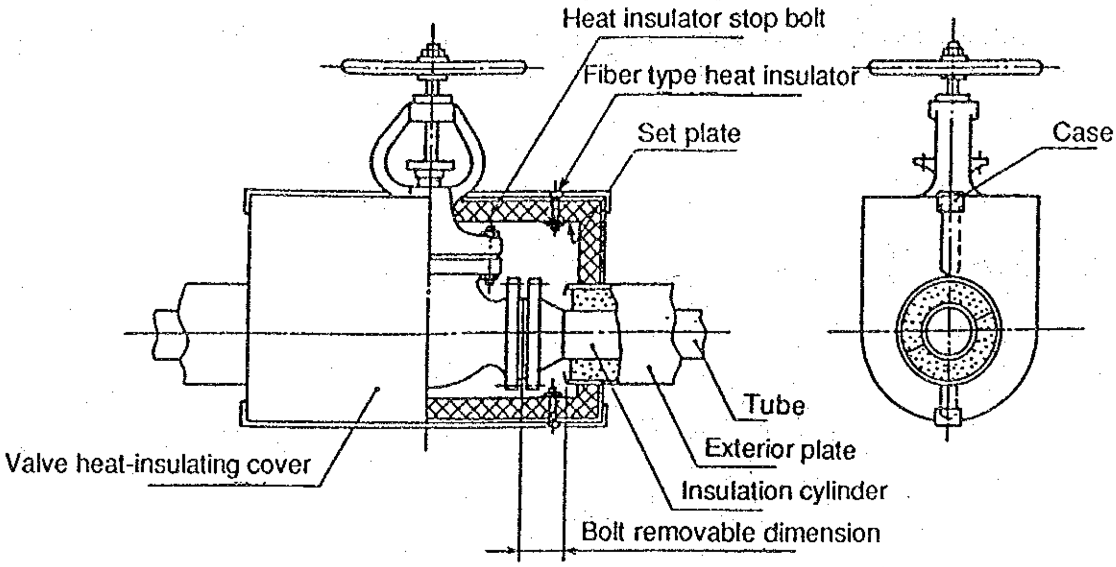
27,730 Nm³/y × 2.2 Lv/Nm³ = 61,600 Lv/y

To provide heat insulation, place wooden frames on large valves, and fill them with rock wool. For the small valves or flanges, put rock wool around them and wind them with water proof cloth. When they are placed outdoors, it is essential to cover them with iron plates and aluminum plates in order to protect them against rain. (See Figure 5.1.14)

Since this repair can be done by employees in the plant, and the material cost is only about 1,000 Lv, this investment can be recovered in a short period of time.

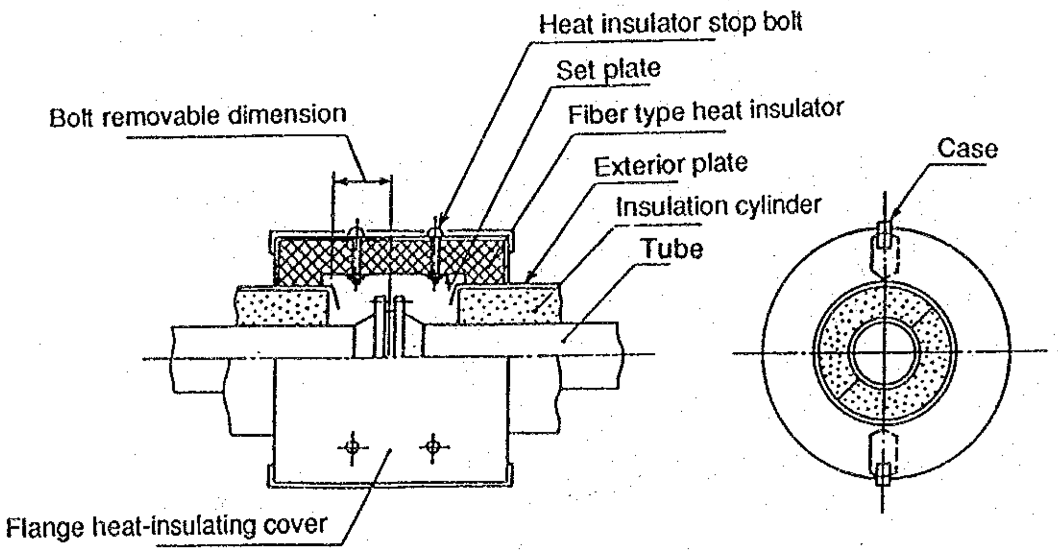
Figure 5.1.14 Insulation of Valve & Flange

Heat Insulation of Valve



Details of case

Heat Insulation of Flange



(4) Steam piping

On March 11, the day following the boiler performance test, the boilers were operating under normal conditions even if almost all the production equipment were stopped. We measured the amount of the feed water at the outlet of the feed water head tanks of all boilers, and obtained the value of 16 tons per hour (amount of generated steam). This is considered to be caused by the leakage from the room heating equipment and material tank heating pipe and steam pipe, and loss of heat from the damaged portion of the heat insulation materials. Immediate actions must be taken to repair them.

As in this plant, where the plant site is wide and production processes are different, it should be divided into blocks to repair steam leakages and insulation material damages. At the same time, the unused pipes should be removed.

A) Pipe adjustment

The plant site is wide and is provided with a great variety of production equipment using steam. Steam is supplied by two steam piping systems; 6-bar and 3-bar systems. So the main pipe has a very long distance.

The piping length from the boiler to the production equipment should be minimized in order to the minimize the heat loss.

One 10-inch steam pipe and two 6-inch steam pipes are laid in parallel over the distance of about 350 meters in the space between the boiler and the synthetic detergent drier room. In the case of 6-bar steam piping system, the former pipe has a steam transport capacity of about 13 tons per hour, while the latter pipe has a transport capacity of about 22 tons per hour. However, these capacities are considered to be excessive under the current production conditions.

Table 5.1.19 shows the amount of heat loss from this pipe:

Table 5.1.19 Heat Loss from Steam Pipe

Diameter inch	Length m	Inner Temp ℃	Heat Loss kcal/(m·h)	kcal/h	Steam Loss kg/h
10	350	164	94.8	33,200	67
6	350	164	64.8	22,700	46

The calculation is based on the following:

Heat insulation by 60 mm glass wool, provided with outer aluminum plate and the ambient temperature of 0 °C

Thus, if three pipes are united into one pipe, the steam loss can be reduced from 159 kg/h to 46 through 67 kg/h. If operation time is 8,000 hours per year, the difference will reach 740 through 900 tons per year. The similar situation is found in the distance of about 250 meters in the direction of the nonionic activator plant, where three to six 3- to 10-inch pipes are laid in parallel.

When the steam is not used, it is recommended to shut off the master valve on the boiler side in order to prevent heat release from surface. However, residual condensate may freeze in winter, causing damage of the pipes. So it is necessary to eliminate the condensate completely. When reheating the pipes which have been cooled completely, it is necessary to use steam of 760 kg in order to heat the 10-inch pipe with a length of 350 meters to 164°C, and to use steam of 360 kg in the case of the 6-inch pipe. So whether the master valve should be shut off or not depends on how long the steam is not used.

It is recommended to integrate the pipes into a 6-bar piping system, and to install the reducing valves at the positions where steam is used, so that the pressure can be reduced according to the application.

The recent trend is that, instead of a central large boiler, small boilers are installed close to the position where steam is used, thereby eliminating use of long steam pipes. Furthermore, it is also a common practice to replace the steam heating by the gas-fired hot air heater in order to heat the place far away from the central part.

B) Optimizing the steam pressure

When meeting the low-temperature heat requirements such as heat retention of vessels in the production equipment or space heating, it will conserve fuels to reduce steam pressure. Evaporation latent heat of the steam is increased at lower pressure, resulting in smaller amount of heat content of condensate. It is recommended to use the minimum possible steam pressure.

For instance, when heat of about 120 °C is required, the 6-bar steam system should be replaced by the 3-bar steam system. Then the latent heat per ton will be increased by 3.3 %, resulting in reduction in the amount of used steam by 3.3 %.

C) Preventing the steam leakage

The outdoor pipe steam leakage is extreme. Especially, in the ground piping on the railway side, almost all the insulation materials of the steam leakage positions are damaged and peeled by steam, resulting in dual heat loss. Even a slight steam leakage, if left unrepaired, will cause wear to be made worse gradually by the steam which passes by the clearance parts at almost the acoustic velocity. This will result in increased amount of leaked steam. So it is essential to take earlier actions to repair them.

The amount of steam leakage can be calculated by the following approximate equation:

$G = 0.5484 \times A \times P^{0.97} \times f$

where,

G	:	Amount of leaked steam	kg/h
A	:	Hole area	mm^2
P	:	Absolute steam pressure	kg/cm^2
f	:	Blowout coefficient (0.8 for piping and valve)	

For example, steam leakage from 10 positions each having a hole of 0.5 mm in diameter is calculated as follows:

Assuming that steam pressure is 6 kg/cm^2 and steam feed time is 4,800 hours per year, then:

$G = 0.5484 \times 0.196 \times 6.63 \times 0.8 \times 10 \times 4{,}800 = 27.4$ t/y

This means that about 27.4 tons of steam is wasted every year.

D) Preventing heat release from pipe surface

a) Current heat insulation

Outdoor heat insulations of the elevated main pipes are generally satisfactory. However, the pipes branched off to the production equipment and steam trace pipes in the acceptance/shipment station are uncovered. As discussed earlier, insulation materials at several steam leaking positions of the ground pipe on the railway side are damaged and peeled off. The outer casing of the insulation materials of some of the outdoor tanks was damaged. If the outer casing is damaged, the insulation material will absorb moisture. The heat conductivity of water is about 0.5 kcal/(m · h · °C); this value is 10 times that of the insulation material, which is 0.05 kcal/(m· h · °C). The result is a great increase in heat loss. Immediate actions must be taken to repair them.

E) Installation of steam trap

a) Necessity of steam trap

Almost no steam trap is installed. The condensate is considered to be discharged from the equipment by manual operation of valves, or the condensate is left to blow. For example, the condensate of the steam collector in the boiler room is discharged manually by valve operations, so it is left to intermittent blow. The steam trace pipe in oil receiving station and the heating pipe in the instrumentation room are not provided with steam trap, so they are always subjected to blow.

In the case of steam heating, when steam retention heat is transmitted to the object to be heated, then the entire steam will become condensate. Heat transfer can be prevented if it is left in heater. In the steam transport pipe, water hammering may occur without removing the generated condensate. If this condensate enters the equipment, the heat transfer efficiency will be reduced.

To solve these problems, it is essential to discharge only the condensate immediately, without allowing uncondensed steam to escape. This adjustment is difficult with manual operation. It is necessary to install the steam trap in order to solve this problem.

Steam trap of Armstrong Inc. is under test in this factory. It is recommended that, based on the test result, the steam traps will be installed, firstly on the main equipment, then on other equipment.

In Bulgaria, there is a case where steam consumption has been reduced 30 to 40 % by installation of the steam trap. So reduction of at least about 10 % is not difficult. If steam traps are installed at 100 positions, the cost is estimated at about 700,000 Lv. Assuming that 10 % of the boiler fuel is conserved, the amount will be calculated as follows:

$$5{,}000{,}000\ Nm^3/y \times 0.1 \times 2.2\ Lv/Nm^3 = 1{,}100{,}000\ Lv/y$$

Thus, the investment can be recovered in a short time.

b) Selecting the steam trap

Generally, the mechanical trap is to be recommended. To determine the steam trap, it is necessary to get correct information on the amount of condensate produced. In the case of the steam transport pipe, the amount of condensate produced at the time of starting up should be used as a standard when determining the steam trap capacity, based on intervals of traps and start-up time. The steam traps of the steam transport pipe should be installed at intervals of 30 to 50 meters.

For example, when the saturated steam of gauge pressure of 6 bars is to be sent to the 8-inch main pipe, the amount of the condensate generated of every meter of the pipe is 1.65 kg per hour while the pipe is heated from the initial temperature of 0 °C to the steam temperature. When start-up is to be completed in 30 minutes, the condensate must be discharged at the rate of 3.3 kg per hour for every meter of the pipe. In the case of the production equipment, the required calorific value of heat is converted into the amount of steam. Then the amount of the condensate is determined. Actually, the capacity of the steam trap is determined by multiplying this amount of the condensate by 2 or 3 to ensure safety.

c) Steam trap installation

Steam traps should be installed on the bottom of the riser, or on the position before the reducing valve, or on the condensate separator. The following care should be taken so that natural flow of the condensate will not be disturbed:

① Install the mechanical steam trap horizontally at the correct position.

② The steam trap inlet pipe should form a downward slope toward the steam trap.

③ No riser is allowed to be laid between the water discharge point and the steam trap.

④ The inlet pipe should be as large as possible, with the minimum bend.

⑤ In the case of the outdoor installation, sufficient measures should be taken to prevent freezing.

d) Steam trap maintenance control

① When the steam trap is placed in service for a long period of time, the inside valve and valve seat will be worn, and steam will be discharged together with the condensate. The service life of the steam trap is said to be 3 to 5 years generally, though it depends on the type. So steam traps must be considered as consumable parts and replaced on a periodic basis.

② The steam trap must be subjected to periodic inspection once a year, and should be disassembled and cleaned as required. To perform periodic inspection, prepare steam trap layout drawing, control register and check list, and record the results.

③ The steam trap failure is classified in three factors; blowing, discharge failure, and steam leakage. When the condensate is discharged into the atmosphere close to the steam trap, the failure can be easily detected by visual observation. When the discharge position is not directly visible, for example, when the condensate is recovered, put on gloves, and hold the inlet pipe and outlet pipe of the steam trap by hands to check the temperature to see if it is operating.

(5) Control of space heating

As can be seen from Figure 5.1.1, the amount of the fuel used in winter is more than twice that used in summer. This shows how big the energy consumption for space heating is.

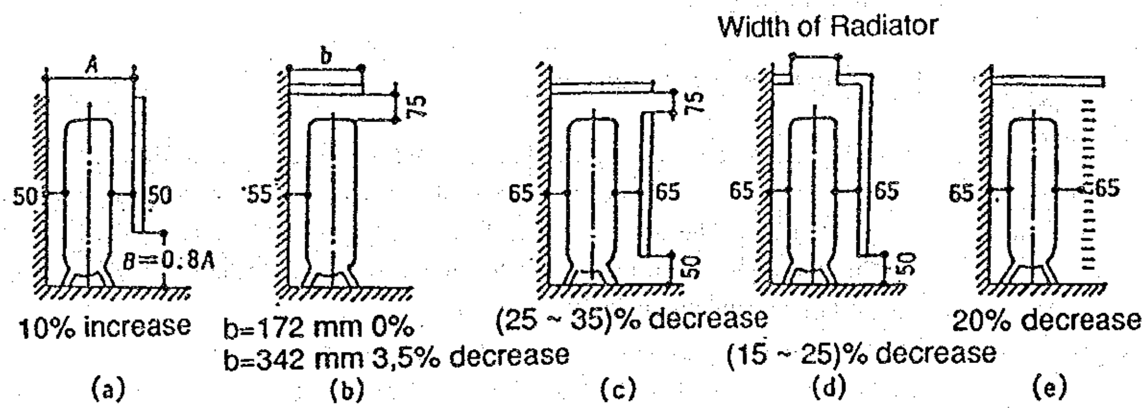
Heating temperature in the office, instrumentation room and resting place is excessive. Room temperature is adjusted by opening the window, while the room heater is kept turned on. The steam pressure for space heating should generally be 0.1 to 0.5 kg/cm^2 in the small building, and 1 to 3 kg/cm^2 in the large building and factory.

Small type mechanical steam traps or thermostatic ones will be effective for the radiator and convector.

The radiator of the office should be installed 50 to 60 cm away from the wall side below the window. This is to protect against cold drift from the window glass surface and cold wind coming through the window gaps. Figure 5.1.15 shows the change of the heat losses depending on installation method. The installation given in (a) provides the optimum heating effect.

When the small building requiring room heating is far from the main steam pipe, much steam will be lost through the branch pipe. So it is recommended to study the use of the individual room heating method, including the electric heater, kerosene oil and gas heater.

Figure 5.1.15 Heating Effect by Radiator Setting



(6) Power receiving, distribution and electric equipment

A) Overview of the electric equipment in the plant

The electric power of 110 kV is supplied from an extra high-voltage line. It is stepped down to 20 kV and is supplied to eight substations in the plant. Supply of high-voltage electric power is intended to reduce the loss of electric power. One 110/20 kV transformer with a capacity of 6,300 kVA is installed to receive power, and one or two 20/0.4 kV transformers with a capacity of 160 to 1,000 kVA are placed in each eight substations, with a total of 13 transformers with a total capacity of 10,680 kVA to supply power to each process in the plant. It also receives standby power from a utility company through the 20 kV extra high voltage line.

Figure 5.1.4 illustrates the electric power one line diagram, and Table 5.1.20 shows the monthly electric power consumption for each substation.

Table 5.1.20 Monthly Electric Power Consumption by Substation

Station	Receiving	Substation							
		2	3	4	5	7	8	9	10
Transformer	6300	1000	1000	1000	630	1000	160	630	1000
(kVA)		1000		1000	630			630	1000
Month	MWh	MWh	MWh	MWh	MWh		MWh	MWh	MWh
1	786	180	120	175	150		46	78	37
2	788	186	75	178	145		48	75	81
3	647	150	74	150	135		46	50	42
4	508	115	70	75	120		47	35	46
5	477	72	98	58	100		52	45	52
6	493	100	75	78	102		54	47	37
7	445	87	77	63	105		58	21	34
8	358	52	50	45	75		59	35	42
9	454	80	62	68	105		56	35	48
10	475	65	88	63	108		68	38	45
11	575	136	95	110	102		46	38	48
12	661	162	75	165	100		44	58	57
4-9	2735								
10-3	3932								
Total	6667	1385	959	1228	1347		624	555	569
%	100	21	14	18	20		9	8	9

Compared with the power receiving capacity of 6,300 kVA, the maximum power demand at the time of the present study was 1,650 kW, and the load factor is as low as 29 %. So in four of the five substations where two transformers are installed, one transformer is cut off to reduce the iron loss.

The expected volume of conserved power is the sum of decrease in iron loss and increase in copper losses.

The following shows the saved amount of power calculated from power consumption in Table 5.1.20 and characteristics of transformers in Table 5.1.21, assuming power factor as 0.9.

Table 5.1.21 Characteristics of Transformers

No	Capacity kVA	Iron loss W	Copper loss W
1	6300	6231	56000
2,3,4,7,10	1000	2100	12750
5,9	630	1440	8500
8	160	500	2820

Decrease of iron loss

(2.1 kW × 3 units + 1.44 kW × 1 unit) × 8,760 h/y = 67,802 kWh/y

Increase of copper loss

No. 2 transformer

12.75 kW × (1,385 MWh/8,000 h/0.91/1,000 kVA) ^{2} × (1 – 2/2^2) × 8,000 h/y
= 1,846 kWh/y

No. 4 transformer

12.75 kW × (1,228 MWh/8,000 h/0.91/1,000 kVA) ^{2} × (1 – 2/2^2) × 8,000 h/y
= 1,451 kWh/y

No. 9 transformer

8.50 kW × (555 MWh/8,000 h/0.91/630 kVA) ^{2} × (1 – 2/2^2) × 8,000 h/y = 498 kWh/y

No. 10 transformer

12.75 kW × (596 MWh/8,000 h/0.91/1,000 kVA) ^{2} × (1 – 2/2^2) × 8,000 h/y
= 312 kWh/y

Annual reduction of electric power

67,802 – (1,846 + 1,451 + 498 + 312) = 63,696 kWh/y

B) Improvement countermeasures and effects

a) Transformer operation improvement

In four of the five substations where two transformers are installed, one transformer is cut off to reduce the iron loss.

In No. 5 substation, two transformers are operating, but according to the actual load conditions, one transformer is sufficient for the purpose.
The following shows reduction in electric power to be achieved by integration of transformers.

Decrease of iron loss

$1.44\ kW \times 8{,}760\ h/y = 12{,}614\ kWh/y$

Increase of copper loss

$850\ kW \times (1{,}347\ MWh/8{,}000\ h/0.91/630\ kVA)^2 \times (1 - 2/2^2) \times 8{,}000\ h/y$
$= 2{,}933\ kWh/y$

Annual reduction of electric power

$12{,}614 - 2{,}933 = 9.681\ kWh/y$

b) Load shift from peak time zone

The maximum contracted power during the peak time zone was controlled to 1,320 kW at the time of the present study. The personnel in charge of the electric power measures the power meter every hour; if the maximum power is likely to be exceeded, he cuts off the specified load circuits (① 100 kW for ferment tank, ② three 22 kW pumps and ③ 80 kW for lithium grease process).

Table 5.1.22 shows electric power tariff for the peak time zone, in the daytime and at night. It shows that the unit cost of the electric power during the peak time zone is about 1.85 times that in the daytime, and about 3.75 times that at night. About 170,000 Lv per year can be saved by shifting the process operation time by one hour.
It is recommended to work out the production schedule with consideration given to this fact.

$(1.217 - 0.655)\ Lv/kWh \times 2{,}735\ MWh/4{,}392\ h \times 183\ d$
$+ (1.395 - 0.754)\ Lv/kWh \times 3{,}932\ MWh/4{,}368\ h \times 182\ d = 169{,}062\ Lv/y$

Table 5.1.22 Electric Power Tariff

Lv/kWh	April-September	October-March
Day time	0.665	0.754
Peak time	1.217	1.395
Night time	0.322	0.374

Time	6	8	10	11	18	20	21	22	6
Jan.-Mar.	D	P	D	D		P	P	D	N
Apr.-May.	D	P	D	D		P	D	D	N
Jun.-Aug.	D	P	D	D		D	P	D	N
Sep.-Dec.	D	P	P	D		P	P	D	N

c) Compressor

The 160 kW and 100 kW compressors (each two) manufactured by Petro-Carbon Inc. of U.K. are installed, and the number to be operated is controlled according to the load conditions. Normally two are used for operation.

The power for these compressors was measured in March 12, 1993 (10:42 to 12:25).

Table 5.1.23 gives the results of the measurement.

Table 5.1.23 Result of Measurement on Compressor

Equipment	Rating kW	Rating A		Voltage (V) V1	V2	V3	Ampere (A) A1	A2	A3	Electric power	Power factor
VMD 500 (1)	100	190	Max.	228	227	228	141.6	143.9	140.4	85.0	0.89
			Min.	225	222	224	136.2	140.2	136.8	82.6	0.88
			Avg.	226	225	226	139.4	141.8	138.4	83.6	0.88
VMD 500 (2)	100	190	Max.	229	230	228	157.5	158.3	156.6	95.5	0.90
			Min.	225	226	224	155.6	157.4	155.4	95.2	0.89
			Avg.	227	228	226	156.7	157.8	155.9	95.4	0.89

The VBD500 (1) and (2) compressor load factor (actual load/ rated capacity) was 83 to 85 % and 95 to 96 %, respectively. They were operated at a high load factor.

The compressor output pressure is set at 0.8 MPa for the 0.6 to 0.8 MPa required pressure in each process. To conserve power, it is necessary to review the pressure required in each process, and to minimize the compressor set pressure. It is also essential to repair the parts where compressed air is leaking.

d) Synthetic detergent dryer blower

The blower motor (capacity rated at 18.5 kW) of the synthetic detergent dryer was measured on March 10, 1993 (14:52 to 15:58). Table 5.1.24 shows the results of the measurement. It was being operated at almost the rated load.

Table 5.1.24 Result of Measurement on Blower

Equipment	Rating kW		Voltage (V) V1	V2	V3	Ampere (A) A1	A2	A3	Electric power	Power factor
Blower	18.5	Max.	234	233	234	37.6	36.7	38.7	17.6	0.67
		Min.	231	230	231	32.0	30.5	33.5	12.4	0.56
		Avg.	233	231	233	35.4	34.5	36.7	15.8	0.64

e) Electric power control

(1) Additional installation of integrating wattmeters
The integrating wattmeter is installed in each of the substations, but not for each process or main equipment. It is recommended to install the integrating wattmeter for each process and to obtain the energy unit consumption rate from the power consumption and production according to the process and product type. Then get correct information of the trends and use it for the production process and work improvement, and energy conservation.

(2) Installation of measuring instruments
The volt meter and ammeter were installed in each substation, but some of them were not indicating the correct values. Some failed to fulfill measurement functions. They are important measuring instruments for safety control and equipment control, and immediate actions must be taken to repair them.

(3) Improvement of one-line diagram

The electric power one line diagram currently stored in the plant was worked out when the equipment was designed. It does not reflect the system modifications and wire connection changes which took place after that. The electric power one line diagram is essential to ensure sufficient power control, and it is necessary to work out the electric power one line diagram to ensure easy-to-read information on the layout of the main electrical equipment and their wire connection. It must be placed in each of the substations as well as the main substation so that it can be checked by any body at any time.

(7) Total effect

Table 5.1.25 shows the above mentioned improvement measures which permit quantitative prediction of the effects when improvement measures are to be taken.

Table 5.1.25 Summary

Item	Expected Saving							Investment	Payback
	Fuel Gas			Power			Total		Year
	Nm^3/y	1000Lv/y	%	kwh/y	1000Lv/y	%	1000Lv/y	1000Lv	y
Detergent Spray Dryer									
Slurry moisture control	93200	207.1	1.5				207.1	0	0
Insulation	31000	68.9	0.5				68.9	2	0.03
Boiler									
Air Ratio Control	44500	98.9	0.7				98.9	0	0
Collector Insulation	27700	61.6	0.4				61.6	1	0.02
Steam Pipe									
Integration	66700	148.2	1.0				148.2	0	0
Installing Steam Trap	500000	1111.1	7.8				1111.1	700	0.63
Transformer									
Integration				9680	6.9	0.2			
Peak Shift				0	169.1	0.0			
Total	763100	1695.7	12.0	9680	176.0	0.2	1871.7	703	0.38

5.2 Results of Study at a Food Oil Factory

5.2 Result of the Study at a Food Oil Factory

5.2.1 Overview of the factory

(1) Factory name
Prima-M

(2) Type of industry
Food manufacturing industry

(3) Main product name and production capacity
Sunflower oil, soy bean oil, groats, fatty acid
Material processing capacity 300 t/d
Raw oil refining capacity 30 t/d

(4) Number of employees
227

(5) Factory address
Polsky Trambesh, Loveshka

(6) History
The factory was founded in 1924, and was engaged only in pressing and refining in the early period. Then in 1980 to 1981, the factory was provided with the press, extractor and refining equipment, which are currently available.

Fifteen food oil manufacturing factories are found in the country of Bulgaria. Ten of them are small-sized factories working only for pressing, and only five factories perform extraction as well, and are of the same size as this company. The refining equipment is designed in a batch system, but with insufficient capacity; introduction of a continuous operation system is being planned.

Production is stable, and is exporting the products overseas. The company is also commissioned by Russia to process the products.

(7) Study period
March 15, 1993 to March 19

(8) Members of study group
Mitsuo Iguchi : Head of the study group, energy management
Teruo Nakagawa : Assistant Head of the study group, measurement
Masashi Endo : Food oil process
Masashi Miyake : Thermal technology
Yukio Nozaki : Thermal technology
Yorihiko Tanaka : Electric engineering

(9) Persons interviewed

Mr. Stefan Tzanov Stefanov : President
Mrs. Yulinya S. Shishkova : Vice President
Mr. Kostadin B. Burnev : Head of Electromechanical Department
Mr. Lyubomir Spirov Varbanov : Electric Engineer

(10) Trend of production

Table 5.2.1 Trend of Production

Name of Product	Unit	1988	1989	1990	1991	1992
Raw Sunflower Oil	t	13005	14770	14160	9193	11418
Soya Oil	t	3022	1994	80	950	72
Refined Sunflower Oil	t	8527	8260	9334	8834	6440
Refined Soya Oil	t					1067
Bottled Oil	t	6317	6247	6315	5298	5101
SunflowerGroats	t	13230	15397	14840	9550	1874
Soy Bean Groats	t	15770	9729	402	4670	4562
Butyric Acid	t	102	114	120	100	145

(11) Trend of energy consumption

Table 5.2.2 Trend of Energy Consumption

Energy	Unit	1988	1989	1990	1991	1992
Fuel Oil	t	4005	3680	2650	2900	2510
Diesel Oil	t	46	52	52	25	
Electric Power	kWh	5075	4898	4141	3406	3336

(12) Trend of unit energy consumption (for a ton of raw oil)

Table 5.2.3 Trend of Unit Energy Consumption

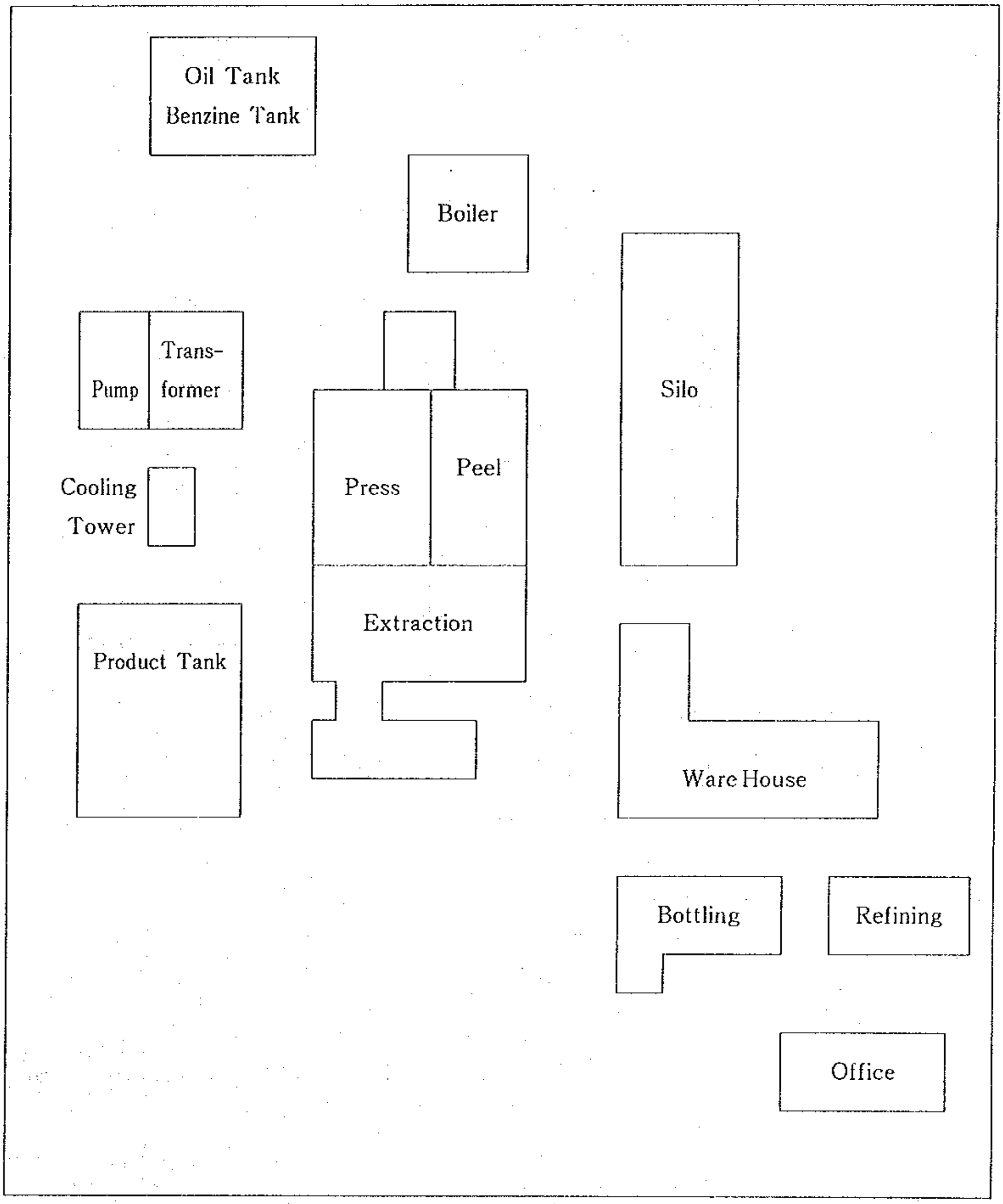
Energy	Unit	1988	1989	1990	1991	1992
Fuel Oil	t/t-Raw Oil	0.25	0.22	0.19	0.29	0.20
Electric Power	kWh/t-Raw Oil	0.32	0.29	0.29	0.34	0.27

(13) Energy prices

Heavy oil	2710 Lv/t (S = 3.5 %) 1993.3.16		
Electric power	Peak	Day	Night
	1.447	0.783	0.386 Lv/kWh 1993.2

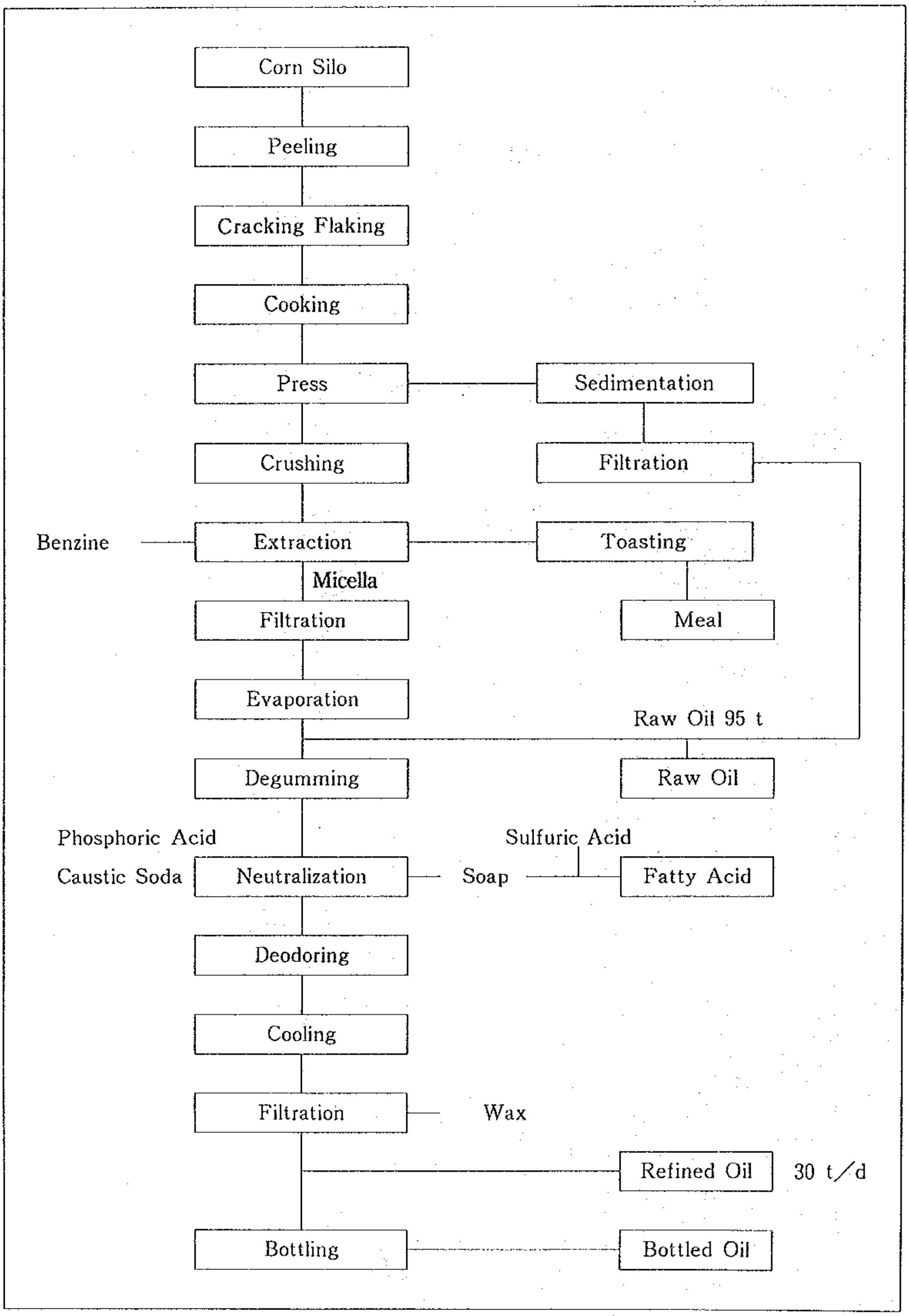
(14) Factory layout

Figure 5.2.1 Factory Layout



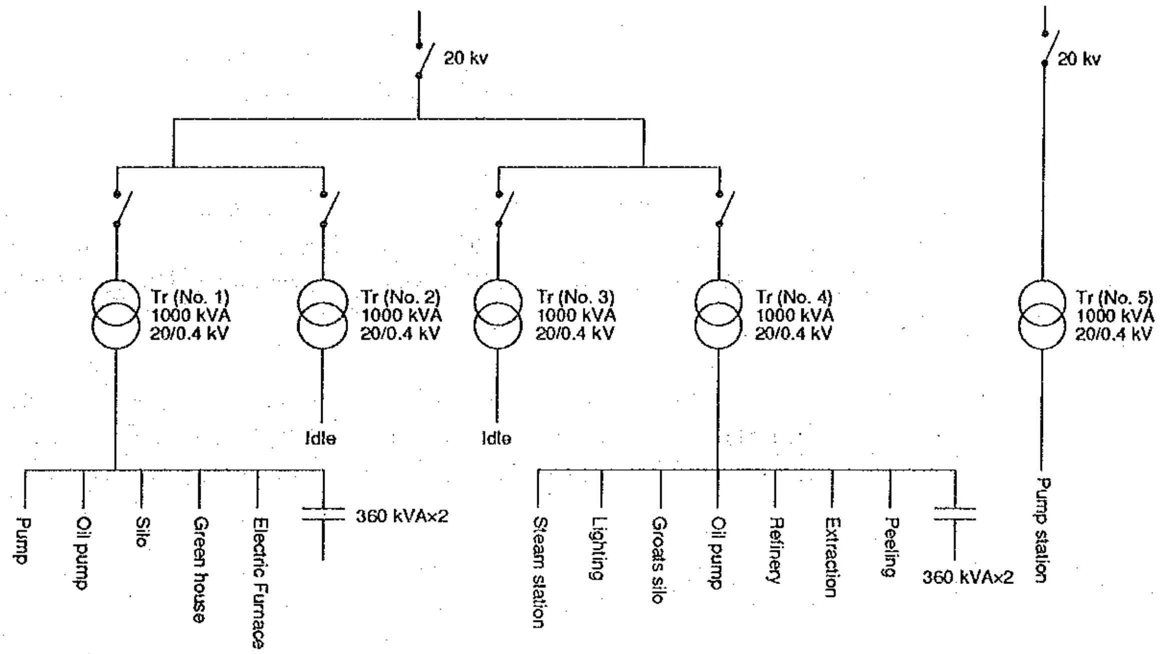
(15) Production process

Figure 5.2.2 Production Process



(16) Electric power one line diagram

Figure 5.2.3 Electric Power One Line Diagram



(17) Outline of principal equipment

Table 5.2.4 Outline of Principal Equipment

Name	Number	Specification
Dehulling Machine	10	60 t/d × 5, 100 t/d × 5
Cracking and Flaking Roll	6	4 roll
Cooker	5	6 stage, Jacket Heater
Press Machine	5	Snake Press, 60 – 80 t/d
Extractor	1	Hildebrandt
Evaporator	2	
Oil Stripper	1	
Desolventizer Toaster	1	10 Stage
Degumming Tank	6	6 m^3
Deacidification Tank	2	
Deodorization Vessel	2	5 ton
Dewaxing Press	2	Filter Press
Boiler	4	Flue & Smoke Tube, Fuel: Oil 13 bar × 12 t/h × 2 Water Tube, Fuel: Husk 12 bar × 10 t/h × 2

5.2.2 Situation of energy management

Energy is used directly or indirectly in various parts of the factory. Energy conservation potential can be said to be present in all the aspects.

Energy consumption efficiency differs according to the performances of the equipment, machinery and operation methods, which depend greatly on the skills and actions of the personnel in charge of operation and maintenance.

Adequate maintenance and servicing must be taken to ensure design performance of the equipment, and minor modification should be made to provide improved performances. It is necessary not only to try to conform to operation standards but also to make improvement efforts to find out better operation methods.

This is related to all the members engaged in the work. To ensure effective promotion of the energy conservation, it is essential to establish an organization to ensure that all the people of the factory make concerted efforts to achieve the target, as well as to take measures for the equipment improvement.

(1) Setting the target for energy conservation

To initiate energy conservation, the top management of the company must define the energy conservation as one of major management targets, demonstrating serious attitude and enthusiasm for energy conservation to the employees. This will convince the employees that making efforts for energy conservation will conform to the policy of the company, and will motivate them for positive efforts.

When palicy is shown by from the top management, mere abstract instruction for energy conservation is not sufficient; concrete target values and the deadline for achieving the goal must be shown to the workers. In response to these instructions, each section of the factory should set up the concrete targets for individual items which can be taken charge of within the scope of the responsibility, so that the overall target can be achieved. Only after the target has been set, concrete action plans to achieve the target can be worked out, including study of various approaches, preparation of the programs and assignment of the works.

However, setting the target requires correct information on the current energy consumption in the factory. In this factory, watt-hour meters are installed for respective substations, and the quality of the purchased fuel oil is known to the factory; however consumption measuring instruments are not installed in the plant, and the daily control is not carried out. The volume of the steam generated by use of fuel oil is not known due to lack of feed water flow meter. The steam meter at the inlet of the extraction process is left under the faulty conditions. Without correct information on how much energy is consumed in each process, it is impossible to compare it with design conditions to make evaluation or to set up the quantitative target value. Even if energy conservation measures are taken, the effects cannot be confirmed. The top priority should be given to procurement of meters and measuring instruments.

(2) Systematic actions

To implement the energy conservation campaign with concerted efforts of all the members, it will be effective to establish a committee comprising representatives of the management division, production division and auxiliary division, so that interaction can be provided between the processes particularly among the production-related divisions. This committee will work out the energy conservation program, determine the budget, approve the technical energy conservation measures, evaluate the results, and introduce various cases. This will ensure uniform understanding to be shared among different divisions, permitting the activity to be made on a priority basis. This will also make it possible to check if a particular action has a total effect including the effect given to the preceding and succeeding processes. It will also permit advice to be given from different angles. To ensure implementation of the items determined at the meeting of this commission, the meeting should be chaired by the chief factory manager or a person having an equivalent authority.

It is also necessary to hold various events in order to keep the employees interested in the energy conservation, or appoint coordinators to make arrangements among different related divisions, in order to ensure smooth implementation of the energy conservation activity.

The employees working in the first line are placed in daily contact with energy consuming equipment, and they get the feel of the problems with their own skin. An effective use of energy cannot be achieved if the equipment are not used effectively and work standards are not observed, no matter how excellent they are. So it is effective to keep the employees in the first line interested in the energy conservation so that they will taken an active part in the activity.

(3) Data-based management

In energy conservation activity, as in the quality control, steady improvement can be gained by repeating the PDCA circle where an improvement plan is worked out (PLAN) and implemented (DO), the results are evaluated (CHECK), the work process is modified or fixed (ACTION) in accordance with the evaluated results; then an improvement plan on a higher level is worked out. Thus the control level is gradually increased, repeating the same cycle.

The problems accompanying energy consumption to be studied in working out the improvement plan and suggestions for improvements can be made clear only through an objective analysis of the data (facts) occurring in the factory. The effects of the energy conservation efforts can be confirmed by means of statistical techniques such as unit consumption rate control chart, histogram and correlation analysis on the basis of the actual data. If there is abnormal data, much information can be gained by checking the cause for such fault.

It is important that the result of the evaluation is made public on a periodic basis so that the result of the efforts can be known to all employees. This will bring up rivalry in a good sense in the factory.

It is also important to award official commendation to job sites having achieved a good result or to effective proposals, thereby encouraging their further efforts.

(4) Education and training of employees

It is necessary to give sufficient information in order to promote voluntary activities of the employees. To motivate efforts for energy conservation, the employees should be informed of the trend of energy prices, the weight of the energy cost in the production cost, possible causes for energy losses, preventive measures, and cases of successful energy conservation efforts in other factories. It is also necessary to promote education and training of the employees by giving instructions through competent staff members, by giving training courses, and by providing them with manuals; thereby increasing their level.

(5) Equipment management

If the equipment is not maintained in proper conditions, a great energy loss will occur. During our visit to this factory, steam pipes and heat insulation repair works were being carried out, and good care was taken of the steam trap operation conditions; this is a good practice. However, the same care was not taken for the heat insulation of the valve and flange; the heat insulation was dropped off from some of the equipment of the refining process, or steam was leaking out of the position close to the valve on the seeam collector. Steam trap operation failure was also observed. To repair the steam leakages, which require suspension of steam supply, the faulty positions should be marked and noted on the record, and should be repaired on a periodic basis.

Drawings are essential for the maintenance of the equipment. Revised drawings must be prepared immediately after any modification work has been made, and they must be put in order so that they can be easily used by any one. In this plant, the drawings were placed in good order for each engineering process.

5.2.3 Problems in the use of energy and countermeasures

(1) Production process

A) Pressing process

The production capacity of the pressing equipment is greater than the extraction equipment, so some of these equipment are not working. The idle equipment should be effectively used for yield improvement and energy conservation. The dehulling equipment, flaking rollers, cookers and presses are operated only 60 percent.

① Effective use of dehulling equipment

Dehulling operation is intended to ensure that the protein content in the extracted meal will conform to the standard, but dehulling is not necessarily required before pressing. About 3 % of oil is contained in the hull, and as shown in Figure 5.2.4, the oil of the hull can also be recovered if dehulling is performed after extraction. This will improve the yield. In that case, however, the product cooler must be installed at the outlet of the desolventizer. So comparison must be made between equipment investment and yield improvement before implementation of this remodeling.

Conditions

1. Annual amount to be treated : 50,000 t/y
2. Dehulling is ceased to leave 22 % as it is, in contrast to the present dehulling up to 12 %.
3. 2 % of the 3 % oil contained in the hull can be recovered.
4. Oil price : 10,000 Lv per ton

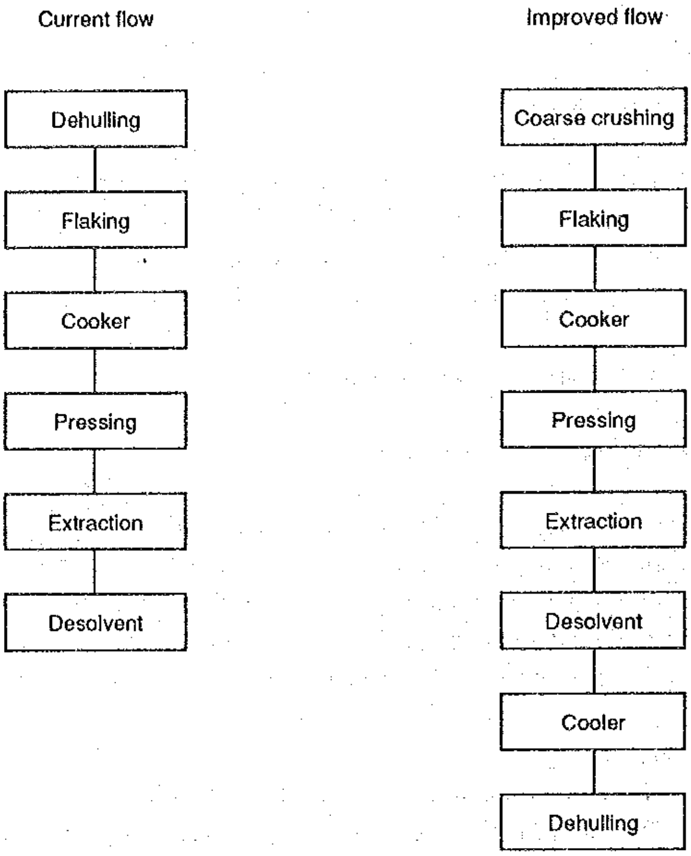
Advantages (value)

= annual treatment × (difference in the percentages of the hull) × oil price
= 50,000 × (0.22 – 0.12) × 0.02 × 10,000
= 1,000,000 Lv/y

The use of the idle material drier and cooker, without introducing new product coolers, will save the investment. In Japan, for installation of the product cooler 100,000,000 to 150,000,000 yen or 20,000,000 to 30,000,000 Lv will be required. Use of the idling equipment will reduce the investment cost to below 5,000,000 Lv.

Part of the dehulling equipment can be used as in a coarse crushing process.

Figure 5.2.4 Dehulling Process Improvment



② Effective use of flaking roller and cooker

If the material is preheated before it is applied to the flaking roller, thin flakes with less powder can be easily made, making it possible to reduce the amount of residual oil in the meals after extraction. It is recommended to ensure the optimum flake production by reducing the volume of treatment per unit roller through the use of the idle cooker for preheating and use of all rollers.

Conditions

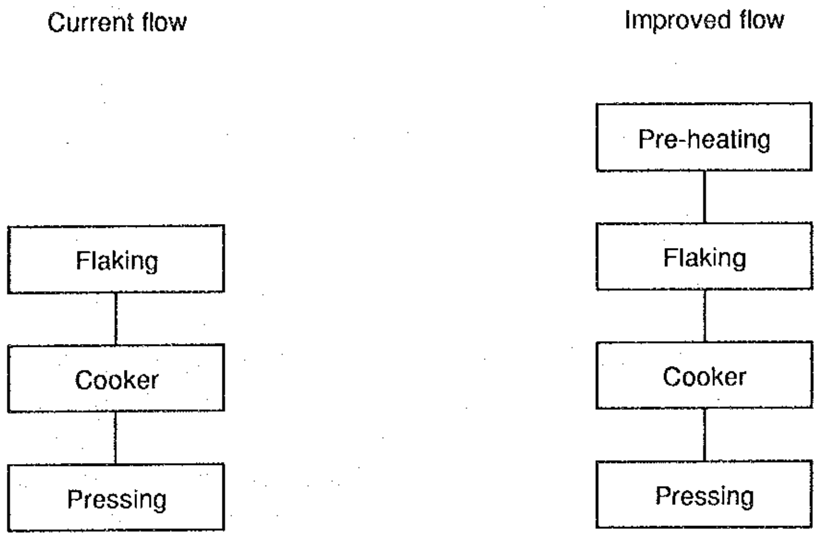
1. The 60 % extracted meals are produced in the annual treatment of 50,000 tons per year.
2. The 2 % residual oil in meals is reduced to 1 %.
3. Oil price: 10,000 Lv per ton

Advantages (value)

= annual meal production × (difference in the percentages of the residual oil) × oil price
= 50,000 × 0.6 × (0.02 – 0.01) × 10,000
= 3,000,000 Lv/y

The transport equipment and electric construction work are expected to require an investment of 4,000,000 Lv to 5,000,000 Lv. This is considered to be recovered in a short period of time.

Figure 5.2.5 Preheat before Flaking



③ Reduction in the use of cooker steam

The cooker uses much direct blow steam as well as indirect steam. Much direct steam was used especially in the lower stage, and steam was often observed to leak out of the equipment. In some case, steam is used for the cooker when the moisture of the material entering the press is too little. In that case, steam must be sent to the upper stage, instead of the lower stage. Careful control of the amount of the steam blown in each stage will substantially reduce the amount of the steam blown in the cooker, and the energy unit consumption rate of the steam in the entire pressing process can be reduced by about 20 %.

In Japan, the energy unit consumption rate of the steam in the entire pressing process is 80 to 120 kg per ton of the material. Assuming that 20 kg can be reduced, annual steam reduction G_1 will be as given below:

$$\begin{aligned} G_1 &= 20 \times 50{,}000 \\ &= 1{,}000{,}000 \text{ [kg/y]} \\ &= 1{,}000 \text{ [t/y]} \end{aligned}$$

where annual amount to be treated is assumed as 50,000 tons.

The volume of heavy oil required to generate 1 ton of steam is 0.116 tons. The following shows the amount of heavy oil that can be reduced:

$$G_1' = 1{,}000 \times 0.116 = 116 \text{ t/y}$$

Assuming that heavy oil is priced at 2,710 Lv per ton, the following value can be saved:

$$G_1'' = 116 \times 2{,}710 = 314{,}400 \text{ Lv/y}$$

The equipment investment for this purpose is not required.

B) Extraction process

① Use of exhaust gas of DT (desolventizer-toaster)

Use of exhaust gas of DT (desolventizer-toaster) for the heat source of No. 1 evaporator is one of the renowned energy conservation measures. The amount of the direct blow steam in the DT is not known and the heat of PT exhaust gas can not be estimated, but the energy required in the No. 1 evaporator can be sufficiently supplied, according to the experience. Figure 5.2.6 shows the flowchart before and after improvement. Figure 5.2.7 shows the material balance in the extraction process.

Calorific value Q required for benzine evaporation can be expressed by the following equation, assuming the efficiency as 0.9:

$$\begin{aligned} Q &= F \times H \div \eta \\ &= 21{,}033{,}000 \times 80 \div 0.9 \\ &= 1{,}870{,}000{,}000 \text{ [kcal/y]} \end{aligned}$$

When this is converted into the amount of steam, it can be shown as:

$$\begin{aligned} G_2 &= 1{,}870{,}000{,}000/520 \\ &= 3{,}596{,}000 \text{ [kg/y]} \\ &= 3{,}596 \text{ [t/y]} \end{aligned}$$

where,

Q	:	Calorific value Q required for benzine evaporation	[kcal/y]
F	:	Amount of benzine evaporated in No. 1 evaporator	[kg/y]
H	:	Evaporation latent heat of benzine	[kcal/kg]
η	:	Efficiency	
G_2	:	Amount of steam saved	[t/y]

The above is based on the assumption that the evaporation latent heat of benzine is 520 kcal/kg.

Figure 5.2.6 Utilization of DT Vapor

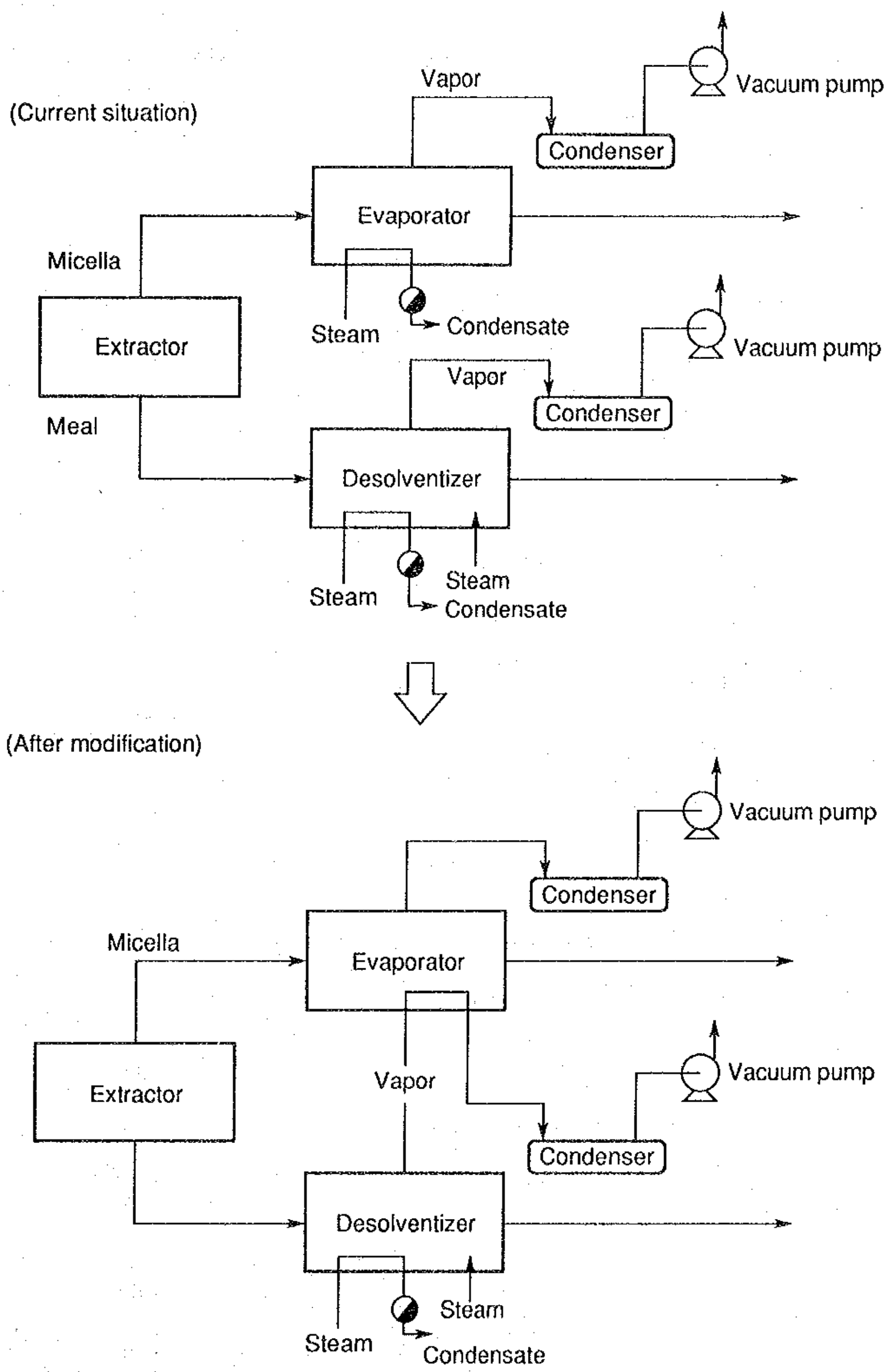


Figure 5.2.7 Material Balance of Extraction Process

Material

	%	t
Oil	21	4432
Water	7	1574
Meal	72	15121
Total	100	21133

Solvent

	%	t
Benzine		30541

EXTRACTOR

Micella

	%	t
Benzine	15	23245
Oil	85	4109
Total	100	27354

Benzine	30	7294
Oil	1	329
Water	6	1574
Meal	63	15121
Total	100	24320

No. 1 EVAPORATOR

	%	t
Benzine	35	2212
Oil	65	4109
Total	100	6321

	%	t
Benzine	100	21033

No. 2 EVAPORATOR

	%	t
Benzine	5	216
Oil	95	4109
Total	100	4325

	%	t
Benzine	100	1996

OIL STRIPPER

	%	t
Oil	100	4109

	%	t
Benzine	100	216

DT

	%	t
Oil	2	329
Water	6	986
Meal	92	15121
Total	100	16436

	%	t
Benzine	100	7296

Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

$$G_2' = 3{,}596 \times 0.116 = 417 \text{ t/y}$$

The following shows the value that can be saved, when the heavy oil cost is considered 2,710 Lv per ton:

$$G_2'' = 417 \times 2{,}710 = 1{,}130{,}100 \text{ Lv/y}$$

Remodeling and heat insulation of the DT exhaust gas duct and No .1 evaporator are considered to require 2 to 3 MLv. This amount is considered to be recovered in less than three years.

② Eliminating the benzine heater

Since the pressed meal temperature is 80 to 90 °C, the extraction temperature can be reached to 55 to 60 °C without heating the benzine.

If the extraction temperature is further increased, benzine will start to boil, and extraction efficiency will be reduced.

The following shows the amount of steam (G_3) which can be conserved by omitting benzine heater.

$$\begin{aligned} G_3 &= 30{,}541{,}000 \times (60 - 20) \times 0.5/520 \\ &= 1{,}174{,}000 \text{ [kg/y]} \\ &= 1{,}174 \text{ [t/y]} \end{aligned}$$

In this case, the specific heat of benzine is assumed as 0.5 kcal/(kg · °C) and the reference temperature as 20 °C.

Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

$$G_3' = 1{,}174 \times 0.116 = 136 \text{ t/y}$$

The following shows the value that can be saved, when the heavy oil cost is considered 2,710 Lv per ton:

$$G_3'' = 136 \times 2{,}710 = 368{,}600 \text{ Lv/y}$$

This does not require equipment investment.

③ Reduction in benzine loss

800 tons of benzine is reported to be purchased in this plant every year. This means 24 ℓ/t of materials.

800,000 kg/y /0.66 = 1,200,000 ℓ/y
1,200,000 ℓ/y /50,000 t/y = 24 ℓ/t

This loss is generally 1 ℓ/t or less in recent years, so the loss in this plant is excessive. The following actions must be taken to reduce this loss:

(1) Thorough cleaning of the condenser or additional installation of condenser
(2) More effective control of the temperature, vacuum and cooling water volume in the evaporation process
(3) Benzine pump sealing control
(4) Reduction of residual benzine in the oil and meal (100 to 300 ppm)
(5) Introduction of an equipment to recover benzine from relief gas

④ Preventing the steam leakage

Much steam was observed to be leaking from two positions; No. 2 evaporator and steam header. Steam leakage from No. 2 evaporator is considered to have been caused by the discharge valve which was intentionally opened in order to reduce the amount of steam in the jacket, since the valve at the steam inlet is difficult to operate.

The steam leakage from the steam header is caused by the failure of the safety valve which has been left unrepaired. Both requires improvement.

The steam leakage can be calculated from the following approximate equation:

$$G = 0.5484 \times A \times P^{0.97} \times f$$

where,

G : Amount of leaked steam [kg/h]
A : Hole area [mm^2]
P : Absolute steam pressure [kg/cm^2]
f : Blowout coefficient (0.8 for piping and valve)

For example, steam leakage at a pressure of 3 kg/cm^2 from a hole of 10 mm in diameter is calculated as follows:

$$G = 0.5484 \times (10/2)^2 \times \pi \times (3 + 1.033)^{0.97} \times 0.8$$
$$= 133 \text{ [kg/h]}$$

Assuming that above steam leakage is on this level and the annual operation time is 200 days by 24 hours, then annual leakage G_4 at two positions can be calculated as follows:

$$G_4 = 133 \times 24 \times 200 \times 2$$
$$= 1{,}277 \text{ [t/y]}$$

Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

$$G_4' = 1{,}277 \times 0.116 = 148 \text{ t/y}$$

The following shows the value that can be conserved, when the heavy oil cost is considered 2,710 Lv per ton:

$$G_4'' = 148 \times 2{,}710 = 401{,}100 \text{ Lv/y}$$

This does not require equipment investment.

⑤ Effective use of steam condensate

The steam condensate generated in the extraction process is fed to the outdoor tank which is not insulated, and is used mainly to heat the facilities outside the plant. However, the steam condensate should preferably be used at the closest possible position in order to reduce the energy loss, so it is necessary to study the possibility of its reuse in the extraction process. Steam condensate can be used as a heat source for preheating micella or as the auxiliary steam of the No. 2 evaporator by flashing. The amount of the indirect steam per ton of the material in the extraction process is about 30 to 50 kg in Japan. The following equation shows the heat to be recovered Q when 10 °C heat of the heat content of the 30 kg steam condensate is assumed to be recoverable:

$$Q = 50{,}000 \times 30 \times 10$$
$$= 15{,}000{,}000 \text{ [kcal/y]}$$

This is converted into the amount of steam as follows:

$$G_5 = 15{,}000{,}000/520/1000$$
$$= 29 \text{ [t/y]}$$

where annual amount to be treated material is assumed as 50,000 tons.

The volume of heavy oil required to generate 1 ton of steam is 0.116 tons. The following shows the amount of heavy oil that can be reduced:

$$G_5' = 29 \times 0.116 = 3 \text{ t/y}$$

Assuming that heavy oil is priced at 2,710 Lv per ton, the following value can be saved:

$$G_5'' = 3 \times 2,710 = 8.100 \text{ Lv/y}$$

The equipment investment for this purpose is not required.

The outdoor steam condensate tank is provided with heat insulation, and condensate after heat recovery can be used for space heating.

Solvent may contaminate the steam condensate in the extraction process because of equipment failure or other reasons. It is safer to use it in the extraction plant which is designed in the electrically explosion proof structure.

C) Refining process

① Omission of heating in degumming process

Oil in the tank is heated to 60 °C in degumming process. If the oil from the extraction plant is sent directly to the degumming process without being put into the tank, steam heating process in the degumming tank can be eliminated. The following equation shows the amount of steam that can be conserved when annual treated amount is assumed as 7,512 tons, average oil temperature as 20 °C, and specific heat of the oil as 0.5 kcal/(kg · °C):

$$G_6 = 7,512 \times (60\text{-}20) \times 0.5/520$$
$$= 289 \text{ [t/y]}$$

Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

$$G_6' = 289 \times 0.116 = 34 \text{ t/y}$$

The following shows the value that can be saved, when the heavy oil cost is considered 2,710 Lv per ton:

$$G_6'' = 34 \times 2,710 = 92,100 \text{ Lv/y}$$

This does not require equipment investment.

② Heat exchange of deodored oil

In the deodoring process, the 60 °C oil is heated to 160 °C by indirect steam, and in the dewaxing process, the oil is cooled down to 20 °C. Steam can be conserved by heat exchange between the 60 °C oil before being deodored and the deodored oil of 160 °C. The following equation shows the amount of steam that can be conserved when the 60 °C oil before being deodored can be heated to 120 °C:

$$G_7 = 7{,}512 \times (120 - 60) \times 0.5/520$$
$$= 433 \text{ [t/y]}$$

Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

$$G_7' = 433 \times 0.116 = 50 \text{ t/y}$$

The following shows the value that can be saved, when the heavy oil cost is considered 2,710 Lv per ton:

$$G_7'' = 50 \times 2{,}710 = 135{,}500 \text{ Lv/y}$$

The equipment cost for the heat exchanger, tank, pipe, pump, heat insulation work, and electric construction works is estimated at 2,000,000 Lv to 3,000,000 Lv. The heat recovery is not economical under the current situation.
Since this plant uses the batch type deodoring process, the tank must be provided to store the treated oil under high temperature conditions, and to complete heat exchange with the new material oil within the processing time of other deodorizers. If oil is stored at high temperature under the atmospheric pressure, quality may be deteriorated.

Introduction of continuous deodorizers is said to be under study in this plant. When this is realized, the heat exchanger should be introduced.

(2) Boiler

This plant has four boilers. The No. 1 and No. 2 boilers are fired by heavy oil, while the No. 3 and No. 4 boilers are fired by the sunflower husk. To get feed water of the boiler, the well water is provided with ion exchange and softening treatment.

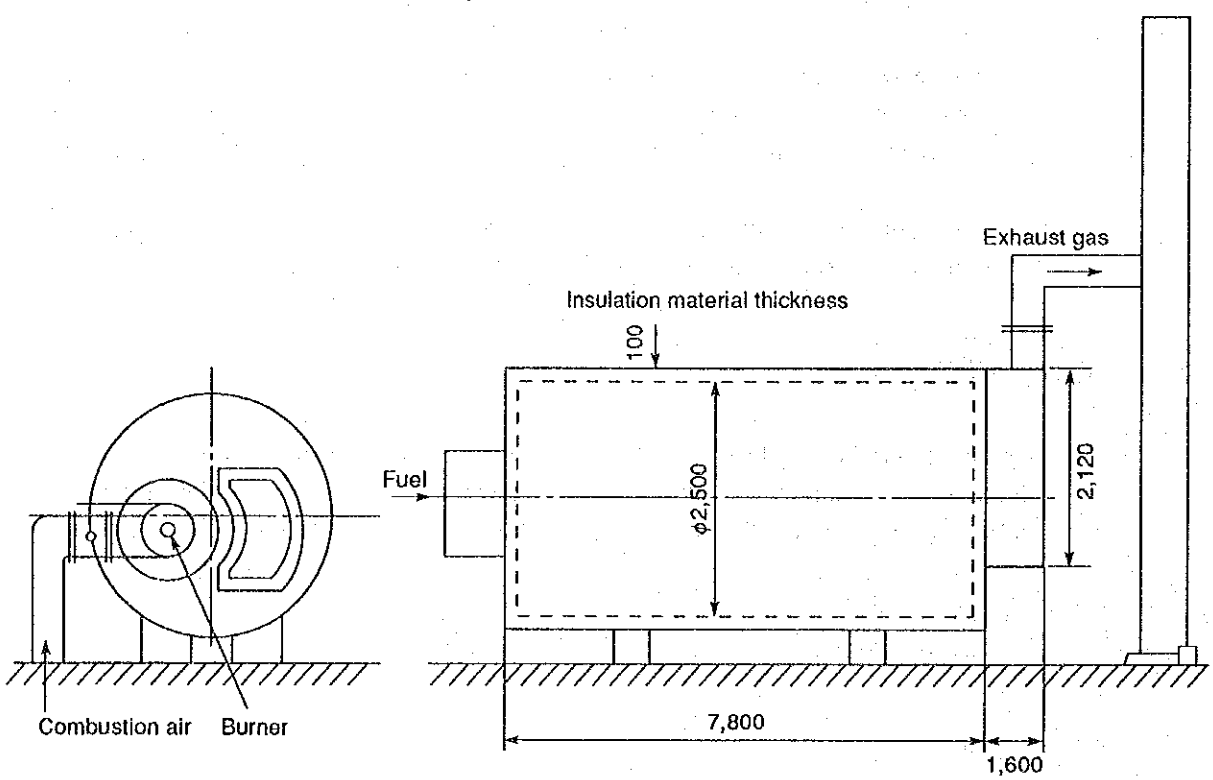
The combustion of heavy oil at burner was poor, and black smoke was observed to be coming out of the stack. Maintenance problems were also found out, including the steam leakage from the safety valve, water leakage from the feed water pump, and insulation damages of the feed water pipe and steam pipe.
They were operated manually, and the damper for combustion air was almost totally closed and limited further adjustment resulting in poor efficiency. A feed water flow meter or fuel flow meter was not installed, which posed problems in operation control. The steam condensate was recovered; this is effective for heat recovery.

The heavy oil fired boiler NO.1 was subjected to the performance test this time.

A) Boiler specifications

Type	: 3-pass flue and smoke tube boiler
Steam amount	: 12 tons per hour
Steam pressure	: 12 bars (rated)
Fuel	: Heavy oil
Heat transfer area	: 305 m^2
Year of manufacture	: 1972
Structure	: See Figure 5.2.8 Boiler Structure.

Figure 5.2.8 Boiler Structure



B) Heat balance

a) The heat balance of the boiler is based on the data measured on March 16, 1993 (from 13:30 to 14:40). The following shows the data:

1) Fuel type : Heavy oil
2) Fuel consumption (based on volume) : 0.700 m^3/h
3) Fuel consumption (based on weight) : $0.700 \times 0.875 \times 1{,}000 = 612.5$ kg/h
4) Calorific value of fuel : 9,550 kcal/kg
5) Fuel specific gravity : 0.925 (15 °C)

The specific gravity at 92.1 °C has been calculated from the following equation:

$d_{92.1} = d_{15} - 0.00065\ (t - 15)$
$= 0.925 - 0.00065\ (92.1 - 15)$
$= 0.875$

6) Fuel specific gravity 0.45 kcal/(kg · °C)
7) Fuel temperature 92.1 °C
8) Reference temperature 16 °C
9) Combustion air temperature 16 °C
10) Oxygen (%) in dry exhaust gas 10.18 %
11) Carbon dioxide (%) in dry exhaust gas 7.43 %
12) Carbon monoxide (%) in dry exhaust gas 0.042 %
13) Exhaust gas temperature 201.33 °C
14) Feed water amount 6.81 τ/h
15) Feed water temperature 41.1 °C
16) Steam pressure 10.23 kg/cm^2 (G)
17) Boiler surface temperatures
    Front plate 80.85 °C
    Shell plate 52.10 °C
    Rear plate 50.80 °C

Since the calorific value and specific gravity of fuel were not clear, we used the estimated values.

b) Calculation of heat balance

Heat balance is calculated per kg of fuel.

[Heat input]

① Fuel low-level calorific value $H\ell = 9{,}550$ kcal/kg-Fuel

② Fuel sensible heat Q_1

$Q_1 = C_f \times (t_f - t_o)$ kcal/kg-Fuel

$= 0.45 \times (92.1 - 16)$

$= 34.25$ kcal/kg-Fuel

where,

C_f :	Average fuel specific heat	kcal/(kg · °C)
t_1 :	Fuel temperature	°C
t_0 :	Reference temperature	°C

③ Total heat input Q_i

$Q = H\ell + Q_1 = 9{,}550 + 34.25 = 9{,}584.25$ kcal/kg-Fuel

[Heat output]

① Heat absorbed by generated steam (effective heat output) Qs

$Q_s = W_1 \times (h_2 - h_1)$

$= 11.12 \times (655.17 - 41.1)$

$= 6{,}827.46$ kcal/kg-Fuel

$W_1 = W/F = 6{,}810/612.5 = 11.12$ kg/kg-Fuel

$h_2 = h_3 - (1.0 - x) \times r$

$= 664.68 - (1.0 - 0.98) \times 475.48$

$= 655.17$ kcal/kg

where,

W_1:	Amount of feed water per kg of fuel	kg/kg-Fuel
W :	Amount of feed water per hour	kg/h
F :	Amount of fuel per hour	kg-Fuel/h
h_1 :	Feed water enthalpy	kcal/kg
h_2 :	Generated steam enthalpy	kcal/kg
h_3 :	Saturated steam enthalpy	kcal/kg
x :	Generated steam dryness	
r :	Steam latent heat of evaporation	kcal/kg

② Retention heat loss of exhaust gas (including water vapor) L_1

$L_1 = G \times C_g \times (t_g - t_0)$ kg/kg-Fuel

$G = G_0 + (m - 1) \times A_0$ Nm^3/kg-Fuel

$G_0 = 15.7 \times H1/10{,}000 - 3.91$

$= 15.7 \times 9{,}550/10{,}000 - 3.91$

$= 11.13$ Nm^3/kg-Fuel

$A_0 = 12.38 \times H1/10{,}000 - 1.36$

$= 12.38 \times 9{,}550/10{,}000 - 1.36$

$= 10.46$ Nm^3/kg-Fuel

We have estimated the values G_0 and A_0 according to the Boie equation since the composition of the fuel (heavy oil) was not clear.

$$m = \frac{21}{21 - 79 \times \frac{(O_2) - 0.5 \times (CO)}{(N_2)}}$$

$$= \frac{21}{21 - 79 \times \frac{10.18 - 0.5 \times 0.042}{82.35}}$$

$$= 1.87$$

$$G = 11.13 + (1.87 - 1) \times 10.46$$

$$= 20.19 \quad \text{Nm}^3\text{/kg-Fuel}$$

$$L_1 = 20.19 \times 0.33 \times (201.33 - 16)$$

$$= 1{,}234.93 \quad \text{kcal/kg-Fuel}$$

where,

m	: Air ratio	
A_0	: Theoretical air amount	Nm^3/kg-Fuel
(CO_2)	: Carbon dioxide (%) in dry exhaust gas	%
(O_2)	: Oxygen (%) in dry exhaust gas	%
(CO)	: Carbon monoxide (%) in dry exhaust gas	%
(N_2)	: Nitrogen (%) in dry exhaust gas $= 100 - \{(CO_2) + (O_2) + (CO)\}$	%
G	: Actual amount of exhaust gas per Nm^3 of fuel (including water vapor)	Nm^3/kg-Fuel
G_0	: Theoretical amount of wet exhaust gas	Nm^3/kg-Fuel
C_g	: Average specific heat of exhaust gas (Generally, 0.33 kcal/(Nm^3 · °C))	kcal/Nm^3-Fuel
t_g	: Exhaust gas temperature	°C
t_0	: Ambient temperature	°C

③ Dissipated heat loss L_2

$L_2 = 53.65$ kcal/kg-Fuel

Table 5.2.5 Heat Loss from Boiler Surface

Part	Temperature (℃)	Surface area (㎡)	Heat loss kcal/h	Heat loss (kcal/kg − Fuel)
Front plate	80.9	5.70	4,244	6.93
Shell plate	52.1	74.62	26,581	43.40
Rear plate	50.8	5.94	2,036	3.32
Total			32,861	53.65

Note: To calculate the heat loss of the shell plate, 1/4 of the surface area was assumed as the top area, and 1/2 of it as the side wall, and 1/4 of it as the bottom.

The heat release from the furnace wall surface has been obtained by substituting the temperature of the outer surface into the following equation:

Heat transfer coefficient by natural convection

$h_c = \alpha \times (t_a - t_o)^{1/4}$ kcal/(m² · h · °C)

Heat transfer coefficient by radiation

$h_r = 4.88 \times \varepsilon \times \{(273 + t_a)^4 - (273 + t_o)^4\} / 10^8 / (t_a - t_o)$

kcal/(m² · h · °C)

Heat release from surface for unit surface

$h = (h_c + h_r) \times (t_a - t_o)$ kcal/(m² · h)

where,

t_a : Temperature of outer surface

t_o : Room temperature $t_o = 16$ °C

ε : Emissivity $\varepsilon = 0.8$

α : Coefficient relative to direction of the natural convection surface

Horizontal upward surface $\alpha = 2.8$

Horizontal downward surface (furnace floor) $\alpha = 1.5$

Vertical surface (side wall) $\alpha = 2.2$

④ Other heat losses L_3

$L_3 = Q_i - (Q_s + L_1 + L_2)$

$= 9{,}584.25 - (6{,}827.46 + 1{,}237.24 + 53.65)$

$= 1{,}465.90$ kcal/kg-Fuel

⑤ Total heat output Q_0

$Q_0 = Q_s + L_1 + L_2 + L_3$

$= 6{,}827.46 + 1{,}237.34 + 53.65 + 1{,}465.90 = 9{,}584.25$ kcal/kg-Fuel

c) Heat balance chart

The above can be summarized as given in Table 5.2.6.

Table 5.2.6 Heat Balance Chart of Boiler

Item		kcal/kg	%
Heat Input			
(1) Calorific value of fuel	Hl	9,550.00	99.64
(2) Sensible heat of fuel	Q_1	34.25	0.36
Total	Q_i	9,584.25	100.00
Heat Output			
(1) Heat absorbed by generated steam (Effective heat output)	Q_s	6,827.46	71.24
(2) Loss by exhaust gas retention heat	L_1	1,237.24	12.91
(3) Radiated heat loss from surface	L_2	53.65	0.56
(4) Other heat losses	L_3	1,465.90	15.29
Total	Q_o	9,584.25	100.00

The amount of fuel supply is adjusted by the amount returned from the burner, and must be calculated by measuring the amounts of both the burner input and return. In the present measurement, we used the ultrasonic flow meter brought from Japan since the fuel flow meter was not installed at the site. The permissible operating temperature of the sensor was below 80 °C, and measurement of the return oil of over 80 °C was possible for only a short period of time before the sensor temperature rose.

This may explain the reason why heat loss caused by unclear reasons was 15 %, a somewhat high value.

C) Boiler water quality control

The feed water and boiler water quality was as shown in Table 5.2.7.

Table 5.2.7 Quality of Feed Water and Boiler Water

	Raw water		Feed water		boiler water	
	pH	Electric conductivity μS/cm	pH	Electric conductivity μS/cm	pH	Electric conductivity μS/cm
	8.66	0.507	8.90	0.664	11.88	5.38
	8.80	0.508	8.75	0.680	11.88	6.56
	8.65	0.499	9.03	0.733	11,96	7.66
Standard			7.0−9.0	11.0−11.8		<4.5

Note: The standard value is based on JIS B 8223-1989 "Boiler feed water and boiler water quality".

The feed water of this plant consists of water treated by the water softener and recovered condensate.

The pH value of feed water and boiler water indicated favorable values, and the electric conductivity of feed water and boiler water also showed favorable values. However, the electric conductivity of boiler water was a little too high, showing that much impurity was contained in the boiler water. This may reduce the service life of the boiler. The reason for high electric conductivity of the boiler water is considered to be an insufficient amount of the blow. At present, blowing off is carried out every two hours. It is necessary to increase the blow-off frequency. Furthermore, the variations in the electric conductivity of the feed water are greater than those in the electric conductivity of the raw water; this is considered to cause variations in the condensate water quality. This requires periodic inspection.

D) Operation control

a) No boiler was provided with a feed water flow meter. The Nos. 1 and 2 heavy oil-fired boilers were not provided with the fuel flow meter. At least these meters must be installed for boiler operation control. Their installation will give correct information on the relationship between the amount of generated steam (amount of feed water) and the amount of fuel, namely, the evaporation multiple (amount of feed water/amount of fuel).

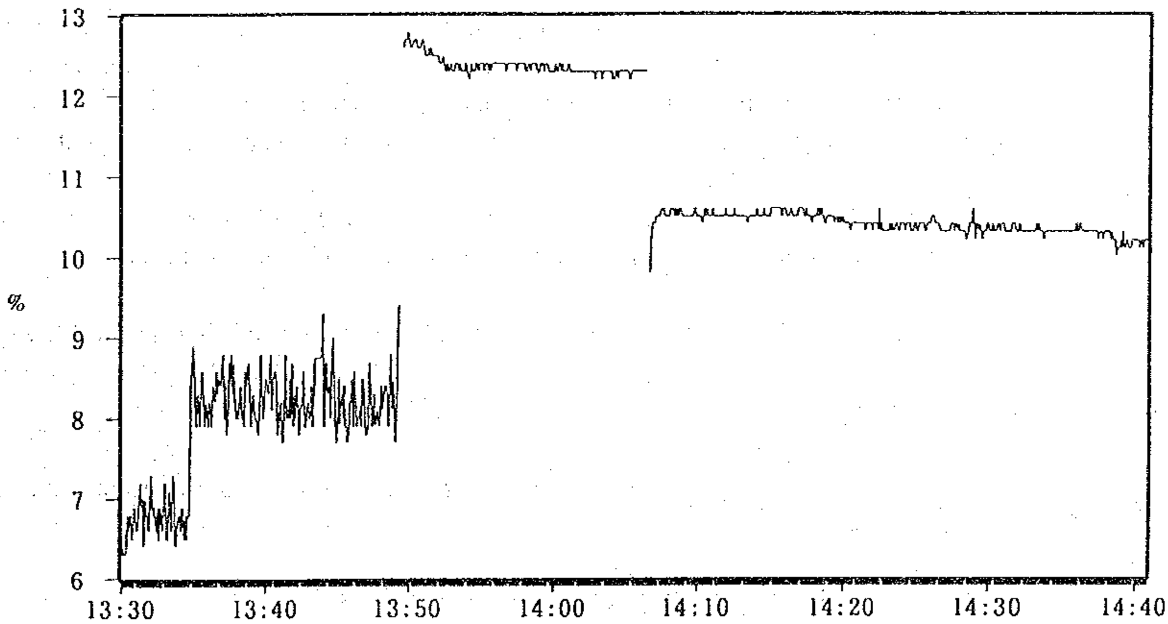
This evaporation multiple serves as a substitute index to represent heat efficiency. It should be made into a graph for easy reading of the long-term trend, and should be checked at all times. If any reduction is observed in the graph, corrective actions such as cleaning of the heat transfer pipe should be taken.

b) Hourly amount of feed water, used fuel, blow-off time point and time duration, and evaporation multiple should be entered in the boiler operation journal. These data must be used to arouse the interest of the boiler operators in more effective operation.

E) Air ratio improvement

The exhaust gas temperature during the performance test is about 201 °C, which is not very high. As Figure 5.2.9 shows, the current oxygen concentration in the exhaust gas fluctuates between 7 and 12.5 %. The average air ratio is 1.87 (O_2=10.18 %); this shows that the extremely excessive amount of air is used for combustion. Air not necessary for combustion is heated and released into the atmosphere, and this means a great heat loss. The standard air ratio in Japan is considered as 1.2 to 1.3 when liquid fuel is used in the boiler where the hourly amount of evaporation is over 10 tons up to 30 tons. It is necessary to adjust the air ratio.

Figure 5.2.9 Change of Oxygen Contents in Exhaust Gas



At present, the amount of the fuel supply is adjusted manually so that the pressure of steam is maintained constant according to the change of the load. Since the combustion air fan has a great capacity, the air control damper is almost totally closed and further adjustment is impossible. So the oxygen concentration in the exhaust gas fluctuates according to the amount of the fuel supply, as shown in Figure 5.2.9. As the amount of the steam (load) reduces, the ratio of the exhaust gas loss will increase all the more.

In order to maintain adequate air ratio, the amount of air must be adjusted according to the changes in the amount of the fuel supply, and it is necessary to improve the current air control damper which is almost totally closed. When the fan is belt-driven, the problem can be solved by changing the pulley diameter and reducing the fan speed. When it is directly coupled to the motor, the problem can be solved by ① the impeller cut (reduction of the impeller outer diameter) and ② power frequency change. The problem can be also solved by releasing part of the air on the fan discharge side into the atmosphere. This is a simple method which does not require investment in equipment, but it consumes the shaft power excessively for the required air force. It is also necessary to install the silencer in order to prevent the noise produced from the discharge outlet.

When the amount of air can be controlled by taking these measures, install the indicator on the heavy oil valve and air control damper, and mark the standard air ratio to make control. To set the angle of the air control damper, observe the exhaust gas discharged from the stack, and determine the angle a little greater than the angle at which thin black smoke is observed slightly.

Even if the air ratio is extremely high, black smoke is observed to be coming out of the stack. Unburnt carbon was caught by the filter of the pre-processor of the exhaust gas analyzer in the performance test. Carbon is observed to be attached to about one fourth of the air register, and this is considered to be attributable to ineffective mixture of the combustion air with the fuel oil mist. The pressure jet type burner has a burner tip with highly accurate structure. If it is clogged by the carbon, atomization failure will often occur. The air register and burner tip should be cleaned or replaced on a periodic basis.

When the fuel oil has turned into heavy oil or the low-quality oil is used, use of the steam spray type burner is more preferred than that of the pressure jet type burner.

The oxygen concentration in the exhaust gas is 10.2 % and air ratio is 1.87. If this oxygen concentration is reduced to 5.0 %, then the air ratio will be 1.31 and the exhaust gas will be reduced by about 29 %.

The fuel reduction rate (S) due to reduction of the air ratio is calculated from Table 5.2.8 and the following equation:

$$S = 1 - \frac{Q_i - L_I}{Q_i - L_I} = 1 - \frac{9,584.25 - 1,237.24}{9,584.25 - 878.85} = 0.0412 = 4.12\ \%$$

where,

Q_i	:	Calorific value of fuel	kcal/kg-Fuel
L_I	:	Current retention heat loss of exhaust gas	kcal/kg-Fuel
L_{II}	:	Retention heat loss of exhaust gas after improvement	kcal/kg-Fuel

The following shows the annual value that can be saved, using the annual fuel consumption of 2,510 tons (according to the 1992 record):

$$2{,}510\ t/y \times 0.0412 \times 2{,}710\ Lv/t = 280{,}247\ Lv/y$$

Table 5.2.8 Reduction of Exhaust Gas Retention Heat by Improving the Air Ratio

Item	Unit	Present	Improved
Amount of oxygen in exhaust gas	%	10.20	5.00
Air ratio		1.87	1.31
Theoretical amount of air		10.46	10.46
Theoretical amount of dry exhaust gas	Nm^3/kg	11.13	11.13
Actual amount of air	Nm^3/kg	19.56	13.70
Actual amount of exhaust gas	Nm^3/kg	20.23	14.37
Exhaust gas temperature	°C	201.33	201.33
Amount of exhaust retention heat	kcal/kg	1,237.24	878.85

F) Improved heat insulation

The surface temperature of the boiler is low and the heat insulation is considered to be satisfactory. However, the heat release from surfaces of the safety valve and steam valve is added, and the heat release from surface becomes greater than the value indicated in the heat balance chart.

The steam collector in the boiler room is poorly heat-insulated, and immediate actions must be taken to repair it. The valve and flange of the steam collector are often not provided with heat insulation to facilitate maintenance and inspection. These parts have comparatively large surface area, and the heat loss is great.

The steam collector valve in the boiler room of this plant is a 6-inch, 20 kg/cm^2-capacity flange type globe valve. The surface area required for heat insulation of this valve is 0.923 m^2. When this value is converted into the straight pipe length of the same size, the value corresponds to 1.78 meters. The steam collector is provided with 12 valves, and the total heat release from surface is calculated to be 30,677 kcal per hour from the following equation:

$$Q = \pi \times d \times \alpha \times (t_1 - t_2) \times L$$

where,

Q :	Total calorific heat loss	(kcal/h)
d :	Pipe diameter	0.165 m
α :	Heat transfer coefficient	18 kcal/($m^2 \cdot h \cdot$°C)

t_1' : Pipe surface temperature 184 °C
Surface temperature after heat insulation 60 °C
t_2 : Room temperature 30 °C
L : Pipe length 1.78 × 12 = 21.36 m

Before heat insulation Q_1 = 3.14 × 0.165 × 18 × (184 – 30) × 21.36
= 30,677 kcal/h
After heat insulation Q_2 = 3.14 × 0.165 × 18 × (60 – 30) × 21.36
= 5,976 kcal/h
Reduction of heat radiation $Q_1 - Q_2$ = 30,677 – 5,976 = 24,701 kcal/h

This can be converted into the amount of steam and the amount of fuel (heavy oil) that can be saved by heat insulation, as shown below, assuming that the steam latent heat of 10.23 kg/cm^2 (G) is 477.3 kcal/kg.

Amount of steam 24,701 kcal/h × 24 h/d × 300 d/y × 1/477.3 (kg/kcal)
= 373 t-steam/y

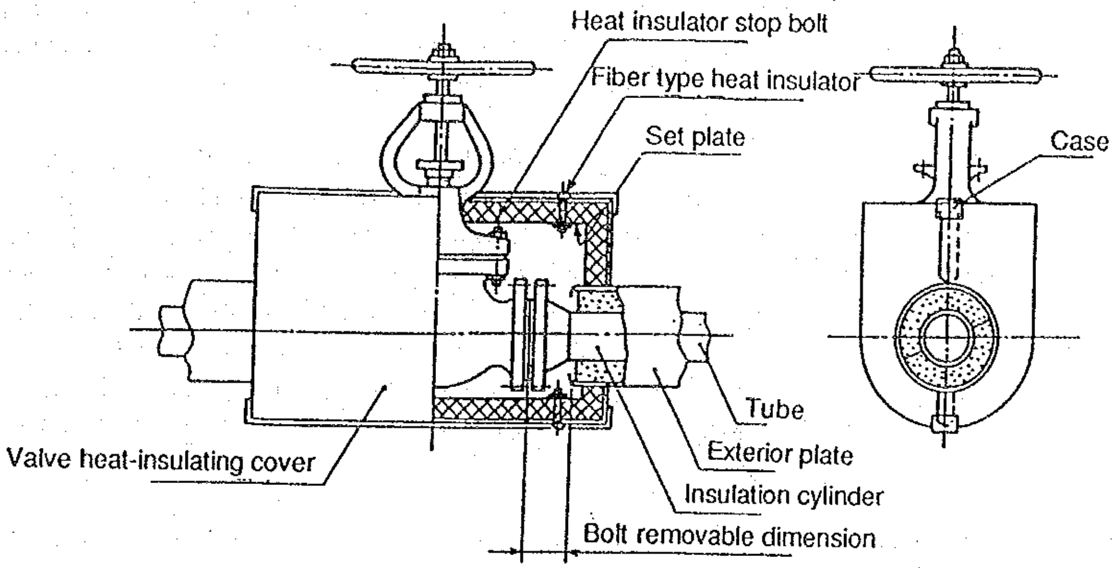
Since 0.116 tons of heavy oil is required to generate one ton of steam, reduction in the amount of heavy oil can be shown as:

373 × 0.116 = 43 t-Fuel/y

To provide heat insulation, put rock wool around the valve and wind it with water proof cloth. This can be done by plant employees, and the material cost is about 700 Lv. The cost can be recovered in a short period of time.

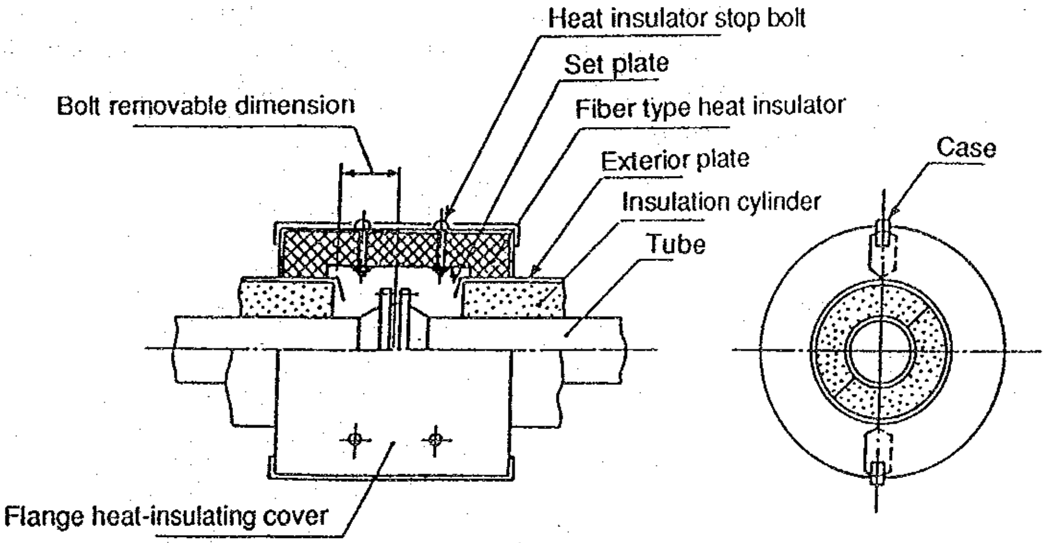
Figure 5.2.10 Insulation of Valve & Flange

Heat Insulation of Valve



Details of case

Heat Insulation of Flange



(3) Steam piping

A) Preventing radiated heat loss from pipe

Outdoor heat insulations of the main pipes are generally satisfactory. Though some of the heat insulations were observed to have been removed, during the present study, they were under repair; faulty insulations are repaired one after another. It is recommended that inspection and repair will be continued on a periodic basis.

The outdoor steam header branched off from the main pipe into the plant was exposed to the outside air and the valve is not provided with heat insulation. Radiated heat loss will be greatly increased when exposed to strong wind, rainfall and cold weather. It is necessary to enclose them with some fences and to provide heat insulation to reduce radiated heat loss. When they are placed outdoors, it is essential to cover them with iron plates or aluminum plates in order to protect them against rain. The heat transfer coefficient of water is about 0.5 kcal/(m.h.°C); this value is 10 times that of the insulation material. If the insulator absorbs moisture, heat loss will increase. So sufficient care should be taken in the work.

Steam leakage from the valve and flange was also observed on this header. The position of steam leakage will be further corroded by steam and leakage will aggravate. To prevent this, immediate actions must be taken to repair it.

C) Steam trap control

The steam trap must be always kept under the good conditions in order to ensure highly efficient operation of the equipment using steam and to minimize steam loss.

a) Steam trap operating conditions

The steam trap operating conditions were checked by the ultrasonic tester brought from Japan. Table 5.2.9 shows the results of the check. Of nine traps measured, four (44 %) were found faulty. Two out of three steam traps of the steam collector in the boiler room were found to have discharge failure, and the condensate was seen to be discharged from the bypass valve.

Table 5.2.9 Inspection Result of Steam Trap

Type	Inspected	No Good
Float	8	3
Disk	1	1
Total	9	4
Blocking		3
Blowing		1

b) Problems in trap management

① Some cooker steam traps of the pressing process were mounted at oblique positions. Float type steam traps must be installed horizontally.

② The disk type steam traps were used in the laboratory, and were left blowing. The disk traps are designed in a small and lightweight configuration with simple structure. They are placed under no restriction for piping installation. However, they are easily affected by outside air, and when exposed to rain or cold weather, they will frequently operate or may blow out even if condensate is not gathered. This will result in substantial steam loss. During the winter, they must be insulated using the empty can. They must not be used when back pressure is applied, for example, in case of the condensate recovery.

c) Steam trap maintenance

① When the steam trap is placed in service for a long period of time, the inside valve and valve seat will be worn, and steam will be discharged together with the condensate. The service life of the steam trap is said to be 3 to 5 years generally, though it depends on the type. So steam traps must be considered as expendable parts and replaced on a periodic basis.

② The steam trap must be subjected to periodic inspection once a year, and should be overhauled as required. To perform periodic inspection, prepare steam trap layout drawing, control register and check list, and record the results.

③ The steam trap failure includes three types; blowing, discharge failure, and steam leakage. When the condensate is discharged into the atmosphere close to the steam trap, the failure can be easily detected by visual observation. When the discharge position is not directly visible, for example, when the condensate is recovered, put on gloves, and hold the inlet pipe and outlet pipe of the steam trap by hands to check the temperature to see if it is operating.

(4) Power receiving, and distribution and electric equipment

A) Overview of the electric equipment in the plant

The electric power is supplied from a utility company through the 20 kV extra high voltage line, and is stepped down to 0.4 kV at two substations in the plant to be supplied to various processes. Each of the two substations is provided with two 1,000 kVA transformers. A substation for the water pump is located 4 km away from the plant. It receives power from the utility company through the 20 kV special high voltage line, and power is stepped down to 0.4 kV by one 250 kVA transformer. In addition, 100 kVA diesel generator is installed for emergency power supply.

Only one transformer is working in each of two substations. Since the maximum power is restricted to 770 kW except during the April to September period, one 1,000 kVA transformer is sufficient for the purpose, even if the 250 kVA pumping transformer is excluded. So improvement work is currently in progress for 0.4 kV system on the secondary side of the transformer. Because of the advantages in reduction of loss and system operation, this work should be implemented immediately.

The electrical system is generally placed under effective control.

B) Improvement measures and effects

a) Relocation of watt-hour meters

Table 5.2.10 shows power consumption by process in the plant for fiscal 1992. The watt-hour meter is not installed in dehulling, pressing and extraction processes which are major processes in the plant, accounting for 51 % of the energy consumption. However, the watt-hour meters are installed in the silo (material and meal) and machine shop where power consumption is smaller. As shown by this example, lack of consistency is observed in the investment for energy control facilities. Immediate actions must be taken to install new watt-hour meters in the dehulling, pressing and extraction processes. Or the watt-hour meters installed in the silo and machine shop must be transferred to the dehulling, pressing and extraction processes to get correct information on the power consumption in these processes.

Table 5.2.10 Electric Power Consumption by Process (1992)

Substation	Transformer	Section	Power Consumption kWh	Share %
No. 1	No. 1	Boiler room	515,517	15
		Silo (Seed)	86,841	3
		Silo (Meal)	29,320	1
		Water Pump	232,818	7
		Lighting	107,359	3
		Others	87,529	3
		Total	1,059,384	32
No. 2	No. 4	Machine shop	7,501	0
		Bottling	75,283	2
		Administration	79,572	2
		Refining	244,192	7
		Dehulling, Press,	1,686,192	51
		& Extraction		5
		Total	2,092,740	63
Pump			183,440	5
Total			3,335,564	100

b) Voltmeter and ammeter improvement

The voltmeters and ammeters were installed in the substation. However, some of them showed incorrect indications or indication failure. The voltmeters were found not equipped in the boiler room. To ensure maintenance of the electric equipment, immediate actions must be taken to repair them.

c) Additional installation of watt-hour meters

Electric power consumption was measured at substation every day -- three times a day -- at 5 o'clock, 13 o'clock and 22 o'clock. For energy unit consumption rate and cost control, it is necessary to measure the power for each of the time zones; the peak time, daytime and night zones. For this purpose, daily measurements should be taken six times for each time zone.

Readings on the watt-hour meters (slave meter) installed in various places are recorded on only 27th or 28th of each month. For the same reasons as above, they should be recorded every week or every day if possible.

d) Pump water leakage

Water pump leakage was observed at several places in the plant. One of them is the dewaxing pump in the refining process, and leakage of about 10 to 15 ℓ/min. was observed. Another was the pump in the boiler tank room, and leakage of about 10 ℓ/min. was observed. As such water has been pressurized by electric power, immediate actions must be taken to repair them.

f) Motor

Motor loads were measured on March 17 and 18. Table 5.2.11 shows the results of the measurement.

Table 5.2.11 Load of Motors

Motor	Rating kW	Data Number		Voltage V	Current A	Load kW	Power Factor
Dehuller No. 1	5.5	17	Avg.	232.6	11.0	0.3	0.05
			Max.	238.5	12.7	0.8	0.10
			Min.	189.9	10.2	0.1	0.02
Dehuller No. 2	5.5	16	Avg.	238.1	5.5	0.9	0.24
			Max.	246.2	5.8	1.0	0.25
			Min.	237.1	5.3	0.9	0.22
Dehuller No. 3	5.5	3	Avg.	237.5	7.7	2.5	0.46
			Max.	237.9	7.9	2.5	0.46
			Min.	237.2	7.5	2.5	0.46
Press No. 1 Crusher	10	5	Avg.	235.4	10.5	3.9	0.53
			Max.	237.4	11.5	4.0	0.54
			Min.	232.2	9.9	3.8	0.52
Press No. 1 Crusher	50	23	Avg.	241.8	48.8	9.8	0.28
			Max.	251.5	55.6	19.6	0.53
			Min.	237.2	43.3	4.7	0.14
Press Roller C	30	18	Avg.	239.2	39.9	19.3	0.66
			Max.	240.9	44.0	21.9	0.72
			Min.	237.2	28.6	6.1	0.29
Cooker Agitator	30	16	Avg.	238.4	18.5	11.2	0.85
			Max.	241.6	20.7	12.6	0.86
			Min.	237.1	16.5	9.7	0.82

Motor	Rating kW	Data Number		Voltage V	Current A	Load kW	Power Factor
Toaster	45	15	Avg.	237.9	37.5	10.1	0.38
			Max.	238.8	38.8	10.9	0.40
			Min.	236.1	36.0	9.1	0.34
Boiler No. 1 Circuit		11	Avg.	244.3	37.7	18.2	0.63
			Max.	246.7	57.2	30.8	0.76
			Min.	239.0	25.4	10.6	0.52
Boiler No. 2 Circuit Blower	30	14	Avg.	244.8	65.2	37.6	0.79
			Max.	247.1	65.6	38.0	0.80
			Min.	238.7	63.6	36.9	0.78
Husk Boiler No. 1 Blower	22	14	Avg.	242.0	26.6	10.9	0.53
			Max.	244.4	27.6	19.7	0.54
			Min.	240.0	25.1	10.1	0.52
Husk Boiler No. 2 Blower	22	13	Avg.	240.9	29.8	14.1	0.63
			Max.	242.7	30.8	21.4	0.63
			Min.	237.8	27.8	13.2	0.62
Husk Conveying Blower	30	13	Avg.	238.6	30.4	17.5	0.81
			Max.	242.7	33.7	17.8	0.81
			Min.	233.2	26.9	16.4	0.80
Pump Room		27	Avg.	241.0	159.8	91.1	0.78
			Max.	247.2	220.2	126.4	0.81
			Min.	238.4	116.6	67.2	0.75

The dehuller is provided with three motors -- for air blowing, dehulling, and sieving. Since the amount of the materials supplied was not sufficient at the time of measurement, each motor load was low, and power factor was extremely low. For the same reason, the power factor of the crusher motor in the pressing process is low.

Low voltage was recorded for No. 1 dehuller. This is temporary low voltage due to load fluctuation.

(5) Total effect

Table 5.2.12 shows the effects of the above mentioned improvements where quantitative prediction is possible.

Table 5.2.12 Summary

Item	Expected Saving							Investment Payback	
	Oil			Power			Total	Year	
	t/y	1000Lv/y	%	kwh/y	1000Lv/y	%	1000Lv/y	1000Lv	y
Press									
Improvement of Dehulling							1000.0	5000	5.0
Preheat before Flaking							3000.0	5000	1.7
Decrease of Cooker Steam	116	314.4	4.6				314.4	0	
Extraction									
Utilization of DT Vapor	417	1130.1	16.6				1130.1	3000	2.7
Benzine Heater Stop	136	368.6	5.4				368.6	0	
Repairing Steam Leak	148	401.1	5.9				401.1	0	
Utilization of Condensate	3	8.1	0.1				8.1	0	
Refining									
Degumming Heater Bypass	34	92.1	1.4				92.1	0	
Boiler									
Air Ratio Control	103	280.2	4.1				280.2	0	
Valve Insulation	43	116.5	1.7				116.5	0.7	0.01
Total	1000	2711.1	39.9				6711.1	13001	1.9

5.3 Results of Study at a Pulp and Paper Factory

5.3 Results of the Study at a Pulp and Paper Factory

5.3.1 Overview of the plant

(1) Factory name
Celhart Ltd.

(2) Type of industry
Paper and pump industry

(3) Major product name and production capacity

Bag making kraft paper	:	63,000 t/y
Corrugating medium paper for corrugated board paper	:	15,000 t/y
Paper bag	:	300,000 /d

(4) Number of employees on the payroll
1760

(5) Factory address
Stamboliiski, privattel. 54-36
str. "B. Paraschkewa" 27

(6) History
Celhart Ltd. has an integrated production process including the lumber, pulp, semi-pulp, corrugating medium paper for corrugated board paper and paper bag.

Starting as a pulp processing factory in 1952, Celhart Ltd. took up production of the corrugating medium in 1954.

In 1968 the company started production of the bag making kraft paper. With the improved production capacity, the company boasts the largest factory in the Balkan area and the only factory manufacturing bag making kraft paper in the country. Coarse terpene oil is collected from the cooker exhaust gas.

Due to sluggish economy after the political renovation, the production has been lowered to 60 percent of the peak level.

In order to recover chemicals from the waste liquid generated in the pulp production, the factory installed the recovery boiler in 1972 to utilize energy of the combustible substances for steam generation. At present, the work is under way to use natural gas instead of heavy oil whose supply for the boiler fuel is not ensured.

Steam generated by the boilers is firstly fed to the turbine to be used for power generation; then extracted steam of the turbine is fed to be used for process. Part of the steam is sold to the neighboring factories or for local heating.

(7) Study period

June 14, 1993 to June 18

(8) Members of study group

Mitsuo Iguchi : Head of the study group, energy management
Teruo Nakagawa : Assistant Head of the study group, measurement
Akira Koizumi : Paper and pulp process
Shoji Nakai : Thermal technology
Takashige Taniguchi : Thermal technology
Tetsuo Ohshima : Thermal technology
Kazuo Usui : Electric engineering

(9) Persons interviewed

Mr. Grigor D. Varsamov : President
Mr. Ananiev : Factory Manager
Mr. Stoyan Roglekow : Chief Engineer
Mr. Rumen Bundev : Energy Manager
Ms. Pranjeva : Electric Engineer

(10) Trend of production

Table 5.3.1 Trend of Production

Name of Product	Unit	1989	1990	1991	1992
Paper (Heavy Duty Sack Paper)	ton	45896	32882	28516	24850
(Corrugating Medium)	ton	15915	15140	11209	10857
(Sub Total)	ton	61811	48022	39725	35607
Pulp	ton	66180	45432	38220	30776
Semi − Pulp	ton	16424	15209	9362	5332

(11) Trend of energy consumption

Table 5.3.2 Trend of Energy Consumption

	Kind of Energy	Unit	1989	1990	1991	1992
	Purchased Energy					
	Coal	ton	40246	0	0	0
	Fuel Oil	ton	5493	72680	49996	44943
	Electric Power	MWh	54993	43370	52114	49835
	Consumed Energy					
	Black Liquor	m³	172775	149240	141825	100715
(A)	Fuel Total	Tcal	1193	947	725	602
(B)	Steam	Gcal	585702	420004	344476	279529
(C)	Generated Power	MWh	92100	77476	43013	37245
(D)	Generated Power	Gcal	79206	88830	36991	32030
(E)	(B)+(D)	Gcal	644908	486634	381467	311559
(F)	(B)+(D)/(A)	%	54.1	51.4	52.6	51.8
(G)	Electric Power	MWh	147093	120846	95127	87080
(H)	Well Water	1000m³	18115	17695	-	13423

Note: Twenty percent of the steam is sold outside.

(12) Trend of unit energy consumption

Table 5.3.3 Trend of Unit Energy Consumption

Kind of Energy	Unit	1989	1990	1991	1992
Purchased Energy					
Fuel	t oil equivalent	93249	72680	49996	44943
	ton/t-Paper	1.509	1.513	1.259	1.262
Electric Power	kWh/t-Paper	890	903	1312	1400
Total	Mcal/t-Paper	15326	15289	13282	13165
Consumed Energy					
Steam	Mcal/t-Paper	9152	8746	8672	7850
Electric Power	kWh/t-Paper	2380	2516	2395	2446
Water	m³/t-Paper	293	368	-	377

(13) Trend of unit energy consumption by process

Table 5.3.4 Trend of Unit Energy Consumption by Process

Process	Item	Unit	1989	1990	1991	1992
Pulp	Output	t	66180	45432	38229	10695
	Steam	Gcal/t	2.97	3.02	3.77	3.93
	Power	kWh/t	486	512	547	433
	Water	m³／t	98	184	163	194
Semi Pulp	Output	t	16424	15209	9362	2719
	Steam	Gcal/t	1.45	1.53	1.77	1.89
	Power	kWh/t	190	210	209	253
	Water	m³／t	58	56	60	56
Bag Paper	Output	t	45896	32882	28516	9563
	Steam	Gcal/t	1.99	1.79	2.17	2.02
	Power	kWh/t	1032	1063	930	853
	Water	m³／t	118	126	155	254
Fluted Paper	Output	t	15915	15140	11209	5618
	Steam	Gcal/t	1.54	1.51	2.33	2.18
	Power	kWh/t	458	475	567	599
	Water	m³／t	50	75	75	97

Figure 5.3.1 Heat Energy Unit Consumption

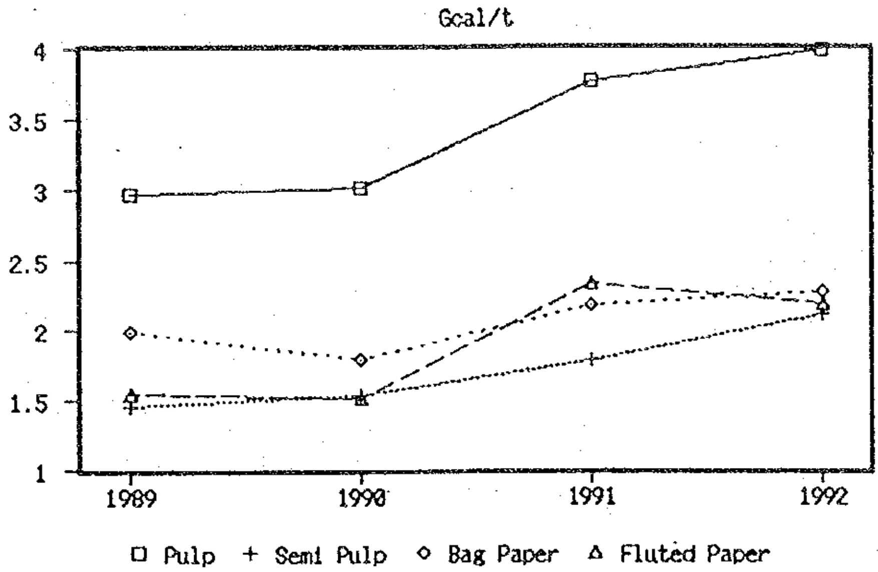


Figure 5.3.2 Electric Power Unit Consumption

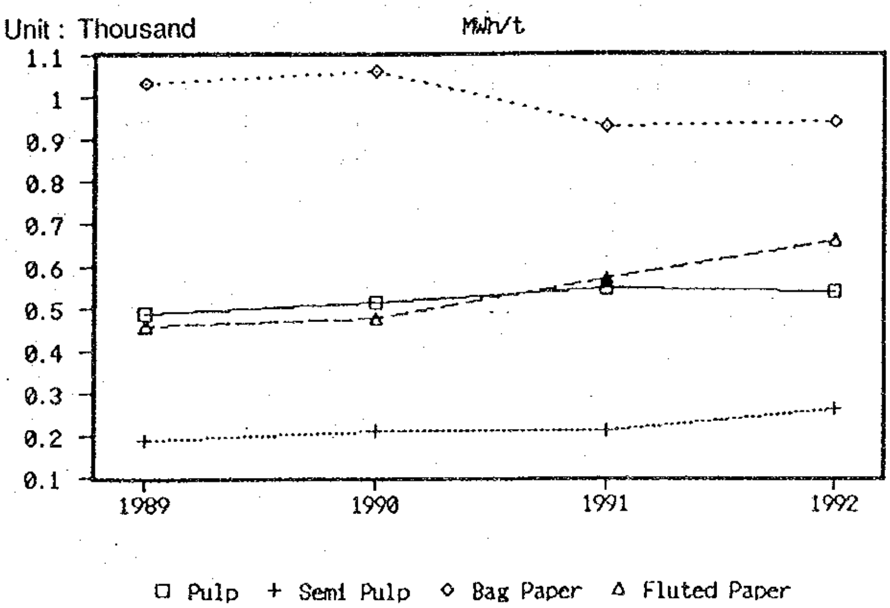
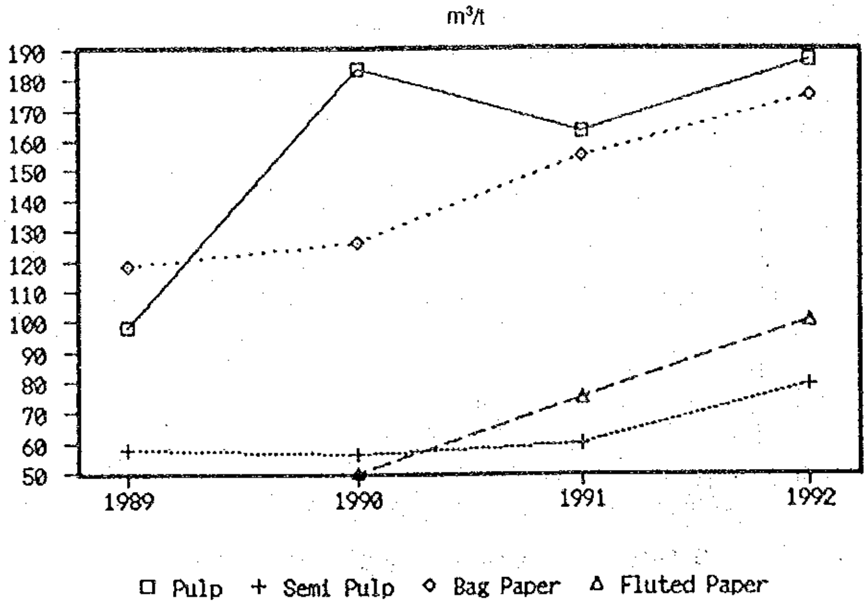


Figure 5.3.3 Water Unit Consumption

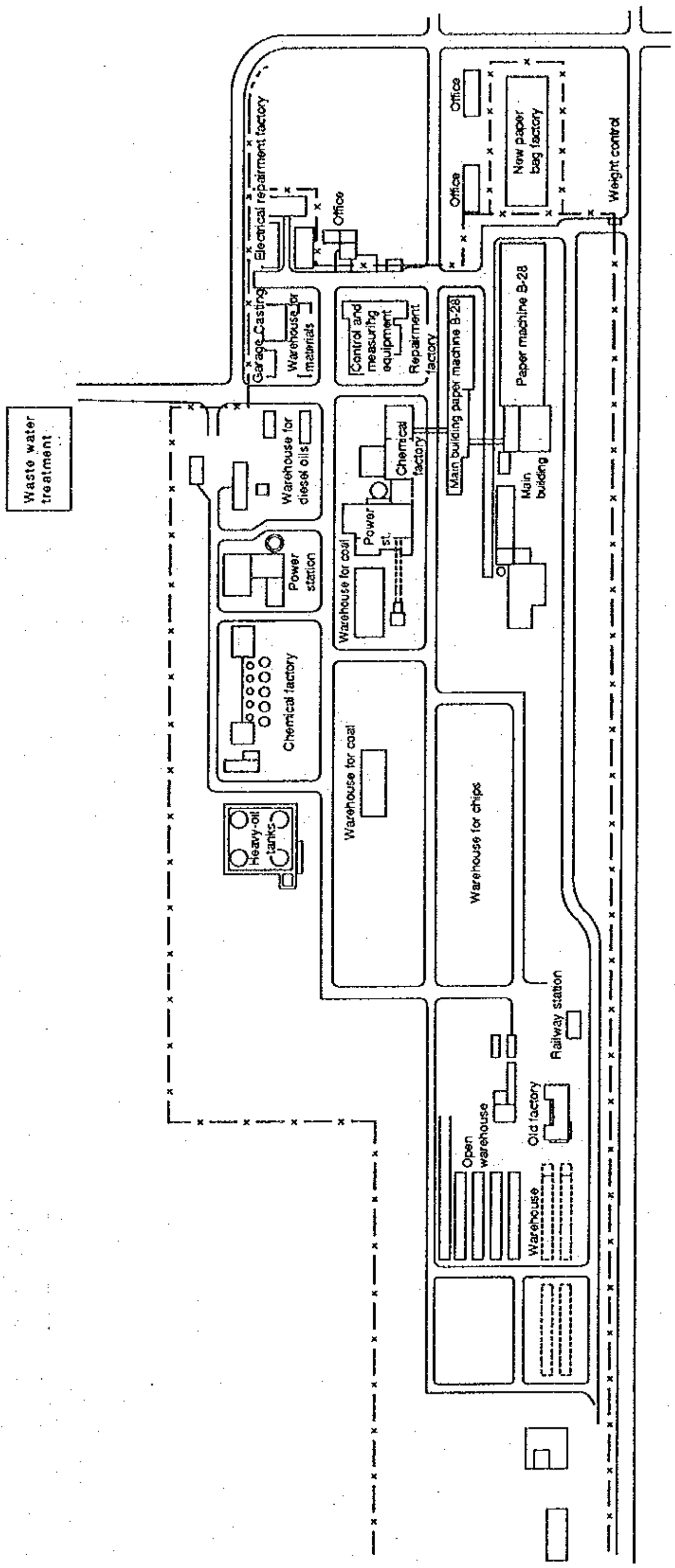


(14) Energy prices

Heavy oil		2240 Lv/t (9980 kcal)			
Steam		433 Lv/Gcal			
Electric power	Time	Peak	Day	Night	
	Lv/kWh	1.395	0.754	0.374	Oct-Mar
	Lv/kWh	1.217	0.655	0.322	Apr-Sep

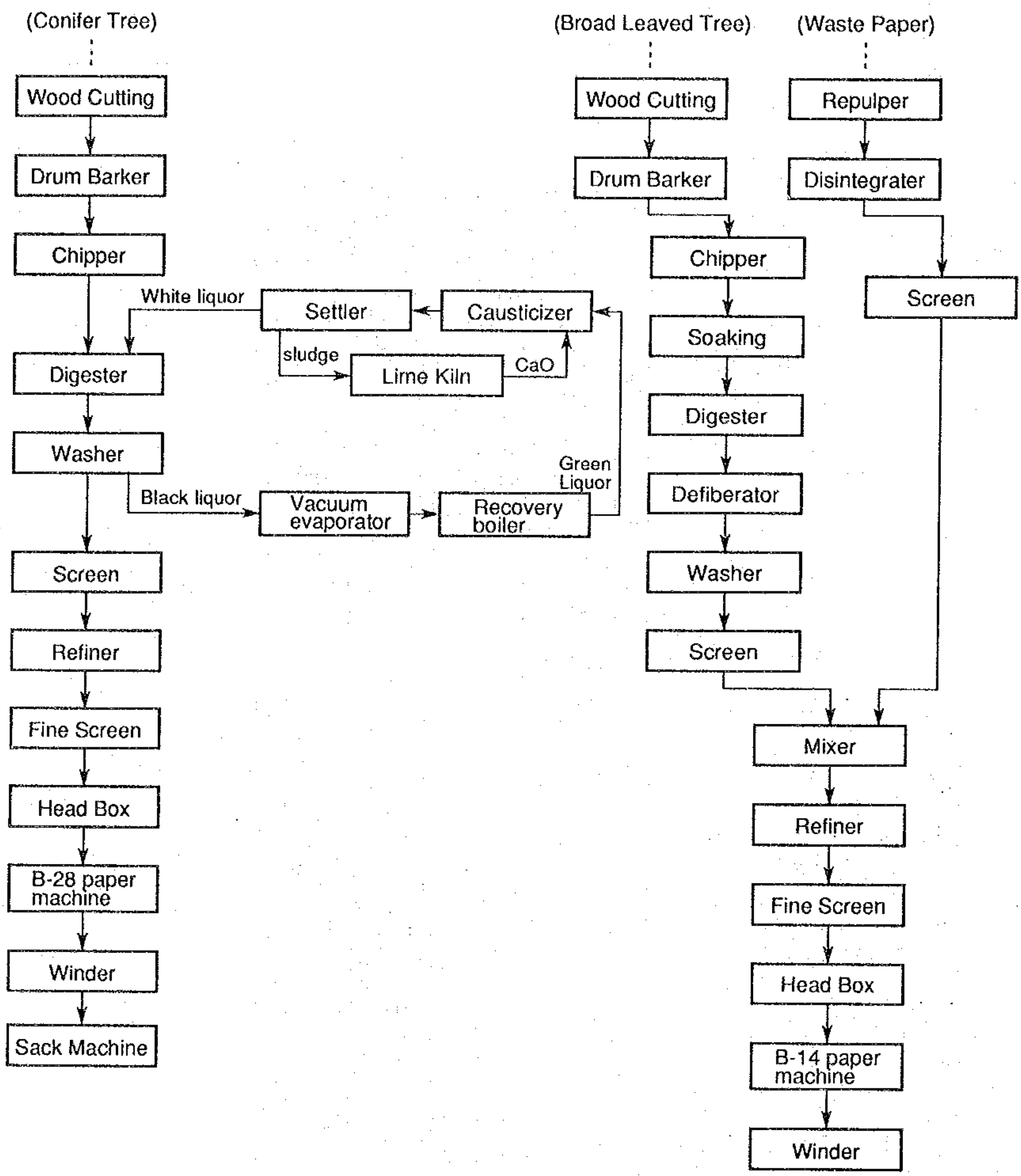
(15) Factory layout

Figure 5.3.4 Factory Layout



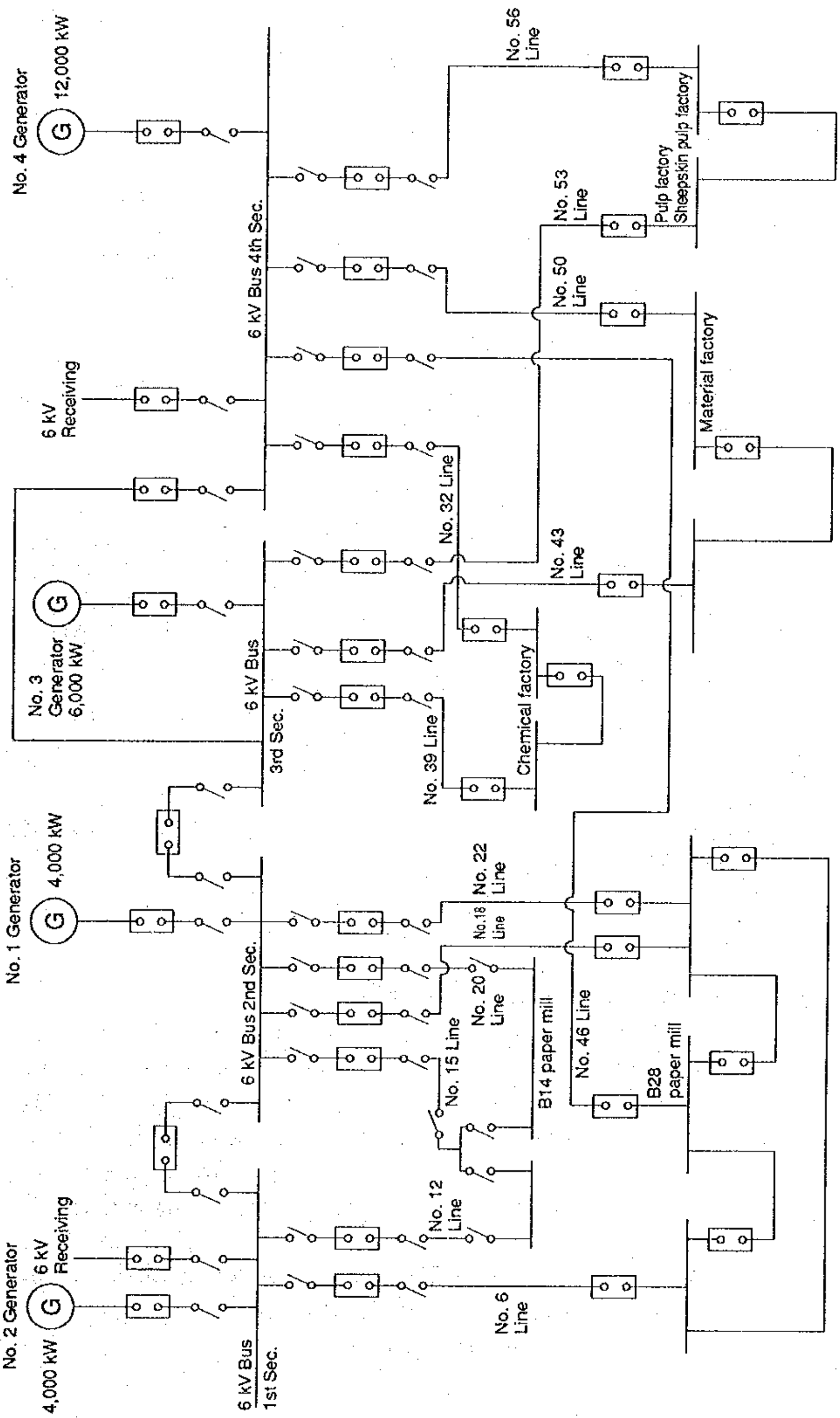
(16) Production process

Figure 5.3.5 Production Processes



(17) Electric power one line diagram

Figure 5.3.6 Electric Power One Line Diagram



(18) Outline of principal equipment

Table 5.3.5 Outline of Principal Equipment

Name	Number	Specification
Wood cutting process		
Drum barker	4	Wet type 1, Dry type 3
Chipper	4	
Cooking process		
Kraft batch digester	6	110 m^3
NSSC continuous digester	1	Pandia type 100 t/d
Brown stock washer	3	3 stage
Screen	16	Knot, Rota closed type
Chemicals process		
Black liquor concentrator	1	6 effect vacuum evaporator
Caustifier	1	Continuous
Lime kiln	1	3 m dia. × 60 m L.
Waste paper pulper	3	
B-14 Paper machine		
Refiner	4	Disk type
Cleaner	1	Centrifugal
Screen	2	Rota vertical type
Wire part	1	Long wire, 2.9 m W. × 43 m L.
Press part	1	Plain + Suction, 2 stages
Dryer part	1	37 cylinders, 1.5 m dia. × 2.7 m W.
B-28 Paper machine		
Refiner	11	Disk type 9, Conical type 2
Cleaner	1	Centrifugal
Screen	6	Rota vertical type
Wire part	1	Long wire, 4.8 m W. × 43 mL.
Press part	1	Twinbar, 3 stages
Dryer part	1	75 cylinders, 1.5 m dia. × 4.9 m W.
Sack making process		
Sack making machine	2	

5.3.2 Situation of energy management

Energy conservation measures are taken in this factory, including the installation of the recovery boiler, modification of the dryer hood, use of thyristor control of the dryer cylinder driving motor, improvement of the press part, updating of the vacuum pump, and conversion of the boiler fuel to natural gas. The energy is placed under effective control, but systematic energy conservation campaign involving all the employees are not yet initiated.

Energy consumption efficiency differs according to the performances of the equipment and machinery and operation methods, which depend greatly on the skills and actions of the personnel in charge of operation and maintenance.

Adequate maintenance and servicing must be taken to ensure design performance of the equipment, and minor modification should be made to provide improved performances. It is necessary not only to try to conform to operation standards but also to make improvement efforts to find out better operation methods.

This is related to all the members engaged in the work. To ensure effective promotion of the energy conservation, it is essential to establish an organization to ensure that all the people of the factory make concerted efforts to achieve the target, as well as to take measures for the equipment improvement.

(1) Setting the target for energy conservation

To initiate energy conservation, the top management of the company must define the energy conservation as one of major management targets, demonstrating serious attitude and enthusiasm for energy conservation to the employees. This will convince the employees that making efforts for energy conservation will conform to the policy of the company, and will motivate them for positive efforts.

When policy is shown by the top management, mere abstract instruction for energy conservation is not sufficient; concrete target values and the deadline for achieving the goal must be shown to the workers. In response to these instructions, each section of the factory should set up the concrete targets for individual items which can be taken charge of within the scope of the responsibility, so that the overall target can be achieved. Only after the target has been set, concrete action plans to achieve the target can be worked out, including study of various approaches, preparation of the programs and assignment of the works.

(2) Systematic actions

Energy consumption is said to be included in the agendas to be studied at the monthly production plan meeting of this factory, and the management people are greatly interested in energy conservation issues. It is recommended that this meeting be used for working out the plan for energy conservation plan, determination of the budget, approval of the technological plan for energy conservation measures, evaluation of the campaign results, and introduction of the cases of similar efforts. This will ensure uniform understanding to be shared among different divisions, permitting the efforts to be made on a priority basis. This will also make it possible to check if a particular action has a total effect including the effect given to the preceding and succeeding processes. It will also permit advice to be given from different angles.

It is also necessary to hold various events in order to keep the employees interested in the energy conservation, or appoint coordinators to make arrangements among different related divisions, in order to ensure smooth implementation of the energy conservation activity.

The employees working in the first line are placed in daily contact with energy consuming equipment, and they get the feel of the problems with their own skin. An effective use of energy cannot be achieved if the equipment are not used effectively and work standards are not observed, no matter how excellent they are. So it is effective to keep the employees in the first line interested in the energy conservation campaign so that they will take an active part in the activity.

(3) Data-based management

In energy activity activity, as in the quality control, steady improvement can be gained by repeating the PDCA circle where an improvement plan is worked out (PLAN) and implemented (DO), the results are evaluated (CHECK), the work process is modified or fixed (ACTION) in accordance with the evaluated results; then an improvement plan on a higher level is worked out. Thus the control level is gradually increased, repeating the same cycle.

The problems accompanying energy consumption to be studied in working out the improvement plan and suggestions for improvements can be made clear only through an objective analysis of the data (facts) occurring in the factory. The effects of the energy conservation efforts can be confirmed by means of statistical techniques such as unit consumption rate control chart, histogram and correlation analysis on the basis of the actual data. If there is abnormal data, much information can be gained by checking the cause for such fault.

In this factory the daily energy consumption for each process is recorded and is compiled into the monthly and yearly records on a cumulative basis. The unit consumption rate is also calculated. If there is a big discrepancy from the original schedule, the causes are checked. The result of energy consumption is notified to the employees in order to encourage their interest for energy.

(4) Education and training of employees

It is necessary to give sufficient information in order to promote voluntary activities of the employees. To motivate efforts for energy conservation, the employees should be informed of the trend of energy prices, the weight of the energy cost in the production cost, possible causes for energy losses, preventive measures, and cases of successful energy conservation efforts in other factories.

It is also necessary to promote education and training of the employees by giving instructions through competent staff members, by giving training courses, and by providing them with manuals, thereby increasing their level. This factory has an educational center where lectures are given by the factory expert staff members for the operators which are going to sit in for higher qualification test. Energy conservation should be included in the instruction agenda for this lesson.

To improve the engineering level, engineers are dispatched to the seminars sponsored by the paper and pulp research institute. The change of exchanging information with the engineers among rival companies is said to have been reduced, it is considered to be effective to set up an industrial association to activate information exchange.

(5) Equipment management

If the equipment is not maintained in proper conditions, a great energy loss will occur. In the paper manufacturing company, the maximally continuous operation and the maximum use of the equipment are effective for energy conservation. To achieve this purpose, maintenance and repair play a major role. In this factory, part of the heat exchanger could not be used due to fouling and damages, causing reduced efficiency. Condensate was observed to be leaking from the pipe and pump. They lead to the waste of energy; this requires establishment of the planned equipment maintenance system.

Drawings are essential for the maintenance of the equipment. Revised drawings must be prepared immediately after any modification work has been made, and they must be put in order so that they can be easily used by any one.

5.3.3 Problems in the use of energy and countermeasures

(1) Production and maintenance system

a) Continuous operation of paper machine

The paper and pulp industry is a process industry registering a great consumption of energy including steam and electric power. It is essential to attach a great importance to efficiency, setting a target to high productivity, uniform quality and low cost production through long-term continuous operation.

Reflecting the sluggish market conditions, this plant is currently operating with reduced production volume, and the operation does not conform to the equipment design conditions. Continued operation of the paper machine below the production capacity will spell out a declined energy efficiency and less operator willingness for production.

During the operation, continuous operation should be ensured at the optimum production level for the longest possible period without operations being interrupted by the machine failure and shortage of paper. The monthly or annual production volume should be adjusted by machine shutdown period, for example, operation for 50 days followed by maintenance for 50 days. Establishing such a production system will pave the way to upgrade energy unit consumption rate. In conformity to operating conditions of the paper machine, various processes of the cooking, concentration of black liquor, recovery boiler can be used to their maximum capacity.

When the equipment operation plan is worked out, it is necessary to consult with the engineering people of the operation division to get correct information as to how long the operation can be continued. Regarding the product order, delivery and inventory conditions, consult with the sales division; based on such correct information, work out an effective production plan for each product type.

Once an accident has occurred and a lot of time is spent for repair, the other processes and boiler operations will be affected, aggravating the plant profits. During shut-down, complete maintenance of the equipment is essential. During the period of continuous operation intended by the operation division, every care should be taken to ensure that decline in efficiency will never be caused by suspension of the equipment operation due to equipment and electric failures. Once any failure has occurred, it should be recovered as soon as possible. These are the responsibilty of the equipment maintenance division. It is important to set up a production system which provides long-term continuous operation through the cooperation of all divisions.

① Factors relevant to the continuous operation period

a) Service life of wire of paper machine
The wire life differs according to type of the product; and material. The bronze wire has a life span of about 40 days, while the plastic wire lasts for 60 days or more.

b) Service life of paper machine felt

c) Reduced efficiency due to the dust deposited on the recovery boiler

d) Scaling on the heat exchanger of the cooker and vacuum evaporator

e) Bricks falling in the lime kiln or similar failure taking a long repair period

f) Cooperation of the labor union in the work system

g) The amount of orders received and storage capacity

Furthermore, the experience with the continuous operation so far is also an item to be taken into account.

② Equipment repair and maintenance system

1) Scheduled inspection

2) Working out the repair work program to ensure smooth and safe repair works (changes in operation time, production plan)

3) Minimum working hour management to minimize the impact on production

Procurement of parts and materials required for repair

Maintenance and operation personnel layout program and work system

Preparation of auxiliary equipment, working tools and scaffolds

Discussion with expert of companies manufacturing the boiler, electric equipment, measuring instrument

4) Safety measures

Repair and maintenance system should be set up with consideration given to above mentioned factors.

When the market is busy, repair and maintenance should preferably be completed within 5 days or 120 hours. If the market is depressed, the extended shutdown time may be unavoidable, but excessive extension of the maintenance time should be avoided for management efficiency.

③ Management by operation efficiency index

The operation division and maintenance division should use the efficiency indices to control availability factor of the production equipment.
The following shows the concept of daily management for the paper machine:

1) Operation efficiency of the paper machine

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

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

2) Preventive maintenance efficiency

$$\text{Preventive maintenance efficiency} = \frac{\text{Actual operation time (min.)}}{\text{Responsible operation time (min.)}} \times 100$$

$$\text{Preventive maintenance efficiency} = (1 - \frac{C}{A - B - D - E}) \times 100$$

where,

A : Paper machine operation time according to the production program (min./day)

B : Power suspension time for which electric utilities are responsible (min./day)

C : Suspension time by machine failure (min./day)

D : Suspension time by electrical failure and voltage drop (min./day)

E : Suspension time by paper machine failure (min./day)

(to be analyzed according to the causes including paper break, wire repair, blanket repair, blanket cleaning, etc.)

Regarding B, ask electric utilities for compensation; the equipment maintenance division for C and electric division for D should make efforts to gain upgraded maintenance technique in order to prevent recurrence of the trouble.

Normally, almost no paper break occurs in the case of kraft paper; it occurs only 0.1 to 0.2 times per day in the case of the newspaper size paper, and 0.1 times per day in the case of the high quality paper. It is necessary to make efforts to improve the technique to eliminate paper break by making reference to the efficiency index.

b) Use of high efficiency equipment

The equipment which contribute to energy efficiency, production efficiency, yield and quality improvement are not used sufficiently; due to poor maintenance such equipment include the heater of the cooker, the multi-effect vacuum evaporator, black liquor oxidizer, bark boiler, polydisk filter, drier and condensate recovery device.

Since the preventive maintenance system of the equipment is not established, the equipment investment is considered to be causing increase in fixed cost and decline in profits, instead of generating profits. To set up an efficiency control system in each of the cooking, washing, black liquor concentration, caustification and refining processes is to keep busy the efficiency improving equipment such as cooker heater, evaporator, polydisk filter. This will save a substantial energy.

c) Energy unit consumption rate

Table 5.3.6 illustrates the records of the unit consumption rate of steam and electric power in each process in the past four years and corresponding average values in Japan which are extracted from the data of the Japan Paper and Pulp Technical Association:

Table 5.3.6 Energy Consumption Unit Rate

	Unit	CELHART 1989	1990	1991	1992	JAPAN 1980	1988
Kraft Pulp(UNKP)							
Pulp Output	t	66,180	45,432	38,229	30,776		
Steam/Pulp	t/t	1.57	1.65	1.95	1.86	1.45	1.33
Power/Pulp	kWh/t	209	201	190	225	196	214
Water/Pulp	t/t	33	29	-	48	86	60
Semi Chemical Pulp(SCP)							
Pulp Output	t	16,424	15,209	9,362	5,331		
Steam/Pulp	t/t	2.01	2.11	2.09	2.23	1.04	1.15
Power/Pulp	kWh/t	185	210	209	261	574	473
Water/Pulp	t/t	57	56	60	77		45
Kraft Paper Machine(B−28)							
Paper Output	t	45,896	32,882	28,516	24,850		
Steam/Paper	t/t	3.07	2.95	3.11	3.48	2.86	2.74
Power/Paper	kWh/t	716	771	694	758	811	744
Water/Paper	t/t	121	149	155	175	112	85
Fluting Medium Machine(B−14)							
Paper Output	t	15,915	15,140	11,209	10,757		
Steam/Paper	t/t	3.25	2.72	3.21	3.06	2.16	1.62
Power/Paper	kWh/t	597	533	574	648	234	440
Water/Paper	t/t	107	90	75	101	95	68

Note: The Japanese average values for the kraft pulp are extracted from the values in the case of the batch cooker and continuous washer, while those for the semi-chemical pulp are extracted from those in the case of the semi-chemical pulp for the liner board and fluting medium. The increase in electric power for fluting medium depends on the product quality requirements.

(2) Pulp production process

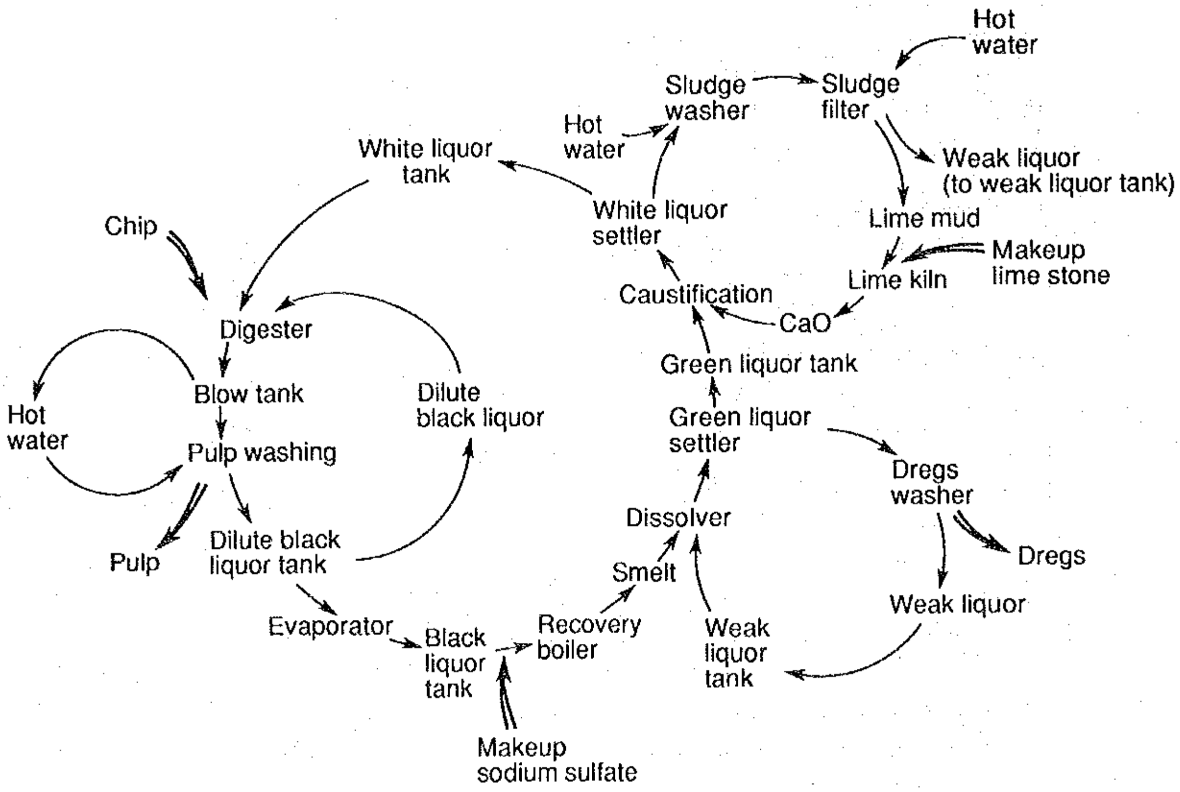
The pulp making process is composed of the following three processes;

Sulfate pulp (kraft pulp) process
Neutral sulfite semi-chemical (NSSC pulp) process
Pulp from recovered waste paper

a) Kraft pulp cooking process

The process in the kraft method comprises cooking, washing, black liquor concentration, recovery boiler and caustification processes, and chemicals are circulating in the cycle shown in Figure 5.3.7. This closed system avoids loss of soda and sulfur, and minimizes energy loss, making a significant contribution to the reduction of pulp manufacturing costs.

Figure 5.3.7 Kraft Pulp Process



1) Cooking

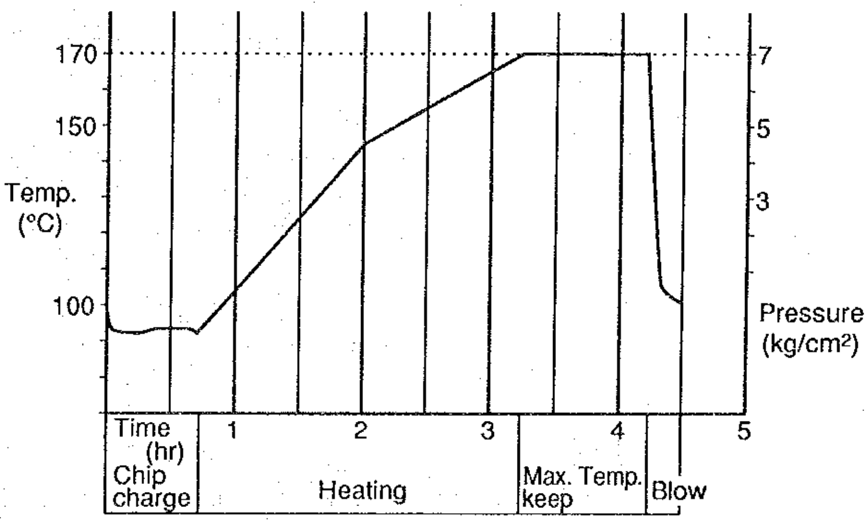
The cooking process is provided with the cooker having a capacity of 110 m^3, the multi-tube heat exchanger with a heat transfer area of 45 m^2, blow tank and blow gas heat recovery jet condenser, and hot water obtained by heat exchange is used to wash the pulp.
The full capacity of a 9.0-ton cooker is about 300 tons per day.

Effective alkali (as Na_2O) is added to the cooking chemical about 13%, which is then heated by a heater and cooking goes on at a maximum temperature of 170 °C. Steam with a pressure of 11 kg/cm^3 at the temperature of 250 °C is used as heating steam.

However, the liquid side of the heater is currently clogged with the scale, and the liquid leaks due to corrosion of the tube. Steam is directly blown into the cooker for cooking process, without using the heater.

The liquid ratio before heating is 3.5. Figure 5.3.8 illustrates the cooking curve. One cooking cycle takes 4 hours and 30 minuets, and heating requires 2 hours 15 minutes. The maximum temperature is 172 °C and pressure is 7.0 kg/cm², while the maximum temperature is retained for 50 minutes. Cooking time seems to be prolonged by direct cooking, in contrast to heating time being 1 to 1.5 hours generally.

Figure 5.3.8 Cooking Curve



Kappa value for cooking is said to be 35 to 40, and the part of fine pulp is somewhat overcooked. Direct cooking affects yield and pulp quality, resulting in ineffective use of energy.

According to the comparison in Table 5.3.6, this plant consumes about 40 % more steam than the Japanese average value. It is necessary to revert to the indirect cooking method for uniform cooking, as early as possible. This will reduce the volume of uncooked knot to eliminate the need of overcooking and ensure improved yield, resulting in improvement of steam unit consumption rate by a minimum of 15 %. Furthermore, heating steam condensate can be recovered; this will bring about such advantages as reduced steam cost and reduced amount of steam to concentrate black liquor because of volume decrease.

Steam consumption in the pulp process in 1992 was about 40,800 Gcal, so the expected volume of the steam saved can be calculated as follows:

40,800 Gcal/y × 0.15 = 6,100 Gcal/y
6,100 Gcal/y × 433 Lv/Gcal = 2,641,300 Lv/y

2) Effective use of heater

It is widely known that scale is deposited on the heat exchanger and chemical strainer, causing chemicals circulation failure. As discussed above, it is essential to set up an effective repair and maintenance system to improve the equipment availability factor and to ensure high quality, effective use of energy and reduced cost. For the elimination of scale, see the subsequent description of the multi-effect vacuum evaporator.

3) Heat recovery from exhaust gas

In the cooking reaction process, heat is recovered from the non-condensable gas produced at the temperature of about 140 °C or more. The heat retained by exhaust gas is recovered by the spiral heat exchanger as 25 to 30 m^3/hour of hot water having a temperature of about 40 °C, and the resultant heat is used to wash the brown stock. Terpentine is by-produced from the vapor condensate.

Furthermore, the heat of the blow gas is absorbed by the jet condenser, and is recovered as hot water having a temperature of about 75 ~ 85 °C, to be used to wash the brown stock.

Pulp is likely to attach or deposit on the interior of the heat exchanger and jet condenser, and should be inspected and cleaned according to the maintenance program.

4) Washing of the brown stock

The pulp in the blow tank (brown stock) is washed by the three-stage continuous washer using the hot water having a temperature of 60 to 70 °C. The purpose of washing is to remove from the pulp the lignin made soluble in the cooking process, resin, organic acid and residual cooking chemicals.

The generated volume of the black liquor is 11.0 m^3/t-pulp, and 1.54 t/t-pulp as solids, as given in Table 5.3.7; it shows values similar to average values.

Table 5.3.7 Generated Black Liquor

Name	Unit	1989	1990	1991	1992	Average
Pulp	t/y	66,180	45,432	38,229	30,776	
Black Liquor	m^3/y	589,903	509,548	484,231	343,870	
	g/100cc	14	14	14	14	
	m^3/t−Pulp	8.9	11.2	12.7	11.2	11.0
Solid Matter	t/t−Pulp	1.25	1.57	1.77	1.56	1.54

Note: The amount of the black liquor is calculated by assuming the solid concentration from the use of the boiler.

If the concentration of black liquor is increased by washing in the smallest possible amount of hot water, it will be possible to reduce the amount of steam used for concentration. The pH value of the water squeezed out of the pulp after washing, the specific gravity of black liquor and the amount of the generated black liquor should be used as items for control, and the amount of washing water should be controlled. At least once a day, clean the nozzle of the washing water shower, using the hook with a long handle, or take similar control care in order to maintain washing effect.

Furthermore, if the equipment investment cost is balanced with the effect of saving the concentration steam, increase the number of washing steps and introduce the filter press to reduce the black liquor.

b) Neutral sulfite semi-chemical pulp cooking

The main pulp for fluted medium is made of broadleaf trees, and is cooked by the neutral sulfite method continuous cooker (Pandia system); the production capacity is 100 tons per day. Chips are dipped in washing waste liquid and cooker exhaust gas condensate of about 60 °C for 1 to 2 hours. When the water content of the chips is increased to 35 to 40 %, put the chips into the cooker and add the chemicals at the mixing ratio of Na_2SO_3 : Na_2CO_3 = 3 : 1 as Na_2SO_3 about 13 to 16 %. Then cook it at the pH value of 7.5 at the temperature of 170 °C and at 8 kg/cm³ for 35 minutes. After cooking, chips are refined by the disk refiner. The pulp yield is about 65 %. The current production volume is reduced to about 50 tons per day due to sluggish market conditions.

Table 5.3.6 shows the comparison of the unit consumption rate of steam and electric power of the neutral sulfite semi-chemical pulp with Japanese equivalents. The yield of Japan is set to 70 to 80 %, so the steam unit consumption rate is low, whereas refining process is considered to consume much electric power.

The solids in the brown stock washing waste liquid (black liquor) is as low as 3.2 to 3.5 g/100 cc. So waste liquid is not recovered. However, this plant is provided with a kraft waste liquid recovery plant, so it is recommended to concentrate it together with the kraft black liquor and burn it. A press thickener or press filter should be installed at the front of the washer to allow washing of the pulp in as small quantity of warm water as possible. Furtuer, increasing the solid content up to 10 g/100 cc will allow the brown stock washing waste liquid (black liquor) to be concentrated with the kraft black liquor. This will generate the following merits:

1) Saving of kraft pulp cooking chemical
2) Reduced load of the waste water treatment equipment
   and
3) Increased amount of black liquor burnt in the recovery boiler, resulting in reduced heavy oil consumption

When the black liquor recovery amount is about 10~12 m^3/t-pulp, steam generation of about 6.5 t/h can be expected.

The energy required to concentrate the semi-chemical pulp waste liquid to the same level as that of the black liquor is said to be equivalent to about 1.5 tons/t-pulp of steam and 125 kwh/t-pulp of electric power. Despite this increase of energy consumption, it is considered to be advantageous.

In some plants which produce the kraft paper and fluting medium as in this plant, they are studying the quality maintenance measures for the ring crush and others and have switched chemicals of the NSSC plant to the kraft method chemicals, thereby manufacturing the fluting medium using the kraft semi-chemical pulp.

c) Pulp from recovered waste paper

To get fluted mediums, waste paper of heavy duty bags such as cement bags and corrugated fiberboards is dissolved with pulper and is subjected to the processes of removing foreign substances, screening and refining, thereby gaining a daily production of the pulp amounting to about 50 tons/day. The fluted medium is composed of 55 % semi-chemical pulp and 45 % waste paper pulp.

The energy required to make waste heavy duty bags and waste corrugated fiberboards into pulp is approximately 0.025 t/t-pulp of steam and 230 kwh/t-pulp of electric power. Compared with the virgin pulp given in Table 5.3.6, its percentage is about 20 %. Increase of the waste paper mixing rate should be promoted to save the energy as well as to conserve the resources. However, when the waste paper mixing rate is increased, dust particles entering from the waste paper should be completely removed, and sufficient care should be taken to ensure that the paper quality will not be deteriorated.