4. RESULTS OF THE STUDY ON THE GLASS INDUSTRY

4. RESULTS OF THE STUDY ON THE GLASS INDUSTRY

4.1 Results of the Study at Ghazvin Glass Company

4.1.1 Outline of the Factory

(1) Plant name

Ghazvin Glass Company

(2) Plant address

Ghazvin City

(3) Number of employees

1,232

(4) Major products

Ordinary sheet glass, figured glass, and mirror

(5) Production capacity

130,000 t/y

(6) Process description

Four side-port regenerator type tank furnaces are provided. Among them, two lines are used to manufacture ordinary sheet glass, while one line is used for figured glass. The remaining one line has an ordinary sheet glass manufacturing machine and a figured glass manufacturing machine, so that both products can be manufactured at the same time. Sheet glass is manufactured by using the Colburn method, while figured glass is manufactured by using the Roll-out method.

(7) Plant history

This plant was established by Industrial Mining Development Bank of Iran (IMDBI) and Pan-Alliance Corporation, a U.S. investment company.

Technology and engineering were furnished by General Glass Equipment Company in the United States. Construction was started in 1964 and completed in 1968, when production was started. As the manufacturing method, Fourcault method was used to manufacture ordinary sheet glass. However, in the initial stage, malfunction of production occurred due to many technical problems. Therefore, cooperation with the U.S. company was canceled and a technical support agreement was made with Nippon Sheet Glass Co., Ltd. in June, 1969. In 1970, No. 2 furnace was constructed and the ordinary sheet glass production facility using the Colburn method was started. In 1972, No. 3 furnace was constructed and, in 1978, No. 4 furnace was constructed. Two years before, in 1976, the Fourcault type machine in No. 1 furnace was dismantled, and instead, a Roll-out type figured glass production facility was installed. In 1979, a Roll-out type figured glass production facility was installed in No. 2 furnace so that both ordinary sheet glass and figured glass could be produced.

Presently, there are four sheet glass production plants in I.R. Iran, which production capacity is approximately 300,000 tons per year. The share of Ghazvin Glass is close to 40 %.

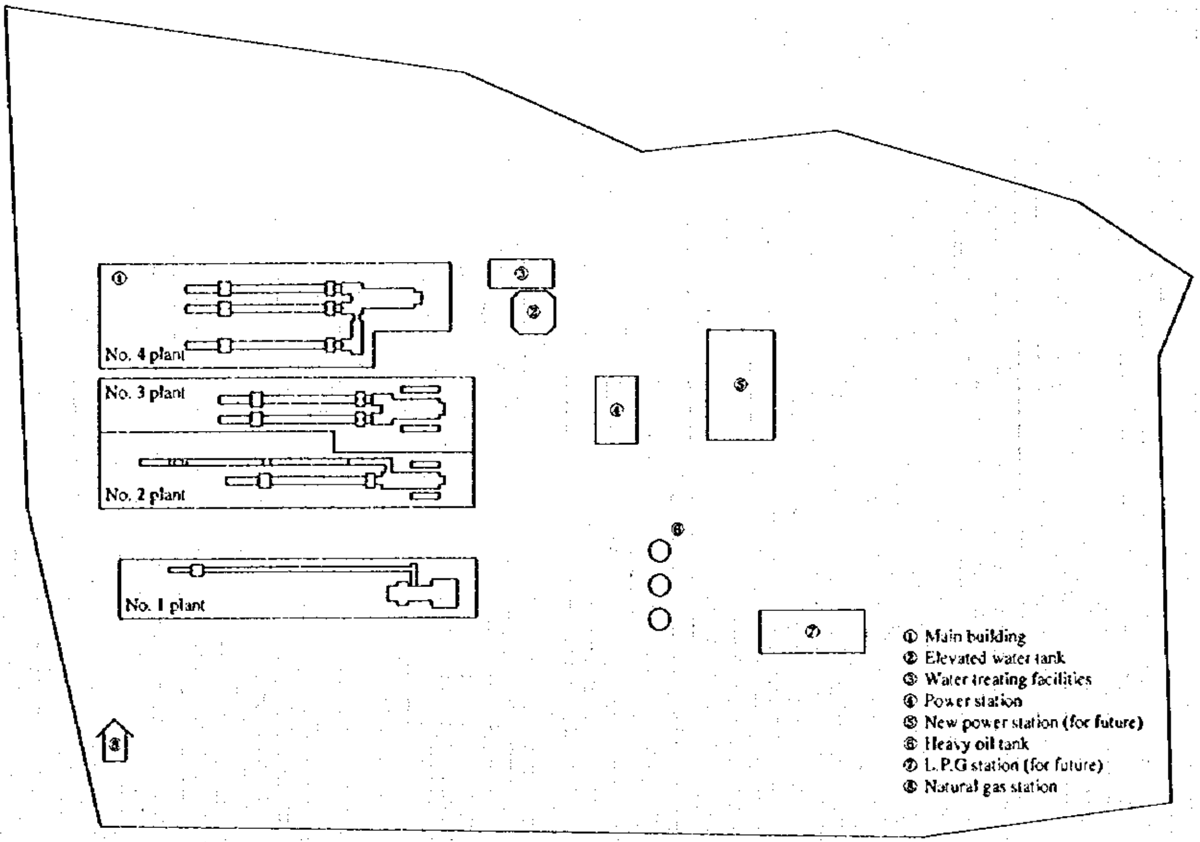
Heavy oil had been used for fuel, which was switched to natural gas for Furnace No. 1 after periodic cold repair in 1995. Since this is a governmental policy, heavy oil will gradually be switched to natural gas also for other furnaces.

For production of sheet glass using the most modern float technology, its introduction has already been determined but the starting time has not been decided yet because of the problem of foreign currency allocation.

(8) Plant layout

Figure 4.1 shows the plant layout.

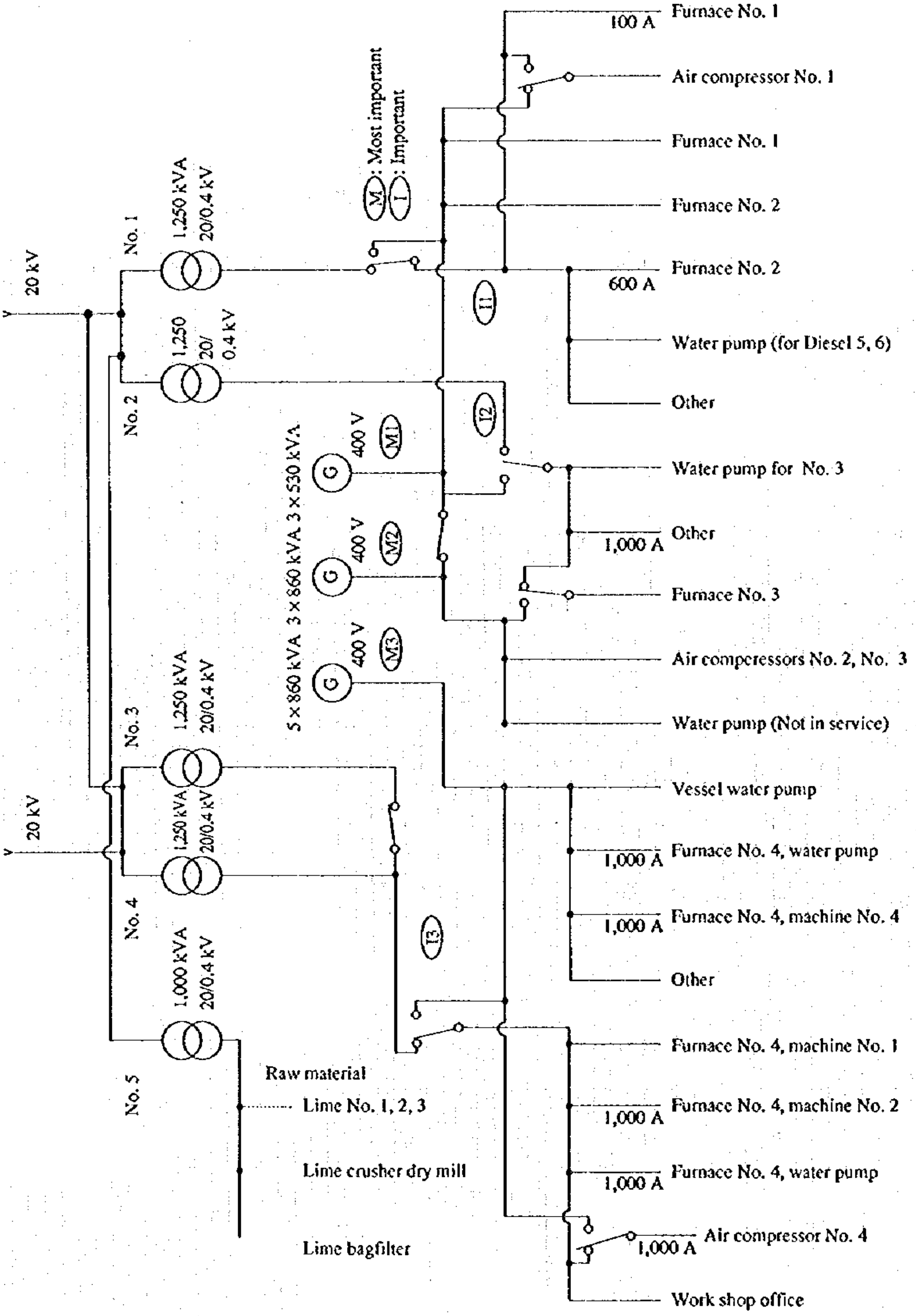
Figure 4.1 Plant Layout



(9) One line diagram

Figure 4.2 shows the one line diagram.

Figure 4.2 One Line Diagram



(10) Outline of major equipment

No. 1 plant:

Side-port regenerator type glass melting furnace	1 set
Roll-out type figured glass continuously manufacturing equipment	1 set

No. 2 plant:

Side-port regenerator type glass melting furnace	1 set
Colburn type ordinary sheet glass continuously manufacturing equipment	1 set
Roll-out type figured glass continuously manufacturing equipment	1 set

No. 3 plant:

Side-port regenerator type glass melting furnace	1 set
Colburn type ordinary sheet glass continuously manufacturing equipment	2 sets

No. 4 plant:

Side-port regenerator type glass melting furnace	1 set
Colburn type ordinary sheet glass continuously manufacturing equipment	3 sets

(11) Energy prices

Table 4.1 shows energy prices.

Table 4.1 Energy Price

Energy	Heat Value	1992	1993	1994	1995
Heavy Oil	Hh = 10,600 kcal/kg	5	5	5	15 Rial/L
Natural Gas	Hl = 9,500 kcal/m^3_N	–	–	–	20 Rial/m^3
Diesel Oil	Hl = 8,462 kcal/kg	10	10	10	20 Rial/L
Electric Power	–	10.5	13.55	28.5	61 Rial/kWh

(12) Study period

a. Preliminary study: Oct. 9, 1995

b. Plenary study : July 14 to 16, 1996

(13) Members of the study team

a. JICA team

Leader : Norio Fukushima
Process management technology
and heat management technology: Masami Kato
Electric management technology : Toshio Sugimoto
Electric management technology : Kazuo Usui (Preliminary study)

b. PBO team

Energy conservation : Mr. Akhavan (Preliminary study)
Micro level energy management: Mr. Mianji
Micro level energy management: Mr. Seyed Reyhani
Instrumentation : Mr. Shayesteh (Preliminary study)

(14) Interviewees

Mr. S. Sabet : Factory Manager
Mr. KH. Manzoori: Chief Engineer, Assistant of Factory Manager
Mr. A. R. Maibodi: Chemical Engineer, R & D Center
Mr. Masoudi : Chief of Electrical Department
Mr. N. Rezaei : Electric Generator Manager
Mr. Miralami : Electrical Expert
Mr. A. Bayat : Master Student, Research Project

4.1.2 Energy consumption status

(1) Trend of production

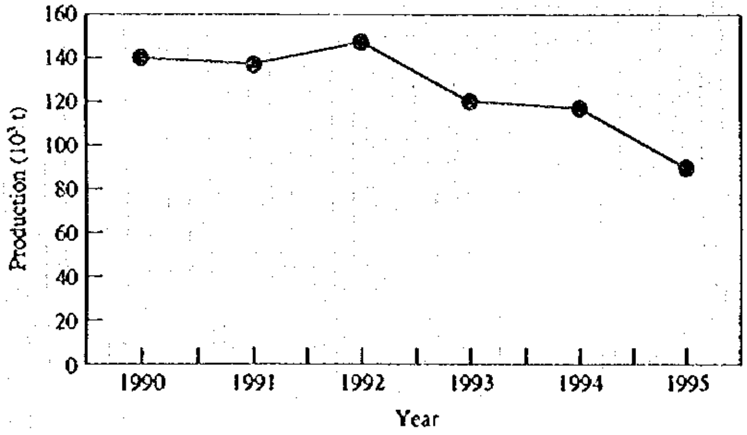
Table 4.2 and Figure 4.3 show annual production.

Production ratio of ordinary sheet glass is approximately 60 % and production ratio of figured glass is approximately 40 %.

Table 4.2 Annual Production

	Unit	1990	1991	1992	1993	1994	1995
Production	10^3 t/y	139.4	136.5	147.3	120.3	117.4	89.4

Figure 4.3 Annual Production



(2) Trend of energy consumption

Table 4.3, Figures 4.4 and 4.5 show the data on annual energy consumption (heavy oil, natural gas, diesel oil, electricity) obtained from Ghazvin Glass.

Table 4.3 Annual Energy Consumption

		Unit	1989	1990	1991	1992	1993	1994	1995
Heavy Oil		10^3 kL/y	64.12	71.42	63.77	72.76	73.74	75.39	66.65
Natural Gas		10^6 m^3/y	9.98	11.47	6.93	8.50	8.17	7.26	8.57
Electric Power	City	10^6 kWh/y	12.7	12.7	12.7	12.7	12.7	12.7	12.7
	Diesel	10^6 kWh/y	–	–	–	11.4	11.1	10.2	9.0
	Total	10^6 kWh/y	–	–	–	24.1	23.8	22.9	21.7
Diesel Oil		10^3 kL/y	–	–	–	3.23	2.79	3.36	3.01

Figure 4.4 Annual Heavy Oil and Natural Gas Consumption

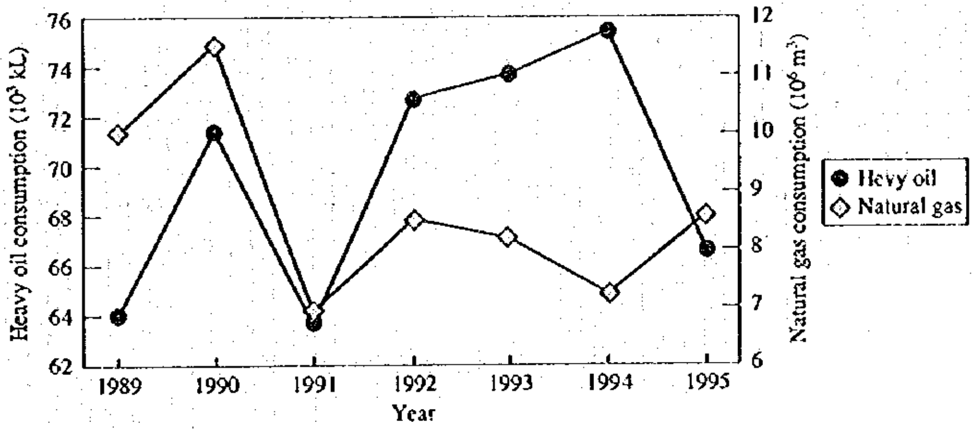
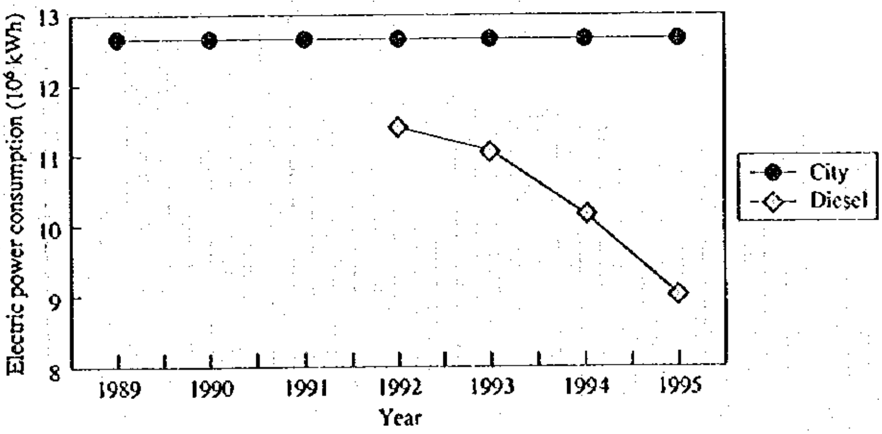


Figure 4.5 Annual Electricity Consumption



(3) Trend of energy intensity

Table 4.4 shows energy intensity derived from the data obtained at Ghazvin Glass. Figure 4.6 summarizes trends of fuel intensity per unit weight of product.

Table 4.4 Annual Energy Intensity

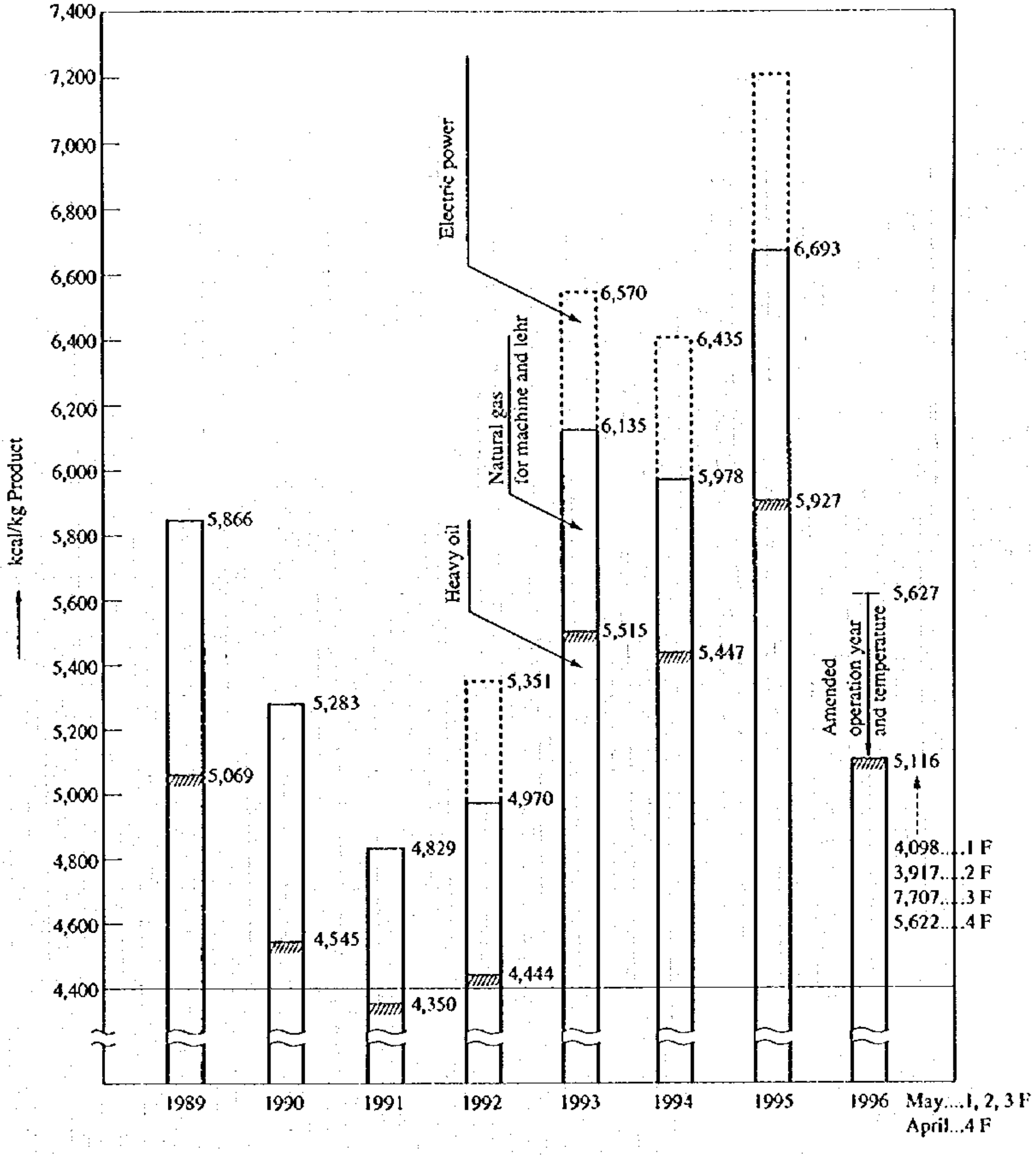
[kcal/kg Product]

	1989(1)	1990	1991(2)	1992	1993	1994	1995(3)
Heavy oil	5,069	4,545	4,350	4,444	5,514	5,447	5,927
Natural gas	797	738	478	525	617	530	770
Diesel oil	(199)	(179)	(194)	179	188	219	241
City power	262	211	226	202	248	239	294
Total	6,327	5,673	5,248	5,350	6,567	6,435	7,232
Σ Electric power [kWh/kg]				0.156	0.189	0.176	0.205
Diesel power efficiency [%]				35.6	40.4	30.9	30.4

Remarks (1): No. 3 Plant: Cold repair
(2): No. 2 Plant: Cold repair
(3): No. 1 Plant: Cold repair

Note: Heat value of city power — 2,450 kcal/kWh
( ) — Presumed value, when it is assumed that the utilization ratio for gas oil is identical to that for 1992 to 1994.

Figure 4.6 Trend of Energy Intensity per Product



Note: Trend of production cf: Figure 4.3
Trend of heavy oil consumption cf: Figure 4.4
Trend of natural gas consumption cf: Figure 4.4
Trend of electric power consumption cf: Figure 4.5
Heat value of energy cf: Table 4.5
Melting energy intensity 1996 cf: Table 4.6

Table 4.5 shows the values on which energy intensity calculation was based according to data such as natural gas composition and calories of various kinds of energy obtained from Ghazvin Glass.

Table 4.5 Basic Data of Energy Heat Values

	Hh			Hl			Specific Gravity
	kcal/kg	kcal/L	kcal/m^3_N	kcal/kg	kcal/L	kcal/m^3_N	
Heavy oil	10,600*	10,070	–	9,900	9,400	–	0.95*
Natural gas	–	–	10,500	–	–	9,500*	0.655/Air
Diesel oil	11,180	8,940	–	10,580	8,462*	–	(0.80)

Note *: Information from Ghazvin Glass.
Cf: Chemical analysis data of natural gas
CH_4 84.11 %, C_2H_6 10.19 %, C_3H_8 3.81 %, C_4H_{10} 0.39 %
Others 1.50 %(C_5H_{12}, CO_2, N_2, etc)

(4) Energy flow and energy intensity at normal operation

To obtain data for each furnace at normal operation, daily operation for the last one month (molten glass volume, cullet utilization ratio, melting energy consumption, and volume of product) was obtained and shown in Figures 4.7 to 4.10.

Figure 4.7 Daily Operation Data on No. 1 Plant (May 1996)

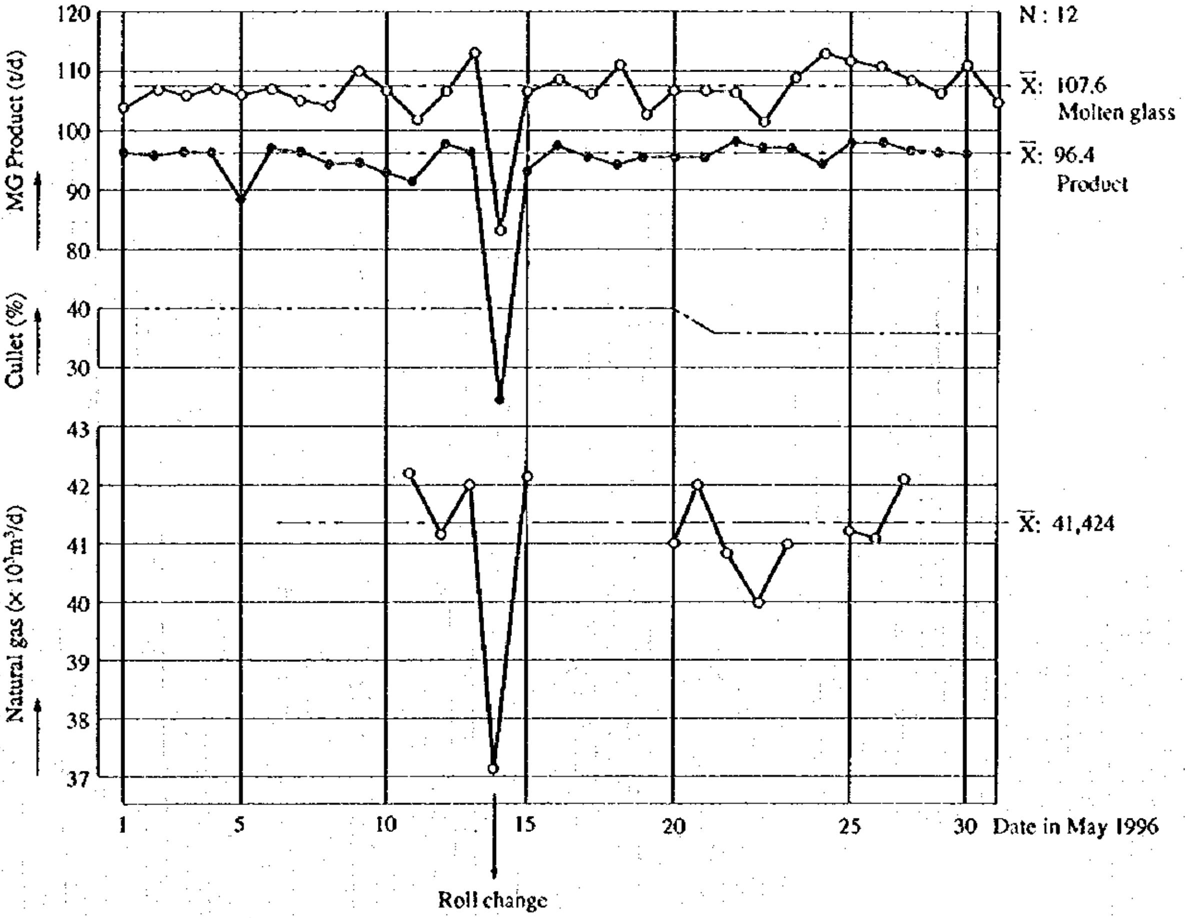


Figure 4.8 Daily Operation Data on No. 2 Plant (May 1996)

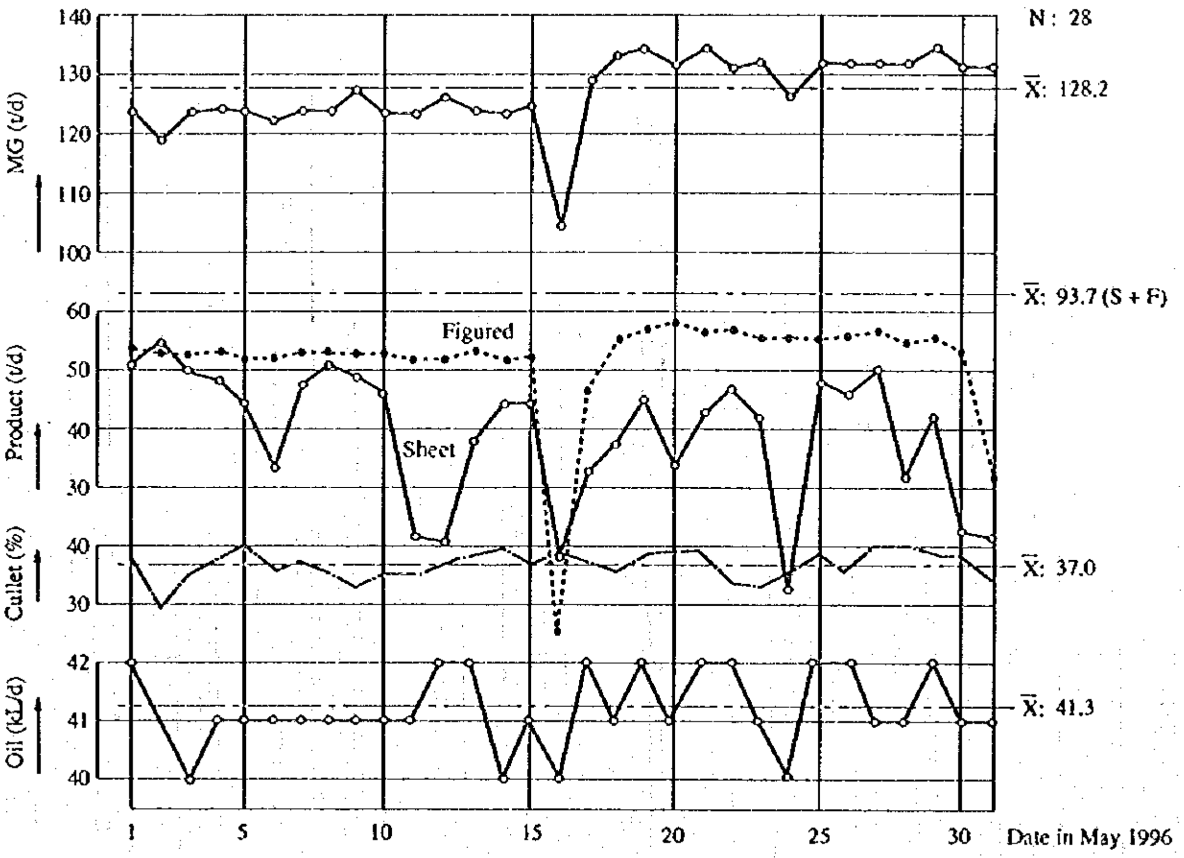


Figure 4.9 Daily Operation Data on No. 3 Plant (May 1996)

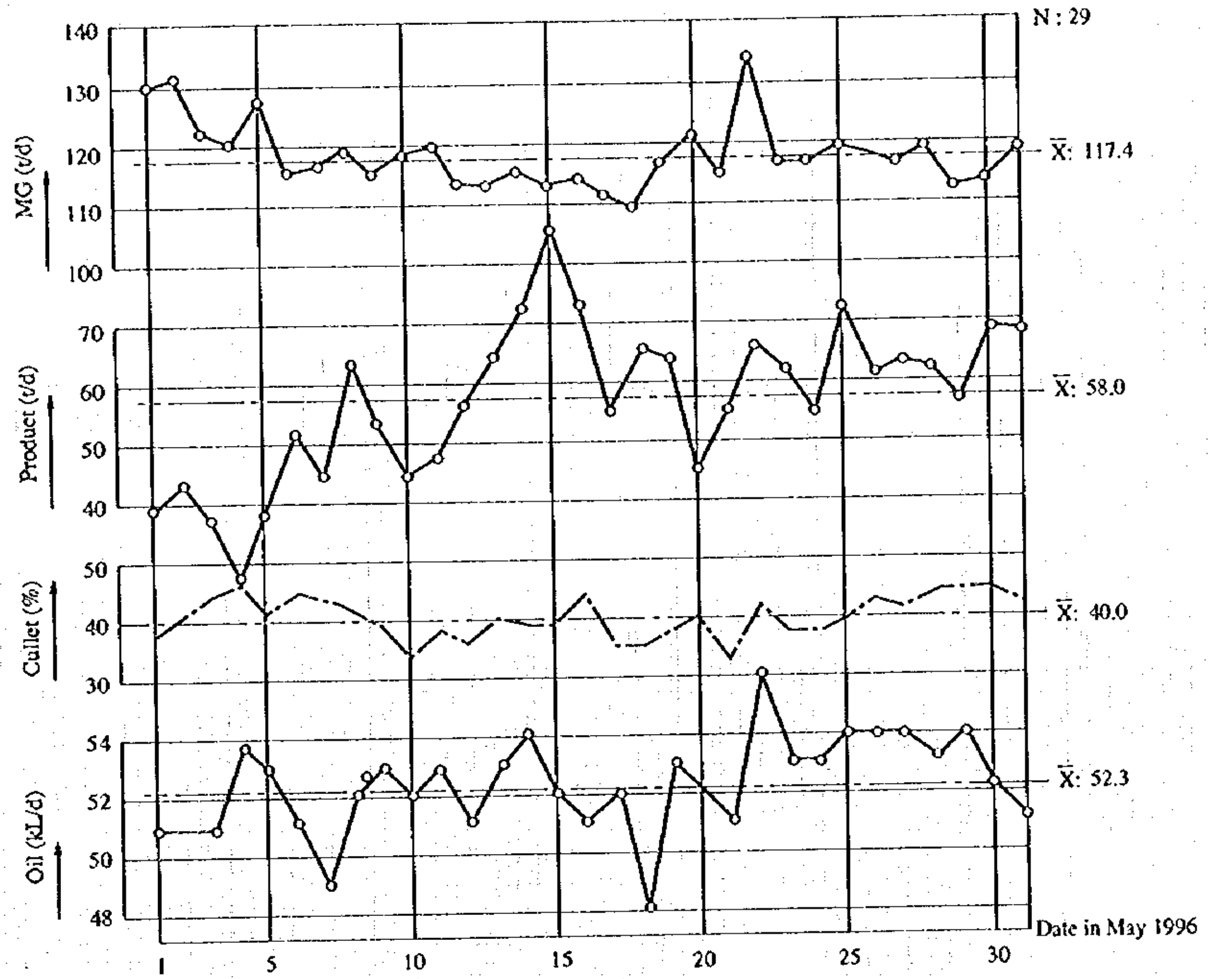


Figure 4.10 Daily Operation Data on No. 4 Plant (April 1996)

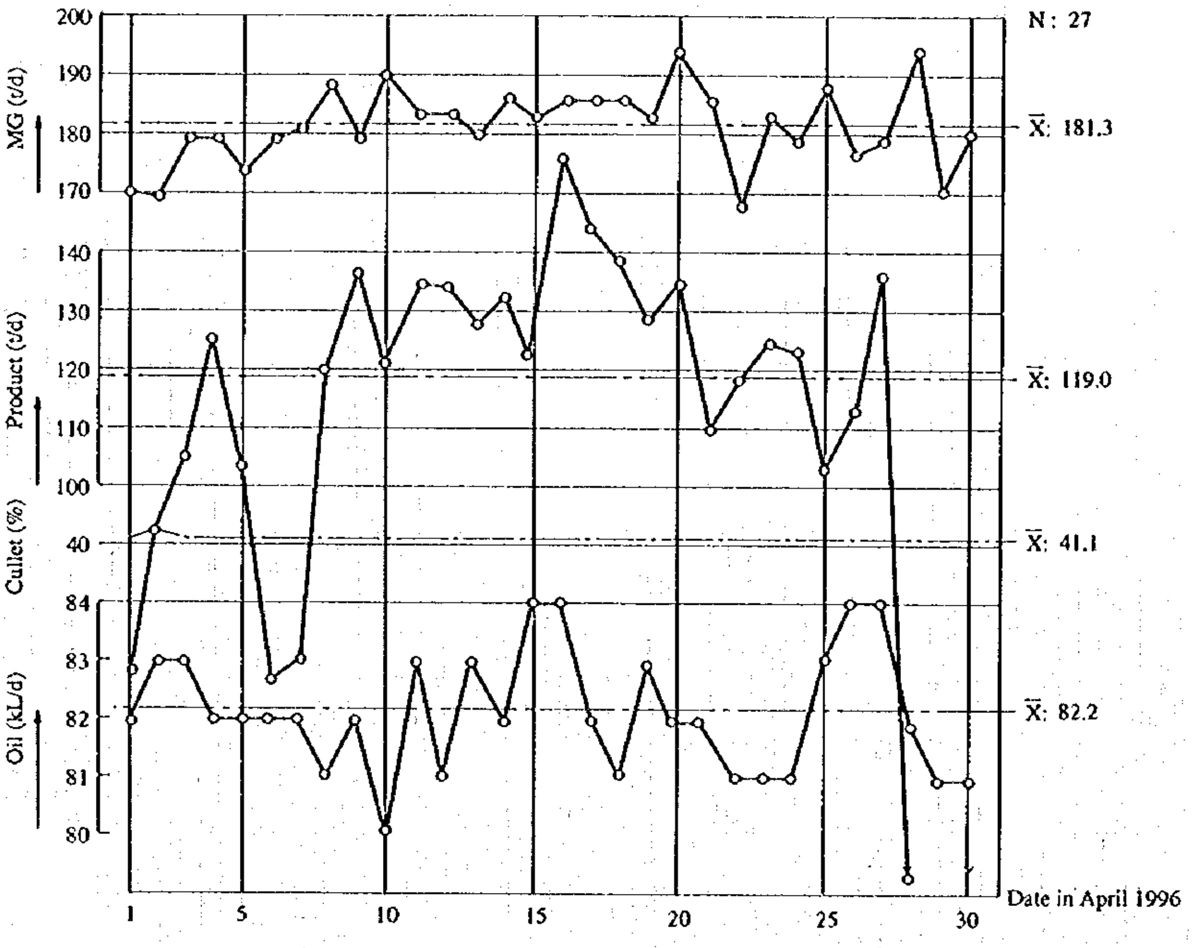


Table 4.6 shows energy intensity by furnace (for melting only) obtained according to above data excluding the days on which normal operation was impossible due to special operations, etc., and based on energy consumption compensated with aging of the furnace and room air temperature.

Table 4.6 Melting Energy Intensity in No. 1, No. 2, No. 3, and No. 4 Plants

Plant	No. 1	No. 2	No. 3	No. 4
Kind of glass	Figured	Sheet and figured	Sheet	Sheet
Color	Clear	Clear	Bronze	Clear
Period	May 1996	May 1996	May 1996	April 1996
No. of data	12	28	29	27
Molten glass (average t/d)	107.6	128.2	117.4	181.3
Cullet (average %)	38.3	37.0	40.0	41.1
MGS (t/d)(1)	101.0	121.1	109.3	167.9
Product (average t/d)	96.4	93.7	58.0	119.0
Yield (%)(2)	89.6	73.1	49.4	65.6
Fuel (average m^3/d)	41,424			
Fuel (kL/d)		41.3	52.3	82.2
Service year (Year)	0.6	4.8	7.3	9.8
Ambient temperature (°C)	22	22	22	17
Revised fuel (m^3/d)(3)	41,598			
Revised fuel (kL/d)(3)		39.0	47.6	71.2
Revised fuel (10^6 kcal/d)(4)	395	367	447	669
Melting energy intensity (kcal/kg MGS)	3,911	3,031	4,090	3,985
Melting energy intensity (kcal/kg prod.)	4,098	3,917	7,707	5,622

Remarks: No. 1 Plant: Natural gas combustion; simple insulation; yield is unbelievably excellent.
No. 2 Plant: 2-machine operation.
No. 3 Plant: Abnormal condition; Furnace draft is not enough and loaded down.
No. 4 Plant: Just before cold repair (3rd May ~); Old furnace

Note (1): MGS: Molten glass on cullet 25 % basis.

$$\mathrm{MGS} = \frac{434 - \mathrm{C}\%}{400 + \mathrm{C}\%} \times 1.04 \times \mathrm{MG}$$

(2): Yield: Product/MG × 100

(3): Revised Fuel: Revised fuel consumption at new furnace and ambient temperature 15 °C.

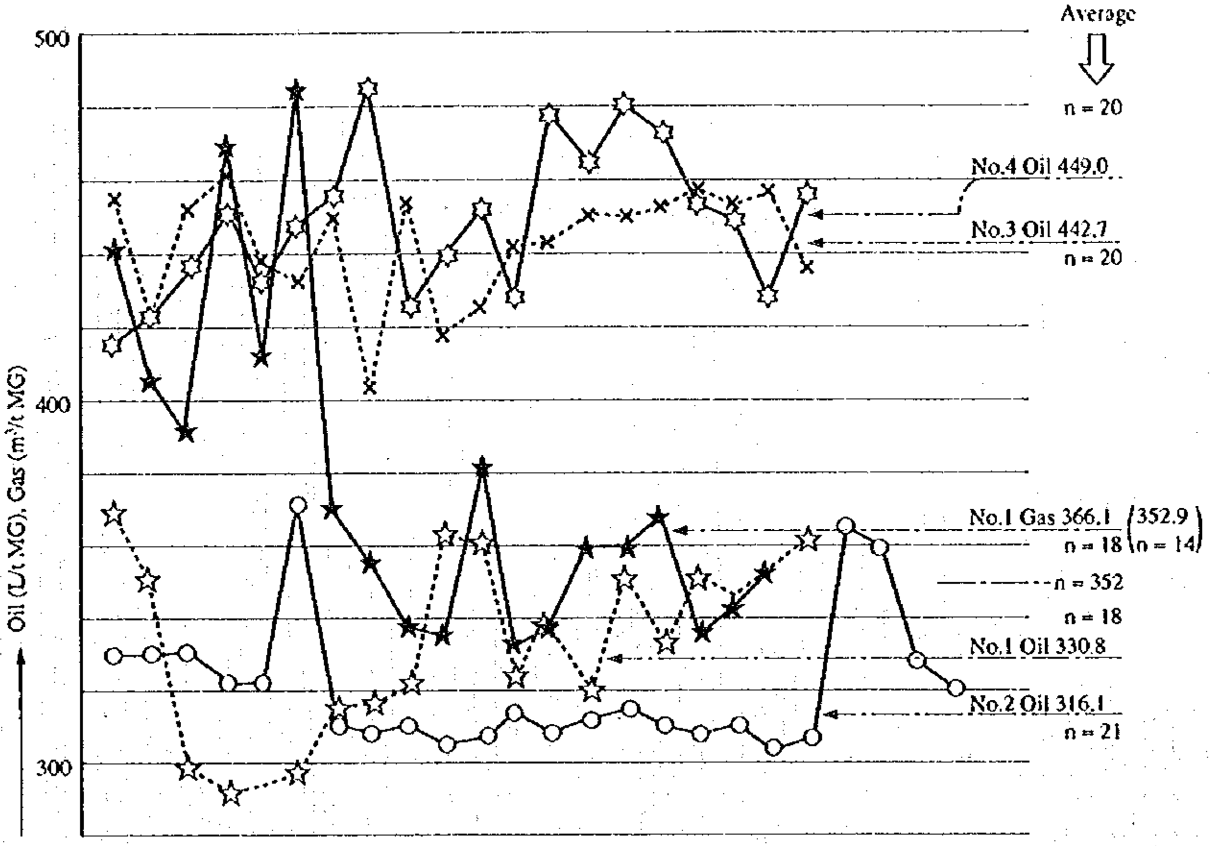
$$\Delta y = -\{0.014 \cdot Y - 0.0018\,(t - 15)\} \cdot y$$

Y: Service year
t : Ambient temperature °C
y : Fuel consumption

(4): Heat value of fuel: Hℓ value (cf. Table 4.5)

Figure 4.11 shows the trend and average value of recent fuel intensity (per molten glass volume) of each furnace separately obtained.

Figure 4.11 Trend of Fuel Intensity



4.1.3 Situation of Energy Management

(1) Setting the energy conservation target

No specific target value has been set yet. However, improvement in terms of energy conservation is applied at periodic cold repair of the furnace. The example is No. 1 furnace that was periodically repaired last year.

Although not directly associated with energy conservation, a governmental policy is to switch the glass melting fuel from heavy oil to natural gas, which they are expected to follow. This policy was implemented for No. 1 furnace last year. Implementation for No. 2 furnace is being planned. For No. 4 furnace currently under periodic repair natural gas will be used after restart. For the promotion of the energy conservation, it is essential to raise the consciousness of every employee for energy conservation; therefore some motivation for such effort should be given.

(2) Systematic activities

In 1995, an energy committee was established. The number of its members is four. The frequency of convening this committee has not been determined yet. To promote company-wide energy conservation activities, the Energy Committee should be revitalized and cooperation between departments should be enhanced.

(3) Data-based management

The objects for these activities include the fuel consumption, excess air ratio, furnace temperature analysis, air infiltration volume, heat radiation from the furnace wall, measurement of the secondary air preheating temperature, etc., and measurement of electrical items such as current and voltage fluctuation, and power factor. On the other hand, the deterioration of the aged measuring equipment is raised as a problem to be coped with.

There are extremely large disparities among annual data, monthly data, and data by furnace; therefore it is hard to determine which data should be used for reference.

As the future subjects, acquisition of reliable data through enhancement of the measuring equipment and measurement control and data utilization through analysis of collected data are essential.

Since storage and maintenance of document and data are in a poor state, any desired document/data cannot be promptly retrieved. This is a problem in quality control (TQC) in its broad sense, and it is also important in terms of energy management.

(4) Education and training of employees

Organizations with which the factory staff keep contact for obtaining technical information are PBO and International Energy Study Institute. Some employees are attending the Energy Forum convened by the Ministry of Petroleum.

For training of general workers, a training leaflet was prepared but it is said to be at too high a level. Therefore, the leaflet has not been distributed.

There is a commending system for effective improvement proposals but it is not particularly intended for energy conservation. A problem which they raise is the fact that employees are not conscious about energy conservation. Education on the necessity and techniques of energy conservation should be promoted.

(5) Equipment maintenance

The largest equipment are tank furnaces whose life is generally about eight years. No. 4 furnace has been operated for ten years, while on the other hand, the No. 3 furnace currently in use shows signs of heavy degradation in the seventh year. Generally, equipment management does not seem to be sufficiently conducted.

Concerning the work area environment, there is no clean work area excluding the diesel power plant. Cleanliness of the work area is the basics not only for equipment management but also for stable operation. These work areas are fairly inferior to the excellent factory. Employees should get accustomed to cleaning the work area themselves. These are the problems in preventive maintenance (TPM).

4.1.4 Problems in the Use of Energy and Countermeasures

(1) Heat balance for the tank furnace

To check the actual status of energy consumption by the tank furnace, heat balance was calculated for each furnace. Since there was no sufficient time available, No. 2 furnace was selected to be measured because its operation was stablest. For the other furnaces, assumption was made based on the values obtained from No. 2 furnace and the interview result. The area for heat balance includes the melting furnace and regenerator.

a. Operating condition

For operating conditions as the basics on heat balance, the average values for the last one month were used. (See Table 4.5.) Table 4.7 shows data of No. 2 furnace on the measurement day. Table 4.8 summarizes the basic data of heat balance derived from Tables 4.6 and 4.7.

Table 4.7 Operation Data on No. 2 Furnace

	Unit	16 July	17 July	Average
MG	t/d	132.43	131.92	132.2
Cullet	t/d	35.2	40.07	37.6
C %	%	22.5	25.9	24.1
MGS	t/d	134.1	131.5	132.9
Oil	kL/d	42.13	41.09	41.6

Table 4.8 Operation Basic Data on Each Furnace

	No. 1 Furnace(1)	No. 2 Furnace(2)		No. 3 Furnace(3)	No. 4 Furnace(4)
Date	May 1996	May 1996	16, 17 July 1996	May 1996	April 1996
MG (t/d)	107.6	128.2	132.2	117.4	181.3
Batch (t/d)	75.7	92.4	118.3	80.0	121.0
Cullet (t/d)	47.0	54.3	37.6	53.4	84.5
Cullet (%)	38.3	37.0	24.1	40.0	41.1
Fuel (m^3/d)	41,424				
Fuel (kL/d)		41.3	41.6	52.3	82.2
Fuel gas HI (kcal/m^3_N)	9,500				
Fuel oil HI (kcal/L)		9,400	9,400	9,400	9,400
Atomized and purged air (m^3_N/h)	(155+155)	(530+155)	(530+155)	(700+195)	(1,055+310)
Room temperature (°C)	(22)*1	(22)*1	32*2	(22)	(17)
Fuel temperature (°C)	(22)*1	(78)*1	78*3	(78)	(78)

Remarks (1): Natural gas; figured glass.
(2): Heavy oil; sheet and figured glass.
(3): Heavy oil; sheet glass bronze color.
(4): Heavy oil; sheet glass just before cold repair.

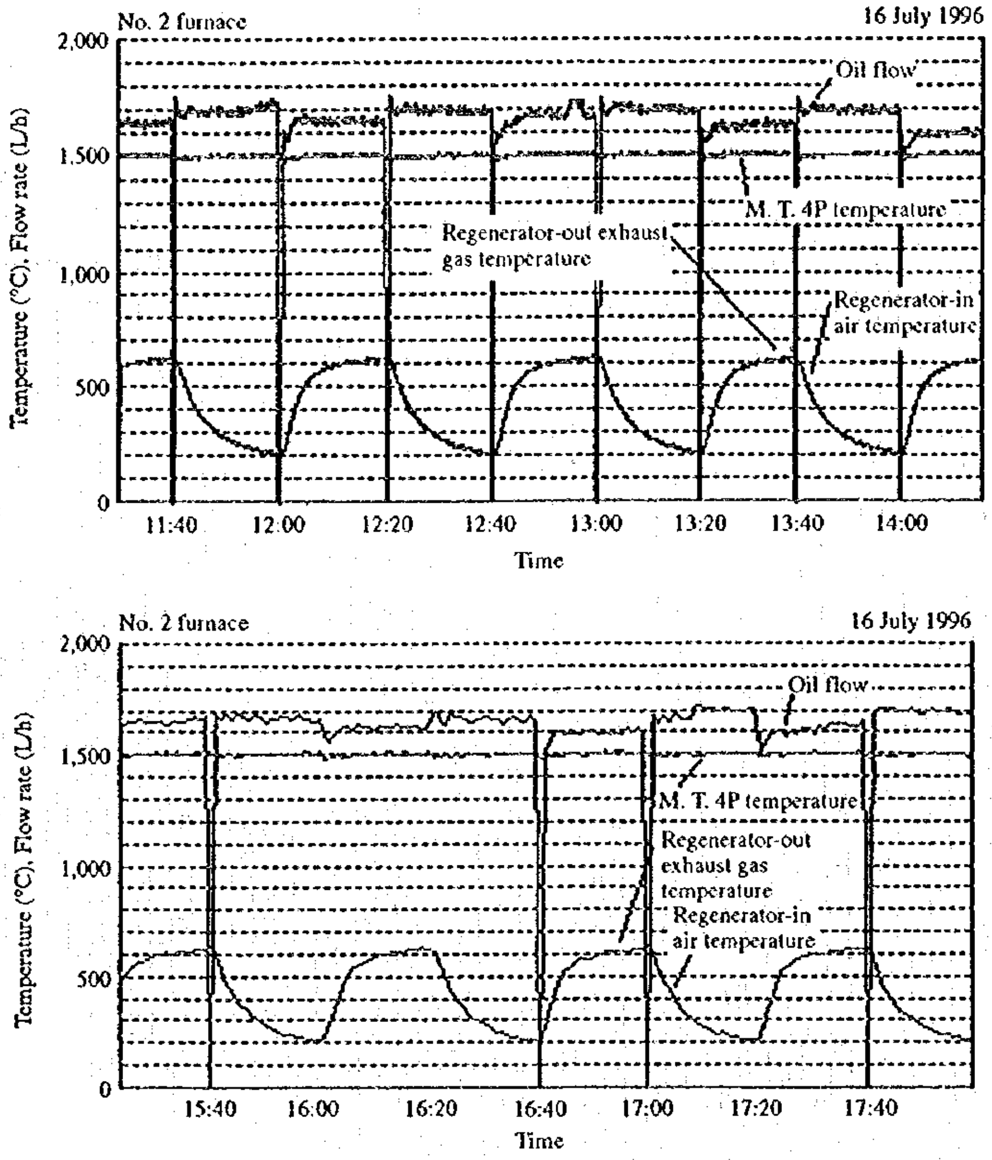
Note *1: ( ): Presumed value.
*2: Measured data by anemometer.
*3: Data at control room.

b. Measured values and available data

1) Heavy oil flow rate, regenerator outlet flue temperature, and crown No. 4 port temperature

Figure 4.12 shows the temperature record that was input from the panel in the No. 2 furnace control room.

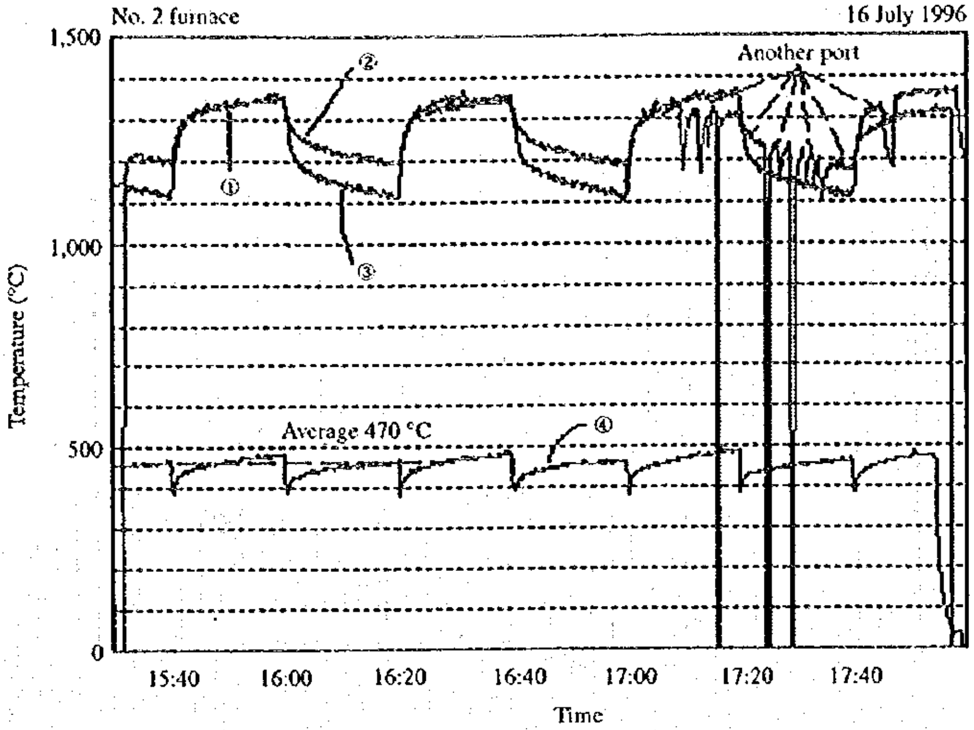
Figure 4.12 Oil Flow Rate and M.T. - 4P Temperature and Regenerator Outlet Temperature



2) Exhaust gas temperature and secondary air preheating temperature (4P)

Figure 4.13 shows the measurement record of the exhaust gas temperature and secondary air preheating temperature (from 1P to 5P), measured through the peep hole over the checker brick of the left regenerator of the No. 2 furnace by using the suction pyrometer (for 4P only) and the ordinary thermocouple and the exhaust gas temperature in the flue below the stack.

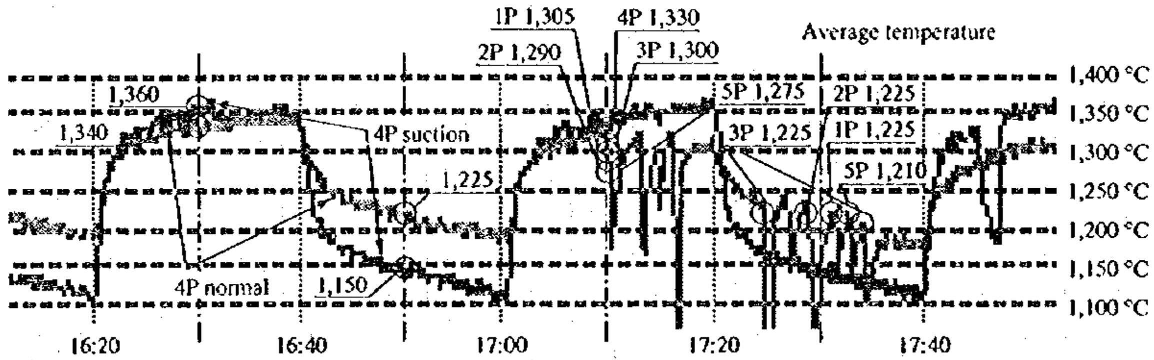
Figure 4.13 Air Preheating Temperature and Exhaust Gas (W. G.) Temperature at Upper and Lower Parts of Regenerator



① regenerator top 4P exhaust gas temperature (suction pyrometer and normal pyrometer)
② upper regenerator 4P air temperature (normal pyrometer)
③ regenerator top 4P air temperature (suction pyrometer)
④ exhaust gas temperature lower part of regenerator

At a location such as the regenerator where the ambient refractory temperature and gas temperature are not equilibrated with each other because the exhaust gas and air alternately pass, a suction pyrometer was used to avoid the effect of radiation from the wall surface and measure the real gas temperature. As a result, for the No. 2 furnace left regenerator 4P, the difference from the ordinary thermocouple was +20 °C for the exhaust gas, and −75 °C for the air. Assuming the similar temperature difference at other locations, correction was made to calculate the average value. (See Figure 4.14.)

Figure 4.14 Calculation of Average Real Temperature of Exhaust Gas and Consumption Air at Upper Part of Regenerator



	Normal W.G - Air	Suction W.G - Air
1P	1,305 —— 1,225	(1,325) —— (1,150)
2P	1,290 —— 1,225	(1,310) —— (1,150)
3P	1,300 —— 1,225	(1,320) —— (1,150)
4P	1,330 —— 1,225	1.350 —— 1,150
5P	1,275 —— 1,210	(1.295) —— (1,135)
Average		1,320 —— 1,147

3) Oxygen content in exhaust gas

The percentage of oxygen in the exhaust gas was measured by using an O_2 meter for 1P to 5P. Table 4.9 shows the result.

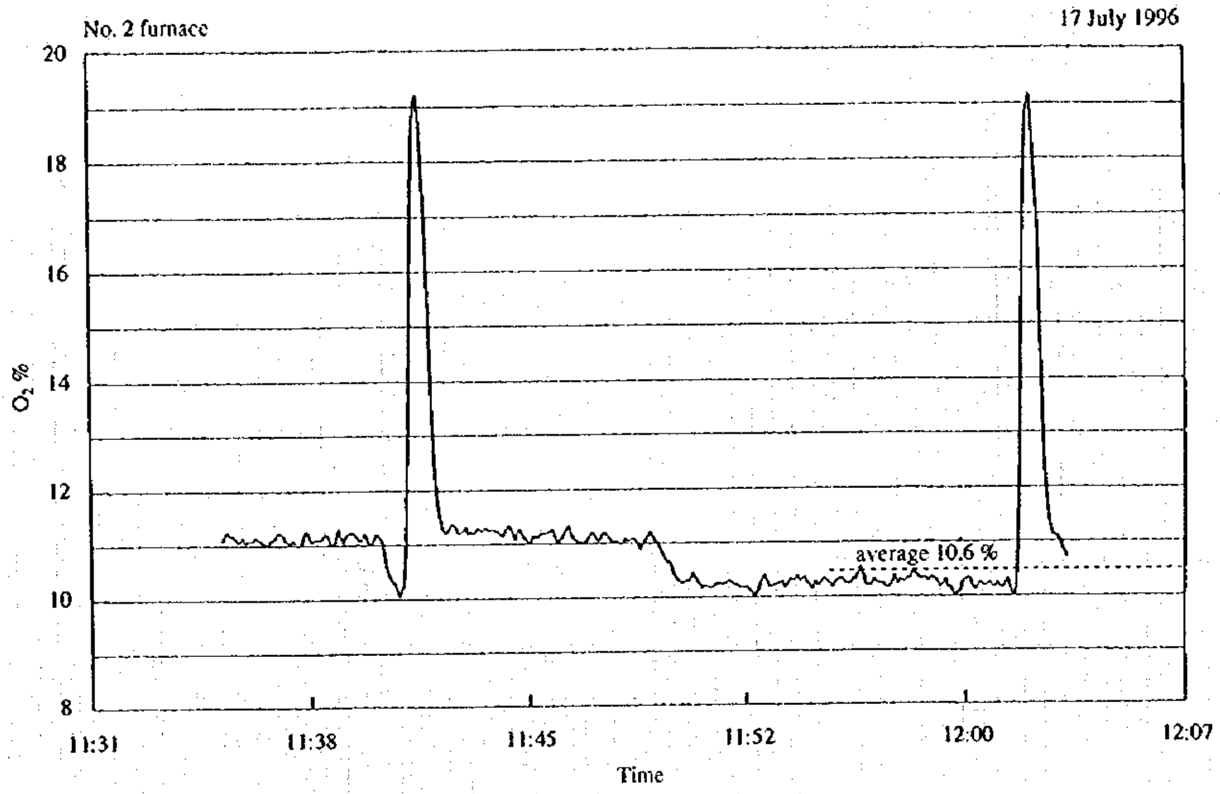
Table 4.9 Oxygen Content in Exhaust Gas at Upper Part of Regenerator

No.2 Plant 15:45 ~ 16:00, 16 July 1996

	1P	2P	3P	4P	5P	Average
O_2 (%)	4.38	4.71	3.82	2.95	5.05	4.18

Figure 4.15 shows the measurement record of the oxygen content in the exhaust gas in the flue duct under the No. 2 furnace stack.

Figure 4.15 Oxygen Content in Exhaust Gas under Stack



4) Recent operation data

Figures 4.16 to 4.18 show the graphs of recent operation data for each furnace.

Figure 4.16 Operation Data on No. 1 Furnace

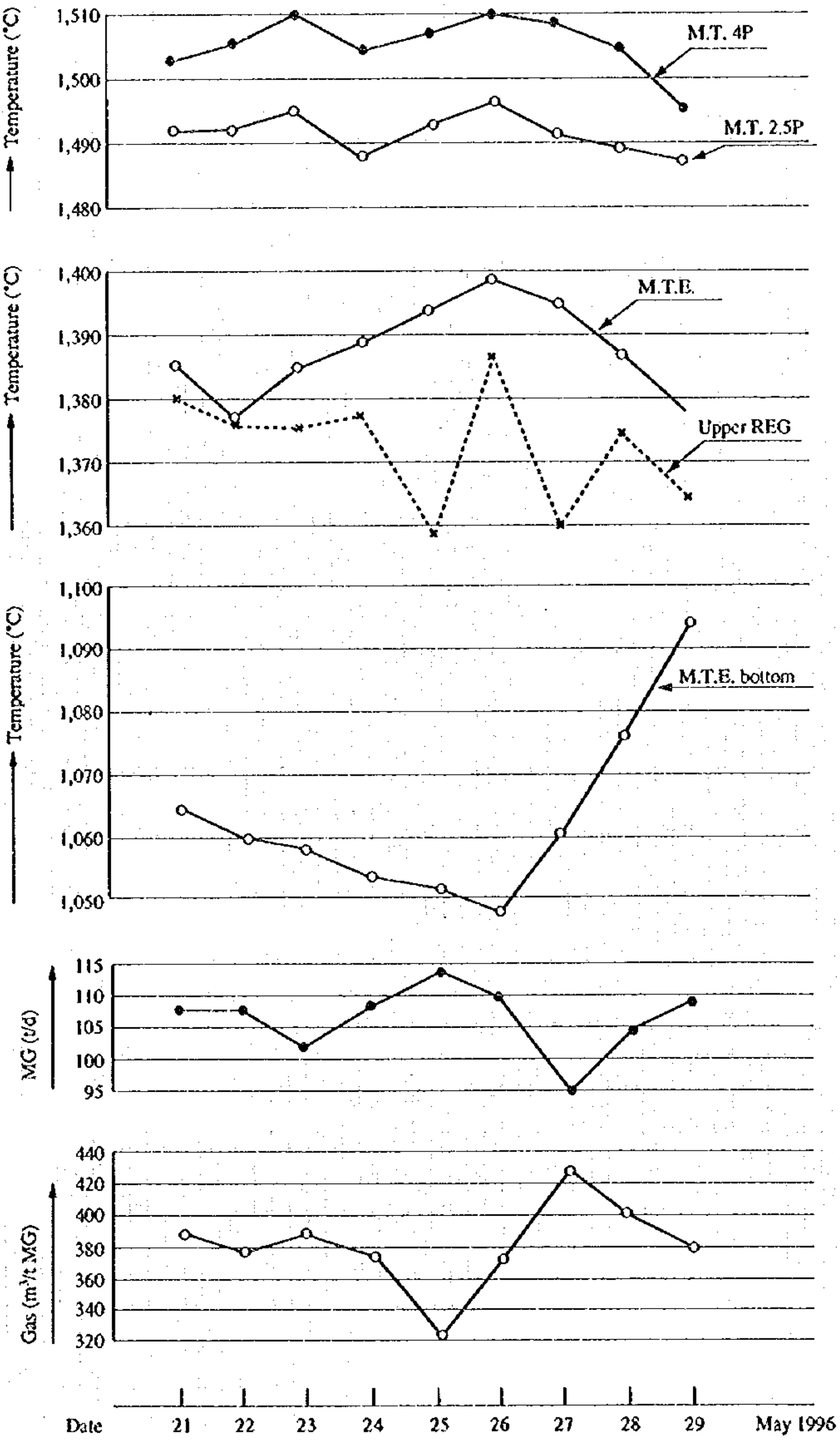


Figure 4.17 Operation Data on No. 2 Furnace

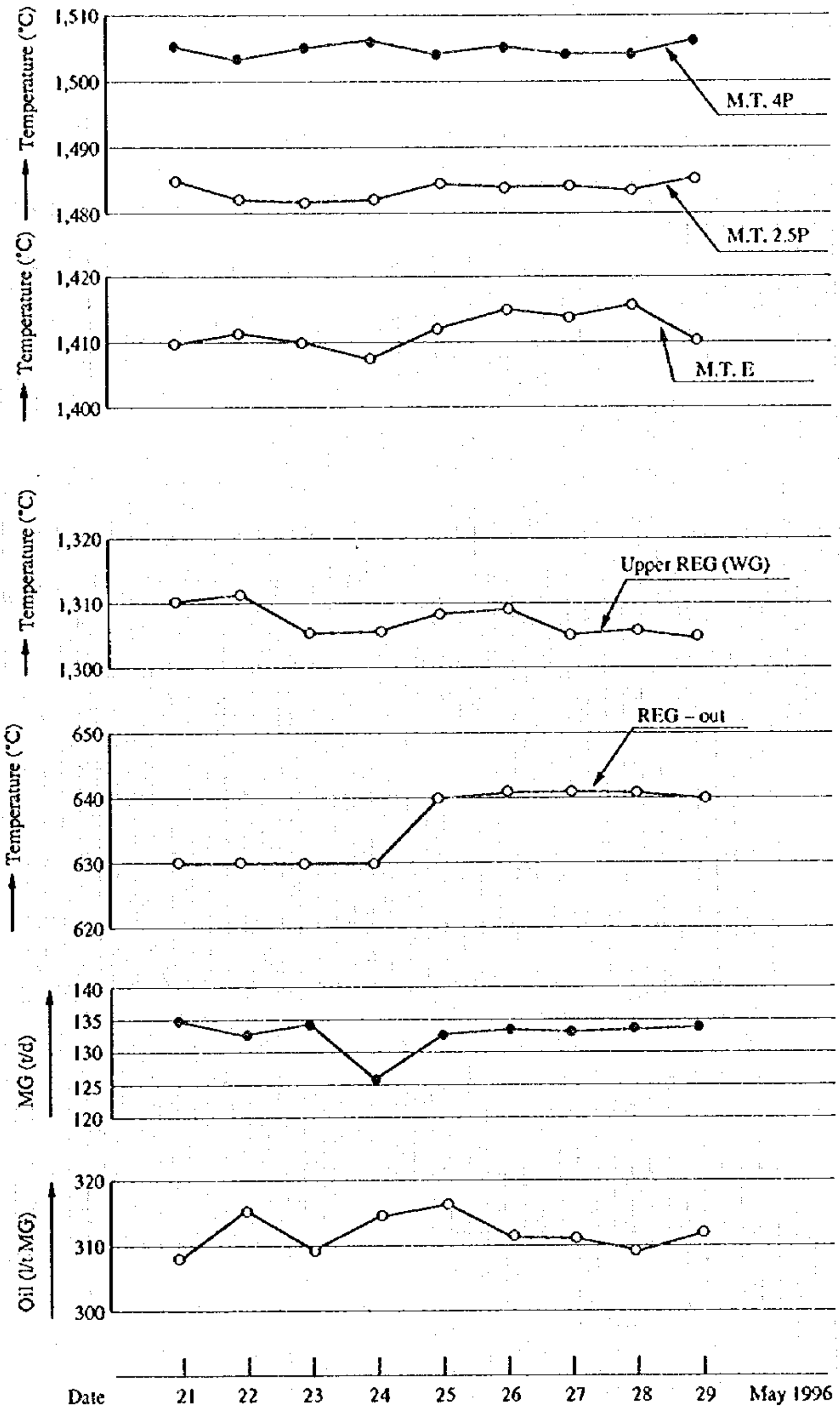
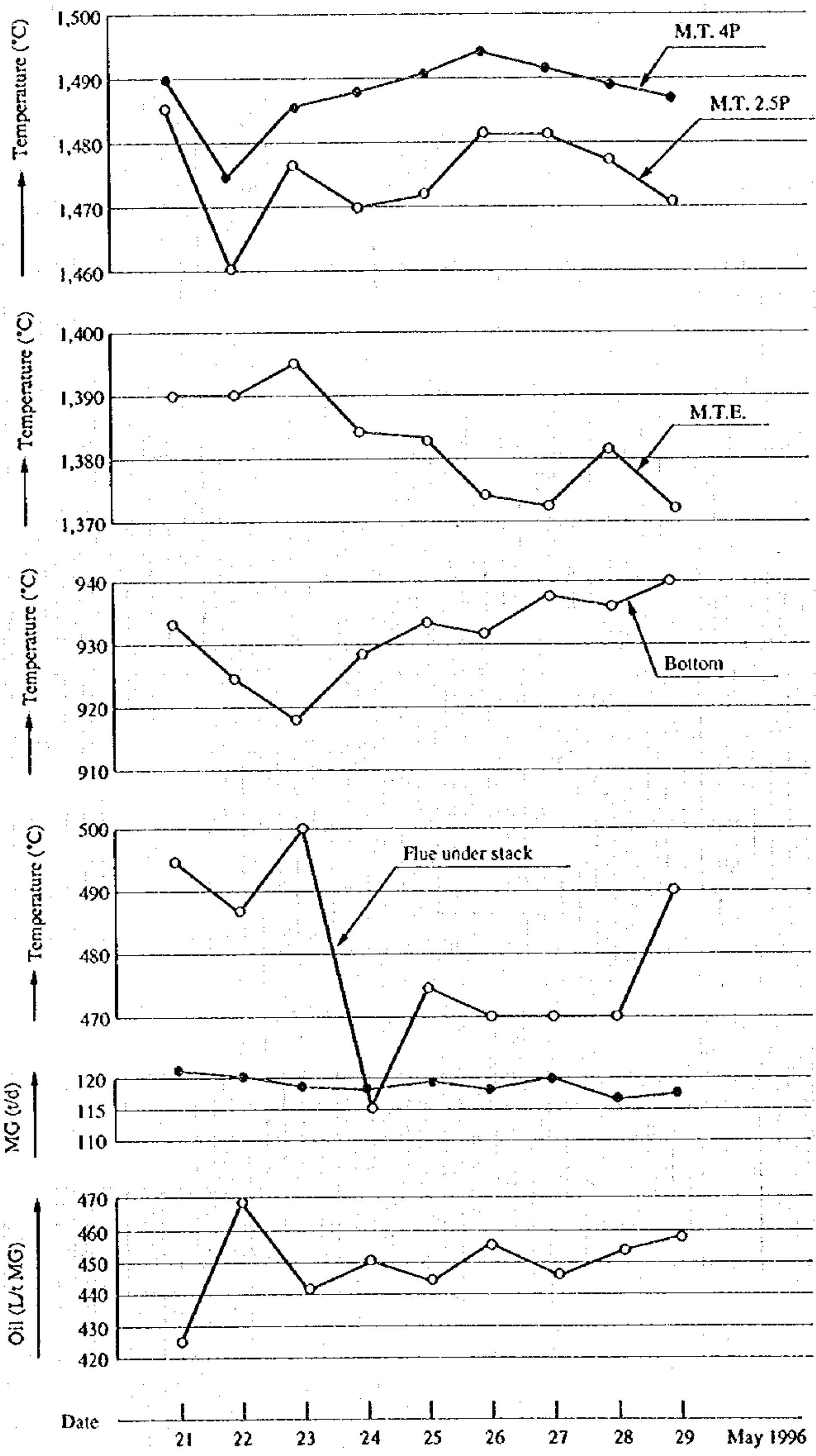
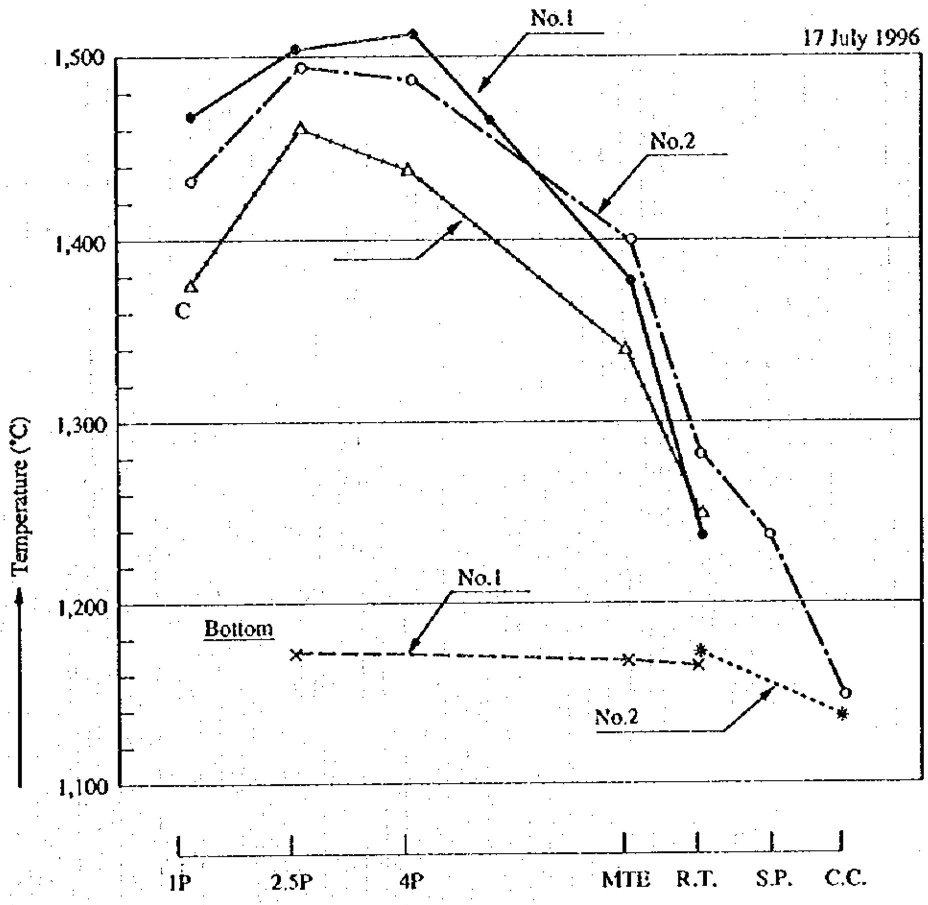


Figure 4.18 Operation Data on No. 3 Furnace (Bronze Color)



5) Figure 4.19 shows the readings of the thermometers in the meter room for each furnace recorded during measurement and plotted in the flow direction.

Figure 4.19 Temperature Distribution Curve



c. Heat Input

1) Calorific value of fuel

For the calorific value of fuel, the net calorific value (Hℓ) is used. Although the fuel temperature during measurement is unknown, it is assumed that gas consumption was indicated in terms of m^3_N. These are shown in Table 4.10. (See Table 4.8.)

Table 4.10 Calorific Value of Fuel

No. 1 Furnace	41,424 × 9,500	= 39.35 × 10^7 kcal/d
No. 2 Furnace	41.3 × 10^3 × 9,400	= 38.82 × 10^7 kcal/d
No. 2 Furnace 16, 17 July	41.6 × 10^3 × 9,400	= 39.10 × 10^7 kcal/d
No. 3 Furnace	52.3 × 10^3 × 9,400	= 49.16 × 10^7 kcal/d
No. 4 Furnace	82.2 × 10^3 × 9,400	= 77.27 × 10^7 kcal/d

2) Sensible heat of fuel

The sensible heat of the fuel is calculated based on 20 °C and shown in Table 4.11. (See Table 4.8.)

Table 4.11 Sensible Heat of Fuel

No. 1 Furnace	$(22-20) \times 0.53 \times 41{,}424 = 0.00 \times 10^7$ kcal/d
No. 2 Furnace	$(78-20) \times 0.48 \times 41.3 \times 10^3 \times 0.95 = 0.11 \times 10^7$ kcal/d
No. 2 Furnace 16, 17 July	$(78-20) \times 0.48 \times 41.6 \times 10^3 \times 0.95 = 0.11 \times 10^7$ kcal/d
No. 3 Furnace	$(78-20) \times 0.48 \times 52.3 \times 10^3 \times 0.95 = 0.14 \times 10^7$ kcal/d
No. 4 Furnace	$(78-20) \times 0.48 \times 82.2 \times 10^3 \times 0.95 = 0.22 \times 10^7$ kcal/d

3) Sensible heat of air

Air consumed for fuel combustion includes the secondary air coming from the reversal, the primary air coming into the burner for atomization, the air coming from the area around the burner tile as a result of the ejector effect, and the air for purging the burner on the suction side. As the total air volume, the sum of the excess air volume obtained from the oxygen content in the exhaust gas coming into the regenerator and the theoretical air volume is shown in Table 4.12. (For details, see the section of Heat Output. For the air temperature, see Table 4.8.)

Table 4.12 Sensible Heat of Air

No. 1 Furnace	$23{,}172\ m^3_N/h \times (22-20) \times 0.31 \times 24 = 0.03 \times 10^7$ kcal/d
No. 2 Furnace	$21{,}293\ m^3_N/h \times (22-20) \times 0.31 \times 24 = 0.03 \times 10^7$ kcal/d
No. 2 Furnace 16, 17 July	$21{,}448\ m^3_N/h \times (32-20) \times 0.31 \times 24 = 0.19 \times 10^7$ kcal/d
No. 3 Furnace	$26{,}964\ m^3_N/h \times (22-20) \times 0.31 \times 24 = 0.04 \times 10^7$ kcal/d
No. 4 Furnace	$42{,}380\ m^3_N/h \times (17-20) \times 0.31 \times 24 = -0.09 \times 10^7$ kcal/d

4) Sensible heat of raw material

Supposing that the raw material is always charged at 20 °C, the sensible heat is ignored.

5) Total heat input

Table 4.13 shows the total heat input.

Table 4.13 Total Heat Input

No. 1 Furnace	$(39.35 + 0.00 + 0.03) \times 10^7 = 39.38 \times 10^7$ kcal/d
No. 2 Furnace	$(38.82 + 0.11 + 0.03) \times 10^7 = 38.96 \times 10^7$ kcal/d
No. 2 Furnace 16, 17 July	$(39.10 + 0.11 + 0.19) \times 10^7 = 39.40 \times 10^7$ kcal/d
No. 3 Furnace	$(49.16 + 0.14 + 0.04) \times 10^7 = 49.34 \times 10^7$ kcal/d
No. 4 Furnace	$(77.27 + 0.22 - 0.09) \times 10^7 = 77.40 \times 10^7$ kcal/d

d. Heat output

1) Heat value for melting raw material

Table 4.14 shows the percentage of each raw material to be mixed.

Table 4.14 Batch Composition

	Unit	No. 1 Plant	No. 2, 3 Plant	No. 4 Plant
Silica sand	kg	480	865	879
Dolomite	kg	132	221	221
Lime stone	kg	9	13	15
Feldspar	kg	–	43	42
Soda ash	kg	156	282	283
Salt cake	kg	11	11	14
Carbon		–	–	–
Cullet	%	37	37 (No. 2), 49 (No. 3)	41
Water in Batch	%	5.6	5.6	5.6
Total (except cullet)	kg	834.7	1,520.1	1,540.3

Table 4.15 shows the kg-mol calculated value of each raw material.

Table 4.15 Calculation of kg-mol

Raw Material	Silica Sand	Dolomite	Lime Stone	Feldspar	Soda Ash	Salt Cake
Molecular formula	SiO_2	$MgCO_3{\cdot}CaCO_3$	$CaCO_3$	$Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2$	Na_2CO_3	Na_2SO_4
No. 1 Plant kg-mol	$\frac{480\times0.95^{(1)}}{60.1}$	$\frac{132\times0.765^{(2)}}{184.4}$	$\frac{132\times0.235^{(2)}}{100.1}+\frac{9}{100.1}$	$\frac{480\times0.05}{525.1}+\frac{0}{525.1}$	$\frac{156}{106}$	$\frac{11}{142.1}$
	≒ 7.587	≒ 0.548	≒ 0.400	≒ 0.046	≒ 1.472	≒ 0.077
No. 2, 3 Plant	13.673	0.917	0.649	0.164	2.660	0.077
No. 4 Plant	13.894	0.917	0.669	0.164	2.670	0.099

Note (1): 5 % of silica sand is feldspar.
(2): 76.5 % of dolomite is $MgCO_3{\cdot}CaCO_3$ and 23.5 % is lime stone.

Table 4.16 shows the heat values of transformation, reaction, melting, and gas heating.

Table 4.16 Heat Value of Transformation, Reaction, Melting and Gas Heating

Raw Material		Dolomite	Lime Stone	Feldspar	Soda Ash	Salt Cake	Total
	kcal/kg-mol	107,614	50,242	26,300⁽¹⁾	45,096	94,249	–
No. 1 Plant	kcal	58,972	20,097	1,210	66,381	7,257	153,917
No. 2, 3 Plant	kcal	98,682	32,607	4,313	119,955	7,257	262,814
No. 4 Plant	kcal	98,682	33,612	4,313	120,406	9,331	266,344

Note (1): In case of $K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$ the heat value is 46,330 kcal/kg-mol.

Table 4.17 shows the heat value for glass heating.

If the specific heat of glass is 0.295 kcal/(kg·°C), the heat value required to heat it from 20 °C to 1500 °C is as follows:

$0.295 \times (1500 - 20) ≒ 436.6$ kcal/kg

Table 4.17 Heat Value of Glass Heating

No. 1 Plant	834.7 × 0.8⁽¹⁾ × 436.6 = 291,544 kcal/Batch
No. 2, 3 Plant	1,520.1 × 0.8 × 436.6 = 530,941 kcal/Batch
No. 4 Plant	1,540.3 × 0.8 × 436.6 = 537,996 kcal/Batch

Note (1): Batch yield (wet): 80 %

Table 4.18 shows the heat values of water evaporation and heating.

Table 4.18 Heat Value of Water Evaporation and Heating

No. 1 Plant	834.7 × 0.056 × 1,366.6⁽¹⁾ = 63,879 kcal/Batch
No. 2, 3 Plant	1,520.1 × 0.056 × 1,366.6 = 116,333 kcal/Batch
No. 4 Plant	1,540.3 × 0.056 × 1,366.6 = 117,879 kcal/Batch

Note (1): Heat value of water
(100 – 20) × 1.0 + 539.6 + (1,500 – 100) × 0.5334 = 1,366.6 kcal/kg

The heat value of batch melting is the sum of the values in Tables 4.16, 4.17, and 4.18. Table 4.19 shows the value per 1 kg of batch.

Table 4.19 Heat Value of Batch Melting

No. 1 Plant	(153,917 + 291,544 + 63,879) ÷ 834.7 = 610.2 kcal/kg
No. 2,3 Plant	(262,814 + 530,941 + 116,333) ÷ 1,520.1 = 598.7 kcal/kg
No. 4 Plant	(266,344 + 537,996 + 117,879) ÷ 1,540.3 = 598.7 kcal/kg
Cf	Heat value of cullet melting = 436.6 kcal/kg

As the effective heat, the heat value required to melt and heat the raw material including cullet is obtained and shown in Table 4.20.

Table 4.20 Heat Value of Raw Material Melting and Heating

	Batch	Cullet	Total
No. 1 Furnace	4.62×10^7	2.05×10^7	6.67×10^7 kcal/d
No. 2 Furnace	5.53×10^7	2.37×10^7	7.90×10^7 kcal/d
No. 2 Furnace 16, 17 July	7.08×10^7	1.64×10^7	8.72×10^7 kcal/d
No. 3 Furnace	4.79×10^7	2.33×10^7	7.12×10^7 kcal/d
No. 4 Furnace	7.24×10^7	3.69×10^7	10.93×10^7 kcal/d

2) Heat value of exhaust gas

2-1) Calculation of theoretical air volume (See Table 4.5.)

Natural gas:

$$A_0 = \frac{1}{0.21}(2\times0.8411+3.5\times0.1019+5\times0.0.381+6.5\times0.0039)$$
$$= 10.74\ \mathrm{m^3{}_N/m^3{}_N}$$

Heavy oil:

$$A_0 = \frac{0.85\times9{,}900}{1{,}000}+2.0 = 10.42\ \mathrm{m^3{}_N/kg}$$

(Calculated from the approximate relational formula with Hℓ since the heavy oil element analysis values are unknown.)

2-2) Calculation of the excess air volume (See Table 4.9 and Figure 4.15.)

$$\text{Air ratio}\quad m \fallingdotseq \frac{21}{21-(O_2\%)}$$

According to the O_2 analysis value during measurement on July 16 and 17 for the No. 2 furnace:

Above the checker brick of the regenerator
: Average O_2 = 4.18 %, m = 1.25
Below the checker brick of the regenerator
: Average O_2 = 10.6 %, m = 2.02

2-3) Calculation of actual air volume

$$A = m\cdot A_0\quad \mathrm{m^3{}_N/kg}$$

The volume of air for combustion for the No. 2 furnace on July 16 is:

$$A = 1.25\times10.42\times41.6\times0.95\times\frac{1{,}000}{24}$$
$$= 21{,}448\ \mathrm{m^3{}_N/h}$$

[Alternative method]

Based on the actually measured air volume for combustion on the inlet of the reversal (i.e. 6 m^3/sec):

$6 \times 3{,}600 = 21{,}600\ m^3_N/h$

On the other hand, the primary air volume for heavy oil burner atomization and purging is 685 m^3_N/h. (See Table 4.8.)

Therefore, the total air volume for combustion is 22,285 m^3_N/h, which is approximately identical with the value obtained from the O_2 analysed value above the checker brick in the regenerator.

2-4) Calculation of theoretical exhaust gas volume (wet) (See Table 4.5.)

Natural gas:

$$\begin{aligned} G_0 &= 1 + A_0 - 0.5 \times (-0.1019 - 2 \times 0.0381 - 3 \times 0.0039) \\ &= 11.83\ m^3_N/m^3_N\text{-fuel} \end{aligned}$$

Heavy oil:

$$G_0 = \frac{11.1 \times 9{,}900}{1{,}000} = 10.99\ m^3_N/\text{kg-fuel}$$

2-5) Calculation of the actual exhaust gas volume (wet)

$$\begin{aligned} G = &\{G_0 + (m - 1) \cdot A_0\}\ m^3_N/m^3_N \text{ or kg-fuel} \\ &+ \text{Volume of the generated gas from raw material} \end{aligned}$$

Volume of the exhaust gas from raw material: 0.13 m^3_N/kg-batch

Table 4.21 shows the calculation result of the exhaust gas volume per hour.

Table 4.21 Volume of Exhaust Gas (Wet)

	Upper Part of Regenerator	Under Stack
No. 1 Furnace	25,053 + 410 = 25,463 m^3_N/h	39,318 + 410 = 39,728 m^3_N/h
No. 2 Furnace	22,225 + 501 = 22,726 m^3_N/h	35,342 + 501 = 35,853 m^3_N/h
No. 2 Furnace 16, 17 July	22,386 + 641 = 23,027 m^3_N/h	35,598 + 641 = 36,239 m^3_N/h
No. 3 Furnace	28,115 + 433 = 28,578 m^3_N/h	44,755 + 433 = 45,188 m^3_N/h
No. 4 Furnace	44,235 + 655 = 44,890 m^3_N/h	70,340 + 655 = 70,995 m^3_N/h

Note: The air ratio of every furnace is assumed to be the same as No. 2 furnace (16, 17 July)

2-6) Calculation of the heat loss of exhaust gas

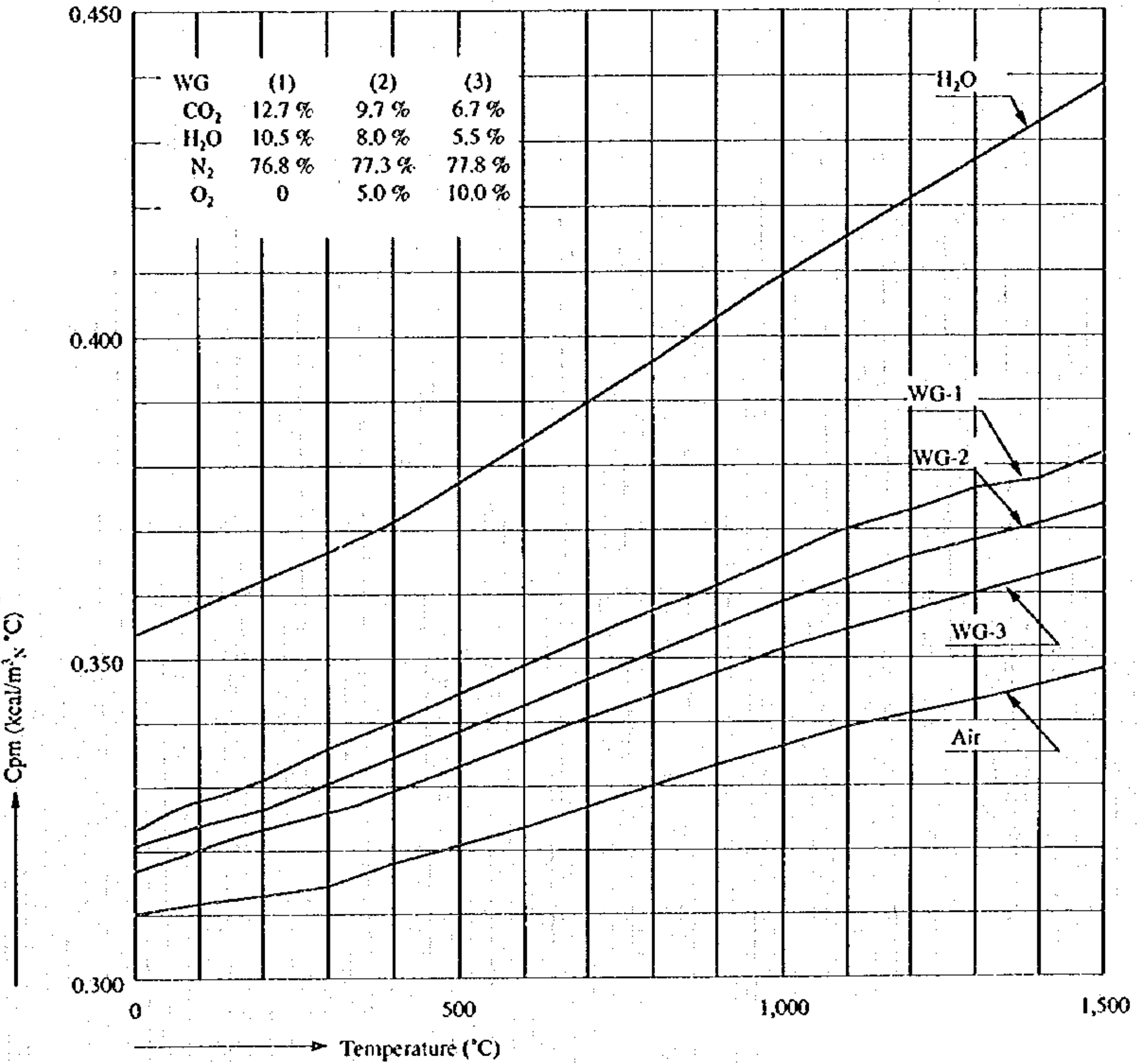
If the sensible heat of exhaust gas below the ckecker brick in the regenerator is presumed to be the heat loss of exhaust gas, it is as shown in Table 4.22. Figure 4.20 shows the average specific heat of exhaust gas and air under the constant pressure.

Table 4.22 Heat Loss of Exhaust Gas

No. 1 Furnace	(470 – 20)(1) × 0.332(2) × 39,728(3) × 24	= 14.25 × 10^7 kcal/d
No. 2 Furnace	(470 – 20) × 0.332 × 35,853 × 24	= 12.86 × 10^7 kcal/d
No. 2 Furnace 16, 17 July	(470 – 20) × 0.332 × 36,239 × 24	= 12.99 × 10^7 kcal/d
No. 3 Furnace	(470 – 20) × 0.332 × 45,188 × 24	= 16.20 × 10^7 kcal/d
No. 4 Furnace	(470 – 20) × 0.332 × 70,995 × 24	= 25.46 × 10^7 kcal/d

Note (1): Exhaust gas temperature of every furnace is assumed to be the same as No. 2 furnace (16 July) (cf: Figure 4.12)
(2): cf: Figure 4.19
(3): cf: Table 4.21

Figure 4.20 Average Specific Heat of Exhaust Gas (W.G.) and Air



3) Recovery heat value of regenerator

The recovery heat value of exhaust gas in the regenerator is obtained by subtracting heat radiation from the outer wall surface of the regenerator from the difference between the sensible heat of the exhaust gas above the checker brick in the regenerator and the sensible heat of the exhaust gas below the checker brick in the regenerator. The ratio of this recovery heat and the total heat input is the regenerator recovery rate. This heat value is used to preheat the secondary air. Actually, the difference between the sensible heat of exhaust gas above the checker brick of the regenerator and the sensible heat of exhaust gas below the checker brick in the regenerator is regarded as the recovery heat value. Heat radiation from the outer wall surface is ignored.

Table 4.23 shows the sensible heat of exhaust gas above the regenerator.

Table 4.24 shows the recovery heat value and recovery rate of the exhaust gas in the regenerator.

Table 4.23 Sensible Heat of Exhaust Gas at Upper Part in Regenerator

No. 1 Furnace	(1,380 – 20)(1) × 0.37(2) × 25,463(3) × 24	= 30.75 × 10^7 kcal/d
No. 2 Furnace	(1,320 – 20) × 0.37 × 22,726 × 24	= 26.24 × 10^7 kcal/d
No. 2 Furnace 16, 17 July	(1,320 – 20) × 0.37 × 23,027 × 24	= 26.58 × 10^7 kcal/d
No. 3 Furnace	(1,320 – 20) × 0.37 × 28,578 × 24	= 32.99 × 10^7 kcal/d
No. 4 Furnace	(1,320 – 20) × 0.37 × 44,890 × 24	= 51.82 × 10^7 kcal/d

Note (1): Exhaust gas temperature of No. 1 furnace cf: Figure 4.16
Exhaust gas of No. 2, 3, 4 furnaces is asumed to be the same as that for No. 2 furnace (16 July).
(2): cf: Figure 4.20
(3): cf: Table 4.21

Table 4.24 Recovery Heat Value at Regenerator and Recovery Rate

No. 1 Furnace	16.50 × 10^7 kcal/d(1)	41.9 %
No. 2 Furnace	13.38 × 10^7 kcal/d	34.3 %
No. 2 Furnace 16, 17 July	13.59 × 10^7 kcal/d	34.5 %
No. 3 Furnace	16.79 × 10^7 kcal/d	34.0 %
No. 4 Furnace	26.36 × 10^7 kcal/d	34.1 %

Note (1): (Table 4.23 – Table 4.22) + (Total heat input)

4) Heat radiation

4-1) Heat radiation from the furnace wall

For No. 1 and No. 2 furnaces, heat radiation from the furnace wall is calculated based on the partially measured furnace outer surface temperature and furnace wall structure, and is shown in Tables 4.25 to 4.28. (For the calculation formula, see the Guideline.)

Note:
MT : Melting Tank
RT : Refining Tank
ST : Settling Tank
SST: Side Settling Tank
CC : Cooling Chamber
Cnl : Canal
FH : Fore house
EW : End Wall
FW : Front Wall
HA : Heating Area
ME : Melting End Area

Table 4.25 Heat Loss from Wall Surface (No. 1 Furnace)

No. 1 Furnace			Surface Area (m^2)	Measuring Surface Temperature (°C)	Unit Heat Loss ($kcal/m^2 \cdot h$)	Heat Loss (kcal/h)
Bottom	MT	Under	113	–	(4,800)	542,400
		Side	14	–	(1,000)	14,000
	RT, ST	Under	47	–	(4,800)	225,600
		Side	5	–	(1,000)	5,000
	CC, Cnl., FH	Under	26	–	(3,000)	78,000
		Side	11	–	(1,000)	11,000
Side wall	MT	Upper	21	350	9,000	189,000
		Under	21	280	5,100	107,100
	RT, ST		21	260	4,400	92,400
	CC, Cnl., FH		34	150	2,000	68,000
Breast wall	MT		48	300	6,000	288,000
	RT, ST		20	–	(3,000)	60,000
	CC, Cnl., FH		30	–	(2,000)	60,000
Back wall			14	–	(6,000)	84,000
Shadow wall			25	–	(7,500)	187,500
Wing wall	RT ~ MT Side		–	–	–	–
	RT ~ ST Side		–	–	–	–
	BW, FW		14	–	(6,000)	84,000
Crown	MT	HA	68	220~370	6,500	442,000
		ME	51	–	(6,500)	331,500
	RT, ST		49	–	(4,500)	220,500
	CC, Cnl., FH		19	–	(2,000)	38,000
Port	Crown		25	–	(7,200)	180,000
	Side		46	–	(5,700)	262,200
	Bottom		24	–	(3,000)	72,000
Regenerator	Crown		52	200	3,000	156,000
	Side	Upper	100	95	1,000	100,000
		Middle	100	–	(1,000)	100,000
		Lower	100	–	(1,000)	100,000
	End wall		58	100	1,100	63,800
	Bottom		50	–	(500)	25,000
Total			1,206	17 July	( ): Presumed	4,187,000
	(M.T.)		(375)	(R/P)		10.05×10^7 kcal/d

Table 4.26 Heat Loss from Wall Surface (No. 2 Furnace)

No. 2 Furnace			Surface Area (m^2)	Measuring Surface Temperature (°C)	Unit Heat Loss ($kcal/m^2 \cdot h$)	Heat Loss (kcal/h)
Bottom	MT	Under	137	–	(4,800)	657,600
		Side	14	–	(1,000)	14,000
	RT, ST	Under	82	–	(4,800)	393,600
		Side	9	–	(1,000)	9,000
	CC, Cnl., FH	Under	16	–	(3,000)	48,000
		Side	4	–	(1,000)	4,000
Side wall	MT	Upper	29	–	(16,000)	464,000
		Under	29	325	7,000	203,000
	RT, ST		35	405	11,500	402,500
	CC, Cnl., FH		6	–	(2,000)	12,000
Breast wall	MT		41	250	4,000	164,000
	RT, ST		22	205	3,000	66,000
	CC, Cnl., FH		7	–	(2,000)	14,000
Back wall			19	180	2,300	43,700
Shadow wall			36	–	(7,500)	270,000
Wing wall	RT ~ MT Side		–	–	–	–
	RT ~ ST Side		10	–	(6,000)	60,000
	EW		–	–	–	–
Crown	MT	HA	112	320	6,800	761,600
		ME	32	–	(6,800)	217,600
	RT, ST		86	–	(4,500)	387,000
	CC, Cnl., FH		17	–	(2,000)	34,000
Port	Crown		25	250	4,000	100,000
	Side		50	–	(5,700)	285,000
	Bottom		25	–	(3,000)	75,000
Regenerator	Crown		78	220	3,300	257,400
	Side	Upper	130	169	2,000	260,000
		Middle	130	–	1,800	234,000
		Lower	130	–	1,500	195,000
	End wall		60	205	3,000	180,000
	Bottom		74	–	500	37,000
Total			1,445	17 July	( ): Presumed	5,849,000
	(M.T.)		(449)	(R/P)	14.04×10^7 kcal/d	

Table 4.27 Heat Loss from Wall Surface (No. 3 Furnace)

No. 3 Furnace			Surface Area (m^2)	Measuring Surface Temperature (°C)	Unit Heat Loss (kcal/m^2·h)	Heat Loss (kcal/h)
Bottom	MT	Under	214	–	(4,800)	1,027,200
		Side	16	–	(1,000)	16,000
	RT, ST	Under	101	–	(4,800)	484,800
		Side	9	–	(1,000)	9,000
	CC, Cnl., FH	Under	29	–	(3,000)	87,000
		Side	7	–	(1,000)	7,000
Side wall	MT	Upper	37	–	(16,000)	592,000
		Under	37	–	(7,000)	259,000
	RT, ST		42	–	(11,500)	483,000
	CC, Cnl., FH		12	–	(2,000)	24,000
Breast wall	MT		50	–	(4,000)	200,000
	RT, ST		36	–	(3,000)	108,000
	CC, Cnl., FH		14	–	(2,000)	28,000
Back wall			22		(2,300)	50,600
Shadow wall			49	–	(7,500)	367,500
Wing wall	RT ~ MT Side		16	–	(6,000)	96,000
	RT ~ ST Side		9	–	(6,000)	54,000
	EW		–		–	–
Crown	MT	HA	173	–	(6,800)	1,176,400
		ME	52	–	(6,800)	353,600
	RT, ST		106	–	(4,500)	477,000
	CC, Cnl., FH		12	–	(2,000)	24,000
Port	Crown		30	–	(4,000)	120,000
	Side		60	–	(5,700)	342,000
	Bottom		30	–	(3,000)	90,000
Regenerator	Crown		108	–	(3,300)	356,400
	Side	Upper	180	–	(2,000)	360,000
		Middle	180	–	(1,800)	324,000
		Lower	180	–	(1,500)	270,000
	End wall		60	–	(3,000)	180,000
	Bottom		103	–	(500)	51,500
Total			1,974		( ): Presumed	8,018,000
	(M.T.)		(650)			19.24 × 10^7 kcal/d

Table 4.28 Heat Loss from Wall Surface (No. 4 Furnace)

No. 4 Furnace			Surface Area (m^2)	Measuring Surface Temperature (°C)	Unit Heat Loss ($kcal/m^2 \cdot h$)	Heat Loss (kcal/h)
Bottom	MT	Under	293	–	(4,800)	1,406,400
		Side	20	–	(1,000)	20,000
	RT, ST, SST	Under	235	–	(4,800)	1,128,000
		Side	30	–	(1,000)	30,000
	CC, Cnl., FH	Under	66	–	(3,000)	198,000
		Side	14	–	(1,000)	14,000
Side wall	MT	Upper	45	–	(9,000)	405,000
		Under	45	–	(5,100)	229,500
	RT, ST, SST		133	–	(4,400)	585,200
	CC, Cnl., FH		14	–	(2,000)	28,000
Breast wall	MT		66	–	(4,000)	264,000
	RT, ST, SST		91	–	(3,000)	273,000
	CC, Cnl., FH		32	–	(2,000)	64,000
Back wall			55	–	(2,300)	126,500
Shadow wall			87	–	(7,500)	652,500
Wing wall	RT ~ MT Side		16	–	(6,000)	96,000
	RT ~ ST Side		9	–	(6,000)	54,000
	SST-EW		19	–	(2,000)	38,000
Crown	MT	HA	186	–	(6,500)	1,209,000
		ME	55	–	(6,500)	357,500
	RT, ST, SST		248	–	(4,500)	1,116,000
	CC, Cnl., FH		58	–	(2,000)	116,000
Port	Crown		81	–	(4,000)	324,000
	Side		64	–	(5,700)	364,800
	Bottom		82	–	(3,000)	246,000
Regenerator	Crown		173	–	(3,300)	570,900
	Side	Upper	280	–	(2,000)	560,000
		Middle	331	–	(1,800)	595,800
		Lower	220	–	(1,500)	330,000
	End wall		196	–	(3,000)	588,000
	Bottom		163	–	(500)	81,500
Total			3,407		( ): Presumed	12,071,600
	(M.T.)		(852)			28.97 × 10^7 kcal/d

4-2) Heat loss of coolers

Table 4.29 shows the heat loss of coolers.

Table 4.29 Heat Loss of Coolers (Presumed Value)

Name of Coolers	Water (t/h)	Temperature ΔT (°C)	No. (pcs)	Heat Value (kcal/h)	No. 1 Furnace	No. 2 Furnace	No. 3 Furnace	No. 4 Furnace
Batch charger	4.0/8.0	5.0	3/2	$60 \times 10^3/80 \times 10^3$	O/	/O	/O	/O
Suspention cooler	10.0	5.0	1	50×10^3	×	O	O	O
Reversal damper	12.5	2.0	2	50×10^3	×	×	×	×
Burner cooler	4.3	3.0	–	$12.9 \times 10^3 \times$ pcs	×	×	×	×
Glass level cooler	3.2	6.0	1	19.2×10^3	O	O	O	O
S. T. floater	30.0	6.0	1 ~ 3	$180 \times 10^3 \times$ pcs	×	①	②	③
J. A. floater	3.0	5.0	1 ~ 3	$15 \times 10^3 \times$ pcs	×	①	②	③
Neck pipe cooler 2"ϕ	28.0	6.0	–	$168 \times 10^3 \times$ pcs	×	×	×	×
Other cooler	–	–	–	–	–	–	–	–
Total	Heat loss value (× 10^7 kcal/d)				0.19	0.83	1.29	1.76

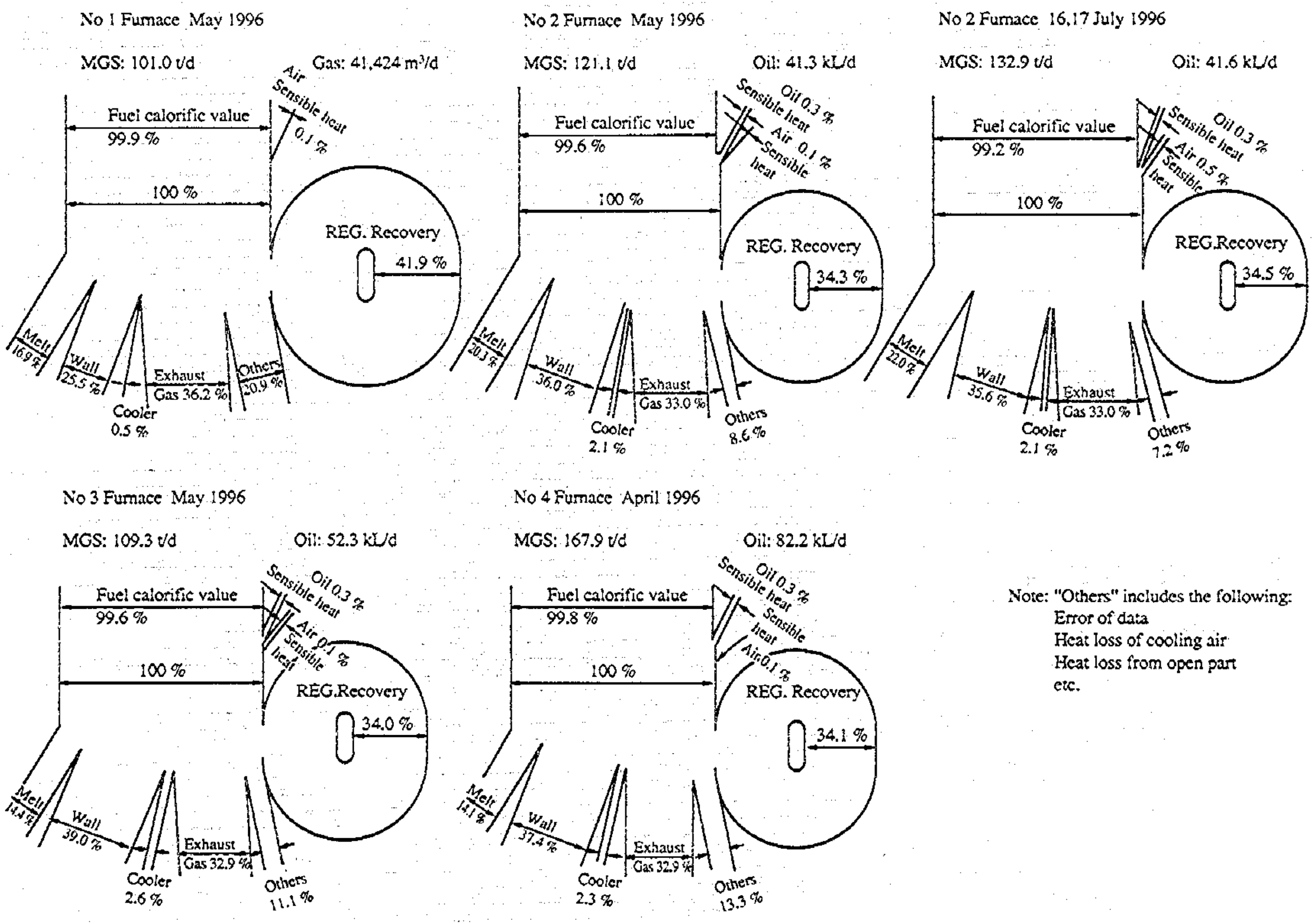
e. Summary of heat balance

Table 4.30 and Figure 4.21 show the summary of heat balance.

Table 4.30 Summary of Heat Balance

	Furnace	No. 1 May 1996		No. 2 May 1996		No. 2 16, 17 July 1996		No. 3 May 1996		No. 4 April 1996	
	Items	× 10^7 kcal/d	(%)	× 10^7 kcal/d	(%)	× 10^7 kcal/d	(%)	× 10^7 kcal/d	(%)	× 10^7 kcal/d	(%)
Heat-input	Fuel calorific value	39.35	(99.9)	38.82	(99.6)	39.10	(99.2)	49.16	(99.6)	77.27	(99.8)
	Sensible heat of fuel	0.00	(0.0)	0.11	(0.3)	0.11	(0.3)	0.14	(0.3)	0.22	(0.3)
	Sensible heat of air	0.03	(0.1)	0.03	(0.1)	0.19	(0.5)	0.04	(0.1)	-0.09	(-0.1)
	Total	39.38	(100.0)	38.96	(100.0)	39.40	(100.0)	49.34	(100.0)	77.40	(100.0)
Heat-output	Effective heat for raw material melting	6.67	(16.9)	7.90	(20.3)	8.72	(22.1)	7.12	(14.4)	10.93	(14.1)
	Heat loss by Exhaust gas	14.25	(36.2)	12.86	(33.0)	12.99	(33.0)	16.20	(32.9)	25.46	(32.9)
	Heat loss by Radiation from wall	10.05	(25.5)	14.04	(36.0)	14.04	(35.6)	19.24	(39.0)	28.97	(37.4)
	Heat loss taken away by cooler	0.19	(0.5)	0.83	(2.1)	0.83	(2.1)	1.29	(2.6)	1.76	(2.3)
	Others	8.22	(20.9)	3.33	(8.6)	2.82	(7.2)	5.49	(11.1)	10.28	(13.3)
	Total	39.38	(100.0)	38.96	(100.0)	39.40	(100.0)	49.34	(100.0)	77.40	(100.0)
Heat-recovery (REG)		16.50	(41.9)	13.38	(34.3)	13.59	(34.5)	16.79	(34.0)	26.36	(34.1)

Figure 4.21 Flow of Heat Balance at Ghazvin Glass Furnace



Note: "Others" includes the following:
Error of data
Heat loss of cooling air
Heat loss from open part
etc.

f. Review of the heat balance result

1) Comparison of the furnaces

No. 1 furnace:

Reduction in heat radiation from the wall as a result of simple heat insulation and improvement in the regeneration heat recovery rate as a result of improving the checker work are recognized.

The reason why the loss represented as others is very large may be that the estimation error became large because the assumption was made based on the measurement data of the No. 2 furnace.

No. 1 furnace is the only one furnace that uses natural gas. The comparison with combustion of heavy oil cannot be estimated from this heat balance, but according to the fuel intensity in Figure 4.10, the status is 7.8 % worse.

$$\frac{\text{Gas combustion } 352.9\ \text{m}^3{}_\text{N}/\text{t}\times 9{,}500\ \text{kcal/m}^3{}_\text{N}}{\text{Heavy oil combustion } 330.8\ \text{L/t}\times 9{,}400\ \text{kcal/L}} = 1.078$$

This may be caused by the difference in the emissivity of flame.

No. 2 furnace:

This furnace was measured. Although the operation period is as long as 4.8 years, two machines are running and the melting load is high. Therefore, the heat value for melting raw material as the effective heat value is 20 to 22 %, which is a satisfactory value for a small furnace.

For the No. 2 furnace, heat balance using the average value in May and heat balance using the average of the measured values on July 16 and 17 were calculated but there was no significant difference.

No. 3 furnace:

The operation period is 7.3 years and this furnace shows signs of heavy degradation. Bronze-color sheet glass was being produced. Due to shortage of draft, the melted volume was reduced. (73 % operation rate against normal operation rate MGS 150 tons/day) Heat balance was made based on abnormal data.

No. 4 furnace:

This is the largest furnace, but measurement could not be made because it was under periodical cold repair. Therefore, heat balance was made based on data of April of this year (9.8 years of operation). Since the No. 4 furnace showed signs of collapse, the molten glass volume is smaller. (75 % operation rate against normal operation MGS 230 tons/day)

2) Comparison with the excellent factory in Japan

① Decision of the current base level

The actual data in 1994 when no periodical cold repair of the furnaces was conducted is used to determine the present values, on which energy conservation measures should be based, considering that period seems most stable. For the Japanese excellent plant the data for 1989 in Japan is used. The average values per day for one kiln are shown in Table 4.31.

Table 4.31 Comparison Basic Data on Ghazvin Glass and an Excellent Factory

Item		Ghazvin Glass	Excellent
Energy intensity	Oil (kL/d)	51.6⁽¹⁾	67.2
	(kcal/kg-product)	5,447⁽²⁾	2,300
	Production (t/d)	89	274
	Yield (%)	68.7	75
	MGS (t/d)⁽³⁾	130	365
	(kL/t-MGS)	0.397	0.184

Note (1): cf: Table 4.3
(2): cf: Table 4.4, (2,300 – 5,447) / 5,447 × 100 = Δ57.8 %
(3): MG = MGS

② Comparison with the excellent factory

For each item that effects energy intensity, the current base value at Ghazvin Glass is compared with that at the excellent factory and the difference is shown in Table 4.32.

Table 4.32 Comparison between Ghazvin and an Excellent Factory

Item	Ghazvin	Excellent	Remarks
Furnace load			
MGS (t/d)	130	214*1	*1: cf: Table 4.35
Calculation oil (kL/d)	52.3	67.5	cf: Note (1)
Oil intensity (kL/t-MGS)	0.402	0.315	Δ21.6 %
Furnace scale			
MGS (t/d)	214	365*2	*2: cf: Figure 4.24
Oil intensity (kL/t)	0.223	0.188	Δ15.7 %
Production yield (%)	68.7 1/0.687	75.0 1/0.750	Δ8.4 %
Subtotal	(1 – 0.216) × (1 – 0.157) × (1 – 0.084) – 1 = –39.5 %		
Insulation			
Heat loss (Melting tank) (kL/d)	29.3	23.4	*2: cf: Note (2) λ: 1.0 → 0.8
Calculation oil (kL/d)	52.3	43.0*2	Δ17.8 %
Regenerator heat recovery			Checker H: 4.35 m → 7.0 m
Surface area (m^2)	2,592	5,617*3	209 m^3 × 12.4 m^2/m^3 → 336 m^3 × 16.7 m^2/m^3
Efficiency (%)	64.0 1/0.640	71.5 1/0.715	*3: cf: Note (3) Δ10.5 %
Combustion control			
Excess air (%)	25	15	
Efficiency (%)	64.0 1/0.640	66.5 1/0.665	ΔEA = 0.25 × (25 – 15) Δ3.8 %
Others			
Difference of furnace year and error etc.			Δ1.4 %
Subtotal	(1 – 0.178) × (1 – 0.105) × (1 – 0.038) × (1 – 0.014) – 1 = –30.2		
Total	(1 – 0.395) × (1 – 0.302) – 1 = –57.8 %		

Note: Oil consumption formula

$$y = \frac{0.065 \cdot MGS + \left(0.63 + 0.37 \frac{MGS}{MGSmax}\right) \cdot Q_L}{\eta}$$

Q_L: Heat loss from melter wall

$Q_L \fallingdotseq 0.05 \cdot \lambda \cdot MA'$

MA': Surface area of melter wall (m^2)

λ: Insulation coefficient

(ex) No insulation : 1.0
Simple insulation: 0.9 ~ 0.95
Heavy insulation : 0.76 ~ 0.82

η: Furnace efficiency

$$\eta \fallingdotseq 83 - 633 \cdot \frac{y}{CV} - 0.25 \cdot EA$$

CV: Heat surface area of checker (m^2)
= Total checker volume in one side REG. (m^3) × unit surface area of checker (m^2/m^3)

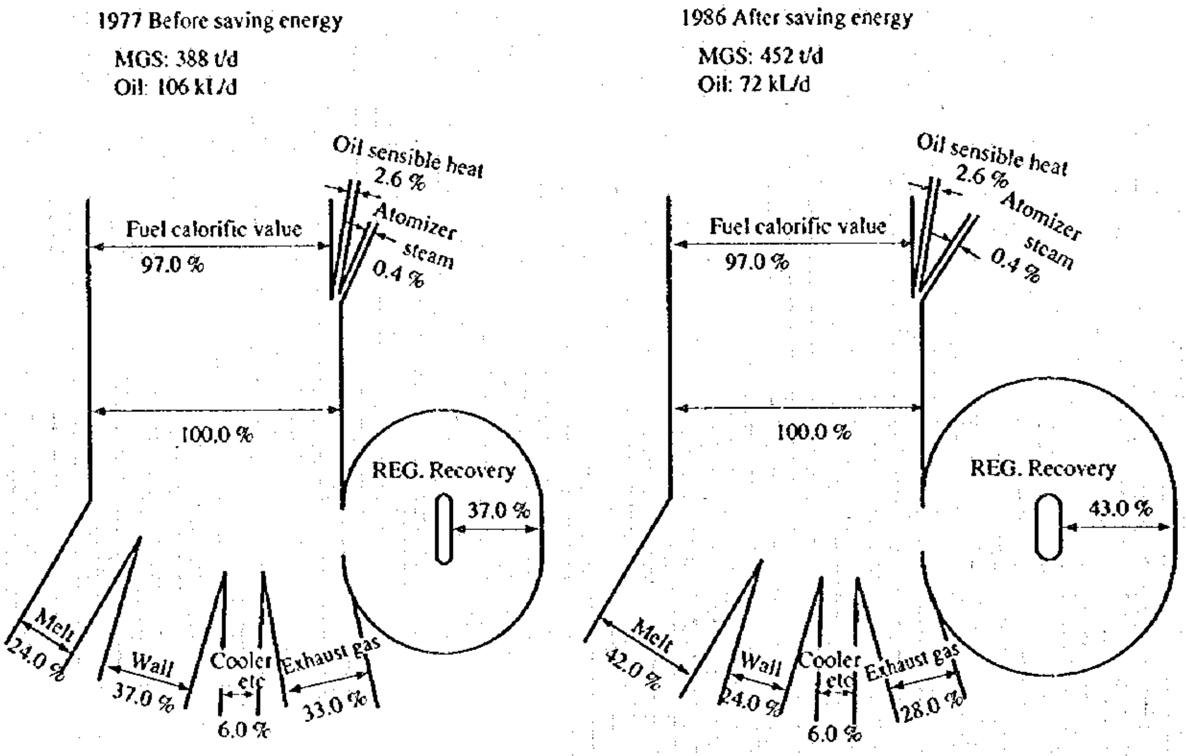
y: Oil consumption (kL/d)

(1) $Q_L = 29.3$ $\eta = 0.640$ $CV = 2{,}592\ m^2$
(2) $Q_L = 23.4$ $\eta = 0.662$ $MA' = 586\ m^2$
(3) $Q_L = 29.3$ $\eta = 0.715$ $CV = 5{,}617\ m^2$

③ Comparison with the result of heat balance

As an example of the excellent factory, Figure 4.22 shows the heat balance for a sheet glass furnace in Japan (in 1977) before the energy conservation measures and that after energy conservation measures (in 1986).

Figure 4.22 Flow of Heat Balance at Japanese Sheet Glass Furnace



Among the heat balances of Ghazvin Glass furnaces, heat output ratio of the normally-running No. 2 furnace based on the measured data is very similar to the heat balance provided before energy conservation measures were taken in Japan. Therefore, the above-mentioned comparison in Japan is just applicable.

In this section, the difference from the Japanese excellent plant was analyzed based on the comparison of the data in this section with the heat balance data.

Table 4.33 Comparison with Heat Balance Data

		Ghazvin Glass						Excellent Factory (Japan)			Remarks
		Heat Balance					Formula(1)	Heat Balance		Formula(2)	
	Unit	1F	2F	3F	4F	Average	1994	FL 1977	FL1986*	FL+F 1989**	
Melting	%	17	20	14	14	16	16	24	42	35	* MGS 452 t/d
Exhaust gas	%	36	33	33	33	34	36	33	28	26	** MGS 365 t/d
Wall etc.	%	47	47	53	53	50	48	43	30	39	
Total	%	100	100	100	100	100	100	100	100	100	

Note (1): $$y=\frac{0.065\times130+\left(0.63+0.37\times\frac{130}{214}\right)\times29.3}{0.640}=\frac{8.45+25.0}{0.640}=52.3\text{ kL/d}$$

Melting: 8.45/52.3 = 16.2 %

Wall: 25.0/52.3 = 47.8 %

Exhaust gas: 100 – (16.2 + 47.8) = 36.0 %

(2): $$y=\frac{0.065\times365+Q_L}{0.715+0.025}=67.2\text{ kL/d}$$

$$=\frac{23.7+Q_L}{0.740}=\frac{23.7+26.0}{0.740}$$

Melting: 23.7/67.2 = 35.3 %

Wall: 26.0/67.2 = 38.7 %

Exhaust gas: 100 – (35.3 + 38.7) = 26.0 %

(2) Energy conservation techniques

a. Furnace wall heat insulation

1) Crown heat insulation: This is the most effective portion. Heat loss is reduced by approximately 20 % by means of one-layer heat insulation and it is reduced to 50 % or less by means of three-layer heat insulation. In this regard, however, high quality silica bricks should be used for the melting tank crown to avoid danger.

2) Side-wall heat insulation: Heat insulation should be provided except for the joints of brick work. To this end, single-piece large blocks matching the height are used so that horizontal joints will not be provided. Also, it is necessary to use the DCL or ENC cut off the casting gate of the electrocast brick. Even in this case, since vertical joints need to be left, heat loss is not so much reduced as calculated.

3) Bottom-block heat insulation: Simple heat insulation should be applied except for the joints of brick work. Even after this measure, heat loss decreases to about 50 %. Actually, heat loss from the joints is large. To cope with this more effectively, it is advisable to take a laminate insulation method, which gives no gap. In this case, however, sub-pavement is required below the pavement.

Also, it is necessary to apply magnetic separation so as to prevent metallic materials from coming in from the raw material batch and cullet.

4) Heat insulation effect: For the current status of Ghazvin Glass furnaces, simple heat insulation is applied to the No. 1 furnace, but no heat insulation is applied to the No. 2 and No. 3 furnaces (No. 4 furnace under periodic cold repair).

If such simple heat insulation as for the No. 1 furnace is applied to all the furnaces, approximately 5 % energy conservation will be possible. If heat insulation as heavy as that for the excellent factory is applied to all furnaces, energy conservation shown in Table 4.42 can be achieved.

b. Increasing the secondary air preheating temperature

1) Making checker brick work as high as possible

To increase the secondary air preheating temperature as much as possible, it is necessary to increase the heat recovery rate in the regenerator.

For this purpose, it is effective to increase the heat transfer surface area of the checker brick. To increase the heat transfer surface area of the checker brick, there are two methods available: one is to make the size of the regenerator larger (i.e. increasing the checker brick height), and the other is to improve the type of checker brick work. For making the regenerator larger, investment may be relatively small for a newly installed regenerator. However, for an existing regenerator, large investment is required. Therefore, every effort should be exerted to make checker work as high as possible in an existing regenerator.

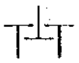
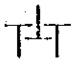
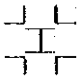
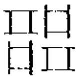
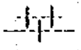
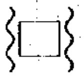
2) Heat transfer surface area by method of checker work

There are several methods available for checker work. The heat transfer surface area varies depending on the brick thickness and size even though the same brickwork method is used.

And regardless of the heat transfer surface area, the difference in thermal conductivity due to the brick material affects the air preheating temperature. However, either basic (magnesia) bricks or electrocast bricks have come to be used in all cases recently; therefore there is no significant difference.

Table 4.34 shows the relationship between the type of checker work and heat transfer surface area.

Table 4.34 Heat Transfer Surface Area of Checker

Name	Pigeon-hole	OBW	OBW	Maerz STV	Inter-weave	Box	Box	Box	Cruci-form	OCTEX -S
Form										
Thickness (mm)	76	75	57	60	44	45	45	40	40	40/27
Measure (mm)	152□	153□	141 × 146	142□	140 × 133	153	170□	140□	140□	140□
Surface area (m^2/m^3)	10.2	11.8	14.3	14.9	16.8	15.1	14.2	16.7	17.3	20.0
Ghazvin Glass	G-4 FI/2	G-2F 3, 4, 5P G-3F G-4 FI/2					G-2F 1, 2P	G-1F	AZS (1681) SEPR	AZS (CS3) T/M

3) Current status of Ghazvin Glass and estimation of the improvement effect

Table 4.34 shows the types of checker brick work for four furnaces of Ghazvin Glass. Table 4.35 shows evaluation of the capability of the regenerator itself.

Table 4.35 Load of Exhaust Gas on Surface of Checker

	No. 1 Furnace	No. 2 Furnace	No. 3 Furnace	No. 4 Furnace
Exhaust gas flow⁽¹⁾ (m^3/h)	25,463	23,380	29,406	46,191
Regenerator W × L (mm)	2,246 × 11,092	2,800 × 13,300	2,800 × 18,420	4,000 × 19,000
Checker height (mm)	4,730	4,350	4,350	4,350
Checker volume (m^3)	118	162	224	331
Surface area (m^2/m^3) and (Ratio)	16.7 (1.52)	12.76 (1.16)	11.8 (1.07)	11.0 (1.00)
Load ($m^3/m^3 \cdot h$)	216	144	131	140
Surface area Load ($m^3/m^2 \cdot h$)	12.9	11.3	11.1	12.7

Note (1): cf: Table 4.11.

As you can see from this table, the checker brick in the No. 1 furnace is as excellent and competitive as that with the Japanese excellent factory. However, since the regenerator was originally small, the load per heat transfer surface area is not so different from those of the other furnaces. For reference, the load per heat transfer surface area in the excellent factory is 4 to 7 m^3/m^2h, which is a half or less than the load in the Ghazvin factory.

If the same checker work as that in No. 1 furnace is used and the effective checker height is 5.4 m (i.e. the current regenerator top is maintained but the rider arch is lowered), approximately 5 % energy conservation can be expected for No. 2, No. 3, and No. 4 furnaces.

c. Reduction in the excess air volume for combustion

The next largest energy conservation factor is reduction of the excess air volume for combustion. Since the average O_2 content above the checker brick in the regenerator measured in the No. 2 furnace is 4.18 %, approximately 25 % excess air is supposed to exist. In the Japanese excellent factory, excess air is approximately 10 %.

For reduction in excess air, approximately 15 % should be reduced by maintaining stable operation and enhancing combustion control even without major modification such as dividing the regenerator for each port.

Table 4.42 shows the possible energy conservation effect resulting from the above energy conservation efforts.

This measure may be applicable to the furnaces other than the No. 2 furnace; therefore exhaust gas should be analyzed periodically to enhance control.

d. Other energy conservation techniques

What we noticed are that openings such as the peep hole on the furnace wall are not sealed, a large volume of cool air comes in from the area around the burner tile, and the man cooling blower under the port is too strong and continuously running. If these many minor points are improved and maintenance and control for furnace wall sealing are enhanced, at least 1 % energy conservation can be achieved.

(3) Relation between melting load and energy conservation

The melting load is the molten glass volume per unit area in the melting chamber. As the melting load is higher, energy per molten volume is smaller, thus leading to energy conservation.

The melting load varies depending on the quality required for the product as well as on the raw material and melting technique.

a. Current status of the melting load

Table 4.36 shows the melting load of each furnace at Ghazvin Glass in normal operation and the recent actual result revealed in this study, compared with the modern technology.

Table 4.36 Comparison in Melting Capacity and Actual Data

	No. 1 Furnace	No. 2 Furnace		No. 3 Furnace	No. 4 Furnace
Glass product	Figured	Figured and Sheet		Sheet	Sheet
Standard MGS by modern technology (t/d)	143	185	129	223	359
Normal data (t/d)	95	110	90	150	230
Latest data (t/d)	101	121		109	168

As you can see from this table, the No. 1 and No. 2 furnaces surpass the normal level but the No. 3 and No. 4 furnaces are largely below that level. If it is the symptom of the equipment at the last stage, furnace maintenance is regarded as a problem. These furnaces are much inferior to those in the excellent factory even without this point.

b. Possibility of improving the melting load

What determines the current melting capacity (i.e. melting load) is not the furnace's melting capability but the machine's "pull" capability. In other words, the furnace temperature is 1,500 °C as the maximum and has an allowance (up to 1,580 °C possible). In case of figured glass, for increasing the forming machine's pull capability, 50 % speedup can be achieved through slight modification of the roll. Therefore, for No. 1 and No. 2 furnaces, full-capacity operation is possible.

On the other hand, for the Colburn machine used to manufacture ordinary sheet glass, an approximately 20 % speedup may be achieved through step-by-step efforts. Although the No. 3 and No. 4 furnaces do not reach the full capacity, the melting capacity can be increased to 200 tons/day and 300 tons/day, respectively.

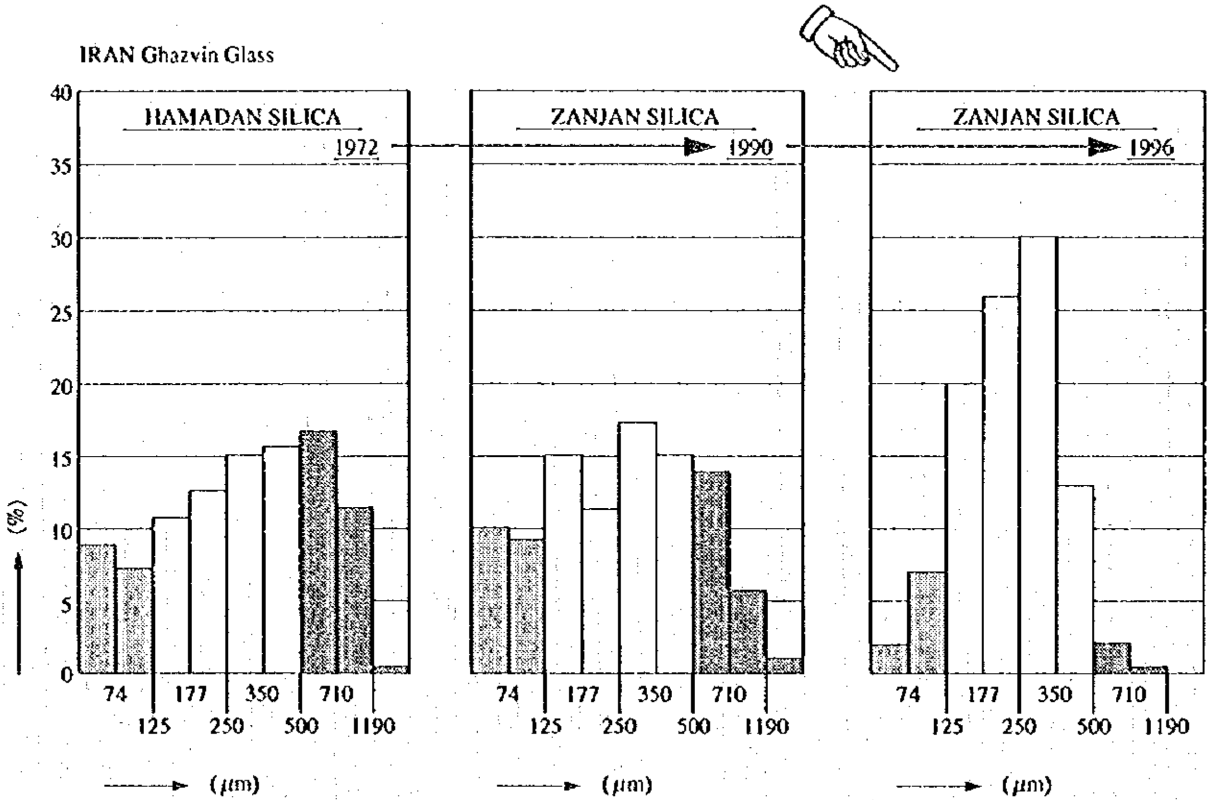
For the float furnace (being planned), the pull capacity matching the furnace's melting capability is possible. Hence improvement of the melting load leads to improvement of the melting capability.

c. Consideration for improving the melting capability

If the furnace design is appropriate and operation and maintenance are properly controlled, the melting capability may as well be said to be influenced by the raw material.

Ghazvin Glass traditionally had used silica sand obtained by crushing quartzite. Therefore, silica sand with proper grain size distribution could be obtained, and in an actual case, the melting capability was largely reduced. Therefore, the current grain size distribution of silica sand was studied, and is shown in Figure 4.23.

Figure 4.23 Grain Size Distribution of Silica Sand

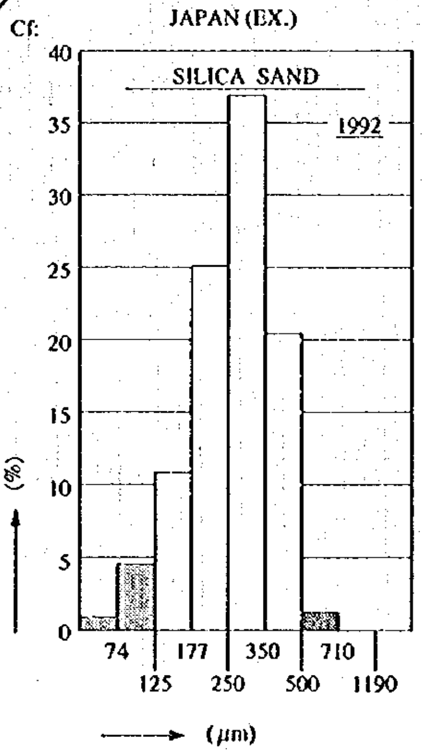


Hearing Data

16 mesh < →	0.01%	← 991μ < →	0.0 %
16 ~ 30	3.2	991 ~ 456	3.3
30 ~ 60	41.9	456 ~ 246	43.6
60 ~ 120	43.3	246 ~ 116	45.1
120 ~ 170	4.7	116 ~ 88	4.9
170 >	3.0	88 >	3.1
Total	96.1		100.0

Modified Data

μm	(%)
1,190μ<	0.0
1,190 ~ 710	0.2
710 ~ 500	1.8
500 ~ 350	13.0
350 ~ 250	30.0
250 ~ 177	26.0
177 ~ 125	20.0
125 ~ 74	6.9
74 >	2.1
Total	100.0



As you can see from this figure, the current status has not reached the excellent factory level, but grain size distribution of silica sand has been improved. Therefore, a large reduction of the melting capability may not be expected.

Then, to study disparities in each raw material composition and the mixing control status, the disparity in product composition was studied, and it is shown in Tables 4.37 to 4.40.

Table 4.37 Glass Composition – 1

Date	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
The latest 20 samples (No. 1 Plant)	70.94	1.27	0.109	7.55	4.39	14.80	0.18
	71.01	1.32	0.115	7.30	4.24	15.05	0.18
	71.39	1.32	0.110	7.36	4.38	14.80	0.18
	70.94	1.34	0.108	7.40	4.40	15.05	0.18
	71.08	1.32	0.110	7.39	4.31	15.05	0.18
	71.16	1.31	0.105	7.55	4.05	15.05	0.18
	70.70	1.26	0.095	7.25	4.29	14.99	0.18
	71.00	1.35	0.110	7.48	4.37	14.97	0.18
	70.87	1.38	0.108	7.57	4.65	14.72	0.18
	70.88	1.20	0.128	7.53	4.22	15.31	0.18
	71.19	1.29	0.126	7.65	4.37	14.70	0.18
	70.67	1.39	0.112	7.58	4.55	15.05	0.18
	70.60	1.28	0.109	7.60	4.51	15.22	0.18
	70.72	1.40	0.113	7.62	4.30	15.14	0.18
	70.73	1.28	0.101	7.58	4.41	15.22	0.18
	71.38	1.27	0.112	7.27	4.33	14.96	0.18
	70.63	1.21	0.100	7.41	4.54	15.41	0.20
	71.09	1.14	0.111	7.51	4.31	15.15	0.20
	70.89	1.15	0.112	7.61	4.43	15.46	0.20
	71.32	1.36	0.105	7.67	3.98	15.22	0.21
$\bar{x}$	70.97	1.29	0.110	7.49	4.35	15.06	0.184
σ	0.23	0.069	0.007	0.128	0.154	0.206	0.009

Table 4.38 Glass Composition – 2

Date	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
The latest 20 samples (No. 2 Plant)	71.71	1.38	0.100	6.96	4.25	14.88	0.18
	71.81	1.37	0.100	7.02	4.01	15.05	0.18
	71.70	1.37	0.111	7.31	4.26	14.66	0.18
	71.84	1.40	0.110	6.99	4.15	14.79	0.18
	71.76	1.41	0.113	6.97	4.28	14.80	0.18
	71.89	1.39	0.110	7.11	4.03	14.79	0.18
	71.71	1.39	0.111	7.13	4.24	14.73	0.18
	71.75	1.39	0.110	7.08	4.23	14.77	0.18
	71.32	1.40	0.116	7.36	4.19	14.99	0.18
	71.31	1.34	0.108	7.26	4.23	15.05	0.21
	71.86	1.33	0.108	7.03	4.30	14.70	0.18
	71.20	1.38	0.108	7.41	4.27	15.05	0.18
	71.78	1.46	0.093	7.11	4.35	14.53	0.18
	71.32	1.34	0.096	7.31	4.30	14.96	0.18
	71.21	1.40	0.097	7.37	4.30	14.96	0.18
	71.50	1.36	0.101	6.82	4.31	15.22	0.18
	71.11	1.34	0.096	6.97	4.38	15.41	0.20
	71.58	1.36	0.098	7.04	4.08	15.15	0.20
	71.34	1.36	0.096	7.21	4.25	15.20	0.20
	71.75	1.46	0.107	7.20	4.19	14.96	0.21
x	71.58	1.38	0.104	7.13	4.23	14.92	0.186
σ	0.25	0.034	0.006	0.16	0.096	0.21	0.011

Table 4.39 Glass Composition – 3

Date	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
The latest 20 samples (No. 3 Plant)	71.69	1.39	0.150	7.05	4.03	15.05	0.18
	71.71	1.41	0.151	7.03	4.23	14.79	0.18
	71.62	1.40	0.156	7.23	4.23	14.66	0.18
	71.78	1.41	0.149	7.03	4.16	14.79	0.18
	71.62	1.40	0.170	7.11	4.39	14.63	0.18
	71.84	1.42	0.151	7.02	4.10	14.79	0.18
	71.40	1.40	0.146	7.07	4.32	14.99	0.18
	71.59	1.40	0.150	7.08	4.32	14.80	0.18
	71.69	1.40	0.152	7.07	4.23	14.77	0.18
	71.62	1.37	0.149	7.17	4.20	14.79	0.21
	71.47	1.39	0.160	7.00	4.34	14.96	0.18
	71.30	1.39	0.146	7.43	4.02	15.05	0.18
	71.50	1.35	0.158	7.35	4.27	14.70	0.18
	71.73	1.35	0.145	7.03	4.28	14.79	0.18
	71.34	1.46	0.154	7.21	4.25	14.88	0.18
	71.38	1.39	0.153	7.23	4.25	14.92	0.18
	71.88	1.36	0.147	6.84	4.40	14.70	0.18
	71.45	1.36	0.143	6.84	4.17	15.34	0.20
	71.46	1.32	0.144	6.98	4.20	15.20	0.24
	71.83	1.46	0.157	7.07	4.15	14.96	0.21
x	71.60	1.39	0.151	7.07	4.23	14.87	0.187
σ	0.17	0.033	0.006	0.14	0.10	0.177	0.015

Table 4.40 Glass Composition – 4

Date	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
The latest 20 samples (No. 4 Plant)	71.92	1.39	0.101	6.78	4.27	14.80	0.18
	71.87	1.49	0.099	7.10	4.28	14.53	0.18
	71.97	1.38	0.102	6.89	4.16	14.53	0.18
	71.91	1.38	0.109	7.07	4.20	14.53	0.18
	71.95	1.36	0.098	7.24	3.86	14.55	0.18
	72.04	1.41	0.121	6.83	4.27	14.64	0.18
	72.07	1.35	0.121	7.09	4.05	14.53	0.18
	71.64	1.40	0.112	7.06	4.21	14.88	0.18
	71.46	1.47	0.128	7.27	4.49	14.46	0.18
	72.07	1.40	0.112	6.97	4.19	14.50	0.18
	72.17	1.38	0.090	6.91	4.44	14.38	0.18
	72.10	1.32	0.100	6.76	4.30	14.53	0.18
	72.14	1.42	0.101	7.05	4.07	14.53	0.18
	72.04	1.51	0.102	6.90	4.13	14.64	0.18
	71.62	1.36	0.101	7.15	4.07	15.05	0.18
	71.88	1.39	0.106	6.99	4.17	14.80	0.18
	71.86	1.39	0.097	7.12	4.19	14.66	0.18
	71.70	1.40	0.107	6.98	4.08	15.05	0.18
	72.16	1.39	0.111	7.01	4.12	14.53	0.18
	71.44	1.39	0.109	7.19	4.30	14.90	0.18
x	71.90	1.40	0.106	7.03	4.19	14.65	0.18
σ	0.22	0.044	0.009	0.13	0.14	0.19	0

The data in this table are values analyzed every three days, where the disparity is 5 to 10 times larger than the excellent factory, which may be due to the material control, though also the number of sample and analytical precision seem to pose problems.

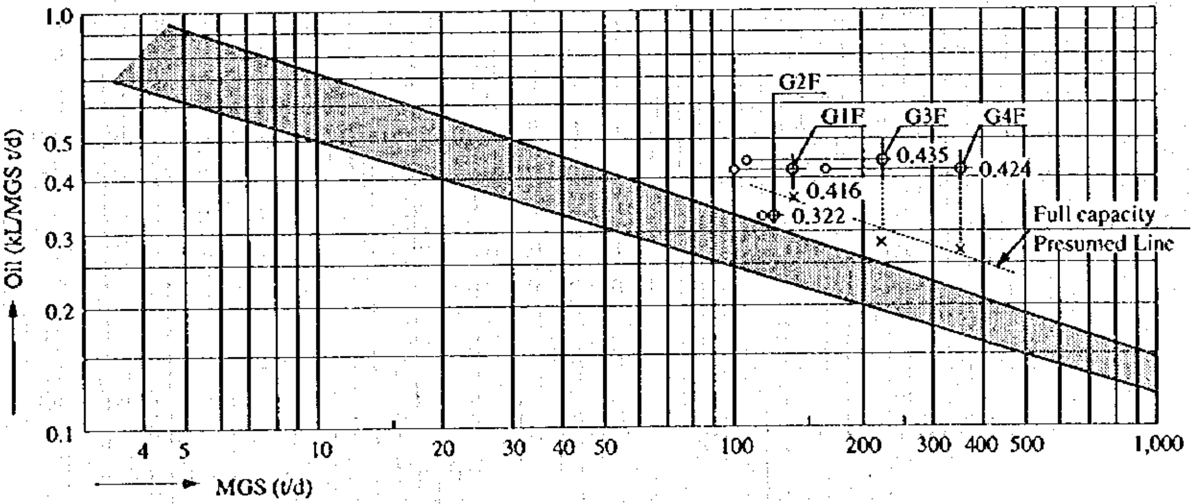
(4) Relation between scale merit and energy conservaion

As the size of a furnace is larger, the molten glass amount per unit area increases. Increasing of the molten amount reduces the energy consumption per molten amount, leading to energy conservation.

A large amount of investment is required for making a furnace larger, that is, integrating small furnaces into larger ones, which may seem difficult. However, as shown in experiences of Japanese glass factories, along with the introduction of the epoch-making forming method called "Floating Process", the number of furnaces which can produce the same quantity of product decreased from 29 to 17 during the period of ten years from 1973. In other words, the molten amount of average 250 t/d per furnace increased to not less than 400 t/d. This leads to a 15 % decrease in energy intensity.

As a factor of melting furnace size, standard molten amount is plotted on the horizontal axis, while heavy oil intensity per molten amount is plotted on the vertical axis. As a result, an approximately straight line relationship between these can be obtained on the logarithmic scale. This relationship is shown in Figure 4.24, where the current situation of Ghazvin Glass is plotted.

Figure 4.24 Relationship between Intensity of Heavy Oil and Size of Melting Furnace in Sheet Glass



Note:	Table 4.6		Table 4.36	Figure 4.16, 4.17, 4.18
No.1 F	Rev Oil 42.0 kL/d	MGS 101 t/d	Capacity 143 t/d	max Temperature 1,508 °C
No.2 F	Rev Oil 39.0 kL/d	MGS 121 t/d	Capacity 129 t/d	1,505 °C
No.3 F	Rev Oil 47.6 kL/d	MGS 109 t/d	Capacity 223 t/d	1,490 °C
No.4 F	Rev Oil 71.2 kL/d	MGS 168 t/d	Capacity 359 t/d	1,490 °C

"X" mark: When melting was performed with a full capacity of the melting furnace without any regard to the limitation due to the speed of the forming machine.

The full capacity presumed line in this figure is an imaginary line based on the presumption of full-capacity operation. This was calculated based on the assumption that heavy oil consumption per t/d MGS is 0.065 kL/d, and heavy oil consumption for every 10 °C of melting temperature changes by 2 % (with the reference temperature as 1,580 °C).

Presently in I. R. Iran, they are behind other countries in switching to the floating process, and to our understanding the first furnace of this type is currently being planned.

In the example of Ghazvin Glass, if the new float process furnace (500 tons/day) being planned is installed, the No. 4 furnace can be modified into a two-machine figured glass plant. Production can be increased by 60 % even though the No. 1, No. 2, and No. 3 furnaces are out of service; therefore a large amount of energy conservation can be expected.

(5) Relation between improvement of yield and energy conservation

Energy conservation is finally evaluated in terms of energy intensity per product. Therefore, improvement of the yield results in energy conservation.

Yield is, in a narrow sense, the product volume against the pull-up quantity, while in a broad sense, it includes the operation rate, loss caused by accidents, etc. In this report, yield refers to that in a broad sense.

Figure 4.6 shows the energy intensity (including electric power) per product based on annual data. It can be found that dispersion among fiscal years is very large.

The cause for this dispersion remains unknown even though the year of periodic cold repair is excluded. Perhaps, it may be due to unstable operation and a wide dispersion in yield unevenness.

Unfortunately, since annual data does not provide data of the molten glass (MG), the yield is unknown. On the other hand, data of the average values in the last one month shown in Table 4.6 indicates that the average of those for four furnaces is 68.7 %, which is fairly good. Individually, the furnace producing figured glass is very good, while the furnace producing ordinary sheet glass, particularly No. 3 furnace, is bad. Since this yield varies depending on the required quality, comparison with the excellent factory is difficult, but the yield may be improved to at least 75 %.

If the yield is improved to 75 %, it corresponds to 5.8 % energy conservation according to our calculation.

Table 4.6, however, reveals that much cullet in stock is used in addition to the cullet generated. It means that energy conservation as a result of improving the yield has been achieved already. Therefore, improving the yield to 75 % will not always lead to energy conservation if this data is used as a basis.

(6) Power receiving/distributing facility

a. Power receiving/distributing facility

Via four transformers, 400 V is supplied from two 20 kV lines to four lines and the raw material plant. On the other hand, 400 V power generated by eleven diesel power generators is supplied to the most important equipment in the factory.

b. Measurement result

Details on measurement are as follows. For the No. 4 plant, measurement was impossible because it was out of service.

1) Power received by the factory
2) Power generated by diesel generators
3) Power generated by diesel generators and purchased power for No. 1 plant
4) Power generated by diesel generators and purchased power for No. 2 plant
5) Power generated by diesel generators and purchased power for No. 3 plant
6) Power consumed by the No. 1 and No. 4 air compressors
7) City power's voltage/current fluctuation

Table 4.41 shows the measurement result.

Table 4.41 Measurement Result of Consumption

1996-7-16, 17

Measurement Items	Line	Power Consumption		Volt	Rating	Remark
		Power (kW)	Cosφ (%)	(V)	Power (kW)	
Source						
A line	DG	340	81	418	848 + 736	1 × 736 kW operating
B line	DG	384	85	421	736 × 4	1 × 736 kW operating
DG total		724	83		4,528	
City power	CP1	559	80	382		
	CP2	249	84	392		
	CP4	238	89.4	392		CP3: Non operating
CP total		1,046	83.1		2,500	Contract
Source Total		1,770	83.0		7,020	
Load						
Furnace No. 1	DG	128	75	406	205	
Furnace No. 1	CP	221	78	376		
Furnace No. 2	DG	139	75	407	185	
Furnace No. 2	CP	138	85	384		
Compressor #1	DG	129	77	411	150	
Compressor #4	CP	123	81	390	150	
Furnace No. 3	DG	223	89	401		
Furnace No. 3	DG	8.3	76	403	11	(Fan No. 7 including Upper)
Furnace No. 3	CP	170	83	377		
Furnace No. 3	CP	7.7	77	374	11	(Fan No. 6 including Upper)
Furnace No. 4	DG			454		stop
Furnace No. 4	CP			471		
Raw materials	CP about 500 kW			380		
Total		DG: 619 CP: 1,152				
Factory Total		1,771				

Note: GP: Diesel generator power (most important), CP: City power (important).

c. Discussion on the measurement result

1) Power used by the factory

For electric energy used in 1995, power generated (DG) is 10,562 MWh and power purchased is 11,212 MWh (totally 21,776 MWh). Therefore, the ratio between both is close to 1:1. When measurement was conducted, the No. 4 plant was out of service; therefore power generated (DG) was 619 kW and power purchased was 1,162 kW (totally 1,771 kW), which are small. Since power used by the No. 4 plant was approximately 1,000 kW according to the past record, these measured values are reasonable.

Factory staff are not allowed to check the purchased power meter for transactions, and the used amount is checked irregularly during one to six months. To measure the used amount, it is necessary to install the watt-hour meter to clarify the power purchased every month.

Although power contracted to be supplied by purchased power is determined to be 2,500 kW (Demand: 2,250 kW), which corresponds to the total used amount. Therefore, this contract is too large.

Possibly, purchased power should be changed into the high-tension power receiving mode with fewer power failures or the contracted amount of city power should be reduced. Against high power charge (1.6 times) during peak hours, in-house generated power should be positively used for demand control.

2) Increasing the output from the private power generating palnt (DG)

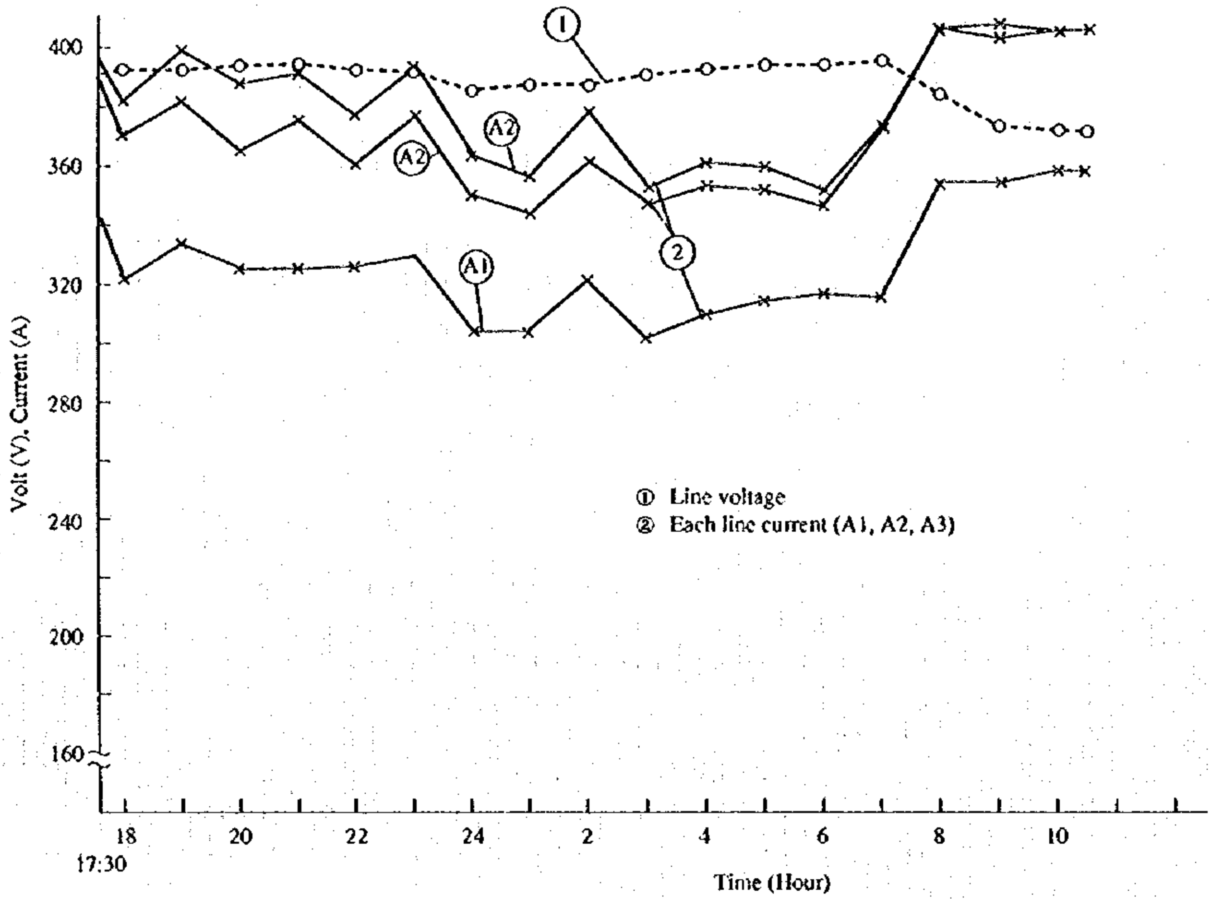
Since this factory is at a high location over the sea level, high-load operation of the DG is difficult. Normally, the diesel engine reduces its output when air density is lower. The degree of output reduction is said to be approximately 10 % when the altitude is 1,300 m. To cope with this problem, ventilation of room should be maintained, the air temperature should be low, and air should be supplied by a supercharger as required. For this improvement, consultation with the manufacturer is recommended. As a result, power generated by the DG can be increased and power generation can be made more efficient.

Additionally, heat held by the engine cooling water should be utilized efficiently.

3) Power supply three-phase unbalance

On the panel in the DG room, voltage and current in the purchased power circuit were measured and recorded. Figure 4.25 shows the result. Also, the single-phase load in the factory was checked.

Figure 4.25 Voltage and Current of City Power



As a result, it was found that current is unbalanced and wire current variation tendency is identical although the supply voltage is well-balanced. The cause of this unbalance may be load connection in the factory.

For example, the electrode load (25 kVA × 2) for the process No. 2 furnace is considered to be one of the major causes and other single-phase loads are also considered. Therefore, for a capacity with a large electrode load, connection should be changed so that three phases will be balanced or three phases should be balanced by using a special transformer.

The present electrode load was only connected with the purchased power used for process No. 2. If the load is also used for the process No. 3 and No. 4 DG circuits, unbalance among three phases may possibly occur.

Consequently, voltage unbalance in the load circuit will result, affecting motor performance. Current unbalance on the motor may result in torque reduction and overheating, and sometimes, vibration, and noise. Thus, it is important to balance three phases.

4) Measures on air compressors

Air compressors in use were water-cooling reciprocating type (150 kW) and two of four compressors were in service. The air pressure was 5.2 kg/cm^2 (G) and the compressors were being used for combustion and machine operation.

As a result of study, the following measures are required:

First, air leakage was found on the reduction valve fixing part at the site. This problem may exist elsewhere; therefore it is necessary to check for air leakage on a regular basis to stop it at an earlier stage. Second, since the cooling water inlet temperature is as high as 45 °C, it is necessary to reduce the cooling water temperature as much as possible.

As an effect, power used is reduced by 2 to 3 % if the cooling water temperature is 5 °C lower. Actions against air leakage normally reduces power used by 6 to 10 % although this reduction depends on the degree of air leakage. Therefore, totally 10 % reduction can be expected and approximately 216,720 kWh (= 252 kW × 0.1 × 8,600 h/y) can be reduced annually.

Note: Cooling water is mainly used to cool the cylinder of DG.

(7) Conclusion

Energy conservation measures are divided into three phases. Table 4.42 summarizes the measures, expected effects, presumed investment, etc.

This table also takes into account the relationship with the actual periodic cold repair time. If start of the float furnace indicated in the third phase is earlier, large correction is required.

Table 4.42 Summary of Proposals

(Japanese Yen base)

Item	Expected Saving								
	Fuel			Electricity			Total Million yen/y	Investment Million yen	Payback Period Year
	kL/y	Million yen/y	%	MWh/y	Million yen/y	%			
Figured machine speed increase 50 %		321.0*7		–			321.0	100	0.3
Excess air 25 % to15 %	2,863*1	48.7	3.8*9	–			48.7	10	0.2
Sheet machine speed increase 20 %		1,123.4*8		–			1,123.4	10	0.01
No. 2, 3 & 4 furnace light insulation	3,955*2	67.2	5.2*10	–			67.2	50	0.7
No. 1, 2, 3 & 4 furnace heavy insulation	8,136*3	138.3	10.8*11	–			138.3	600	4.3
Production yield improvement	4,728*4	80.4	6.3				80.4	0	0
Checker height increase	7,910*5	134.5	10.5*12	–			134.5	200	1.5
Compressed air leakage stop	–			217	2.2	0.9*14	2.2	0	0
Float plant construction				–					(16.1)
No. 4 furnace improvement	(62,196)*6	(1,057.3)	(82.5)*13				(1,057.3)		In the future
No. 1, 2 & 3 machine stop									
Total	27,592	1,913.5	36.6	217	2.2	0.9	1,915.7	970	0.5

(Iran Rial base)

Item	Expected Saving								
	Fuel			Electricity			Total Million Rial/y	Investment Million Rial	Payback Period Year
	F.oil kL/y	Million Rial/y	%	MWh/y	Million Rial/y	%			
Figured machine speed increase 50 %		5,618*7		–			5,618	1,750	0.3
Excess air 25 % to15 %	2,863*1	215	3.8*9	–			215	175	0.8
Sheet machine speed increase 20 %		19,660*8		–			19,660	175	0.01
No. 2, 3 & 4 furnace light insulation	3,955*2	297	5.2*10	–			297	875	2.9
No. 1, 2, 3 & 4 furnace heavy insulation	(8,136)*1	(610)	(10.8)*11	–			(610)	(10,500)	(17.2)
Production yield improvement	4,728*4	355	6.3				355	0	0
Checker height increase	7,910*5	593	10.5*12	–			593	3,500	5.9
Compressed air leakage stop	–			217	2.2	0.9*14	22	0	0
Float plant construction				–					(63.8)
No. 4 furnace improvement	(62,196)*6	(4,665)	(82.5)*13				(4,665)	(297,500)	In the future
No. 1, 2 & 3 machine stop									
Total	19,456	26,738	25.8	217	2.2	0.9	26,760	6,475	0.2

Remarks: The items to be implemented in the future are not included in the total column.

*1 51.6 × 4 × 365 × 0.038 = 2,863 kL/y
*2 51.6 × 3 × 365 × 0.07 = 3,955 kL/y
*3 51.6 × 4 × 365 × 0.108 = 8,136 kL/y
*4 51.4 × 4 × 365 × (0.75 - 0.687) = 4,728 kL/y
*5 51.6 × 4 × 365 × 0.105 = 7,910 kL/y
*6 (500 + 300) × (0.397 – 0.184) × 365 = 62,196 kL/y
*7 Merit by production increase: ((143 – 101) + (143 – 121)) × 0.687 × 365 × 20,000 = 321.0 Million yen/y
*8 Merit by production increase: ((200 – 109) + (300 – 167)) × 0.687 × 365 × 20,000 = 1,123.4 Million yen/y
*9 2,863 / 75,390 × 100 = 3.8 %
*10 3,955 / 75,390 × 100 = 5.2 %
*11 8,136 / 75,390 × 100 = 10.8 %
*12 7,910 / 75,390 × 100 = 10.5 %
*13 62,196 / 75,390 × 100 = 82.5 %
*14 217 / 23,000 × 100 = 0.9 %

Energy price in Japan:
Fuel oil price: 17,000 yen/kL
Electricity price: 10 yen/kWh
Energy price on Iran Rial base:
Fuel oil: 75 Rial/L
Electricity: 100 Rial/kWh
Exchange rate: 1,750 Rial = 1 US Dollar = 100 Japanese Yen
Calorific value of fuel: Oil: 9,000 kcal/kL

Investment cost is based on that in Japan.

5. RESULTS OF THE STUDY ON THE TEXTILE INDUSTRY

5. RESULTS OF THE STUDY ON THE TEXTILE INDUSTRY

5.1 Results of the Study at Polyacryl Iran Company

5.1.1 Outline of the Plant

(1) Plant name

Polyacryl Iran Company

(2) Address

45 km Esfahan Mobarake Rd.

(3) Number of employees

2,924

(4) Major products

Polyester fiber, polyester filament, polyster tops, acrylic fiber and acrylic tops

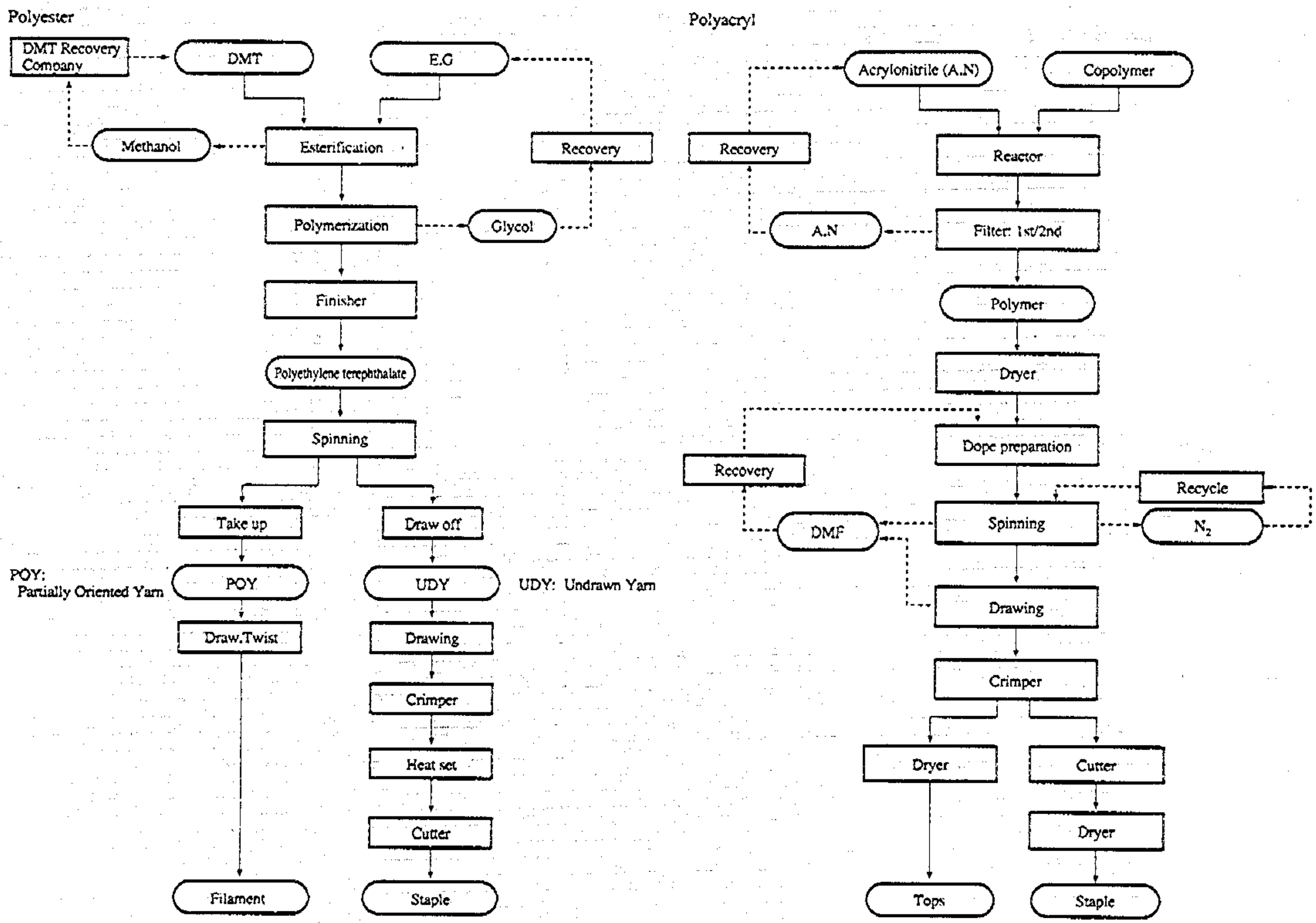
(5) Production capacity

Polyester fiber	30,800	54,880 t/y
Polyester filament	21,880	
Polyester tops	2,200	
Acrylic fiber	23,500	40,020 t/y
Acrylic tops	16,520	

(6) Production process

Figure 5.1.1 shows the production flow of polyester and acrylic products.

Figure 5.1.1 Process Flow



This polyester and acrylic product manufacturing plant introduced the world's newest and highest-level technologies such as continuous polymerization and the POY system in the polyester spinning process and started operation in 1978. At the point of this study, approximately 20 years later, operation with the world's highest-level facilities is still maintained.

Acrylonitrile (AN) as the raw material for acrylic fiber is 100 % imported, while DMT and EG as raw materials for polyester are those domestically produced.

Methanol extracted from the polyester polymerization process is returned to another company in the factory premises and supplied again as DMT.

The polyester and acrylic product manufacturing processes are outlined below.

a. Polyester

1) Polymerization process

This process consists of the first stage that produces terephthalate (BHET) from refined dimethyl-terephthalate (DMT) and ethylene-glycol (EG) and the second stage that produces polymer by removing EG.

BHET is produced while methanol is being distilled. After all of methanol is distilled, the polymerization catalyst and stabilizer are added to BHET and heating at vacuum of 2 Torr is applied. As a result, EG is discharged and condensation polymerization is performed, producing polyethylene-terephthalate (PET).

2) Spinning process

Molten polymer of a temperature of approximately 280 °C is fed by the extruder to the spinning head in the spinning process directly connected to the polymerization process.

Molten polymer is pushed out of the fine holes of the spinneret. The molten polymer is then uniformly cooled and hardened with cool air at 21 °C by the cooling cylinder, named the quencher. The number of fine holes of the spinneret is 20 to 34 for filament and 1,000 to 2,000 for staple.

3) Drawing and post-processing processes

The yarn wisp drawn and set by the cooling cylinder is wound onto a cheese (40 kg/piece) in a semi-drawn state. Then, the yarn is drawn and false twisted as the filament yarn (POY system).

On the other hand, for staple, the cooled and set yarn wisps are bundled together into a tow shape and crimped by the winding and crimping machine. Then it is subjected to heat treatment and is cut into the specified length as the staple fiber.

4) Characteristics in the use of energy

① Polymerization process

Steam (10 kg/cm^2 (G); 175 °C) is used to heat the reactor jacket and drive the ejector.

The heat medium (320 °C, 4 kg/cm^2 (G)) is used as liquid-phase heating for the No.1 to No.3 reactor jackets.

② Spinning process

To heat the spinning head (290 °C), the heat medium in gaseous phase is used. Cool air for quenching is temperature-controlled by the chiller water at 16 °C throughout the seasons.

③ Post-processing process

For heating during drawing and false twisting, electric heat is used as the heating source.
Steam is used for thermal elongation, washing, and drying of the staple.

④ DMT recovery equipment

Methanol extracted from the first reactor for polymerization (ester replacement) is fed to the DMT recovery equipment of another company in the same premises, and then supplied again as DMT.

Energy used here is placed in a separate account.

b. Polyacryl

1) Polymerization process

Acrylonitryle (AN) as the major raw material for acryl fibers is blended with copolymer, forming a monomer. This monomer is continuously supplied to the polymerization reactor along with the catalyst separately adjusted and water as the polymerization medium.

In the reactor, the constant temperature and pH are maintained by stirring. Slurry generated with the progress of polymerization is continuously taken out. After filtering by No.1 and No.2 filters, washing and dehydrating, the slurry is fed out of the extruder. The polymer is then dried by the hot air dryer, and then stored in the polymer storage tank.

The filtrate containing the unreacted monomer, coming out of the filtering and rinsing processes, is recycled by the monomer recovery equipment.

2) Stock solution process

In this process polymer is dissolved in solvent and adjusted to uniformly concentrated solution as the original liquid for spinning. DMF is used as the organic solvent.

In the stock solution process, the polymer and solvent are measured continuously and supplied to the melter.
In this process degassing is performed, and non-dissolved substances and foreign matters are removed. Then the stock solution is fed to the spinning process.

3) Spinning process

Polymer solution pressurized by the polymer feeding booster pump is supplied to each spinning head by the metering pump.

In the spinning spool, the spinning atmosphere is kept by the N_2 gas heated to 400 °C as inert gas.

The organic solvent gas is extracted from the end of the spool and fed to the solvent recovery equipment.

Also, the N_2 gas is extracted from the bottom, and is heated again and recycled to the spool after having DMF cooled and extracted by the recycling equipment.

4) Post-processing and finishing processes

Yarn wisps from spinning nozzles are bundled together into a rope and stored in the can. Then, the rope is heated and washed by the drawing machine. After removal of the residual solvent, the rope is drawn, heat-treated, dried, crimped, and then divided into the staple process and top lines.

In the staple line, the staple is cut into a specified size, dried, and then unraveled into staple fibers.

On the other hand, in the top line, the rope is dried and taken up into a drum as the top.

5) Characteristics of energy use

① Polymerization process

The stirring machine's power for the reactor is as large as 380 kW. As the heating source for monomer reaction (60 °C), hot water is supplied to the jacket.

② Stock solution process

Electric power is used to stir for dope adjustment and the transfer, while steam is used as the heating source.

③ Spinning process

Steam and electric heat (500 kW) are available as the heating sources for the N_2 gas of 400 °C to be supplied to the spool. A significantly large amount of electric power is required for cooling to extract the DMF vapor in the N_2 gas and for cooling and transfer of the chiller cooling water.

④ Post-processing and finishing processes

A relatively large amount of steam is used to wash and dry both staple and top.

⑤ Solvent recovery equipment

A large amount of steam is used as the heating and evaporating heat source for recovering the solvent DMF.

(7) History of this plant

This plant was founded by Bank of Industry and Mines in 1974 and started operation in 1978. Bank Shau AT va Madon funds 66 %, Bank Melli Iran funds 26 %, and other banks fund the rest.

The process licensor, Du Pont, offers engineering, while Brown & Root is the constructor.

In 1993, Chemitex and Mitsubishi added two lines of POY, and consequently, polyester production was increased by 30 %.

Presently, further addition of one-line POY is being planned.

Polyester and acrylic fibers are solely produced by this company, which supplies 60 % of domestic consumption. There are two other synthetic fiber factories, which produce Nylon 6.

(8) Plant layout

Figure 5.1.2 shows the layout of this plant.

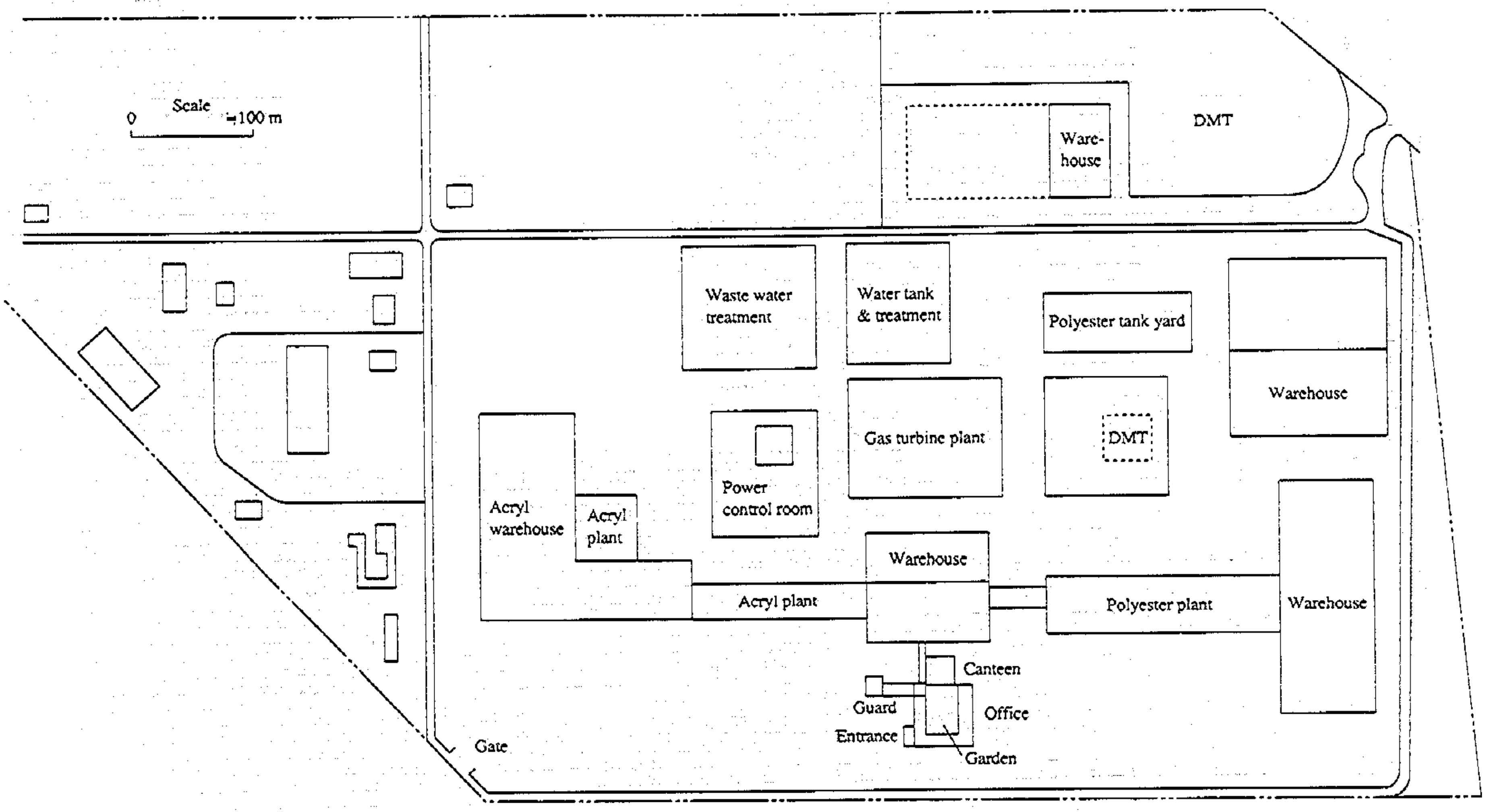
(9) One line diagram

Figure 5.1.3 gives the one line diagram.

(10) Outline of main equipment

Table 5.1.1 outlines the utility and production facilities.

Figure 5.1.2 Plant Layout



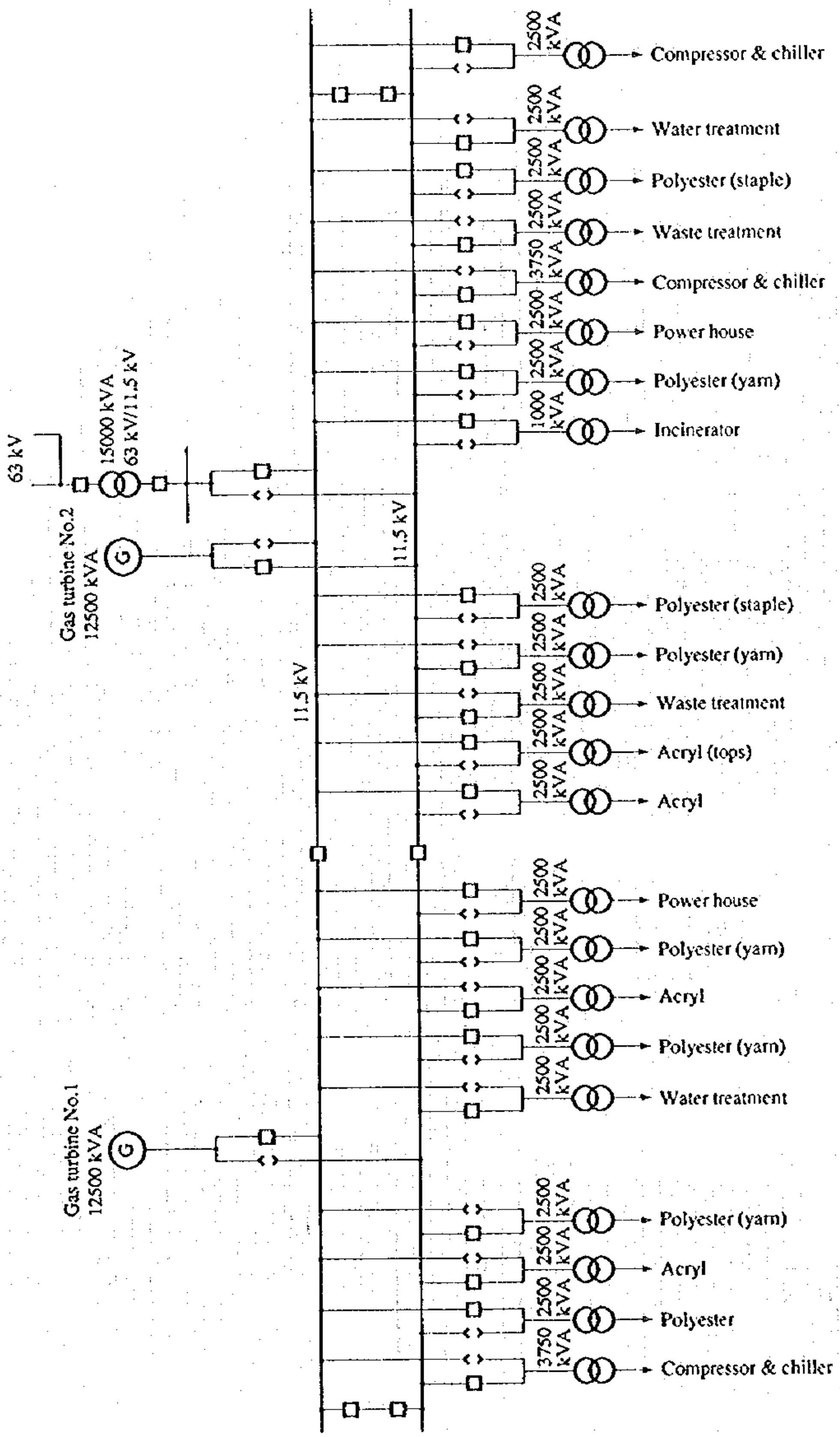


Figure 5.1.3 One Line Diagram

Table 5.1.1 Main Equipment

Factory	Equipment	Number	Specification
Utilities	Gas turbine	2	10 MW
	Waste heat boiler	2	59 t/h × 17 kg/cm^2·220 °C
	Fire tube boiler	1	15 t/h × 15 kg/cm^2
	Water tube boiler	1	60 t/h × 16 kg/cm^2
	Dowtherm vaporizer	4	30 t/h × 230 ~ 240 °C
	Air compressor	3	1,100 kg, 2,500 m^3_N/h centrifugal
		5	125 kg, 1,200 CFM reciprocating
	Nitrogen generator	2	900 m^3_N/h
	Chiller unit	3	900 RT
	Deep well	1	220 m^3/h
	Water treatment	1	Filter + Water softener
	Waste water treatment	1	Active sludge system
Polyester	Productive capacity	1	54,880 t/y (Filament & Staple)
	Dissolution tank	1	750 m^3 for DMT
	Esterification	1	Continuous tray tower
	Polymerization	1	Continuous
	Finisher	1	Horizontal tube bar
	Extruder	2	1 × Filament / 1 × staple
	Spinning unit	5	1 × udy / 4 × POY
	Take up	4	For Filament
	Draw off	1	For staple
	Drawing	1	For staple
	Draw twister	1	For filament
	Crimper	1	For staple
	Recovery equipment	2	1 × EG / 1 × methanol
Acryl	Productive capacity	1	40,020 t/y (Staple & Tops)
	Polymerizer	1	Continuous system 65.3 t/d
	1st filter	1	Drum type vacuum
	2nd filter	1	Drum type vacuum
	Extruder	1	50 kg with dryer
	Crusher	1	
	Dope preparation unit	1	
	Spinnig	5	14 positions
	Draw machine	1	With washings
	Crimper	1	
	Cutter	1	For staple
	Staple dryer	1	For staple
	Tow dryer	1	For tops
	DMF recovery unit	1	
	Inert gas recycle unit	1	N$_2$

(11) Energy prices

Energy prices for the fiscal year 1996 are shown below:

Electric power (purchased):	Demand charge	3,200 Rial/kW
	Energy charge	38 Rial/kWh
	Seasonal charge	7.6 Rial/kWh
	Time on charge	30.4 Rial/kWh
Natural gas	: 23.5 Rial/m^3	

(12) Study period

a. Preliminary study: October 1, 1995

b. Plenary study : August 3 through 7, 1996

(13) Members of the study team

a. JICA team

Leader : Norio Fukushima
Process management technology : Takashige Taniguchi
Heat management technology : Jiro Konishi
Heat management technology : Shiro Honda
Electricity management technology: Kazuo Usui

b. PBO team

Energy conservation : Mr. Mazhari
Micro level energy management: Mr. Mianji
Factory management : Mr. Sajadifar
Instrumentation : Mr. Shayesteh (Preliminary study)
Ministry of Industry : Mr. Parsi (Preliminary study)
Behshahr Industry Co. : Mr. Alavizadeh (Preliminary study)

(14) Interviewees

a. Preliminary study

Mr. Sobhani : Electrical Engineer
Mr. Azimi : Power Supervisor
Mr. Koohi : Electrical Engineer, Power Preparation
Mr. Najafzadeh : Process Engineer, Polyester Plant

b. Plenary study

Mr. Ghazai	Engineering Section Director
Mr. Shikhbahai	Manager of Waste Water Treatment
Mr. Saidi	Engineer of Polyester Section
Mr. Torabian	Operation Engineer Power Plant Section
Mr. Joobandi	Senior Operating Engineer of Polyester Section
Mr. Mardani	Operation Engineer, Pawer Plant Section

5.1.2 Energy Consumption Status

(1) Trends of production amount, energy consumption and energy intensities

a. Production amount

Table 5.1.2 shows the trend of the production amount in 1992 through 1995.

The top production amount is indicated by dividing the sum of polyester and acryl according to the past production ratio.

As compared with the production capacity, the production amount in 1995 is 102 % for polyester and 60 % for acryl.

For the acrylic production amount, production variation occurs due to external factors such as procurement of raw materials.

Table 5.1.2 Production

Name of Product			1992	1993	1994	1995	Note
Polyester	(f + s)	t	43,204	50,210	49,024	54,994	s: staple
	(tops)		597	1,278	1,214	937	f: fiber
	Sub-total		43,801	51,488	50,238	55,931	
Acryl	(s)	t	18,129	17,368	16,158	19,275	
	(tops)		9,353	7,848	6,880	5,307	
	Sub-total		27,482	25,216	23,038	24,582	
Grand total		t	71,283	76,703	73,276	80,513	
Transition			100.0 %	107.6 %	102.8 %	112.9 %	

Note: The production of tops was based on the assumption of the following ratio:

	1992	1993	1994	1995
Production of tops (t)	9,950	9,125	8,094	6,244
Share: polyester	0.06	0.14	0.15	0.15
: acryl	0.94	0.86	0.85	0.85

b. Energy consumption

Table 5.1.3 shows energy consumption in each year of 1992 through 1995.

Table 5.1.3 Energy Consumption

			1992	1993	1994	1995	Note
	Domestic	MWh				118,594	
Electricity	Purchased	MWh				3,446	
	Total	MWh	108,709	122,187	106,912	122,040	
Natural gas		1,000 m^3	46,288	70,612	74,535	83,362	9,200 kcal/m^3
Diesel oil		kL	286	273	200	484	8,616 kcal/L
Steam		t	428,123	413,806	391,019	427,812	
Wellwater		1,000 m^3	2,700	2,700	2,760	2,750	

Consumption of natural gas has sharply increased since 1993 and is still increasing. The reason is the increase in the ratio of in-house power generation using gas turbines.

c. Utility facility power consumption

Table 5.1.4 shows the electric power consumption and ratio in 1995 for each equipment's purpose of use.

Table 5.1.4 Power Consumption Ratio

Item	Consumption (MWh)	Ratio (%)	Remarks
Polyester	34,979	28.66	
Acryl	28,821	23.62	
Subtotal	63,800	52.28	
GT-auxiliary	657	0.54	
Steam boiler	1,251	1.03	
Heat media boiler	748	0.61	
Air-compressor	16,979	13.91	
Nitrogen	377	0.31	
Chiller	9,318	7.64	
Water treatment	7,470	6.12	
Waste water treatment	4,892	4.01	
Subtotal	41,691	34.16	
Grand total	105,492	86.44	
Miscellaneous	16,548	13.56	for insufficient data
Supply power	122,040	100.00	Supplied power

The entire production process consumed 53 % of the supply power, while utility facilities consumed 34 %. Among the utility facilities, the consumption ratio of air compressors is high, then followed by that of chillers and supply/waste water facilities.

The difference between the supply power amount and the actual consumption is more than 13 %; therefore it is necessary to identify what facility consumes the difference.

All of these are important themes to be studied for specific energy conservation actions.

Table 5.1.5 shows the power generation status of the gas turbine power generation facility at the point of this study (August 5 through 6, 1996). The total load in the factory is 12.8 MW as an average on a 24-hour basis and its variation width is between 12.5 MW and 13 MW.

The power factor is 0.8 on average and its variation width is between 0.79 and 0.81, which is approximately constant.

The power balance at the point of this study is estimated as shown in Table 5.1.6.

Table 5.1.5 Power Generation by Gas Turbine Power Generation Facility

	Gas turbine No. 1		Gas turbine No. 2		Total	
	kW	p. f.	kW	p. f.	kW	p. f.
Average	6,468	0.800	6,356	0.791	12,824	0.796
Maximum	6,567	0.823	6,625	0.803	13,043	0.809
Minimum	6,409	0.781	5,934	0.770	12,501	0.786

Table 5.1.6 Power Balance

Supply	(kW)	Demand	(kW)	(Ratio %)
Gas turbine No. 1	6,470	Polyester	5,230	(41)
Gas turbine No. 2	6,360	Acryl	2,960	(23)
		Compressor & Chiller	2,410	(19)
		Water treatment	1,070	(8)
		Power house	530	(4)
		Others	630	(5)
Total	12,830	Total	12,830	(100)

(2) Trend of energy intensity

a. Energy intensy

Calculation of energy intensity is based on the sum of polyester and acrylic fibers produced in consideration of the consistency with the total production amount.

Table 5.1.7 shows the energy intensity in each year of 1992 through 1995.

Table 5.1.7 Energy Intensity

		1992	1993	1994	1995
Power	kWh/t	1,525	1,593	1,459	1,516
Natural gas	m^3/t	649	921	1,017	1,035
Diesel oil	L/t	4.0	3.6	2.7	6.0
Steam	t/t	6.0	5.4	5.3	5.3
Well water	m^3/t	37.9	35.2	37.7	34.2

In 1994, the electricity intensity was 8 % smaller than the maximum value but it is approximately stable in each year.

In 1994, the fuel intensity was greatly reduced. This fluctuation can be supposed to be caused by the decrease in acryl production as well as electricity intensity.

b. Energy intensity by utility

Table 5.1.8 shows the results of calculating the gas turbine power generation efficiency, and electricity intensity for compressed air and service water from the utility production amount and power consumption in 1995.

Table 5.1.8 EnPolyacryl

Gas Turbine Efficiency

Power Generation Efficiency (No. 1 + No. 2)		
Natural gas consumption	10^3 m^3	60,503.7
Power generation output	MWh	118,594
Intensity	kcal/kWh	4,694
Power generation efficiency	%	18.3

Utility Electricity Intensity

Electric Power Intensity for Compressed Air		
Electricity consumption	MWh	16,979
Compressed air production	10^3 m^3	67,005
Electricity intensity	m^3/kWh	3.95
Electric Power Intensity for Feedwater		
Electricity consumption	MWh	7,470
Feedwater consumption	10^3 m^3	2,750
Electricity intensity	m^3/kWh	0.37

c. Energy intensity by process

Table 5.1.9 shows the energy intensity of each utility required for production of polyester and acrylic products in 1995.

Table 5.1.9 Energy Intensity by Process

		Consumption			Energy Intensity		(Polyester) + (Acrylic)	
		Polyester	Acrylic		Polyester	Acrylic	Consumption	Energy Intensity
Production	t	55,931	24,581		–	–	80,512	–
Electricity	MWh	34,979	28,821	kWh/t	625.4	1,172.5	63,800	792.4
Steam	t	98,351	252,625	t/t	1.76	10.28	350,976	4.36
Heat media	Gcal	41,301	0	Mcal/t	738.4	0	41,301	513.0
Compressed air	10^3 m^3	57,347	13,658	m^3/t	1,025	555.6	71,005	881.9
Nitrogen	10^3 m^3	2,164	4,879	m^3/t	38.7	198.5	7,042	87.5
Chiller water	10^3 m^3	3,158	4,062	m^3/t	56.5	165.2	7,220	89.7
Raw water	10^3 m^3	332.9	–	m^3/t	6.0	–	332.9	4.1

Power consumption referred to here is that in the production processes only.

The energy intensity for acryl production is extremely high. Variations of electricity intensity and fuel intensity in the total of acryl and polyester can be linked to the acryl production amount. (See Table 5.1.7.)

The reason for the high nitrogen gas consumption rate and chiller electricity intensity in the acryl processes is that a large volume of nitrogen gas is required for solvent separation at the spinning head and the chiller circulating water is large as the coolant to separate the solvent in the nitrogen gas.

(3) Energy flow

a. Total energy flow

Figure 5.1.4 shows the supply energy flow to the production processes.

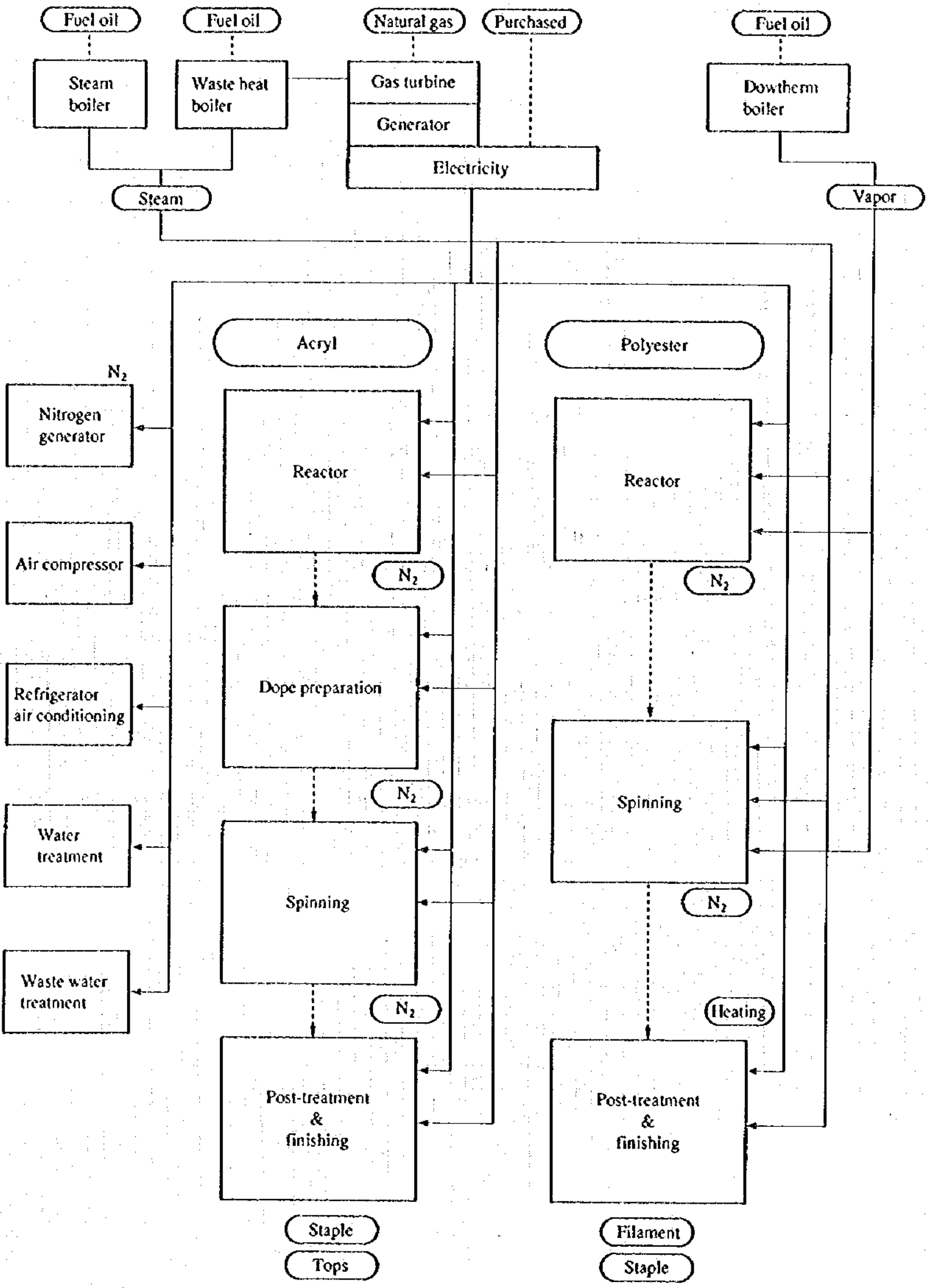
All utilities required for production are controlled in a centralized manner by the power center.

This factory uses the cogeneration system that introduces the gas turbine exhaust gas into the waste heat boiler to generate steam. This waste heat boiler is used as the base and the insufficient portion of steam is covered by two steam boilers.

Since the steam load declines in the summer season, part of the gas turbine exhaust gas is vented from the bypass flue.

All of the electric power used in this factory is normally isolated from the external power system, and is supplied by the in-house power generation plant. Power is purchased only in case of emergency such as shutdown of the in-house power generation plant. Since no synchronous motor nor power capacitor exists, the action for improving the power factor has not been taken.

Figure 5.1.4 Energy Flow



5.1.3 Energy Management Situation

(1) Setting the energy conservation target

The Energy Conservation Committee was established in June, 1995 and the energy conservation activities were newly started.

When the committee was established, the specific activity targets were:

a. Action against the faulty steam trap function

b. Reduction of 300 m^3/d in raw water used

c. Reduction of 300 m^3/d in soft water used

At the point of this study, the target values have been achieved except for a reduction in the soft water volume.

As a basic requirement for successful energy conservation activities, it is necessary to let everyone know the practically possible target values. It is also necessary to clarify the accomplishment deadline, roles of personnel, and budget. Continuation of these activities will expand and deepen, which is supposed to bring about an ever greater result. We expect energy conservation to be further promoted based on the present energy conservation promoting system.

(2) Organized activities

As described in (1) above, organized energy conservation activities are being promoted, achieving remarkable results.

Although promotion of the company-wide energy conservation activities is favorable, it requires background structuring including enlightenment and motivation of employees' consciousness by management and setting up of a supporting organization. To establish the energy conservation system, promotion of the activities based on the present Energy Conservation Committee will be realistic and immediately effective as described in (1) above.

Effects of energy conservation actions will, of course, lead to the reduction in energy intensity and cost reduction.

Although it is now very inexpensive and the economic effect is very low, the energy price is supposed to be increased in the future.

Furthermore, as the synergistic effect of promoting the energy conservation actions, many derived effects such as improvement of productivity, quality, facility reliability, safety, and working environments can be expected.

For the promotion of energy conservation by Japanese companies in recent years, the energy conservation committee as described above plays the role of management, and QC circle activities (hereinafter referred to as small-group activities) by sub-divided workshops are extended throughout the company, thus contributing greatly to the revitalization of company and the reduction of the production cost. Of course, energy conservation activities should be based on these small-group activities. (Small-group activities are further described in (4))

(3) Data-based management

a. Current situaton of the measuring system

Synthetic fiber manufacturing plants consume a huge amount of energy. Measurement/metering of energy is the management factor indispensable to proper evaluation as well as grasping of the production cost.

In this factory, the energy supply facilities, mainly including the power center, have advanced control systems and various measurement management equipment.

Although twenties years have passed since installation, these equipment are functioning very well, and useful data such as the flow rate, pressure, and temperature have been automatically recorded into the daily operation log.

Therefore, data collection can be fully covered by the current system.

b. Data utilization

Many useful data are simply recorded but not utilized for calculation of the energy intensity.

Data can not be said to achieve its role unless it is analyzed and utilized.
Valuable and useful data collected should be tabulated, analyzed, and utilized effectively.

c. Energy intensity evaluation items

Energy intensity management items include the following:

1) Energy intensity for production

Consumption rates of the power, steam, heat medium, compressed air, nitrogen, chiller water, and service water in the polyester and acryl plants (Sub-dividing these further into the polymerization process, spinning process and other subsequent processes is preferable.)

2) Energy intensities for the utility facilities

- Efficiency of gas turbine power generation and waste heat recovery equipment
- Electricity for compressed air, nitrogen gas, and chiller load
- Electricity power for utility water (raw water, soft water)

These energy intensities should be calculated every month, allocated from tabulation to a graph, and distributed to the related groups monthly. This can be expected to raise the employees' consciousness for energy management.

In addition, if data is controlled on a yearly basis, many data can be accumulated.

Tabulation of data and its representation into graphs can be easily processed by tabulation software for personal computer.

d. Management of energy intensity

The production energy intensity has not been grasped for both polyester and acryl.

By graphing the trend of energy intensity, the energy intensity reduction effect is visualized, and the graph can be the property shared by related personnel as well as employees.

Presently, the energy efficiency of major equipment such as the generator are not evaluated either.

Energy intensity management is also required for evaluating efficiency of the equipment and machines as well as for judging the capacity allowance.

Obtaining and tracking energy intensitys are the necessary tool for business administration.

(4) Training and education of employees

Since information on the entire training system is not available, no conclusive comment can be made. However, the polyester and acrylic fiber manufacturing processes are generally put in good order and thoroughly cleaned.

Desktop work such as recording the operation is put in good order as well. Training of employees and plant production control seem to be also at a very high level.

Basic concepts on training of employees in Japan are as follows:

a. Management attempts to renovate and raise the employees' consciousness to allow the employees themselves "to recognize how bad the situation is". The intent is productivity improvement, quality stabilization and improvement, safety, and working environment improvement, including, of course, energy conservation.

b. As specific activities:

   - Promotion of small-group activities by each workshop and presentation of the performance inside/outside the company

   - Establishment of the work improvement proposal system, and encouragement and enlightenment of employees for participation in proposals

   These are positively promoted on a company-wide basis. For a remarkable performance in these activities, an individual or small-group circle is awarded and a bonus is supplied. As a feature of the fiber factory, stains on the intermediate and final product result in the production loss and energy loss; therefore the drastic "Keep it tidy, neat and clean!" campaign is being carried out. As a traditional spirit in the Japanese industry, a motto "Do not drop a cotton fly! Pick it up." has been inherited.

   QC circle activities (i.e. small-group activities) positioned in TQC (Total Quality Control) in Japanese firms are introduced by many companies and bringing satisfactory results as a powerful tool for activating the company and enhancing cost competitiveness.

   Also, through the small-group activities, standardization of operation and facility maintenance can be reviewed. In this way, technical transfer from experts to beginners is allowed, thus continuing vigorous activities on a long-term basis every year.

(5) Equipment management

Facilities and equipment are generally maintained well and the control status is good. When we patrolled the polyester and acryl plants, no steam leak and compressed air leak were found.

Although slight steam leak and compressed air leak were found in the outdoor energy supply yard, the maintenance status is generally good.

Heat emitting positions in the polyester and acryl plants are heat-insulated nearly completely.

Heat insulation is almost completely applied to heat radiating parts in both plants, and in this respect, the level of the daily management techniques is highly evaluated. However, the following should be considered for future improvement:

a. Gas turbine's air intake and cooling system

The gas turbine air intake and cooling equipment with evaporative cooling of outdoor air for the purpose of increasing the power generation output in the summer season is not effectively used. The reason is corrosion of the air supply compressor. The cause of the corrosion should be clarified and the practical action to be taken should be examined in the case requiring the action of increasing the generator output in future.

b. Water supply (i.e. circulation) pump

The current pump delivery pressure is 5 to 6 kg/cm^2 (G), which is relatively higher. Since detailed data is not available, it is hard to determine anything but the specifications of the pumps may be excessive to the operation base. The pump performance should be evaluated on a current operation basis for major pumps with a long operating time. Performance degradation due to aging is considered to occur for the impeller and mouth ring.

During pump overhauling maintenance, these matters affecting the pump performance should be checked in detail. Thereafter, scheduled and positive measures such as pump function restoration, impeller cutting as an action for energy conservation, and renewal to a compact high-efficiency pump should be promoted.

c. Facilities master file

By preparing the individual master file for major equipment and machines and recording the maintenance history, an attempt is made to add the function as the maintenance master file. Maintenance management is to perform rational and scientific maintenance, which will lead to the outstanding energy conservation effects and improvement of facilities' reliability.

d. Metering facilities

The basic of energy intensity management is adequate metering management. Total check of metering components, regular practice of priority overhauling, and preparation and maintenance of the metering components master file for recording the result are essential.

5.1.4 Problems in the Utilization of Energy and the Countermeasures

(1) Comparison with a Japanese excellent factory

a. Evaluation of production process energy intensity

Table 5.1.10 compares the energy intensity at Polyacryl Iran (PAI) with that in the Japanese chemical fiber manufacturing industry (i.e. companies surveyed by MITI). It is understood that the PAI's energy intensity is approximately 1/3 in Japan for both electric power and fuel. As the background, the following are implied:

Table 5.1.10 Comparison of Production Composition and Energy Intensity

	Unit	PAI	Japan
Production	10^3 t/y	80.5	1,748.4
Polyester	10^3 t/y	55.9	717
Acryl	10^3 t/y	24.6	355
Others	10^3 t/y	0	676.4
Electricity intensity	MWh/t	0.79	2.31
Fuel intensity	kL/t	0.11	0.34

Source: Data of PAI : Actual data of Polyacryl Iran in 1995
Data of Japan: Textile Handbook, 1993

Note: The fuel for PAI does not include that for power generation.
"Others" in the Production item in the data on Japan include mainly Nylon (240 t) and Rayon & Acetate (307 t).

1) At the point of construction in 1974, PAI introduced the facilities nost modern in the world. Also, efficient use of energy in production processes was also considered.

2) Manufacturing processes of both polyester and acryl use the continuous polymerization and direct spinning system. What deserves to mention is particularly productivity improvement and energy conservation enhancement by the POY system for four lines among five polyester spinning lines through omission of the process.

3) The reasons for higher energy intensity in Japan are as follows:

- A batch system is, in many cases, used for the polymerization process in the polyester manufacturing plant. The production capability per batch is small.
- As the recent needs for the product, high quality and high-value addition are required, resulting in higher energy intensity.

b. Comparison with a Japanese excellent factory

For both polyester and acryl, a Japanese excellent company corresponding to PAI is selected to compare the energy intensity.

1) Polyester

The licenser for the Japanese polyester production factory is Vickers Zimmer. Manufacturing process uses the continuous polymerization and direct spinning system. As the raw material, DMT, also used by PAI, is used.

Table 5.1.11 shows the intensity of electricity, steam, and fuel.

Table 5.1.11 Comparison of Energy Intensity for Polyester Production

	Unit	PAI	Japan
Electricity	MWh/t	0.62	0.24
Steam	t/t	1.76	1.60
Fuel	kL/t	0.11	0.51

Note 1): Energy intensity for Japan: For polymerization to the spinning process
2): Production scale:
PAI : 55,931 t/y (Capacity: 54,880 t/y)
Japan: About the same as PAI.

Regarding the table of the energy intensity of electricity and fuel in the polyester manufacturing processes, the following can be considered:

- Method of heat utilization for the cogeneration system in in-house power generation
- Alteration of electricity into heat energy in production processes
- Method of efficient utilization of electricity in utility facilities
- Methods of metering and alloting the energy consumption result

For further differential analysis of energy intensity, detailed data should be collected.

2) Polyacryl

Table 5.1.12 shows the intensity of electricity, steam, and fuel for polyacryl.

Table 5.1.12 Comparison of Energy Intensity for Acryl Produciton

	Unit	PAI	Japan
Spinning method		Dry process	Wet process
Electricity intensity	MWh/t	1.17	1.24
Steam intensity	t/t	10.3	10.0

Although the spinning process at PAI is the dry type, the process in Japan used for comparison is the wet type. Both energy intensities are approximately equivalent.

c. Improvement of energy intensity

Although energy intensity at PAI is ranked in a worldwide advanced level, the following actions can be considered for possibility for further reduction of energy intensity:

1) Production processes

- Possibility of increasing the current temperature (21 °C) for quenching air in polyester spinning
- Recovery of exhaust heat from waste water of the washing facility in hot drawing in the acryl post-processing process

2) Utility facilities

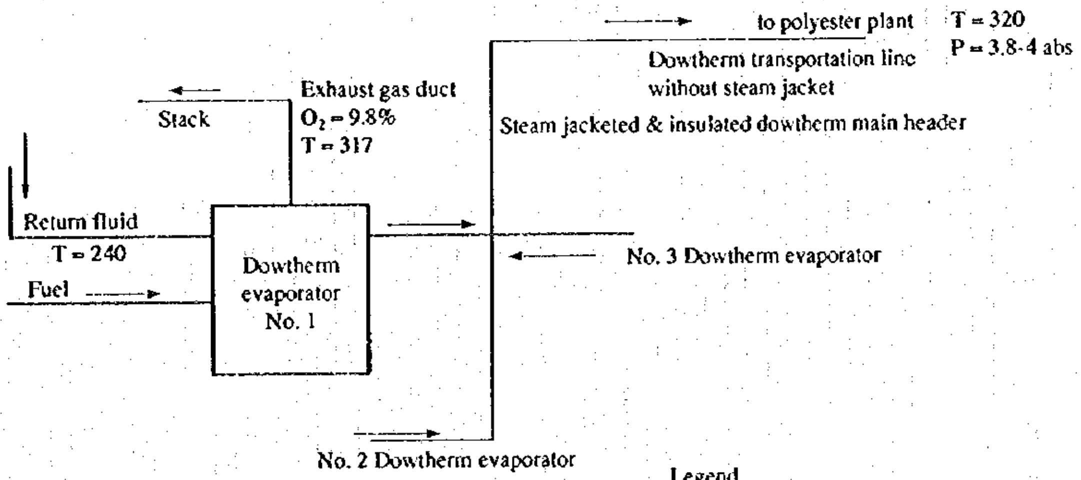
- Improvement and stable maintenance of overall efficiency in gas turbine operation
- Improvement of the air ratio for the steam and Dowtherm boiler
- Reduction in electricity for the chiller by using the cooling heat source of outdoor air
- Reduction in electricity consumption by the waste water treatment equipment
- Evaluation of the specifications and efficiency of the cooling water pumps and their high-efficiency operation
- Management of electricity intensity for compressed air and rational use of compressed air
- Building an energy intensity management system by re-examining the metering/measurement system

(2) Dowtherm boiler

This factory uses Dowtherm as the heat medium for processes. Dowtherm is fed from the Dowtherm boiler (also called the Dowtherm evaporator) located in the utilities area to processes as vapor. After being used in processes, Dowtherm is returned to the Dowtherm boiler and circulated again.

Figure 5.1.5 shows the measurement result of exhaust gas and so on from the Dowtherm boiler.

Figure 5.1.5 Dowtherm Evaporator Measurement



Legend
F: Flow rate, m^3/h
T: Temperature, °C

Block letter: Measured values
Italic letter: Panel reading

Control panel readings:

	Vapor flow	Fuel flow
No. 1	*17,600*	*280*
No. 2	*24,000*	*280*
No. 3	*18,000*	*140*
	kg/h	m^3_N/h

Dowtherm pipe surface temperature in polyester plant:

Main header surface	**T = 58**
Ambient temperature	**T = 34**
Bare surface (flange)	**T = 214**

Table 5.1.13 shows the heat balance obtained based on this exhaust gas analysis result.

Table 5.1.13 Heat Balance on Dowtherm Evaporator No. 1

Heat-in	kcal/h	%
Fuel combustion heat	2,815,500	100
Fuel sensible heat	0	0
Air sensible	0	0
Return dowtherm	1,844,304	66
Total	4,659,804	166
Heat efficiency: Fuel heat based		49.1

Heat-out	kcal/h	%
Dowtherm sensible	1,993,605	71
Dowtherm evaporation	1,232,000	44
Exhaust gas	549,797	20
Miscellaneous	884,402	31
Total	4,659,804	166

Note: Heat balance is based on an ambient temperature of 30 °C.
Air & gas temperatures are assumed to be the same as ambient.

If the air ratio of this boiler is adjusted to 1.3 (i.e. 5 % as oxygen content in exhaust gas) which is the standard value for the air ratio of boilers in Japan, approximately 6 %, 2,664 Gcal/y (= 2,815,500 × 0.06 × 8,760 × 0.9 × 2 units) fuel saving can be achieved if 100 % is in use presently, according to calculation. Consequently, the heat balance is improved as in Table 5.1.14. As shown in this table, adjustment of the air ratio reduces the exhaust gas loss rate as well as the required fuel.

Table 5.1.14 Estimated Heat Balance After Air Ratio Adjusting

Heat-in	kcal/h	%
Fuel combustion heat	2,660,686	100
Fuel sensible heat	0	0
Air sensible	0	0
Return Dowtherm	1,844,304	69
Total	4,504,990	169
Heat efficiency:		
Fuel heat based		51.9

Heat-out	kcal/h	%
Dowtherm sensible	1,993,605	75
Dowtherm evaporation	1,232,000	46
Exhaust gas	394,983	15
Miscellaneous	884,402	33
Total	4,504,960	169

Furthermore, since the exhaust gas temperature is high (317 °C presently), several % fuel saving can be achieved by installing the air preheater and preheating the combustion air. However, it is difficult to pay back investment cost of the air preheater in small-sized furnaces like this furnace. This item should be considered in installing equipment in future.

(3) Gas turbine

In this factory, two gas turbine generators with waste-heat boilers are always run to supply electric power and processes steam. Table 5.1.15 shows the outline of these facilities.

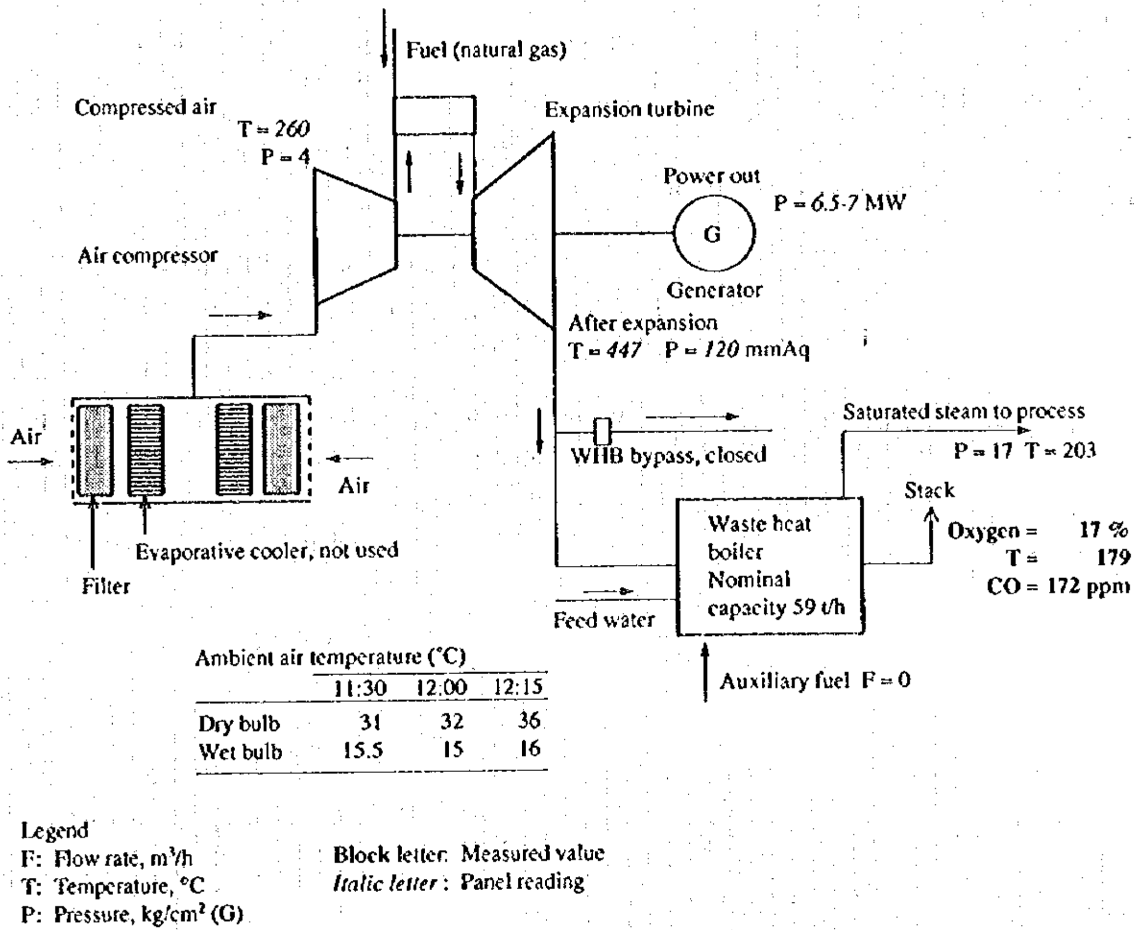
Table 5.1.15 Gas Turbine System

No. of units, installed	2
Generating capacity (MW)	10
Manufactured by	G. E.
Type	Single shaft, Open cycle
Fuel	Natural gas
Waste heat boiler (t/h)	59

a. Measurement and heat balance

Figure 5.16 shows the result of measuring the oxygen content and temperature of the exhaust gas at the outlet of the waste heat boiler in these facilities.

Figure 5.1.6 Exhaust Gas Measurement for Gas Turbine No. 2



Ambient air temperature (°C)

	11:30	12:00	12:15
Dry bulb	31	32	36
Wet bulb	15.5	15	16

Legend
F: Flow rate, m^3/h
T: Temperature, °C
P: Pressure, kg/cm^2 (G)

Block letter: Measured value
Italic letter: Panel reading

Table 5.1.16 shows the result of calculating the heat balance of the gas turbine system

Table 5.1.16 Gas Turbine Heat Balance

Heat-in	kcal/h	%
Fuel combustion heat	35,162,325	100.0
Fuel sensible heat	0	0.0
Air sensible heat	0	0.0
Feed water sensible heat	0	0.0
Auxiliary fuel for WHB	0	0.0
Total		100.0

Heat-out	kcal/h	%
Electricity	5,810,375	16.5
Steam/WHB	15,920,000	45.3
Exhaust gas heat	10,994,295	31.3
Miscellaneous	2,437,655	6.9
Total		100.0

Notes: Base temperature is 30 °C of ambient temperature.
Temperature of air, gas & feed water is assumed to be the same as ambient.
Steam amount is only assumption.

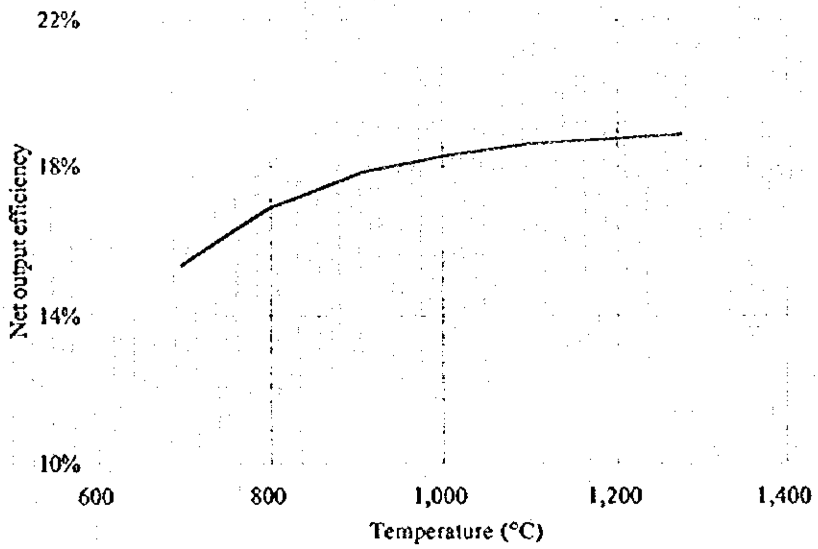
As shown in Table 5.1.16, 16.5 % of the combustion heat of fuel loaded to the gas turbine is converted into electric power and 45 % is recovered as steam by the waste heat boiler. The adiabatic temperature of combustion, calculated from oxygen content (17 %) in exhaust gas and the air temperature (260 °C) at the air compressor outlet, is 778 °C.

b. Improvement of turbine inlet gas temperature

For this gas turbine system, a simple simulation model with compression and expansion was created to study the gas temperature at the turbine inlet and the air temperature at the air compressor inlet.

For gas turbines, efficiency can be improved by increasing the gas temperature at the turbine inlet. Figure 5.1.7 shows the result of simulation using the model.

Figure 5.1.7 Combustion Temperature and Efficiency



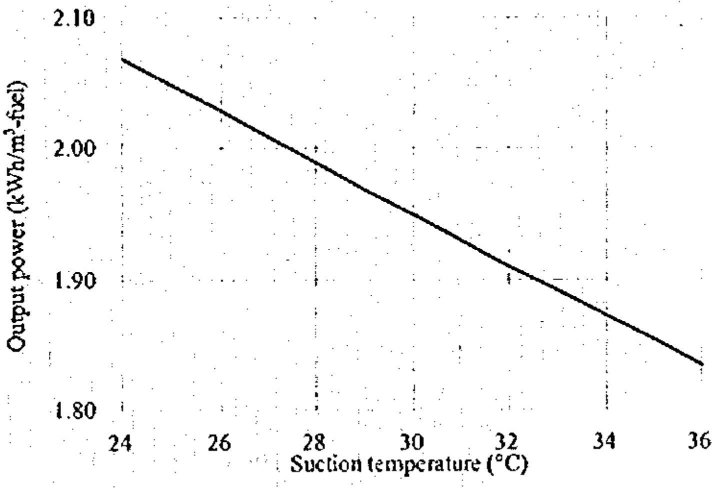
The turbine inlet temperature in the present gas turbine design conditions is unknown. As shown in Figure 5.1.7, a rise in the inlet temperature greatly affects the increase in turbine output. Therefore, it is desirable to examine the possibility of the temperature rise by checking the design conditions.

c. Cooling of intake air

This turbine has an intake air cooling equipment, which is currently not in use. This equipment cools the intake air by atomizing water into the intake air after the air filter. If the intake air is cooled, the air compressor can compress more air, thus increasing the turbine output.

Figure 5.1.8 shows a calculation example.

Figure 5.1.8 Suction Temperature and Net Output Power



In this case, efficiency is slightly improved.

Examples of intake air cooling can be seen in both Japan and the United States. For the method of intake air cooling, cold water made by the chiller is used or, in an area where the atmospheric humidity is lower, cooling by evaporation as seen in this factory is used. According to the hearing at this site, the intake air cooling equipment was used in the past but the use was canceled because turbine blades generated corrosion. It is desirable to re-examine the use at this point.

(4) Polyester quenching

Presently, to control the polyester spinning cooling air at 21 °C (DB)/16 °C (WB), the chiller supplies cold water throughout the year.

The outdoor air temperature is lower in the winter season and transient seasons before and after winter. For reference, it is examined to the use outdoor air instead of chiller water as the cold heat source in operation during the period in which the wet bulb temperature is 8 °C or lower. Table 5.1.17 shows the annual weather conditions and the result of power consumption by the chiller in the Esfahan district.

Table 5.1.17 Electricity Consumption by Chiller and Climatic Conditions

Month	Electricity consumption MWh	Dry bulb temperature °C	Wet bulb temperature °C	Relative humidity % RH
1	720.0	3.4	0.2	50
2	720.0	6.2	1.8	48
3	696.0	10.5	3.7	34
4	781.2	15.3	7.2	32
5	781.2	20.5	9.6	24
6	781.2	25.4	11.3	17
7	892.8	28.3	12.9	17
8	892.8	27.0	12.0	16
9	892.8	22.8	9.6	20
10	720.0	16.7	8.8	37
11	720.0	9.7	4.0	41
12	720.0	4.9	1.4	56
Total/Average	9,318.0	15.7	13.0	36

Source for climatic conditions: Science Almanac (edited by Tokyo Astronomical Observatory)
Esfahan district
Dry bulb temperature 1951 to 1971
Relative humidity 1965 to 1967
Relative humidity was calculated based on the environmental diagram at 1,500 mm above the sea.

Power consumption by polyester in 1995 is obtained from the circulated water volume ratio:

- Polyester: 9,318 MWh/y × 0.44 = 4,100 MWh/y
- Acryl : 9,318 MWh/y × 0.56 = 5,218 MWh/y

a. Improvement plan

Assuming that the spinning quenching cooling air condition remains as it is and the period in which outdoor air can be used is 6 months (excluding May through October in summer season in Table 5.1.17), it will be as follows:

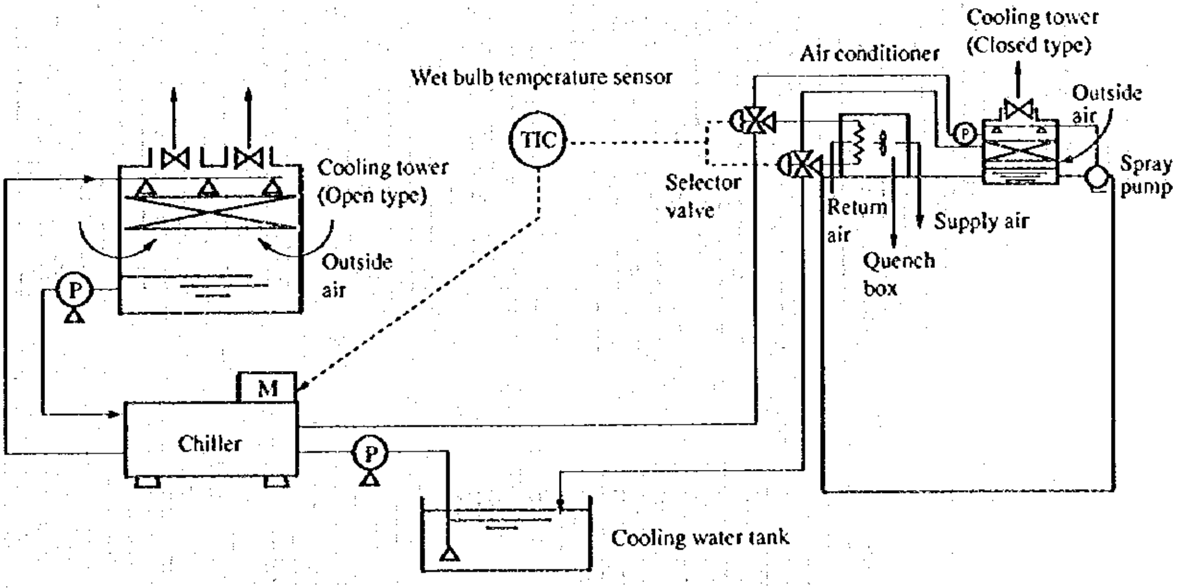
If the spinning quenching air condition is 24 °C which is 3 °C higher than the current condition, the period in which outdoor air can be used is 9 months.

As a case in Japan, quenching cooling had been reviewed for energy conservation since the last half of 1970s. As a result of increasing the cooling air temperature to 24 or 25 °C, the period in which outdoor air could be used was increased. Also, the air condition of the POY system has been mitigated.

However, since the higher-quality, multi-yarn wisp, and speedup tendency is accelerated by the recent market needs, the quenching temperature is likely to decrease gradually.

Hence, a case study is conducted by using the quenching condition at PAI as the current condition. Figure 5.1.9 shows the concept of the entire cooling system. As the basic concept of this system, the outdoor air wet bulb condition is always detected, and the system automatically selects the chiller water when the temperature of the cooling water obtained becomes higher than the reference value. Here, the cooling tower used to obtain the cooling water is a fully closed type, which is regarded to work as a rooftop equipment on the polyester building. Thus, it is intended to reduce a resulting large amount of electric power for the cooling water.

Figure 5.1.9 Concept of Outside Air Cold Heat Utilization



b. Expected effect

If electric power for the chiller that can be saved is estimated to be 50 %, the effect is as follows:

4,100 MWh/y × 0.5 = 2,000 MWh/y (for the chiller pump).

Also, the outdoor air in the winter season can be used as the cold heat source for cooling the chiller water for other purposes. It is desirable to include the acryl plant in examination of the plan.

(5) Recovery of acryl process waste heat

Waste water from the heat treatment and washing processes in the acryl and polyester plants is fed to the total waste liquid processing equipment, where the contamination matter is removed by the biological treatment. Figure 5.1.10 shows the flow of the waste water treating system.

The waste water volume in the acryl processes is 75 % of the entire water volume. The waste water temperature is high and the average temperature of all incoming water is as high as 65 °C.

Therefore, a cooling tower is provided in the waste water treatment process to cool water down to 30 °C.

a. Improvement measures

By attempting heat exchange between the hot waste water in the acryl plant where 75 % of waste water is generated and the fresh washing water, thus heating steam for heating fresh water can be reduced, and decrease the temperature of the waste water coming into the waste water treatment equipment.

b. Expected effect

Conditions for calculating the effect are as follows:

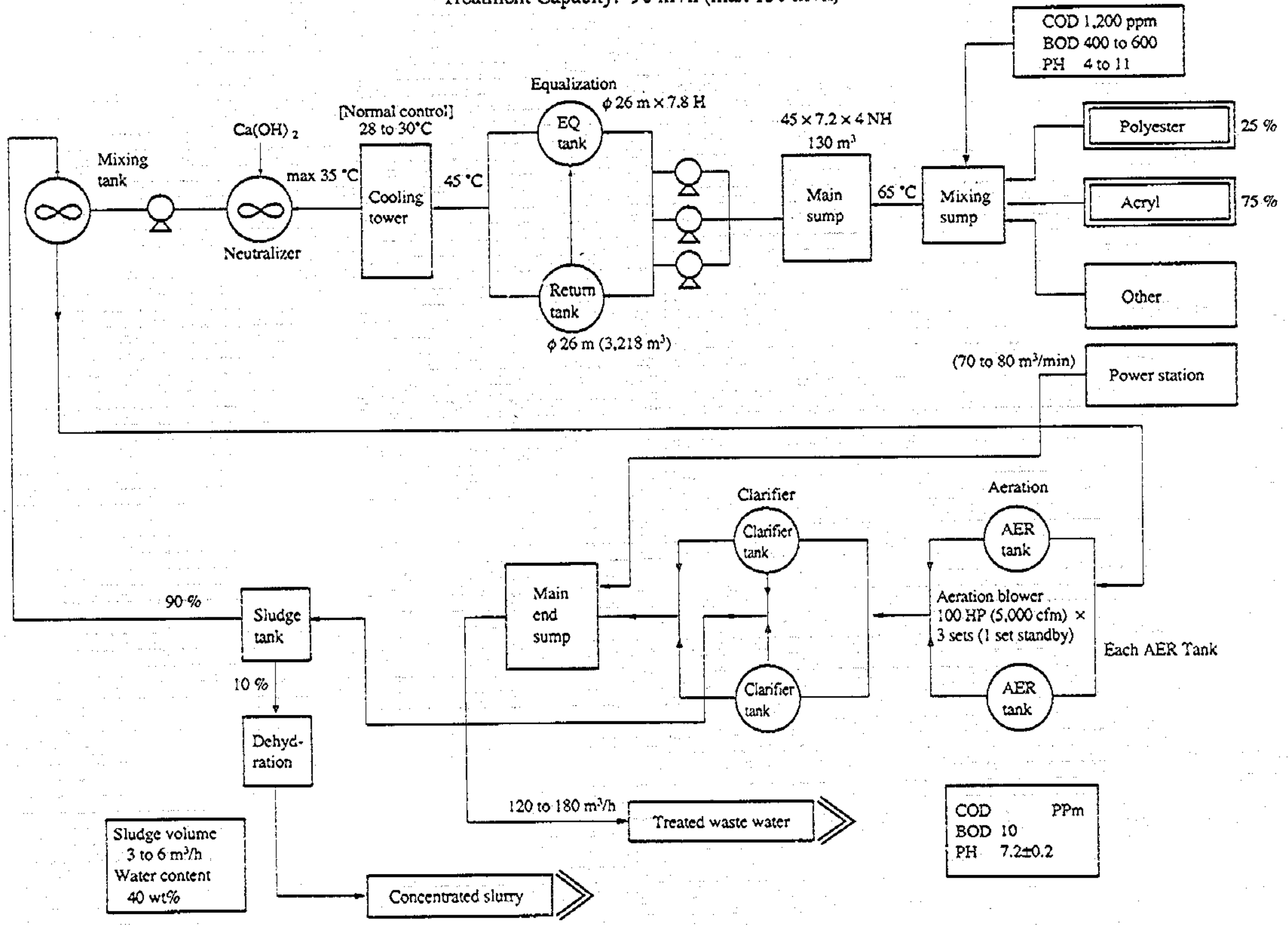
- Acryl hot waste water volume : 60 m^3/h (75 % of entire effluent)
- Waste water temperature at the washer outlet: 80 °C
- Temperature efficiency of heat exchanger : 66 %
- Supply water temperature : 20 °C
- Utilization efficiency : 80 %

$60 \times 103 \times 24 \times 365 \times 0.8 \times 0.66 (80 - 20) / 10^6 = 16{,}800$ Gcal/y

- Expected heat exchange characteristics
  Waste water side Inlet: 80 °C, Outlet: 40 °C
  Fresh water side Inlet : 20 °C, Outlet: 60 °C

Figure 5.1.10 Biologically Oriented Overall Waste Water Treatment System

Treatment Capacity: 90 m³/h (max 130 m³/h)



(6) Pumps

Among pumps using a large motor, electricity for five pumps (2 cooling tower water feed pumps, 1 chilled water pump, 1 raw water pump, and 1 soft water pump) was measured. Table 5.1.18 shows the electricity measurement result. For the utilization factor, the raw water pump is approximately 70 % and the soft water pump is 60 % minus.

Table 5.1.18 Measurement Result of Power Consumption by Pump Motor

Measuring date: 6 August 1996

	Cooling Tower Water Pump							
	No. 1 Pump			No. 2 Pump			(No. 1 + No. 2) Pump	
	kW	p. f.	U. F.	kW	p. f.	U. F.	kW	p. f.
Average	194.3	0.905	0.880	189.2	0.910	0.857	383.5	0.908
Maximum	194.3	0.906	0.880	189.2	0.911	0.857	383.5	0.908
Minimum	194.3	0.904	0.880	189.2	0.910	0.857	383.5	0.907

	Chilled Water Pump No. 1			Raw Water Pump No. 1			Soft Water Pump No. 1		
	kW	p. f.	U. F.	kW	p. f.	U. F.	kW	p. f.	U. F.
Average	172.8	0.912	0.940	77.6	0.884	0.703	66.5	0.849	0.585
Maximum	173.2	0.912	0.942	78.9	0.885	0.715	65.8	0.852	0.596
Minimum	172.5	0.912	0.938	76.4	0.881	0.692	63.2	0.845	0.573

The upper section in Table 5.1.19 shows the pump efficiency calculated from the water pressure and the water volume on the control panel for these pumps. From this result, efficiency of each pump is as low as 60 % or less.

The lower section in Table 5.1.19 shows the result of the effect calculated on the assumption that this operation is continued and the pumps are replaced by high-efficiency pumps.

Table 5.1.19 Efficiency Calculation of Main Pumps

Water Pump Name	Cooling Tower Pump No. 1	Cooling Tower Pump No. 2	Cooling Tower Pump Total	Chilled Water Pump No. 1	Raw Water Pump No. 1	Soft Water Pump No. 1
Pressure (kg/cm² (G))	4.6	4.6	4.6	5	5.3	5.6
Water flow (m³/h)	750	750	1,500	620	155.4	191.4
Efficiency of motor	0.9	0.9	0.9	0.9	0.9	0.9
Motor input (kW)	194.3	189.3	383.5	173.2	77.6	64.5
Efficiency of pump	0.537	0.551	0.544	0.542	0.321	0.503
(After improvement)						
Efficiency of pump	0.7	0.7		0.7	0.7	0.7
Calculated output (kW)	134.2	134.2		120.6	32.0	41.7
Selected motor capacity (kW)	160	160		132	37	45
Efficiency of motor	0.9	0.9		0.9	0.9	0.9
Motor input (kW)	149.1	149.1		134.0	35.6	46.3
Reduced input (kW)	45.2	40.2		39.2	42.0	18.2
Reduced kWh/y	361,330	321,330		313,566	335,658	145,659
Reduced Fee/Y (¥)	5,781,283	5,141,283		5,017,060	5,370,527	2,330,546
Investment (¥)	16,000,000	16,000,000		13,200,000	3,700,000	4,500,000
Simple payback period (y)	2.8	3.1		2.6	0.7	1.9

(7) Electricity supply/demand

Since electricity supply relies on private power generation alone, the factory's safe and stable operation is important in terms of energy conservation. At the point of this investigation, the generator's utilization factor (= average electric power/generator rating output) was 65 % for the No. 1 machine and 64 % for the No. 2 machine, which implies operation with a sufficient allowance. The current load is 12.8 MW, which cannot be supplied by one generator. Therefore, electric power is supplied by two generators. As a result, light-load operation seems inevitable. However, gross thermal efficiency is 14 to 15 % due to the effect of the light-load operation.

According to the characteristic curve of the gas turbine, the heat consumption rate is improved by 12.3 % if the utilization factor is increased from 65 % to 100 %.

Although the external power line is separated presently, it is desirable to select the optimum energy supply mix considering the external electric power, control of the number of gas turbines, and general boilers' efficiency if the external power line is reliable, selling power is possible, and cost recovery is possible.

For fuel consumption for gas turbines in 1995, the natural gas was 60,503,712 m^3/y. Therefore, the volume of natural gas that can be reduced is as follows:

$60{,}503{,}712 \times 0.123 = 7{,}442{,}000\ m^3/y$.

Although 80 % as the plant load power factor is not satisfactory, reduction in power loss only will not be the merit of installing the condenser. At the point of parallel operation with the external line in future, the problem of the power factor should be solved along with the utilization factor problem described above.

(8) Power consumption for feed/waste water treatment

Table 5.1.20 shows the power consumption load on the supply water/waste water facility in the entire factory.

The total load of feed/waste water treatment occupies 12 % in the entice factory.

Table 5.1.20 Component Ratio by Electricity Consumer (1995)

Electricity Consumer		Consumption (MWh)	Consumption Ratio (%)
Production process	Polyester	34,979.4	33.16
	Acryl	28,821.1	27.32
	(Sub-total)	(63,800.5)	(60.48)
Heat generating equipment	G-T auxiliary equipment	657.3	0.62
	Steam boiler	1,251.2	1.19
	Heat medium boiler	748.2	0.71
	(Sub-total)	(2,656.7)	(2.52)
Chiller equipment		(9,318.8)	(8.83)
Air compressor equipment	Air compressor	16,978.8	16.10
	N_2 production system	376.7	0.35
	(Sub-total)	(17,355.5)	(16.45)
Equipment for raw water and waste water	Raw water treatment	7,469.6	7.08
	Waste water treatment	4,891.7	4.64
	(Sub-total)	(12,361.3)	(11.72)
Grand total		105,492.8	100.00

As the evaluation method for electric power for treating the feed/waste water, the pumping electricity intensity (kWh/m^3) is considered for the feed/waste water pump power. For electricity of the aeration blower in the waste water process, the aeration electricity per treated waste water volume (kWh/m^3) and the aeration electricity per BOD load (kg)(kWh/kg-BOD) are considered.

Evaluation of the result in 1995 is as follows:

Feed well water volume : $2,750 \times 10^3$ m^3/y (314 m^3/h)
Circulating water volume : $27,500 \times 10^3$ m^3/y
(assumed as ten times that of well water)
Electric power for feed water: 7,469.6 MWh/y (852 kWh/h)
Pumping electricity intensity : $\frac{7,469.6 \times 10^3 (kWh)}{27,500 \times 10^3 (m^3)} = 0.271$ kWh/m^3

For evaluation of the total pump head, the pump delivery pressure for the entire water volume is obtained assuming that the average efficiency of all pumps is 60 %:

$$H = \frac{7,469.6 \times 10^3 \times 102 \times 3,600 \times 0.60}{27,500 \times 10^6} = 60 \text{ m}$$

In this formula, 60 m (6 kg/cm^2 (G)) represents the total pump head indicating the piping line friction loss and the height from suction to top.

Electricity for waste water treatment is as follows:

Accepted waste water volume : 80 m^3/h
Electricity consumption for the waste water treatment: 4,891.7 kWh/y (558 kWh/h)
Waste water treatment electricity intensity : $\frac{558}{80} = 7.0$ kWh/m^3
Power consumption load of the aeration blower : $\frac{100 \times 0.746 \times 0.9 \times 2}{558} = 0.24$
Electricity intensity for the aeration blower : $\frac{558 \times 0.24}{80} = 0.67$ kWh/m^3

a. Improvement plan

Basically, promotion of the rational use of feed water is the first step. The result will directly lead to reduction in electricity for processing waste water.

The aeration blower in waste water treatment adjusts the volume of air blown in according to the contamination load accompanying the production fluctuation. By using the dissolved oxygen content in the waste water being treated as an index, the automated system performs alternate and intermittent operation of three blowers.

As can be seen from the pump efficiency measurement result shown above, each pump should be exchanged to a proper capacity and high efficiency based on the actual load along with reduction in the volume of feed/waste water.

Presently, although the temperature of water coming in the waste water process is as high as 65 °C, the effect of reducing power for cooling the waste water can be expected by waste heat recovery.

b. Expected effect

1) Expected reduction in feed/waste water volume

The water volume can be reduced by 15 %.

Reduced electric energy : $7{,}469.6 \times 0.15 = 1{,}120$ MWh/y
Treated waste water volume: 10 m^3/h reduced from 80 m^3/h
Reduced electric energy : $4{,}891.7 \times (1 - 0.24) \times \frac{10}{80} = 464$ MWh/y

2) Expected reduction in aeration electricity

There is a fluctuation in the volume of acryl produced. If expected reduction in the aeration air volume as a result of proper control of dissolved oxygen is 20 %, electric energy reduced is as follows:

$$4{,}891.7 \times 0.24 \times 0.2 = 234 \text{ MWh/y}$$

3) Total reduction in electric energy

1,818 MWh/y (= 1,120 + 464 + 234)

4) Reduction in water feed electricity intensity

The total pump head described above, 6 kg/cm^2 (G), is a very large value. It is necessary to prepare the overall piping line diagram (i.e. engineering flow sheet) to check the characteristics of each pump.

Problems extracted should be corrected repeatedly by using the maintenance timing in a skilled manner. In other words, aiming at shifting to the pump's proper capacity and high efficiency may reduce pumps' power consumption to 50 %.

Electric power corresponding to 50 % is 3,000 MWh/y.

The preliminary step for practical actions is to calculate electricity intensity for each waste water processing equipment and manage their tendency by using a graph.

(9) Electricity consumption for compressed air

As shown in Table 5.1.20, electricity consumption by air compressors accounts for 16 % of overall power consumption (N_2 compressor excluded).

The required electric energy per 1 m^3 of compressed air, that is electricity intensity, is obtained from the actual values in 1995.

Calculation basis:

Electricity consumption: 16,978.8 MWh/y
Compressed air used : 57,347 × 10^3 m^3/y for polyester
13,658 × 10^3 m^3/y for acryl
71,005 × 10^3 m^3/y for total
Electricity intensity : $\frac{16,978.8\times10^3}{71,005\times10^3} = 0.24\ \mathrm{kWh/m^3} \left(= 4.18\ \mathrm{m^3/kWh}\right)$

Judging from the receiver tank pressure (3.5 kg/cm^2 (G)), the compressed air manufacturing efficiency is low. However, since the conditon for calibration to normal state of temperature and pressure is unknown, it is difficult to make a judgment.

The general value of intensity in the normal state (0 °C at atmospheric pressure) in Japan is 7 to 8 m^3_N/kWh.

a. Improvement plan

1) Reduction in compressed air consumption

As a general compressed air consumption pattern, the consumption load by blowing is large. Also, leak from compressed air devices and piping cannot be ignored.

Depending on the case, electricity consumption may be reduced by 30 to 40 % by leak management and blowing air system improvement.

2) Macro evaluation of the compressor's efficiency

The operation time and the electricity consumption of each compressor can be managed relatively easily. As a result, compression characteristics of each compressor can be obtained as the basis for high-efficiency operation.

3) Management of overall electricity intensity

From the volume of compressed air manufactured and its electricity consumption, the compressed air's electricity intensity is managed monthly. Tracking using a graph allows easy trend management of various action results.

b. Expected effect

According to the general action result, the target value for reduction is considered to be 20 %.

This target value seems to be fully achievable by listing the locations consuming compressed air, the use of purpose, and the use conditions, matching them with the actual application result and promoting the improvement plan.

Electric energy corresponding to 20 % reduction is as follows:

16,978.8 × 0.2 = 3,400 MWh/y

(10) Summary of proposals

Table 5.1.21 shows the energy conservation measures described above.

Table 5.1.21 Summary of Proposals

(Japanese Yen base)

Item	Expected Saving						Total Million yen/y	Investment Million yen	Payback Period Year
	Fuel			Electricity					
	10^3 m^3/y	Million yen/y	%	MWh/y	Million yen/y	%			
Improvement of Dowtherm boiler air ratio	290*1	5.0	0.3*3	–			5.0	0	0
Review of quench cooling	–			2,000	20.0	1.6*7	20.0	20	1.0
Recovery of waste heat in the acryl process	2,282*2	39.2	2.7*4	–			39.2	15	0.4
Replacement of chiller system pumps	–			996*6	10.0	0.8*8	10.0	45	4.5
Improvement of gas turbine utilization rate	7,442	127.9	8.9*5	–			127.9	0	0
Reduction of supply/waste water and aeration volume	–			1,818	18.2	1.5*9	18.2	30	1.6
Optimization of pump capacity	–			3,000	30.0	2.5*10	30.0	25	0.8
Rational use of compressed air	–			3,400	34.0	2.8*11	34.0	30	0.9
Total	10,014	172.1	12.0	11,214	112.2	9.2	284.3	165	0.6

(Iran Rial base)

Item	Expected Saving						Total Million Rial/y	Investment Million Rial	Payback Period Year
	Fuel			Electricity					
	N.gas 10^3 m^3/y	Million Rial/y	%	MWh/y	Million Rial/y	%			
Improvement of Dowtherm boiler air ratio	290*1	36	0.3*3	–			36	0	0
Review of quench cooling	–			2,000	200	1.6*7	200	350	1.8
Recovery of waste heat in the acryl process	2,282*2	281	2.7*4	–			281	262	0.9
Replacement of chiller system pumps	–			996*6	100	0.8*8	100	648	6.5
Improvement of gas turbine utilization rate	7,442	915	8.9*5	–			915	0	0
Reduction of supply/waste water and aeration volume	–			1,818	182	1.5*9	182	525	2.9
Optimization of pump capacity	–			3,000	300	2.5*10	300	438	1.5
Rational use of compressed air	–			3,400	340	2.8*11	340	525	1.5
Total	10,014	1,232	12.0	11,214	1,122	9.2	2,354	2,748	1.2

*1 $2,664 \times 10^6$ kcal/y / 9,200 kcal/m^3 = 290×10^3 m^3/y
*2 $16,800 \times 10^6$ kcal/y / (9,200 kcal/m^3 × 0.8) = $2,282 \times 10^3$ m^3/y
*3 $290 \times 10^3 / (83,362 \times 10^3) \times 100 = 0.3$ %
*4 $2,282 \times 10^3 / (83,362 \times 10^3) \times 100 = 2.7$ %
*5 $7,442 \times 10^3 / (83,362 \times 10^3) \times 100 = 8.9$ %
*6 Excluding that for raw water, soft water (361,330 + 321,330 + 313,566) / 10^3 = 996
*7 2,000 / 122,040 × 100 = 1.6 %
*8 996 / 122,040 × 100 = 0.8 %
*9 1,818 / 122,040 × 100 = 1.5 %
*10 3,000 / 122,040 × 100 = 2.5 %
*11 3,400 / 122,040 × 100 = 2.8 %

Energy price in Japan:
Natural gas: 17,000 yen × 9.2 / 9,100 = 17.19 yen/m^3
Electricity: 10 yen/kWh

Energy price on Iran Rial base:
Fuel oil: 75 Rial/L
Electricity: 100 Rial/kWh

Exchange rate: 1,750 Rial = 1 US Dollar = 100 Japanese Yen
Investment cost is based on that in Japan.