8. SURVERY OF ENERGY USE IN THE MODEL FACTORY

8.1 Results of the Study at Steel Factory

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8.1.1 Factory outline

(1) Factory name

Y Co., Ltd.

(2) Type of industry

Steel making and rolling section bar

(3) Major product name and production capacity

Billet	120,000	M/tons / year
Angles	60,000	M/tons / year
Channels	48,000	M/tons / year

(4) Number of employees on the payroll

441 persons

(5) Factory address

In Bangkok

(6) History

The factory started operation as a small-scale factory since 1974, by using 5 ton per hour reheating furnace till 1977, Y Co., Ltd. was established in July and funded by the Thai investments only. The second reheating furnace was set up additionally for a 20 ton per hour capacity in 1980. Later on the factory expanded by setting up an electric arc furnace of 30 ton per charge with a continuous casting machine primarily based on the Taiwanese technology and techniques. In 1987, the third reheating furnace has been added operating with capacity at 20 ton per hour to facilitate the production of billet. The electric arc furnace was modified to raise its capacity up to 35 ton per charge.

The scraps are mostly available locally in Thailand. The main products of the factory are angles steel, channels steel and other shapes, of which their standards comply with Industrial Standards of Thailand (Thai Standards for Industry). Presently, the factory's staff comprises of 400 employees including electrical engineers, chemical engineers and production experts.

(7) Study period

4 - 14 July 1994

(8) Members of study group

name	assignment
1. Mr. Hiroshi Ishida	Leader
2. Mr. Norio Fukushima	Deputy leader
3. Mr. Mitsuo Iguchi	Energy management expert
4. Mr. Yukio Nozaki	Heat expert
5. Mr. Akira Koizumi	Heat Expert
6. Mr. Toshio Sugimoto	Electric expert
7. Mr. Shosuke Noguchi	Electric expert
DEDP members	
1. Mr. Pinyo Tanthumart	Technician heat
2. Mr. Chartree Peamparvut	Technician heat
3. Mr. Somphot Kongpan	Technician heat
4. Mr. Phruttapong Sarakasetrin	Electrical Engineer
5. Mr. Virat Songngam	Electrical Engineer
6. Mr. Aithaphon Hongsamat	Electrical Engineer

(9) Interviewees

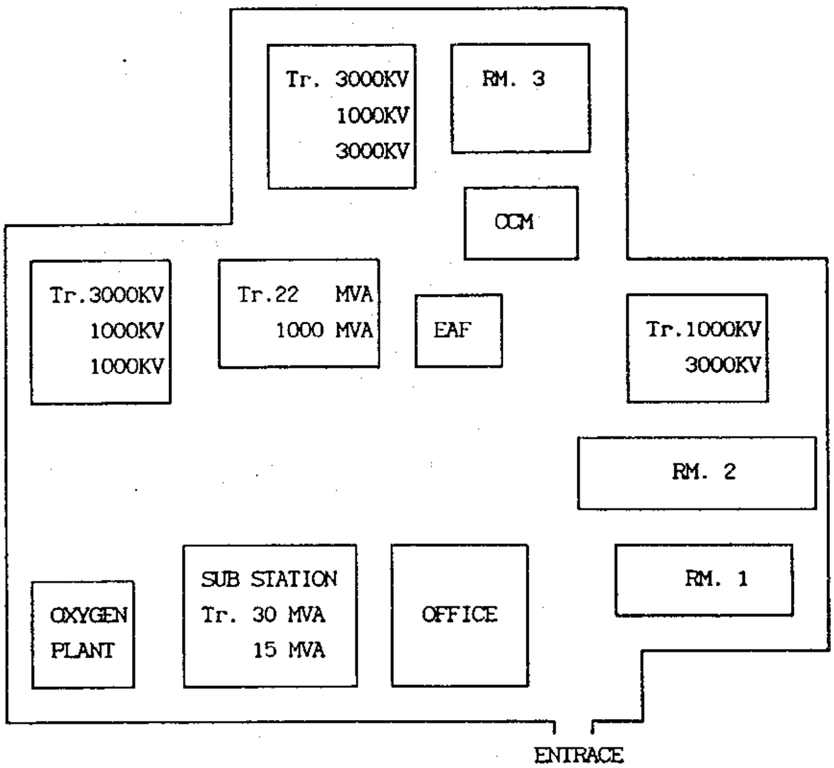
1. Mr. A	Deputy Managing Director
2. Mr. B	General Manager
3. Mr. C	Chief Electrical Engineer

(10) Energy prices

"A"- Heavy oil (l)	= 3.0	Baht/Litre
"C"- Heavy oil (l)	= 2.7	Baht/Litre
Electricity (kWh)	= 1.504	Baht/kWh
Diesel fuel	= 8	Baht/Litre

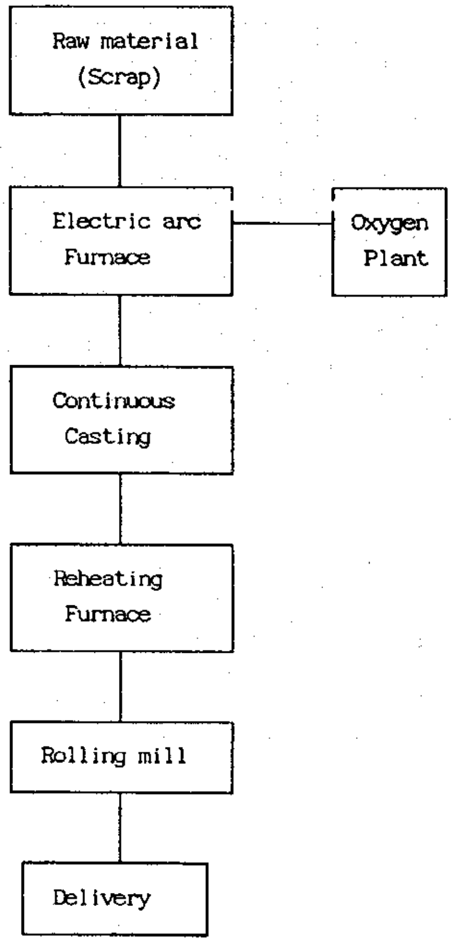
(11) Factory Layout

Figure 8.1.1 Factory Layout



(12) Production Process

Figure 8.1.2 Production Process



(13) Outline of Principal Equipment

Table 8.1.1 Principal Equipment

Name	No. of Unit Installed	Type, etc.
Electric Arc Furnace	1 Unit	30 Ton/hr
Continuous Casting Machine	1 Unit	3 Stand Nominal Capacity 35 Ton/hr
Reheating Furnace	3 Units	No.1 5 Ton/hr No.2 20 Ton/hr 3 Zone, Pusher type No.3 20 Ton/hr 2 Zone, Pusher type
Rolling Mill	2 Lines	Rolling Stands No.1 3hight-1,2hight-6 units No.2 3hight-1,2hight-5 units
Oxygen Plant	1 Plant	Pressure Swing Absorption Compressor Power

8.1.2 Situation of energy management

(1) Setting the target for energy management

The factory manager takes an interest in energy conservation. The factory carries out an electric power saving by demand control and the lighting by means of timer. The factory does not have a concrete energy conservation target for reducing energy consumption rate. In this factory the electric arc furnace used 70 - 80 % of electric power consumption in the whole factory. Therefore, it is necessary to determine the target of energy conservation or energy consumption on the electric arc furnace.

(2) Systematic actions

Implementation on energy conservation such as for lighting, controlling the temperature and oxygen content in an exhaust gas, for examples, have not been started to operate in anyway. Presently, only maintenance of equipment and machinery, in general, has been done in the factory.

(3) Data-base management

The factory keeps a record of electric power consumption, type of steel, charging amount, melting temperature and operation time per each batch with respect to the electric arc furnace.
The reheating furnace does not install the measuring instruments, and keeps an only record of amount of charging billet per hour.

Under the circumstance, if abnormality is found in energy consumption and furnace condition, it is impossible to determine the cause and take appropriate improvement. After the minimum measuring equipment are installed, it is important to grasp daily the actual circumstance of the furnace, to process the data and operational conditions and to complete the statistical data to be used for comparative investigation.

(4) Education and training of employees

Training and education on energy conservation for employees in the factory are not provided nor are they sent to be trained for such the courses on energy saving. Even currently, the government and private sectors have provided some training courses on energy conservation for many times, such as by the Energy Conservation Division of DEDP and by the ECCT, for examples.

It is important to provide some training courses and education on energy conservation technique for employees.

(5) Equipment maintenance

The electric arc furnace is periodically repaired but insufficient maintenance was noted for the reheating furnace.

The reheating furnace was causing air suction at the door of inspection hole and charging hole. It must be repaired as soon as possible. Arrangement of drawings and technical data for major equipment appeared generally satisfactory.

It is necessary that design calculation data and renovation record are prepared for formulating the future improvement plan.

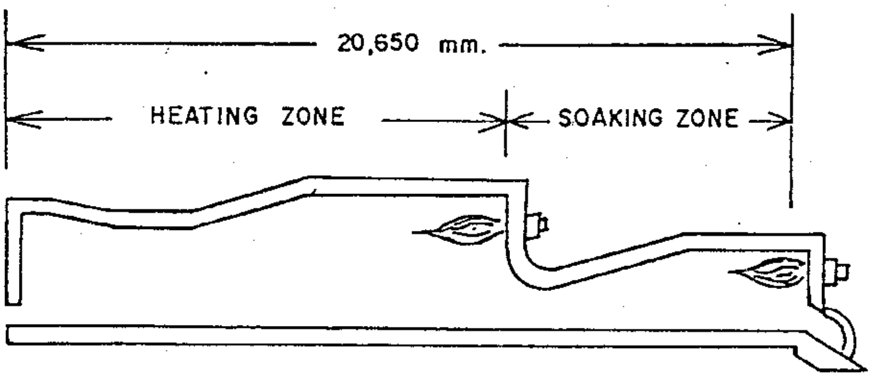
8.1.3 Problems in the use of energy and countermeasures

8.1.3.1 Heat balance on the reheating furnace

(1) Outline of reheating furnace

Type	=	upper 2 heating zone, pusher type
Capacity	=	20 ton/hr
Effective length, width	=	17,800 mm, 3,800 mm
Fuel	=	"A" Heavy oil (Hh = 10,509 kcal/kg)
Date of manufacture	=	1987
Structure	=	as shown in Figure 8.1.3

Figure 8.1.3 Reheating Furnace 3



(2) Results of measurement

The heat balance was calculated using the data collected for four hours from 13:00 to 17:00 on July 13, 1994.

1)	Kind of fuel	=	fuel oil "A"	
2)	Fuel consumption	=	813.75	Litre/hr
3)	High calorific value of fuel	=	10,509	kcal/kg
4)	Specific gravity of fuel	=	0.95	
5)	Fuel temperature	=	41.8	°C
6)	Reference temperature	=	37	°C
7)	Temperature of combustion air	=	50.1	°C
8)	O_2 % in exhaust gas	=	6.65	%
9)	Temperature of exhaust gas	=	596.2	°C
10)	Amount of charged billet	=	14	Ton/hr
11)	Charging temperature of billet	=	37	°C
12)	Discharging temperature of billet	=	1,328	°C

13)	Amount of cooling water	= 165.094	M^3/hr
14)	Temperature of cooling water		
	Inlet temperature (average)	= 30	°C
	Outlet temperature (average)	= 34.5	°C
15)	Generated scale (estimate) 2 % of charged billet		
16)	Temperature of outer wall		
	Surface at each part of furnace		
	Heating zone left side	= 107.1	°C
	Heating zone right side	= 106.55	°C
	Heating zone ceiling	= 105.42	°C
	Soaking zone left side	= 131.8	°C
	Soaking zone right side	= 106.0	°C
	Soaking zone ceiling	= 129.0	°C
	Charging side	= 362.0	°C
	Discharging side	= 88.6	°C
	Discharging door	= 390.0	°C

(3) Calculation of heat balance

The heat balance per ton of charged billet is calculated.

1) Calculation of input amount and output amount

(a) Input amount

a)	Charged billet	= 1	ton
b)	Fuel consumption	= 3,255	Litre/hr
	or	= 813.75	Litre/hr
	Specific gravity of fuel at 15 °C (d_{15})	= 0.95	
	Specific gravity of fuel at 41.8 °C (dt)		
	d_{15}	= dt + 0.00065 (T - 15)	
	dt	= d_{15} - 0.00065 (41.8 - 15)	
		= 0.95 - 0.00065 (41.8 - 15)	
		= 0.932	
	Fuel consumption	= 813.75 × 0.932	
		= 758.415	kg/hr
	Amount of charged billet	= 43 × 325/1000	
		= 13.975	
		= 14	ton/hr
	Therefore, fuel consumption	= 758.415 / 14	
	For 1 ton of billet	= 54.2	kg/ton

c) Amount of air for combustion

Theoretical amount of combustion (Ao)

(Hl = 9,801) Ao $= 12.38 \times (Hl - 1100)/10000$

$= 12.38 \times (9,801 - 1100)/10000$

$= 10.772$ M^3N/kg fuel

Air ratio (M)

O_2 % in exhaust gas $= 6.65$ %

M $= 21/(21-O_2)$

$= 21/(21-6.65)$

$= 1.46$

Actual amount of air input per kg fuel (A)

A $= M \cdot Ao$

$= 1.46 \times 10.772$

$= 15.73$ M^3N/kg fuel

Therefore, the amount of air for combustion for 1 ton of billet

$= 15.73 \times 54.2$

$= 852.6$ M^3N/ton

(b) Output amount

a) Theoretical amount of exhaust gas (Go)

Go $= [15.75 \times Hl/10,000] - 3.91$

$= [15.75 \times 9,801/10,000] - 3.91$

$= 11.350$ M^3N/kg fuel

Actual amount of exhaust gas (G)

G $= Go + (M-1)Ao$

$= 11.350 + (1.46-1) \times 10.772$

$= 16.35$ M^3N/kg fuel

Therefore, amount of exhaust gas for 1 ton billet

$= G \times$ fuel consumption

$= 16.35 \times 54.2$

$= 883.737$ M^3N/ton

b) Amount of generated scale

Generated scale (2%) = 20 kg/ton

c) Amount of discharged billet

Generated scale 20 kg per 1 ton of charged billet
The ratio of Fe by weight in scale is assumed to be 75.5 %.

$= 1 - (0.02 \times 0.755)$

$= 0.985$ ton

d) Amount of cooling water

$= 165{,}094$ kg/hr

$= 165{,}094 / 14$

$= 11{,}792.43$ kg/ton

(4) Calculation of heat input and heat output

1) Heat input

a) Combustion heat of fuel (Qc)

Hl = Hh - 600 (9h + w)

High calorific value (Hh) = 10,509 kcal/kg.fuel

h = Hydrogen content in service condition of fuel "A"

= 13 %

w = Moisture content in service condition of fuel oil "A"

= 1 %

Hl $= 10{,}509 - 600\,[(9 \times 0.13) + 0.01]$

= 9,801 kcal/kg fuel

Combustion heat of fuel per 1 ton of billet

Fuel consumption = 54.2 kg/ton

Qc $= 9{,}801 \times 54.2$

= 531,214.2 kcal/ton

b) Sensible heat of fuel (Qf)

Specific heat of heavy oil = 0.45 kcal/kg°C

Qf = Fuel consumption × Specific heat × (To-Ta)

$= 54.2 \text{ X } 0.45 \times (41.8 - 37)$

= 117.1 kcal/ton

c) Sensible heat of combustion air (Qa)

Specific heat of air	= 0.31	kcal/kg°C
Qa	= Air for combustion × Specific heat × (To - Ta)	
	= 852.6 × 0.31 × (50.1 - 37)	
	= 3,462.4	kcal/ton

d) Heat of formation of scale (Qfs)

Heat is assumed to be 1,335 kcal/kg Fe for 1 kg of Fe
Contained in scale (heat of oxidizing reaction)
The ratio of Fe is assumed to be 75.5 %

Generated scale (2 %)	= 20	kg/ton
Qfs	= 1,335 × (20 × 0.755)	
	= 20,158.5	kcal/ton

e) Total net input (Qi)

Qi	= Qc + Qf + Qa + Qfs	
	= 531,214.2 + 117.1 + 3,462.4 + 20,158.5	
	= 554,952.2	kcal/ton

2) Heat output

a) Contained quantity of heat of discharged billet (Qb)

Amount of discharged billet	= 0.985	ton
Required heat capacity from 37 °C (Charged billet)	= 4.14	kcal/kg
Required heat capacity from 1,328 °C (Discharged billet)	= 215.5	kcal/kg
Qb	= $0.985 \times 10^3 \times (215.5 - 4.14)$	
	= 208,189.6	kcal/ton

b) Sensible heat of scale (Qss)

The mean specific heat of scale	= 0.215	kcal/kg°C
Generated scale (2 %)	= 20	Kg/ton

The temperature of scale is assumed the same as the temperature of discharged billet

Charging temperature of billet	= 37	°C
Discharging temperature of billet	= 1,328	°C
Qss	= 0.215 × 20 × (1,328-37)	
	= 5,551.3	kcal/ton

c) Sensible heat of exhaust gas (Qe)

The mean specific heat of exhaust gas	= 0.33	kcal/M³N°C
Temperature of exhaust gas	= 596.2	°C
Qe	= 883.737 × 0.33 × (596.2-37)	
	= 163,081.29	kcal/ton

d) Heat taken away by cooling water (Qw)

The mean specific heat of water	= 1	kcal/kg °C
Inlet temperature of cooling water	= 30	°C
Outlet temperature of cooling water	= 34.5	°C
Qw	= 11,792.43 × 1 × (34.5 - 30)	
	= 53,065.9	kcal/ton

e) Heat radiation from furnace surface

Table 8.1.2 Heat Loss from Reheating Furnace Surface

		Temp (°C)	Surface area(m²)	Heat loss (Kcal/m²-h)	Heat loss (10^3 Kcal/h)
Heating zone	Left side	107.1	27.078	928.962	25.1525
	Right side	106.55	27.076	919.590	24.8988
	Ceiling	105.42	62.64	1,018.50	63.7988
Soaking zone	Left side	131.80	11.16	1,381.52	15.4177
	Right side	106	11.16	910.317	10.1591
	Ceiling	129	36.793	1,498.68	55.1409
Dis-charging side	Top	88.6	4.742	630.294	2.9888
	Door	390	3.952	10,997.715	43.4629
Charging side		362	7.059	9,423.876	66.5231
				Total	307.5426

Charged billet	= 14	Ton/hr
Qr	= $307.5426 \times 10^3/14$	
	= 21,967.3	Kcal/ton

f) Other heat losses (Q1)

$$
\begin{aligned}
Q1 &= Qi - (Qb + Qss + Qe + Qw + Qr) \\
&= 554{,}952.2 - (208{,}189.6 + 5{,}551.3 + 164{,}827.6 + 53{,}065.9 + 21{,}967.3) \\
&= 101{,}350.5 \quad \text{kcal/Ton}
\end{aligned}
$$

g) Total heat output (Qo)

$$
\begin{aligned}
Qo &= Qb + Qss + Qe + Qw + Qr + Ql \\
&= 208{,}189.6 + 5{,}551.3 + 164{,}827.6 + 53{,}065.9 + 21{,}967.3 + 101{,}350.5 \\
&= 554{,}952.2 \quad \text{kcal/Ton}
\end{aligned}
$$

h) Heat balance table

The data shown above are summarized in Table 8.1.3 and Figure 8.1.4

Table 8.1.3 Heat Balance of Reheating Furnace

Heat Input	Kcal/ton	%
1. Heat of Fuel Consumption	531,214.2	95.7
2. Sensible Heat of Fuel	117.1	0.02
3. Sensible Heat of Air	3,462.4	0.62
4. Heat Formation of Scale	20,158.5	3.63
Total	554,952.2	100
Heat Output	Kcal/ton	%
1. Heat of Discharged Billet	208,189.6	37.5
2. Sensible Heat of Scale	5,551.3	1.0
3. Sensible Heat of Exhaust Gas	163,081.29	29.4
4. Heat Taken Away by Cooling Water	53,065.9	9.6
5. Heat Radiation From Furnace Surface	21,967.3	4.0
6. Others	103,096.8	18.5
Total	554,952.2	100

Figure 8.1.4 Heat Balance Diagram

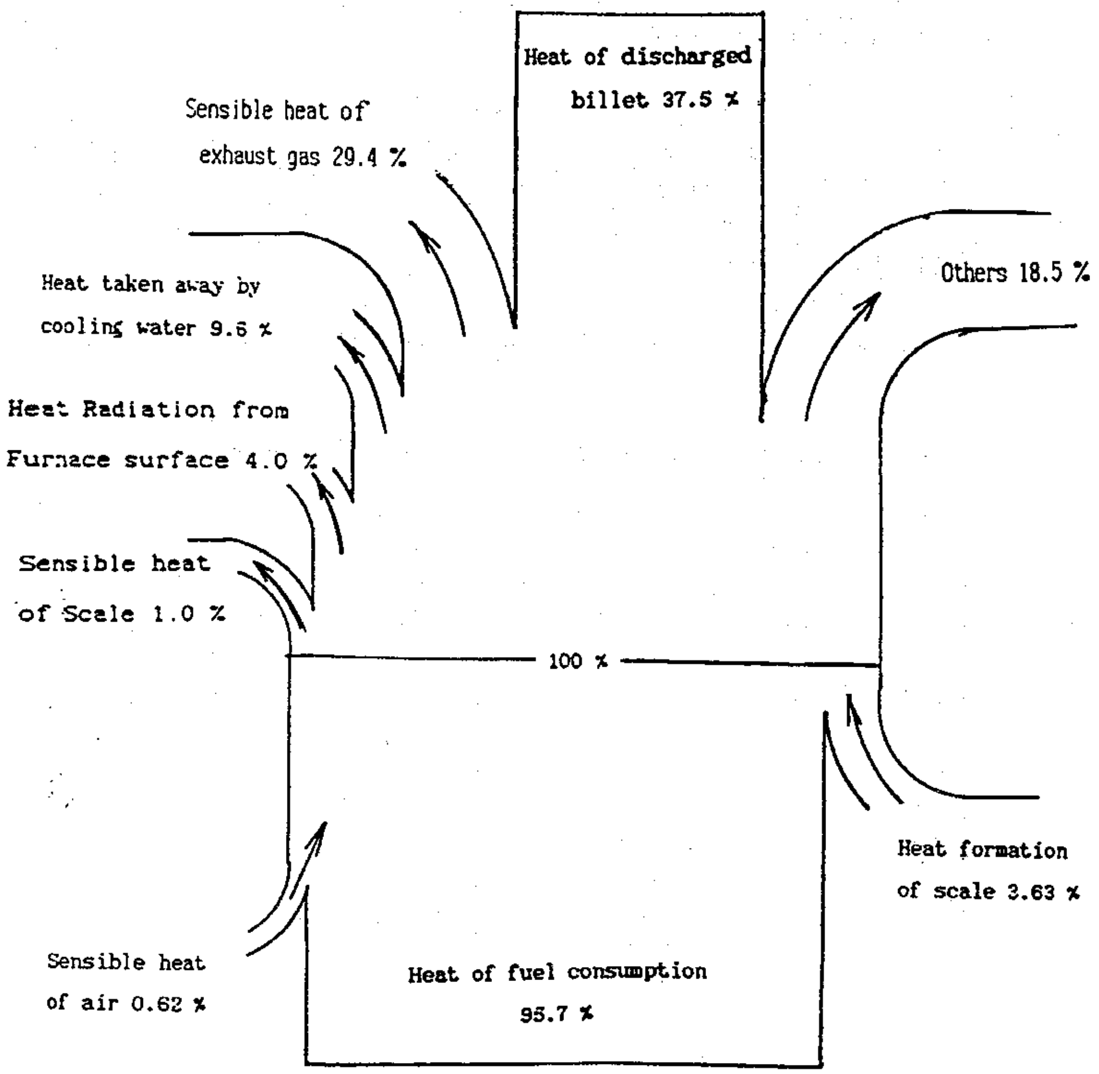


Figure 8.1.4 shows Heat Balance Diagram of Reheating.

Furnace No.3. Heat from calculation will be separated in two (2) parts as Heat Input and Heat Output.

As shown in Figure 8.1.4 :

(a) Composition of Heat Outputs will be

- Heat of discharged billet at 37.5%

- Sensible heat of exhaust gas at 29.4%
- Heat taken away by cooling water at 9.6%
- Heat radiation from furnace surface at 4.0%
- Sensible heat of scale at 1.0%
- Others at 18.5%

(b) Composition of Heat Inputs will be :

- Sensible heat of air at 0.62%
- Heat of fuel consumption at 95.7%
- Heat of formation of scale at 3.63%

It is seen that a furnace efficiency at approx. 37.5% is too low. Waste heat of exhaust gas values at approx. 29.4% is a high heat loss. The factory should consider to improve the furnace for higher efficiency, and to make use of waste heat recovery from exhaust gas. This will benefit the factory by saving a part of energy and reducing the production costs. The calculation and efficiency improvement will be shown in the next section.

8.1.3.2 Problems and countermeasures

(1) Prevention of introduction of air.
(2) Improvement of combustion condition.
(3) Prevention of heat loss from openings.
(4) Improvement in billet charging method.
(5) Implementation of measurement.
(6) Recovery of waste heat in exhaust gas.
(7) Changing to substitute "A" Heavy oil for Diesel fuel reheating of electric arc furnace body

(1) Prevention of Introduction of Air

The proportioning type burners are adopted for use in Reheating Furnace No.3. This proportioning type burner supplies all combustion air including atomized air into the burner and interlocks air adjustment with oil adjustment.

Therefore, the air ratio can be maintained with relatively high accuracy. From measuring results, the oxygen content in the exhaust gas of the reheating furnace ranged between 4% - 10% as shown in Figure 8.1.5

The fluctuation of oxygen content shown in the figure is very large and repeats itself in an interval of 1 - 2 minutes. This interval is approximately equal to the interval of discharging billet from the reheating furnace. When billet is discharged, outside air is sucked into the furnace because of minus pressure inside the furnace. Then, the oxygen content in the exhaust gas will increase and negatively affects the combustion efficiency.

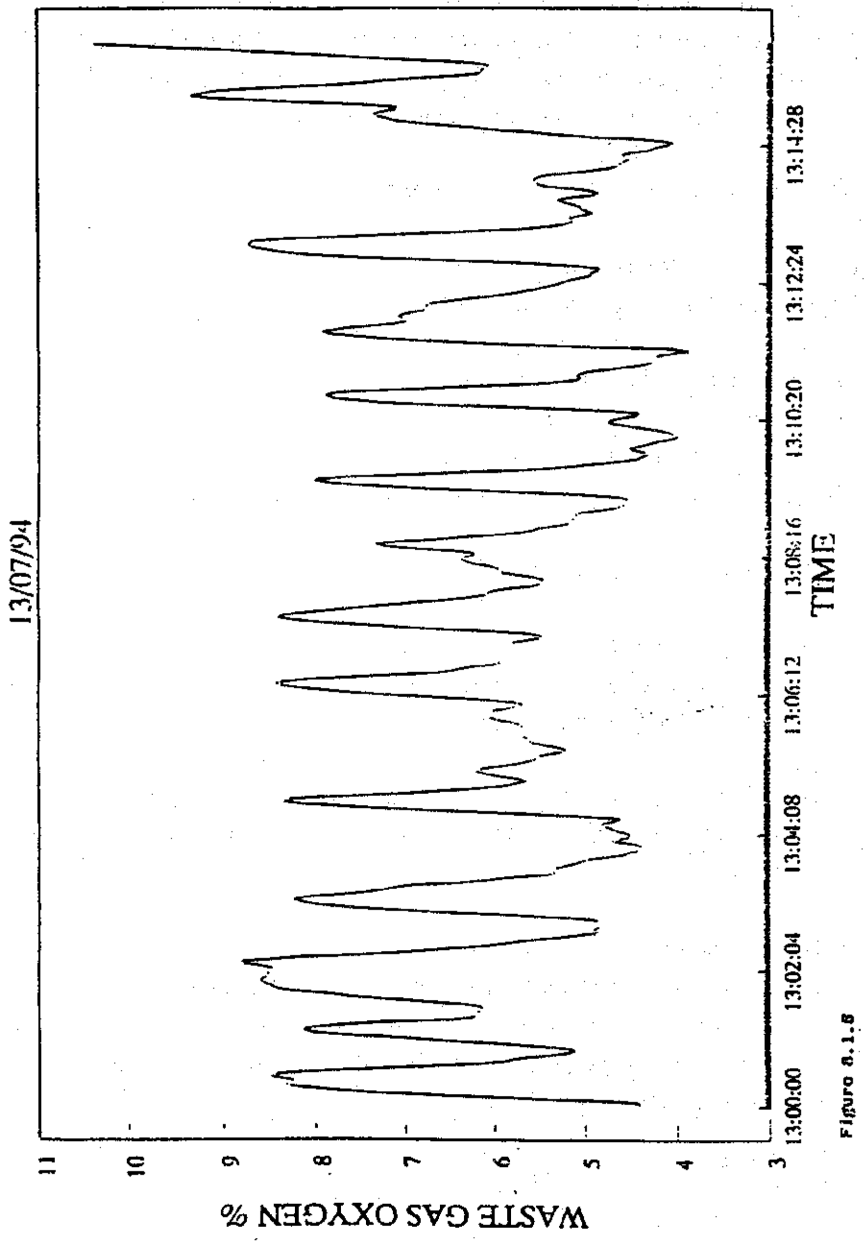
Countermeasure

1) Necessity for Pressure Control in Furnace

From the viewpoint of energy conservation, normally the hearth line pressure is always at 0.2 ~ 0.4 mm H_2O. Result from measurement indicated that, pressure inside Reheating Furnace is averaged at - 2.2 mm H_2O and the hearth line at the soaking zone is averaged at - 2.1 mm H_2O.

In the present condition, the stack of Reheating Furnace makes use of natural draft without any damper installation in the flue duct. Hence, it is unable to control pressure in the furnace. Therefore, the factory should install a damper in the flue duct to control pressure in the furnace at 0.2 ~ 0.4 mm H_2O.

Figure 8.1.5 Waste Gas Oxygen Content of Reheating Furnace #3



2) Shortening of Opening Time of Discharge Door at Billet Discharge

At the existing condition, a rolling mill operator in cockpit operates the discharging door and a pusher operator operates the pusher by signal lamp and bell from the rolling mill operator. Sometime, the opening time is left long and causes heat loss and oxygen leak into the furnace. Thus, the factory has to install a pusher unit with an interlocking device to the opening of a discharging door.

3) Results of Oxygen Reduction in Furnace

By using the above measure, the present condition of oxygen content at 6.65% can be reduced to 5%. Heat loss in the exhaust gas will reduce to 9.8%.

CHANGING O_2% FROM 6.65% TO 5% CALCULATION

From heat balance Table 8.1.3 (heat output)		
No. 3 Sensible heat of exhaust gas (Qe_1)	= 163,081.29 kcal/ton	
From 8.1.3.1 (2) Results of measurement		
O_2% of exhaust gas	= 6.65	%
Air ratio (M_1)	= 1.46	
Reducing O_2% in exhaust gas from 6.65% to 5%		
O_2% of exhaust gas	= 5	%
Theoretical amount of combustion air (A_O)	= 10.772	M^3N/kg
Air ratio (M_2)	= 1.31	
Theoretical amount of exhaust gas (G_O)	= 11.527	M^3N/kg fuel
Actual amount of exhaust gas (G_2)	= Go + (M_2-1)Ao	
	= 11.527 + [(1.31-1) × 10.772]	
	= 14.866	M^3N/kg fuel
Amount of exhaust gas for 1 ton billet	= G_2 × Fuel consumption	
	= 14.866 × 54.2	
	= 805.737	M^3N/ton
Sensible heat of exhaust gas (Qe_2)		
The mean specific heat of exhaust gas	= 0.33	kcal/kg °C
Temperature of exhaust gas	= 596.2	°C
Qe_2	= 805.737 × 0.33 × (596.2-37)	
	= 148,687.48	kcal/ton

Reduction by changing O_2% from 6.65% to 5%		
	= Qe_1-Qe_2	
	= 163,081.29-148,687.48	
	= 14,393.81	kcal/ton
Low calorific value of "A" heavy oil	= 9,801	kcal/kg
Reduced saving of "A" heavy oil	= 14,393.81/9801	
	= 1.469	kg/ton
	= 1.469/0.932	Liter/ton

	= 1.575 × 14	Liter/hr
	= 22.064	Liter/hr
	= 22.064 × 24 × 300	
	= 158,860.8	Liter/year
Reduced costs by decreasing O_2% from 6.65% to 5%		
	= 158,860.8 × 3	
	= 476,582	Baht/year

<u>Payback Period</u>

Expenditures for improvement will be costs of : electronic measuring instruments, and installation costs in total about

	= 100,000	Baht
Reduced costs by changing O_2 content from 6.65% to 5%		
	= 476,582	Baht/Year
Equipment including installation costs	= 100,000/476,582	
	= 0.2	Years

(2) Improvement of Combustion Condition

1) Presently, Reheating Furnace No.3 has 3 sets of burners at the heating zone. The factory took off 2 sets of burners while leaving one set in use which is located at the central position. This burner is bad at atomizing oil, and causes unsteady flame. The burner nozzle needs to be checked, cleaned, and adjusted periodically. The left and right holes of the taken off burners should be completely closed with fire-brick to prevent suction of air and heat loss from the furnace to the surroundings.

2) Burners at the soaking zone consist of 3 sets. It is found from the observation that the left side burner has bad nozzle setting. Burner tile is stained by carbon soot and its flame directly touches the billet. In the right way of heating, billet obtains heat by radiation from the flame and high-temperature wall. If billet is touched directly by the flame, it will cause much production of scale. The burner setting should be adjusted correctly.

(3) Prevention of Heat Loss from the Openings

1) Hot gas blowing off charging hole.

In the existing condition, the charging hole of Reheating Furnace No.3 remains open and hot gas always blows off. The specific gravity of hot gas and that of outside air are different. It results in heat loss from hot gas blowing off and in cold air suction. Thus, it effects reduction of combustion efficiency. To improve this, the factory should install a charging door or iron curtain in order to control hot gas blow off at a minimum.

2) Close the openings at the side wall of furnace.

A door hinge of the inspection hole at the side wall of the furnace is bad. So the inspection hole is partially open due to incomplete closing of the door. These cause outside air to be sucked into the furnace. The repair must be performed, and the door must be closed completely and tightly. Also some openings, and partial by open inspection hole should be closed, or plugged by fire brick.

(4) Improvement of Billet Charging Method

During our observation, we found piles of billets which were discharged via the discharge door and left on the rolling line for some times. In this condition, the lower parts of the billets get heated less. They have to be returned for recharging and lose a large mount of heat. Therefore, more careful charging operation is recommended.

(5) Implementation of Measurement

At present only the oil flow meter is installed at main oil pipe. Temperature control in the furnace is done manually by controlling the oil valves of the burners. This manual control may not be precise. It will create fluctuation of temperature inside the furnace and affects the stability of billet quality as well as energy efficiency. (see Figure 8.1.6)
Presently, the factory estimates the billet temperature visually which may not be accurate and also effects billet quality.
Temperature of the discharged billet is very high at approx. 1,300°C. Therefore, it should be reduced to 1,200°C to save energy.
The factory should consider installing the necessary measuring instruments to measure for examples furnace pressure, furnace inner temperature both at the heating zone and the soaking zone, as well as oil flow at both zones. Installation of such instruments will enable accurate control of temperature inside the furnace. Measuring instruments for oxygen content and temperature of the exhaust gas should be in use as well.
For reference, a typical example of a reheating furnace equipped with automatic proportioning control for air-fuel ratio is given in Figure 8.1.7

(6) Recovery of Waste Heat in Exhaust Gas

Recovery of waste heat in the exhaust gas not only yields advantage from waste heat utilization but also results in lower temperature of the exhaust gas at the stack.

Figure 8.1.6 Furnace Gas Temperature of Reheating F'ce #3

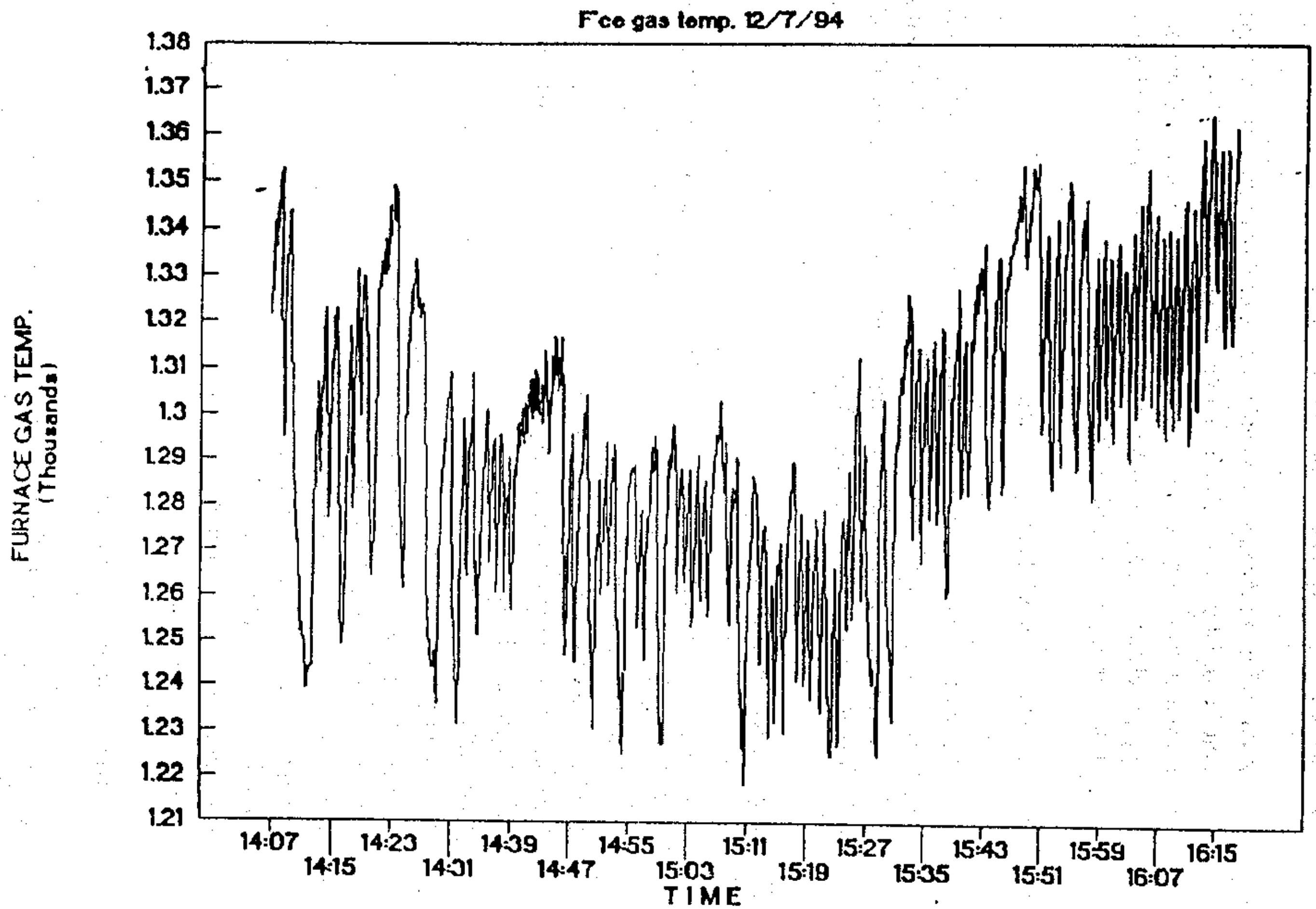
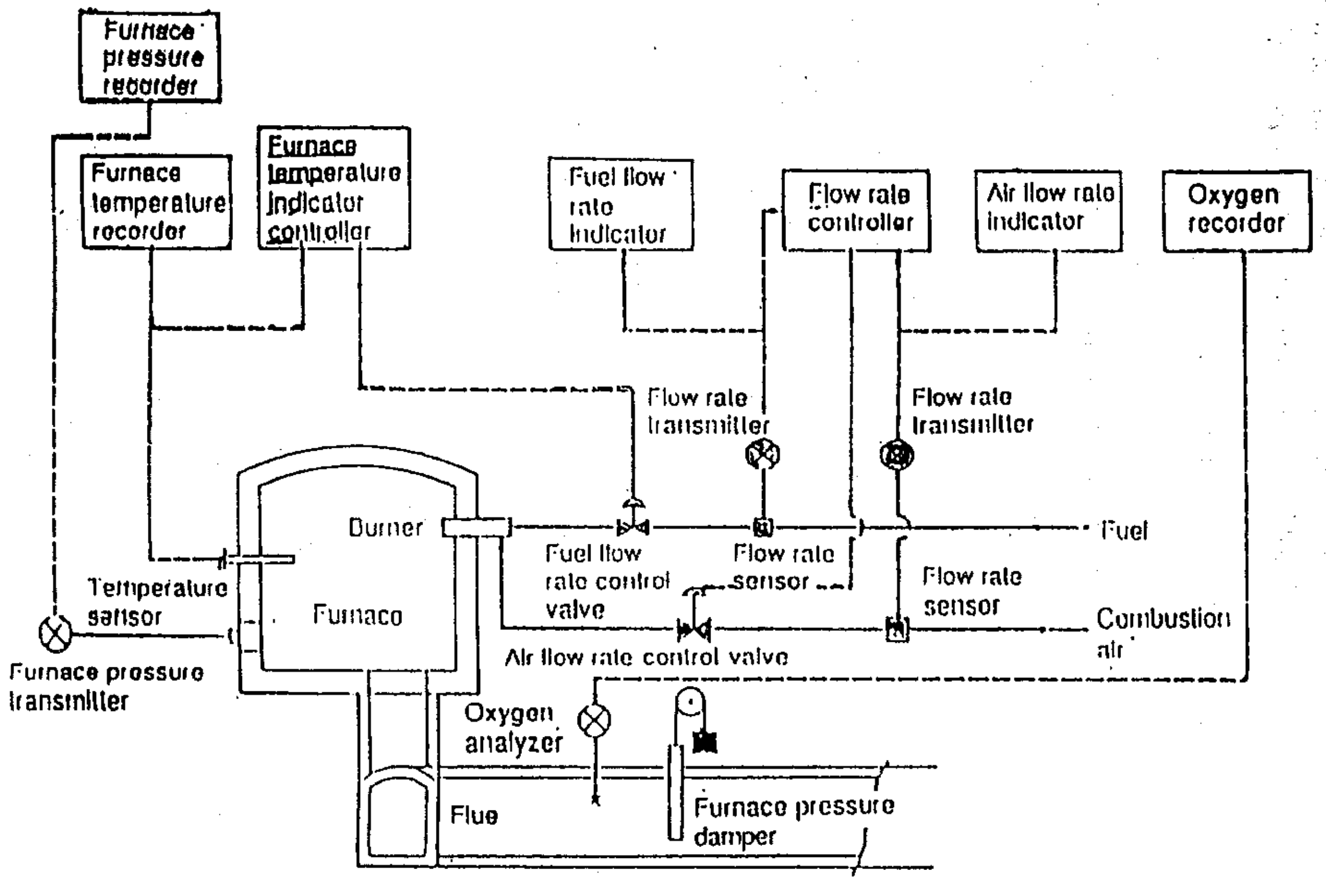


Figure 8.1.6

Figure 8.1.7 Air/Fuel Ratio Control System with a Flow Rate Controller



At present, little space around the stack of Reheating Furnace No. 3 is available to install a recuperator since it needs sizable space. But, in the near future if the factory considers expansion, a consideration should be made to installing recuperator together with a new reheating furnace.

See a recuperator installation in Figure 8.1.8

Table 8.1.4 Data for Heat Recovery Calculation

Item	unit	data
Fuel oil after improvement	Kg/ton	51.9
Air ratio		1.31
Theoretical combustion air	M^3N/kg	10.772
Theoretical exhaust gas	M^3N/kg	11.527
Actual amount of air (A)	M^3N/kg	14.11
Actual amount of exhaust gas(G)	M^3N/kg	14.87
Ambient temperature (T1)	°C	37
Exhaust gas temperature (T2)	°C	596.2

Air outlet temperature for the proposed heat exchanger is set at 200 °C

From Table 8.1.4,

Heat quantity recovered by preheated air (P)

$P = A \times Cpa \times (T1 - T2)$
$= 14.11 \times 0.31 \times (200 - 37)$
$= 713$ kcal / kg fuel

Exhaust gas temperature after installing recuperator (Y)

$713 = 14.87 \times (596.2 - Y)$
$Y = 451$ °C

The fuel conservation rate (S) from using preheated air

$S = [P/(F + P - Q)] \times 100$
P = Quantity of heat recovered by preheated air
= 713 kCal/kg fuel
F = Low calorific value of fuel
Q = Quantity of heat taken away by exhaust gas

The mean specific of exhaust gas = 0.33 kcal/kg

$Q = 14.87 \times 0.33 \times (451 - 37)$
$= 2{,}032$ kcal/kg. fuel
$S = [713 / (9{,}801 + 713 - 2{,}032)] \times 100$
$= 8.4\%$

Therefore, the amount of fuel saving per ton of billet

= 4.4 kg/ton

= 4.72 litres/ton

If billets at 100,800 tons/year are annually produced,

(14 ton × 24 hr × 300 days)

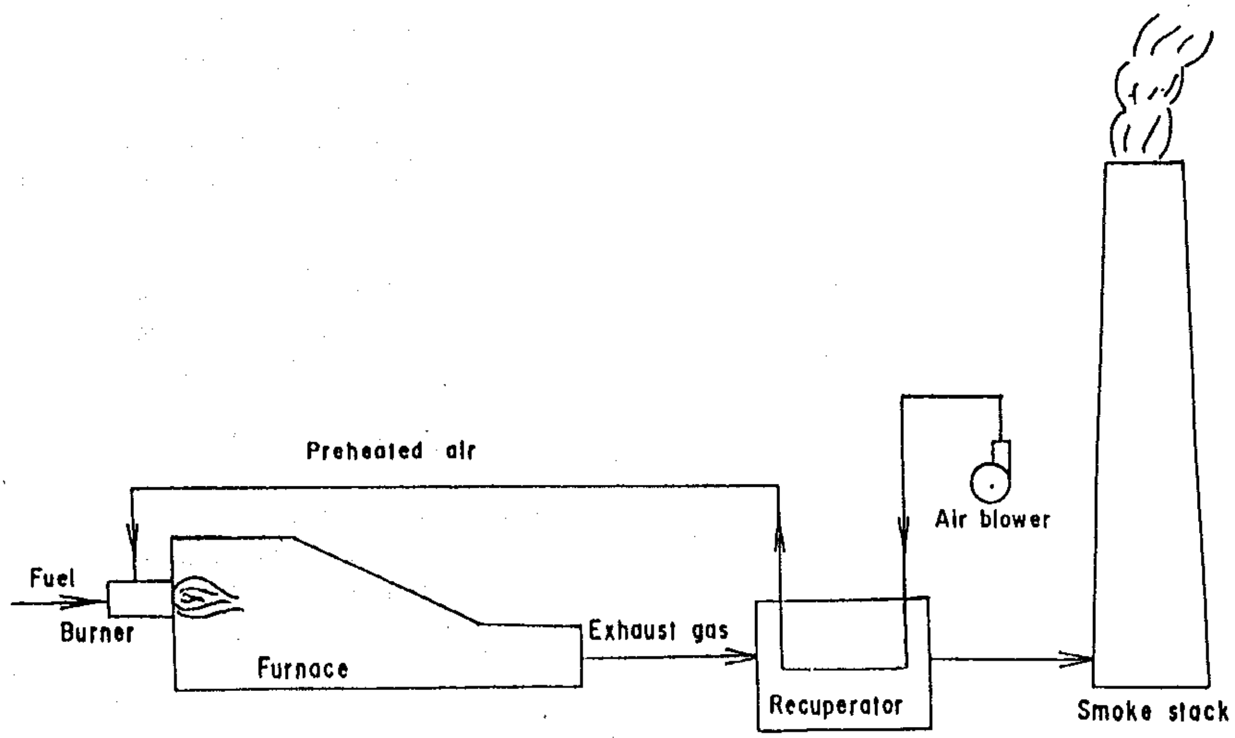
the amount of fuel saving per year will be :

= 3 Baht/litre × 4.72 litres/ton × 100,800 tons/year

= 1,427,328 Baht/year

Note: The amount of money calculated from recovery of waste heat in exhaust gas does not include the equipment and installation costs for this arrangement.

Figure 8.1.8 Reheating of Air for Burning



(7) Changing to "A" Heavy Oil from Diesel Fuel for Preheating of Electric Arc Furnace

When changing to "A" heavy oil from diesel fuel for preheating of electric arc furnace body, expenditures for improvement will consist of : burner, electric oil preheater, air compressor, fuel pump, and the installation costs that come to a total of approx. 300,000 Baht.

Calculation of cost saving

Unit price for "Diesel fuel"	= 8	Baht/Litre
Unit price for "A" Heavy oil	= 3	Baht/Litre
Reduced cost	= 5	Baht/Litre

Fuel consumption per annum for preheating electric arc furnace body

Fuel consumption	= 1,300	Litre/day
(300 Days/year)	= 1,300 × 300	
	= 390,000	Litre/year
Cost saved	= 390,000 × 5	Baht/year
	= 1,950,000	Baht/year

Calorific value required for increasing oil temperature from 37 °C to 90 °C
Currently "A" heavy oil is preheated at 90 °C

Heat required to raise temperature	= Fuel consumption (l/y)	
	× Specific heat (kKcal/kg °C)	
	× Density × (To-Ta)	
	= 390,000 × 0.45 × 0.936 × (90-37)	
	= 8,706,204	kcal/year

Fuel costs for preheating oil temperature

Converted to electricity	= 8,706,204/860	kWh/year
(1 kWh = 860 kcal)	= 10,123.5	kWh/year
Unit price for electricity	= 1.504	Baht/kWh
Electricity costs	= 10,123.5 × 1.504	
	= 15,226	Baht/year

Reduced costs by changing to use "A" heavy oil instead of diesel fuel

	= 1,950,000-15,226	Baht/year
	= 1,934,774	Baht/year

Payback Period

Reduced costs by changing from diesel fuel to heavy oil "A"

	= 1,934,774	Baht/year
Equipment including installation costs	= 300,000	Baht
Payback Period	= 300,000/1,934,774	Year
	= 0.15	Year

8.1.3.3 Circumstance of Electric Power Consumption

Transformer and factory layout is shown in Figure 8.1.9. The electric power of this factory is very high therefore, receiving voltage from MEA is 69 kV. Two transformers of 30 MVA and 15 MVA, 69/12 kV are installed at substation and the others are shown in Figure 8.1.10(a)-8.1.10(f).

(1) Electric power consumption in each division

The main facilities from factory layout can be divided into 11 divisions. The electric power measuring in each division is shown in Table 8.1.5.

Table 8.1.5 Electric Power Consumption of Each Division

Measuring Date : July 11-13, 94

No	Division	TR No	Rating kVA	Rating Volt	Measuring kW	Measuring kVA	Measuring Volt	PF
1	Electric Arc Furnace	1	22,000/ 26,000	400	22,915	25,500	420	0.900
2	EAF Plant & Air Comp.	2	750	400	264.8	383	390	0.690
3	Oxygen & CCM Plant	3	1,000	400	590.3	706	400	0.840
	(1) Oxygen Plant (Cooling Tower, Pump)			400	17.4	34	396	0.518
	(2) CCM Indirect Cooling water treatment (A,B)			400	572.9	672	385	0.852
4	Dust Collector	4	3,000	3,300	1,131.8	1,258	3,300	0.900
5	Oxygen Plant (Vacuum Pump, O_2 gas comp.)	5	1,000	3,300	412.9	486	3,300	0.850
6	CCM Plant	6	1,000	400	172.1	308	405	0.560
7	Rolling Mill Plant#3	7	1,000	400	346.0	673	368	0.510
8	Rolling Mill Plant#3	8	3,000	3,300	1,795.2	2,063	3,300	0.870
9	Rolling Mill Plant#2	9	1,000	400	158.4	203	400	0.780
10	Rolling Mill Plant#2	10	3,000	3,300	1,851.8	1,829-2,286	3,300	0.900
11	Rolling Mill Plant 1	11	1,250	400	531.8	485-696.8		0.900

Figure 8.1.9 Factory and Transformer Layout

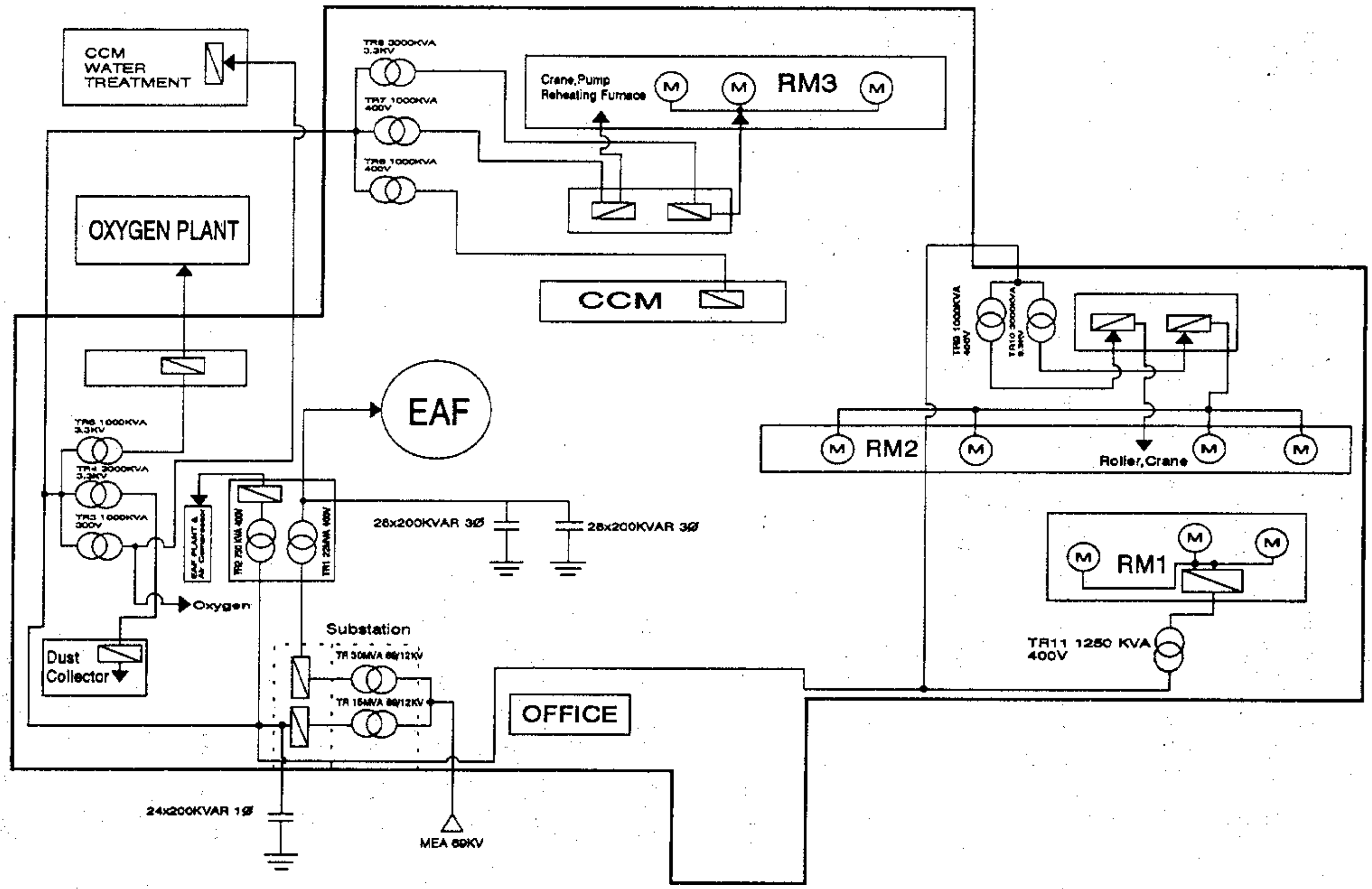


Figure 8.1.10 (a) Single Line Diagram

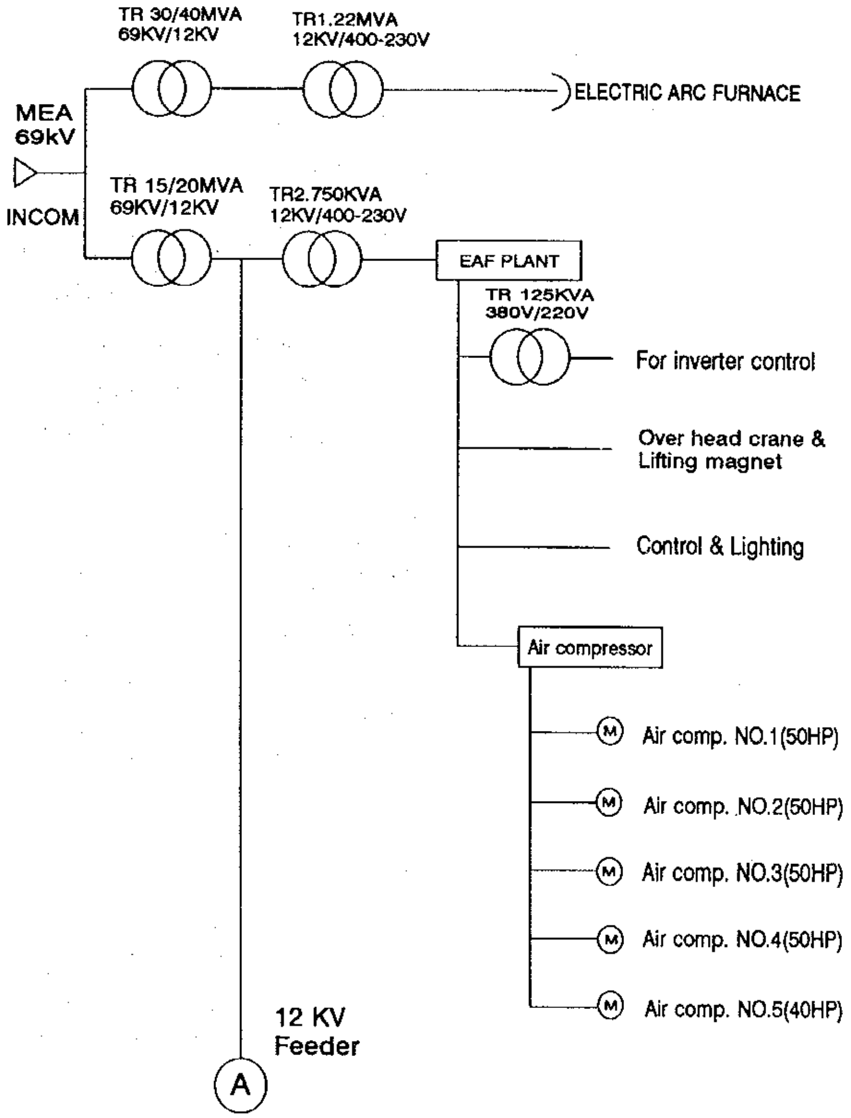


Figure 8.1.10 (b) Single Line Diagram

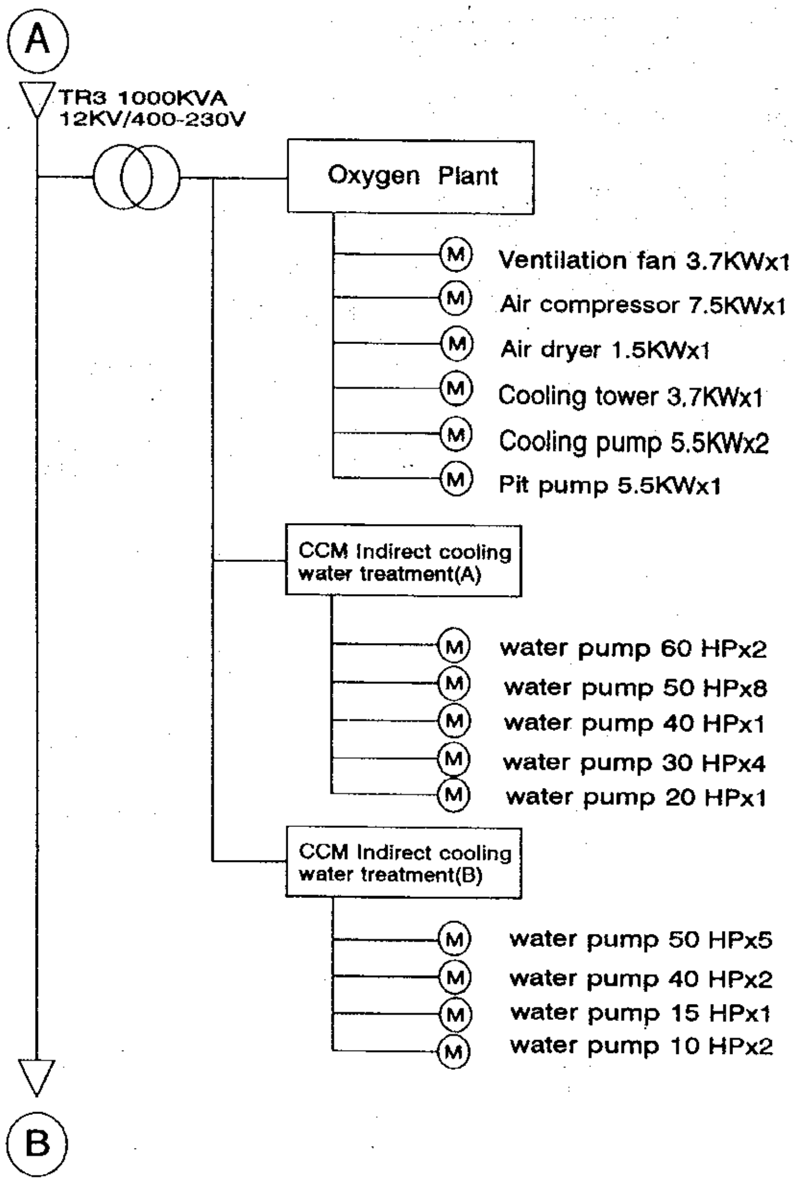


Figure 8.1.10 (c) Single Line Diagram

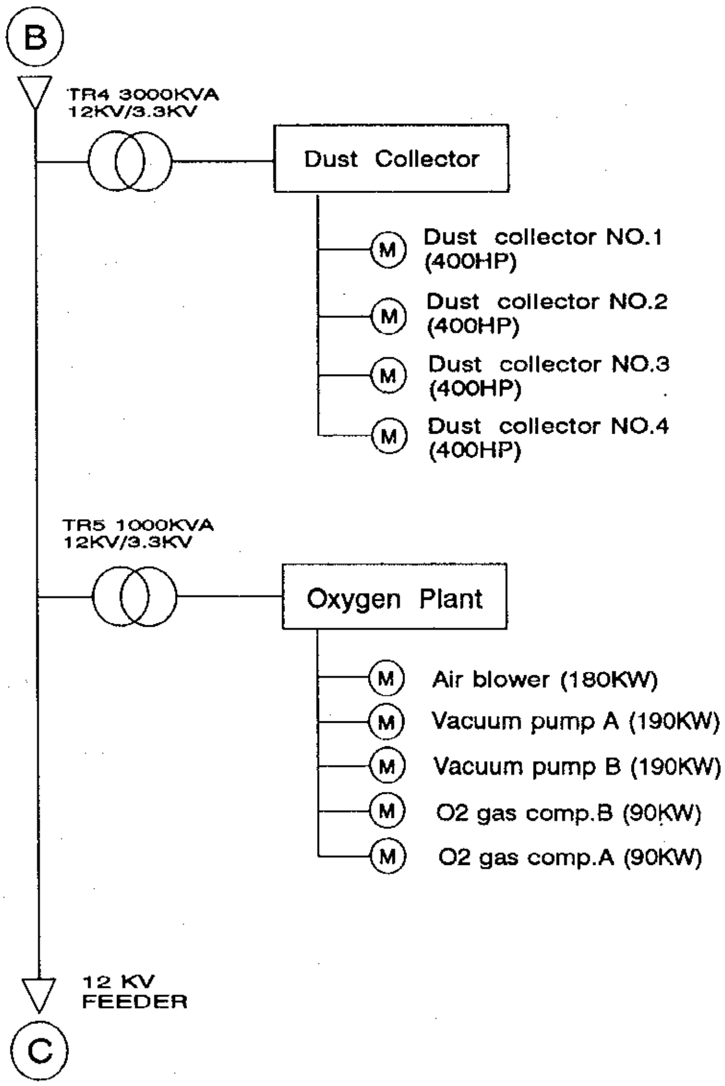


Figure 8.1.10 (d) Single Line Diagram

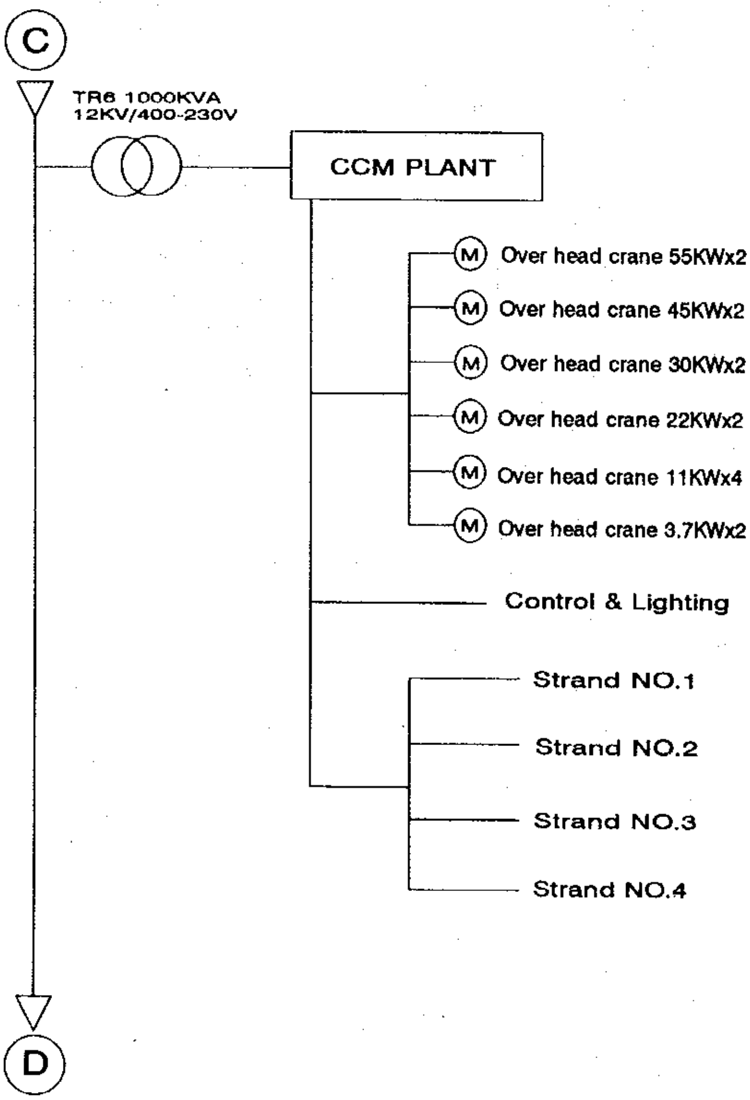


Figure 8.1.10 (e) Single Line Diagram

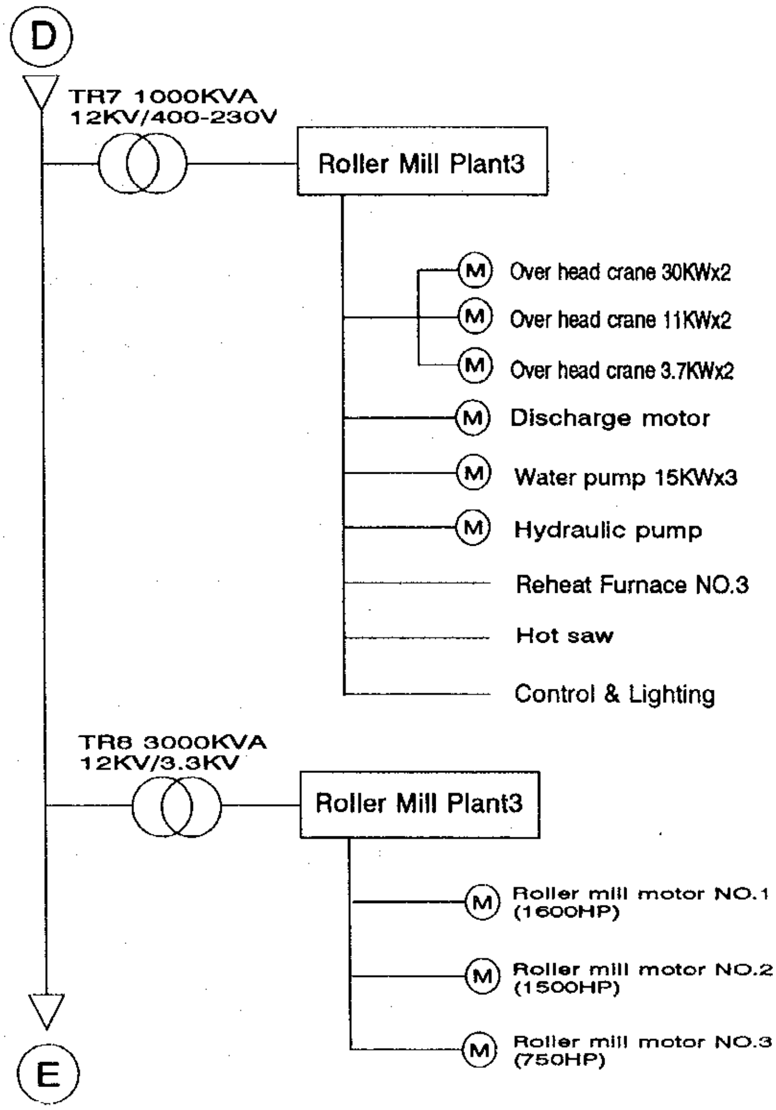
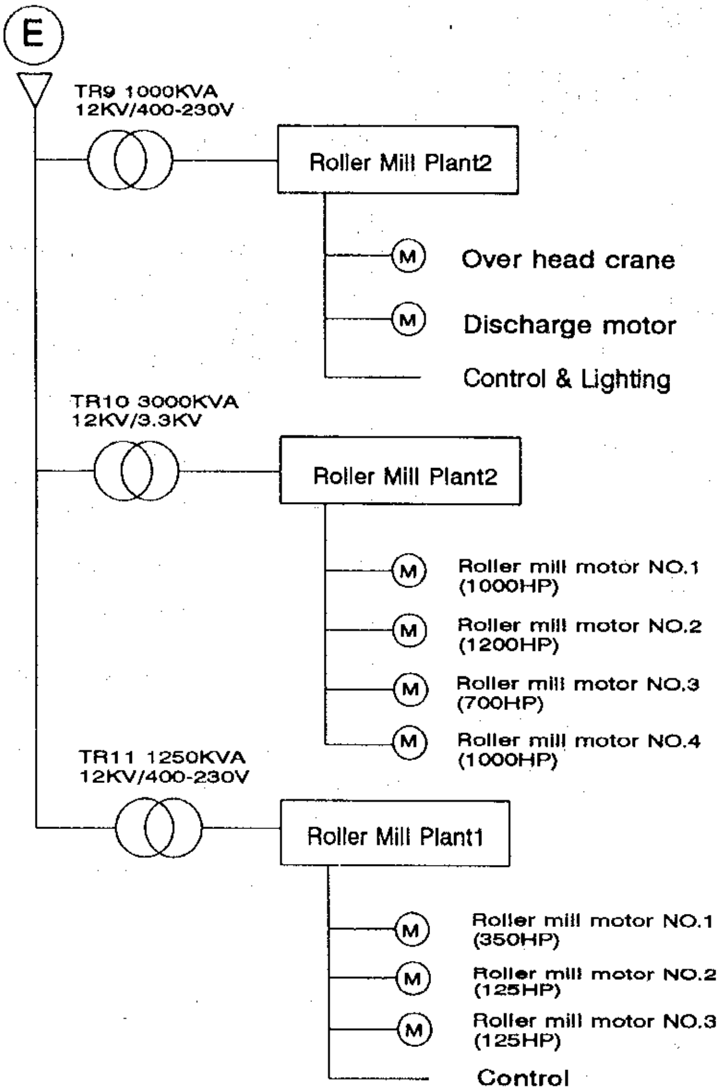


Figure 8.1.10 (f) Single Line Diagram



From Table 8.1.5, Measuring voltage of Rolling Mill Plant 3 is too low, 368 volt.

On the second visit to Triumph Steel factory, the teams collected additional data of each transformer as shown in Table 8.1.6.

Table 8.1.6 Rating and Measuring Load of Each Transformer

Measuring Date : Aug 5, 94

Tr No.	Rating kVA	Rating Volt	kW	Measuring V_L (V)	Measuring V_P (V)	Measuring I_p (A)	Line Size (Sq.mm)	Line Qnt./phase	Line Length (m)
2	750	400	231	379	220	443	Na	Na	0
				377	220	471			
				380	221	471			
3	1,000	400	24.1	401	226	49.1	50	3	120
				402	226	58.1			
				399	226	57.2			
3	1,000	400	487	404	235	837	185	3	40
				403	235	899			
				405	235	868			
6	1,000	380	172.1	401	Na	366	240	3	200
				415	Na	493			
				400	Na	458			
7	1,000	400	335	369	Na	959	185	4	150
				368	Na	1,017			
				368	Na	1,029			
9	1,000	380	256	363	Na	632	30	2	185
				360	Na	590			
				363	Na	643			
11	1,250	400	Na	Na	Na	Na	25	4	185

The voltage measured at the main distribution board of transformer No. 7 and No. 9 is too low, 368 and 363 volt respectively. Then the adjustment of increasing transformer tap is recommended.

(2) Result of measurement of major load

Electric Arc Furnace consumes the most of electric demand, 76%. The load at 25,500 kVA is nearly transformer rated 12 kV/400V and 22/26 MVA. The load of other transformers (3,000, 1,250, 1,000 and 750 kVA) is low power factor. The operating state of motors is shown in the table 8.1.7 (1), 8.1.7(2) and 8.1.7(3).

Table 8.1.7 (1) Operating State of Electric Load

Measuring Date : July 11-13, 94

Division	Load	Rating			
		kW	Hp	Volt	Speed
EAF Plant					
	- Air Compressor#1		50	380	1,460
	- Air Compressor#3		50	380	1,460
	- Air Compressor#4		50	380	1,460
	- Air Compressor#5		50	380	1,460
CCM (A)					
CCM (B)					
Roller Mill Plant#1 Main					
	- Roller Mill Motor #1		350	380	588
	- Roller Mill Motor #2		125	380	1,590
	- Roller Mill Motor #3		125	380	1,590
Roller Mill Plant#2					
	- Motor & Crane				
Roller Mill Plant#2					
	- Motor Roller Mill #1		1,000	3,300	
	- Motor Roller Mill #2		,200	3,300	
	- Motor Roller Mill #3		700	3,300	
	- Motor Roller Mill #4		1,000	3,300	
Roller Mill Plant#3					
	Main Water Pump	15*3			
	- Water Pump #1	15		380	1,655
	- Water Pump #215		380	1,655	
	- Water Pump #3	15		380	1,655
Roller Mill Plant#3					
	- Motor Roller Mill #1		1,600	3,300	
	- Motor Roller Mill #2		1,500	3,300	
	Dust Collector No. 1 - 4		400*4	3,300	

Table 8.1.7 (2) Operating State of Electric Load

Measuring Date : July 11-13, 94

Division	Load	kW	KVA	Volt	Ir (A)	Is (A)	It (A)	PF
EAF Plant								
	- Air Compressor#1	35.0	36	393	53.1	53.6	53.9	0.968
	- Air Compressor#3	37.7	40	397	58.0	59.2	59.0	0.945
	- Air Compressor#4	29.7	34	393	49.7	50.2	50.0	0.872
	- Air Compressor#5	24.4	28	382	42.5	42.5	42.0	0.878
CCM (A)		313.0	388	383	540	534	531	0.807
CCM (B)		259.9	288	387	477	423	429	0.904
Roller Mill Plant#1 Main			485~ 692.8		no load		loaded	
	- Roller Mill Motor#1		138.6~ 554.3	400	200		400-800	
	- Roller Mill Motor#2		69.3~ 173.2	400	100		250	
	- Roller Mill Motor#3		34.6~ 124.7	400	50		180	
Roller Mill Plant#2								
	- Motor & Crane	158.4		377	313	300	307	0.78
Roller Mill Plant#2			1,829~ 2,286		no load		loaded	
	- Motor Roller Mill#1		285.8~ 571.6	3,300	50		80-100	
	- Motor Roller Mill#2		342.9~ 685.9	3,300	60		120	
	- Motor Roller Mill#3		285.8~ 771.6	3,300	50		135	
	- Motor Roller Mill#4		457.3~ 971.7	3,300	80		170	
Roller Mill Plant#3								
	Main Water Pump	46		387	79.9	77.9	77.9	0.87
	- Water Pump#1	14.74		387	26.4	26.4	26.4	0.83
	- Water Pump#2	14.74		387	26.6	26.6	26.6	0.83
	- Water Pump#3	14.74		387	26.6	26.6	26.6	0.83
Roller Mill Plant#3								
	- Motor Roller Mill#1		905.4	3,300				
	- Motor Roller Mill#2		1,118.0	3,300				

Table 8.1.7 (3) Operating State of Electric Load

Measuring Date : July 11-13, 94

Division	Load	Measuring						
		kW	KVA	Volt	Ir (A)	Is (A)	It (A)	PF
Dust Collector								
	- Dust Collector#1		285.8	3,300		50		
	- Dust Collector#2		240.1	3,300		42		
	- Dust Collector#3		308.7	3,300		54		
	- Dust Collector#4		411.5	3,300		72		

At EAF plant, power factors of air compressor No. 1 and No. 3 are too high. It can recommend that there are errors indicating vibration of timing.

At Roller Mill Plant#2, the highest range of two motor roller No. 3 and No. 4 are over rating KVA, at peak load.

At the second visit to the factory, the teams collected additional data of motor pump as shown in Table 8.1.8.

Table 8.1.8 Rating and Measuring of Motor Water Pump From CCM

Measuring Date : Aug 5, 94

No	Rating				Measuring						
	Hp	Volt	Hz	A	kW	V_{rs} (V)	V_{rt} (V)	V_{st} (V)	Ir (A)	Is (A)	It (A)
1	30	380	50	21.0/43.4							
2	50	380	50	68	45.2	370	369	371	84.5	82.8	81.0
3	40	380	50	33.7/58.5							
4	30	380	50	41							
5	60	380	50	86	41.7	366	368	366	72.8	72.6	69.2

The voltage of motor pump is quite low. The efficiency of induction motor will be reduced.

8.1.3.4 Problems, countermeasures and effect in electric power

(1) Electric Arc Furnace (EAF)

Most of electric energy consumption of Triumph Steel manufacture is used in electric arc furnace, so the study should be concentrated on production time and electric energy consumption.

1) EAF Improvement

The data of melting time, scrap charging number, volume and power consumption are collected from EAF operating record of the double visit by JICA and DEDP staffs. The method of analyzing these data is statistical method. The relation between melting time, charging and energy consumed can be summarized in the items below;

(a) According to the data on June 23 to 25, 1993, the relation between melting time and melting power consumption is shown in Table 8.1.9, and Figure 8.1.11.

This relation is explained in the next revolution formula.

$$Y = 1.3536x + 39.1466$$

Y = power consumption ('00 KWH)
x = melting time (min)

This relation has a meaning of out probability 0.5%.

Table 8.1.9 The Relation between Melting Power Consumption and Melting Time

Date	No	Melting Time (min)	Electric Consumption '00 kWh	Calculation				
		x	y	u = x −45	v = y − 100	u^2	v^2	uv
25/6/94	1	54	138	9	38	81	1444	342
	2	46	111	1	11	1	121	11
	3	60	124	15	24	225	576	360
	4	45	86	0	−14	0	196	0
	5	51	104	6	4	36	16	24
	6	48	110	3	10	9	100	30
	7	54	114	9	14	81	196	126
	8	60	115	15	225	225	225	
24/6/94	9	44	109	−1	9	1	81	−9
	10	42	91	−3	−9	81	27	
	11	46	110	1	10	1	100	10
	12	46	112	1	12	1	144	12
	13	36	86	−9	−14	81	196	126
	14	49	107	'4	7	16	49	28
	15	43	102	−2	2	4	4	−4
	16	50	90	5	−10	25	100	−50
	17	45	61	0	−39	0	1521	0
	18	61	116	16	16	256	256	256
	19	41	98	−4	−2	16	4	8
	20	47	109	2	9	4	81	18
23/6/94	21	53	101	8	1	64	1	8
	22	46	116	1	16	1	256	16
	23	43	107	−2	7	4	49	−14
	24	42	94	−3	−6	9	36	18
	25	32	83	−13	−17	169	289	221
	26	39	97	−6	−3	36	9	18
	27	29	74	−16	−26	256	676	416
	28	50	93	5	−7	25	49	−35
	29	45	109	0	9	0	81	0
	30	41	87	−4	−13	16	169	52
	31	47	102	2	2	4	4	4
	Total n =	31	Σ	40	56	1656	7110	2244

$\overline{U} = 1.2903$ $\overline{X} = 46.290355$

$\overline{V} = 1.8065$ $\overline{Y} = 101.8065$

Su = 1,656 - 51.61290	= 1,604.3871		Sx =	1,604.3871
Sv = 7,110 - 101.1612	= 7,008.8387		Sy =	7,008.8387
Suv = 2,244 - 72.2581	= 2,171.7419		Sxy =	2,171.7419

b = 1.3536

y - 101.8065 = 1.3536 (x - 46.2903)

y = 1.3536x + 39.1466

Sxy^2/Sx = 2,939.7288

square root of SxSy = 3,353.3402

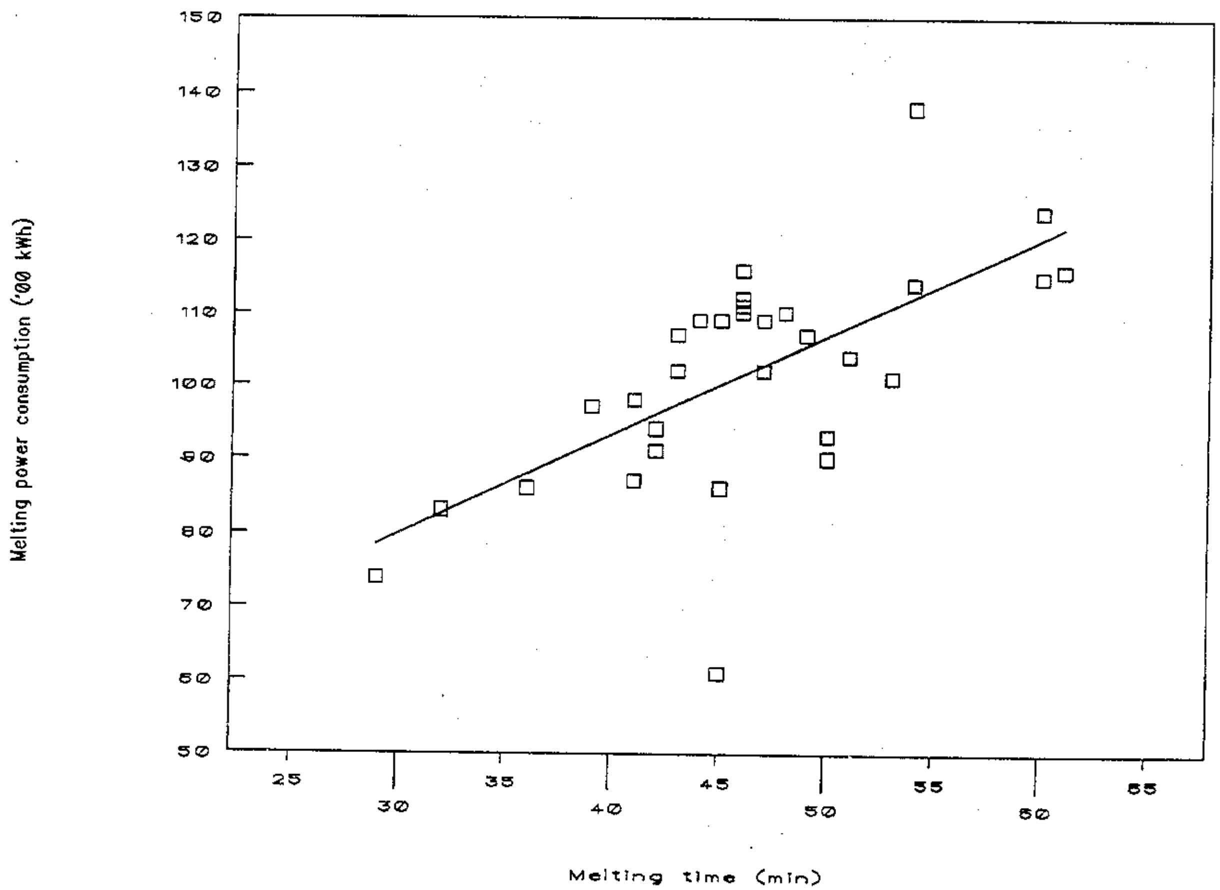
therefore,

r = 0.647635 r = correlation factor

r^2 = 0.42 r^2 = contribute factor

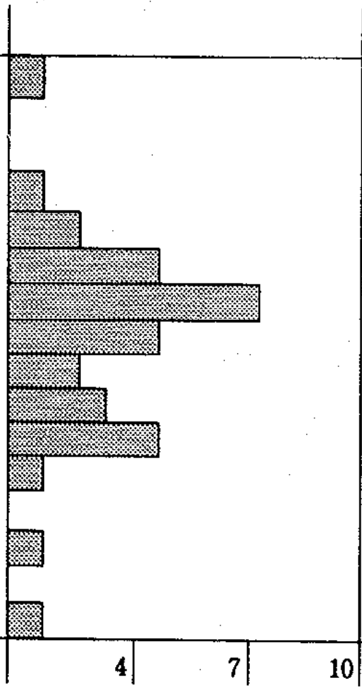
Fluctuation	Sum of square	Freedom	Impartial Variance	Impartial Variance Ratio	Remark
Revolution	2,939.7288	1	2,9393.7288	20.951	F^1_{29}(0.005) =
Rest	4,069.1099	29	140.3141		9.23<20.951
Total	7,008.8387	30			

Figure 8.1.11 The Relation between Melting kWh and Melting Time



Melting power used in EAF is shown in Table 8.1.10.

Table 8.1.10 Melting Power Consumption Distribution



Range KWH	Frequency	Sum	%
135.1 ~ 140	1	31	
130.1 ~ 135			
125.1 ~ 130			
120.1 ~ 125	1	30	96.8
115.1 ~ 120	2	29	93.6
110.1 ~ 115	4	27	87.1
105.1 ~ 110	7	23	74.2
100.1 ~ 105	4	16	51.6
95.1 ~ 100	2	12	38.7
90.1 ~ 95	3	10	32.3
85.1 ~ 90	4	7	22.6
80.1 ~ 85	1	3	9.7
75.1 ~ 80	0	2	6.5
70.1 ~ 75	1	2	6.5
65.1 ~ 70	0	1	3.2
60.1 ~ 65	1		

All data is plotted in probability sheet as shown in Figure 8.1.12. Melting time distribution is shown in Figure 8.1.13.

From this distribution curve, there are two trends appearing. The way to limit melting power is to approach line 1 and try to operate at low percentage.

Figure 8.1.12 Melting Power Consumption Distribution

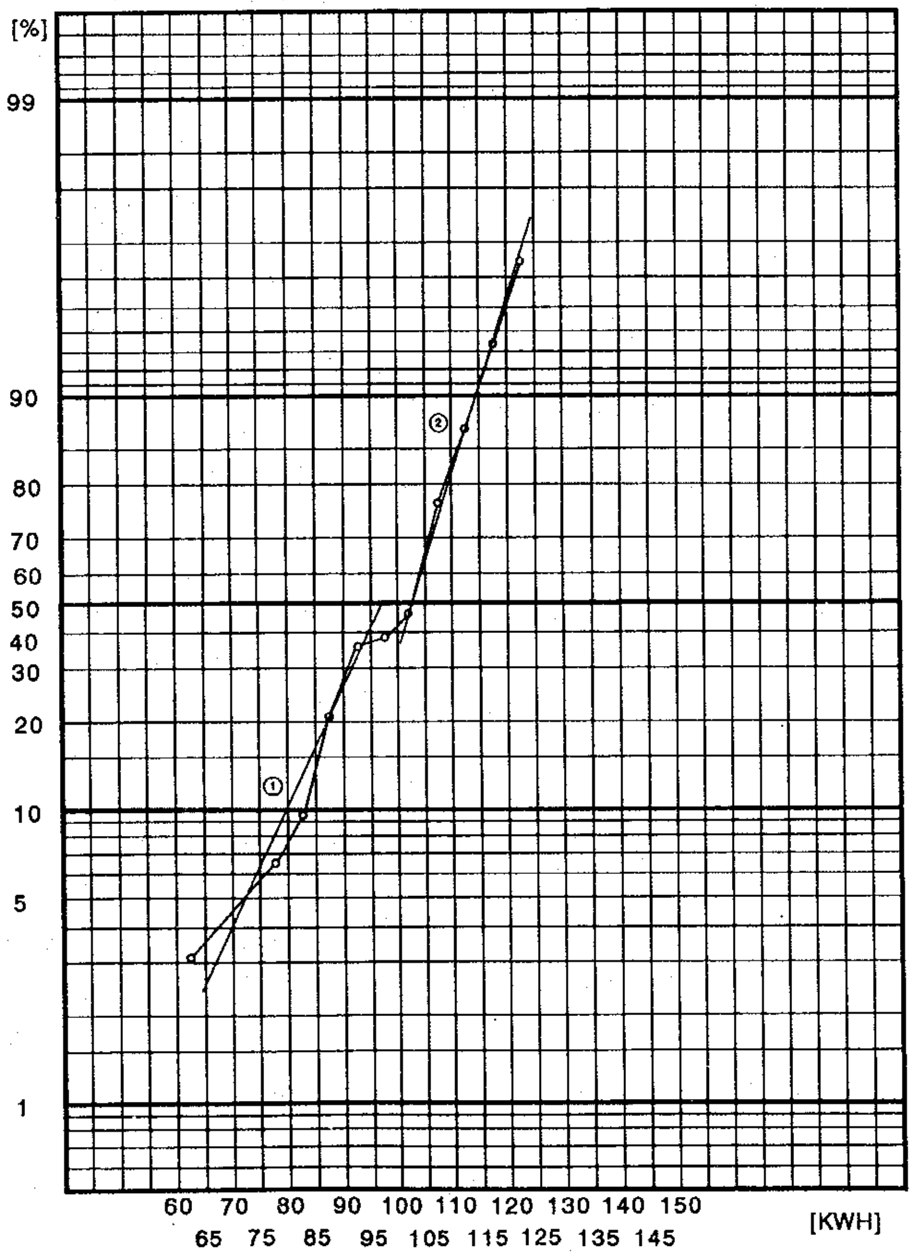
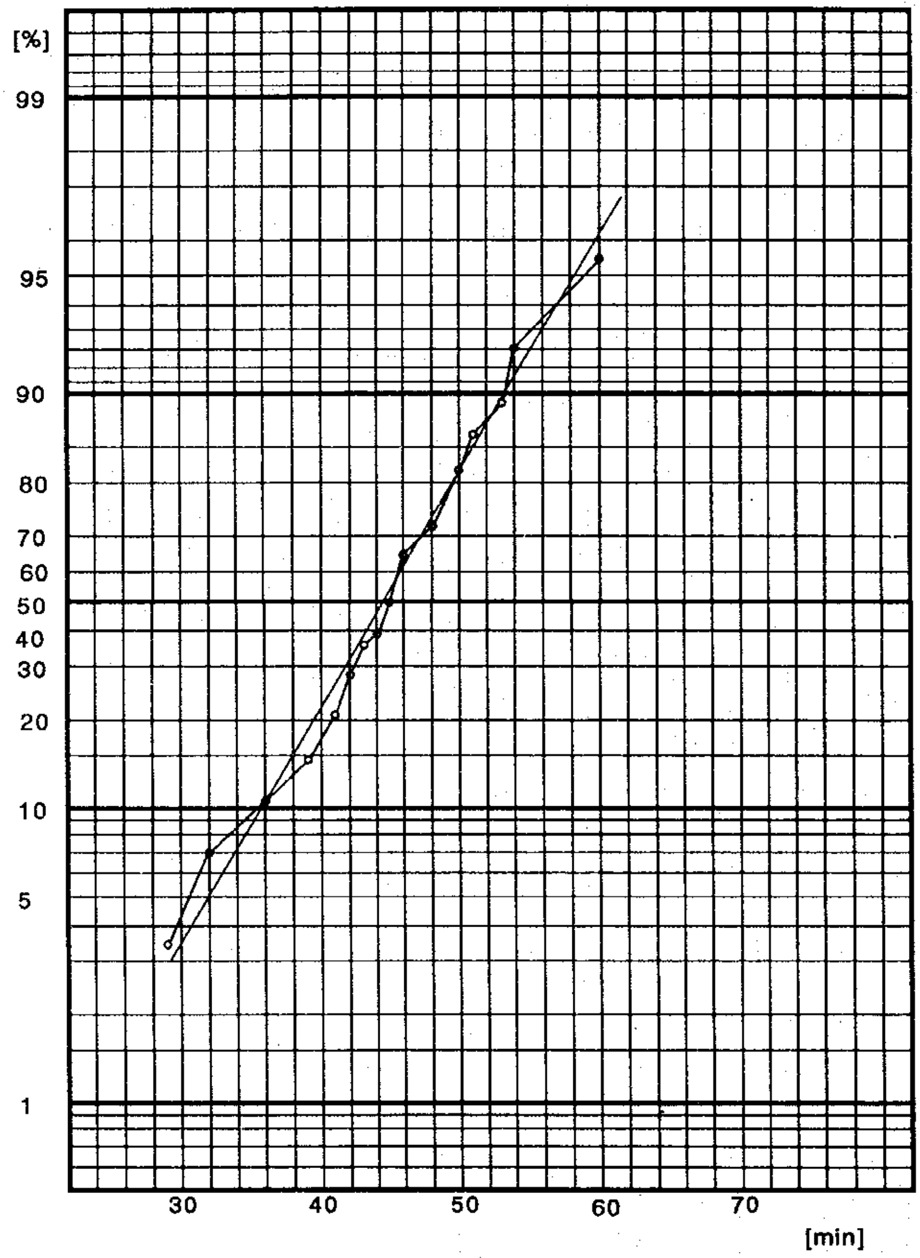


Figure 8.1.13 EAF Melting Time Distribution



(b) According to the data on June 23 to 25, 1994, the relation between oxidizing·slag off·refining time and electric power consumption is shown in Table 8.1.11 and Figure 8.1.14.

This relation is explained in the next revolution formula.

Y = 1.1684x + 38.3964
Y = power consumption ('00 KWH)
x = time (min)

This relation has a meaning of out probability 0.5 %.

Table 8.1.11 The Relation between Power Consumption and Oxidizing-Slag Off-Refining Time

Date	No	Ox, S1, Re Time (min) x	Electric Consumption '00 kWh y	Calculation u = x – 30	v = y – 70	u^2	v^2	uv
25/6/94	1	34	87	4	17	16	289	68
	2	21	58	–9	–12	81	144	108
	3	23	67	–7	–3	49	9	21
	4	44	60	14	–10	196	100	–140
	5	23	60	–7	–10	49	100	70
	6	22	55	–8	–15	64	225	120
	7	24	68	–6	–2	36	4	12
	8	39	90	9	20	81	400	180
24/6/94	9	25	64	–5	–6	25	36	30
	10	16	42	–14	–28	196	784	392
	11	29	71	–1	1	1	1	–1
	12	28	83	–2	13	4	169	–26
	13	30	104	0	34	0	1156	0
	14	30	80	0	10	0	100	0
	15	27	70	–3	0	9	0	0
	16	31	50	1	–20	1	400	–20
	17	50	83	20	13	400	169	260
	18	19	51	–11	–19	121	361	209
	19	36	97	6	27	36	729	162
	20	27	75	–3	5	9	25	–15
23/6/94	21	21	54	–9	–16	81	256	144
	22	31	71	1	1	1	1	1
	23	22	67	–8	–3	64	9	24
	24	26	80	–4	10	16	100	–40
	25	33	101	3	31	9	961	93
	26	30	83	0	13	0	169	0
	27	23	53	–7	–17	49	289	119
	28	36	76	6	6	36	36	36
	29	27	74	–3	4	9	16	–12
	30	26	72	–4	2	16	4	–18
	31	24	69	–6	–1	36	1	6
	Total n =	31	Σ	–53	45	1691	7043	1793

$\overline{U}$ = -1.7097 $\overline{X}$ = 28.2903
$\overline{V}$ = 1.4516 $\overline{Y}$ = 71.4516

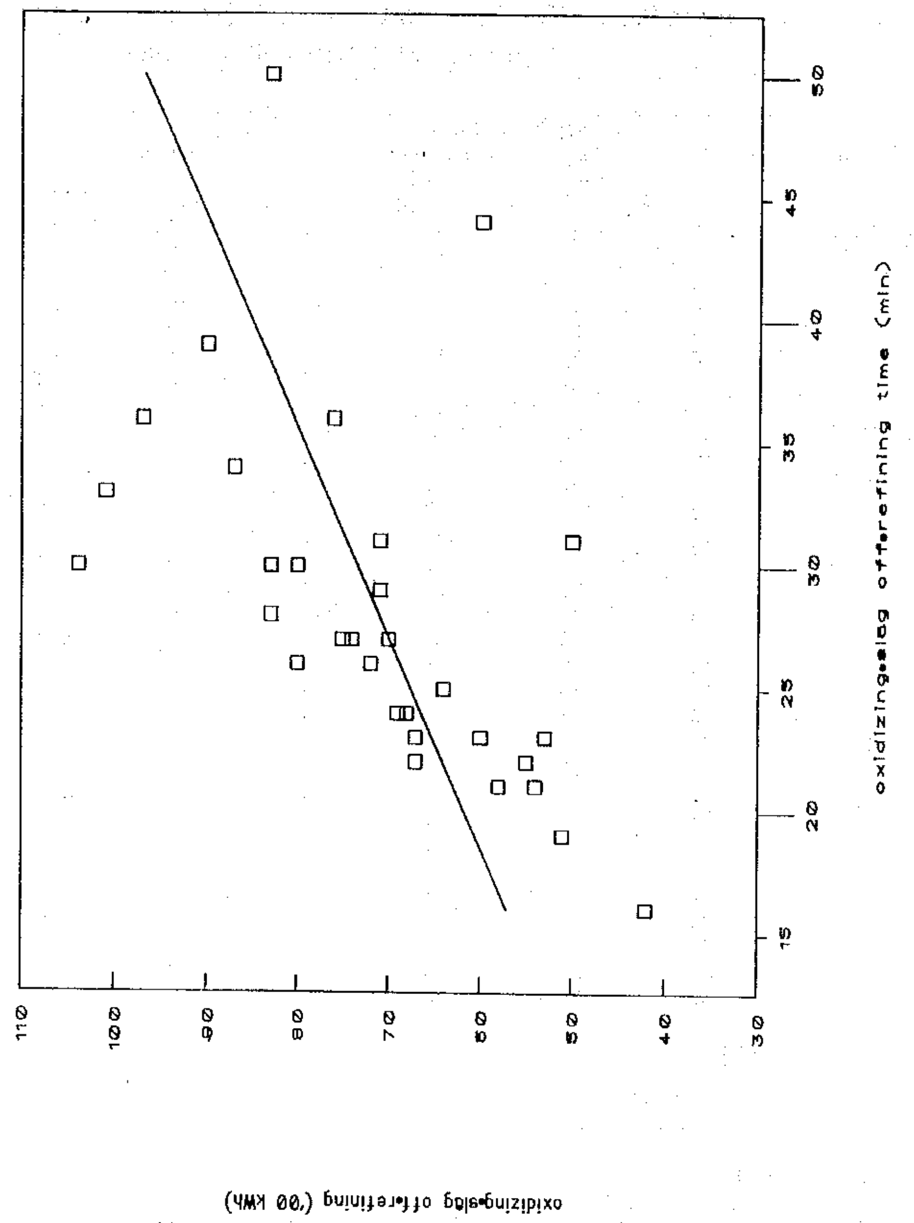
Su	=	1,691 - 90.61290	= 1,600.3871	Sx	=	1,600.3871
Sv	=	7,043 - 65.32258	= 6,977.6774	Sy	=	6,977.9774
Suv	=	1,793 - 76.9354	= 1,869.9355	Sxy	=	1,869.9355

b = 1.1684
y - 71.4516 = 1.1684 (x-28.2903)
y = 1.1684x + 38.3964

Sxy^2/Sx = 2,184.8831
square root of SxSy = 3,341.7039
r = 0.559575 r = correlation factor
r^2 = 0.31 r^2 = contributing factor

Fluctuation	Sum of square	Freedom	Impartial Variance	Impartial Variance Ratio	Remark
Revolution	2,184.8831	1	2,184.8831	13.22	$F^1_{29}(0.005)$ = 9.23<13.22
Rest	4,792.7943	29	164.2688		
Total	6,977.6774	30			

Figure 8.1.14 The Relation between Power Consumption and Oxidizing-Slag Off-Refining Time



On Oxidizing Slag off Refining period power consumption, distribution curve is shown in Figure 8.1.15 and time distribution is shown in Figure 8.1.16.

This result shows oxidizing slag off refining time.

- it is necessary to minimize for example composition adjustment.
- work standardization.

Figure 8.1.15 Oxidizing·Slag Off·refining Power Consumption Distribution

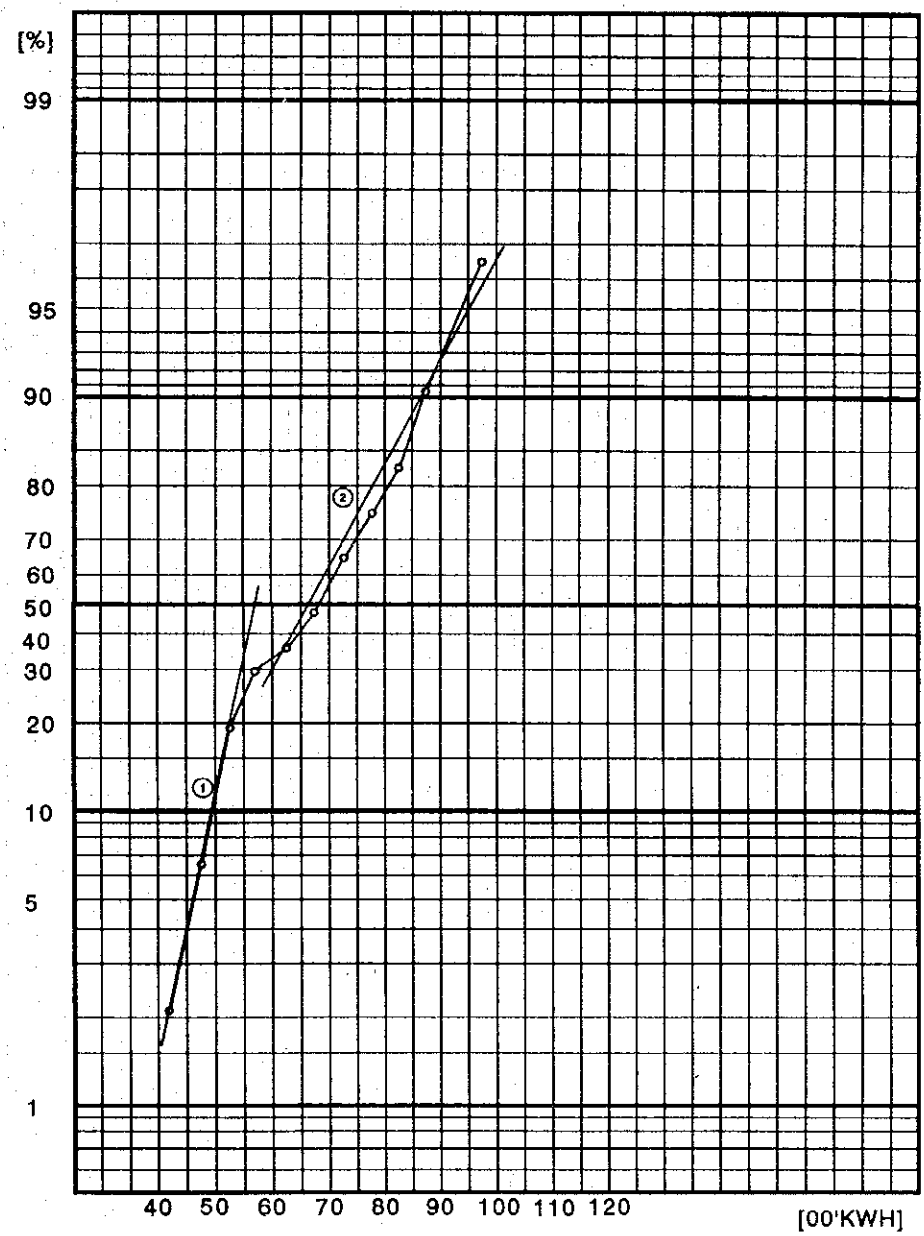
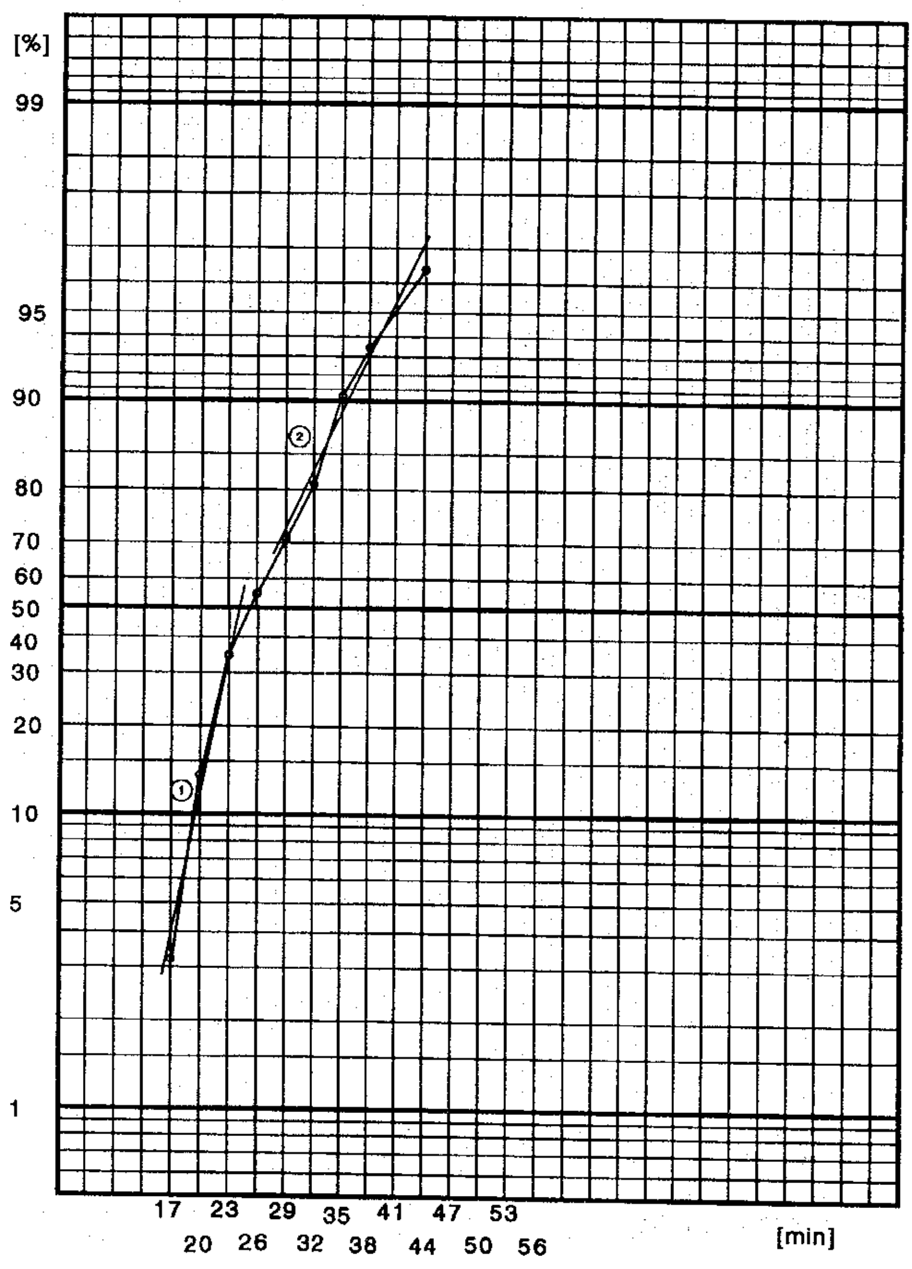


Figure 8.1.16 Oxidizing•Slag off•Refining Time Distribution



(c) The data of Aug. 2 to 4 is shown on Table 8.1.12.

a) according to the data of Table 8.1.12 ,the relation between billet volume and charging volume is shown on Figure 8.1.17.

Figure 8.1.17 shows that there is no relation.

It's doubtful;

It is considered to understand, there is some problem.

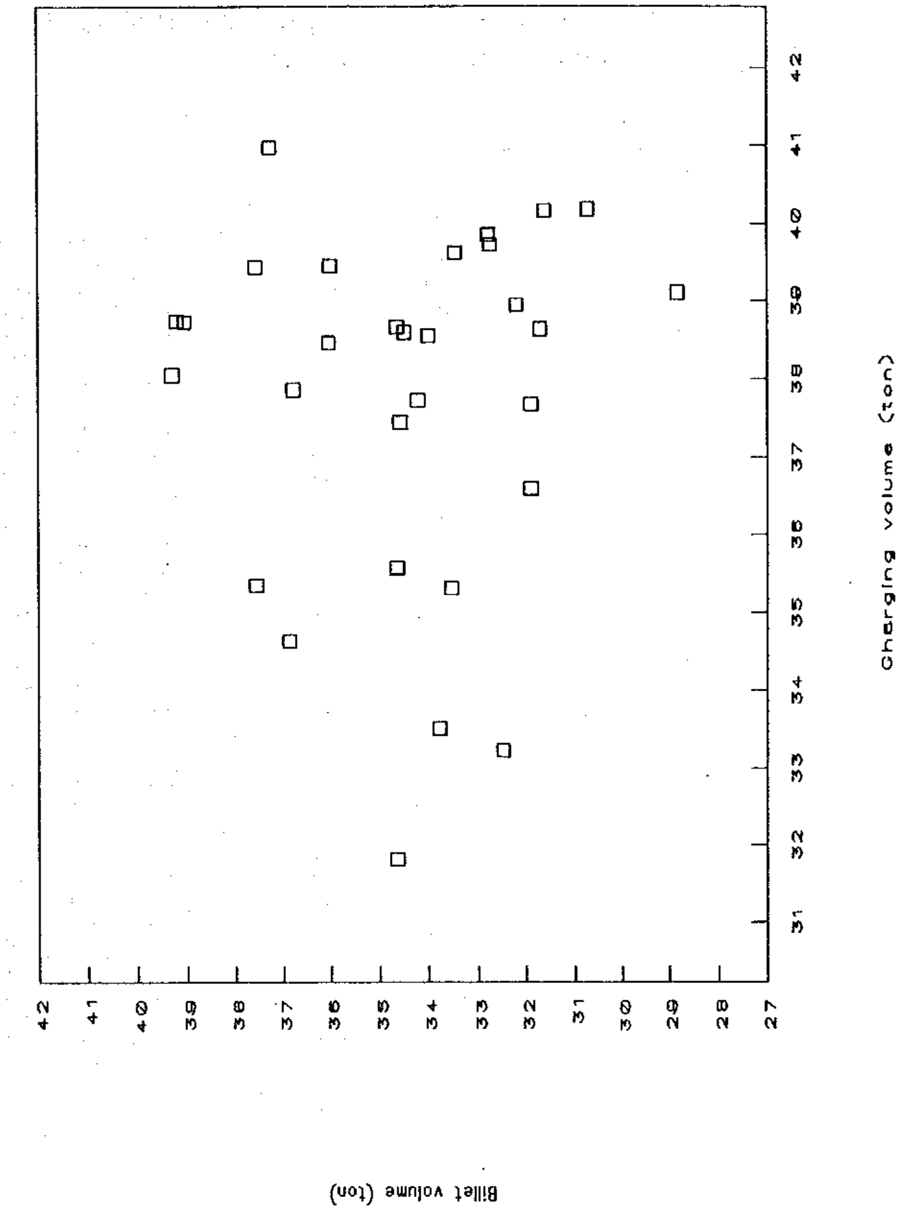
(1) measurement accuracy
(2) measuring accuracy
(3) particularly, charging measurement and measuring

Including that problem, analyzing Table 8.1.12 data, we can get interesting result. Next, we would like to show such interesting result.

Table 8.1.12 Data Collecting from EAF Operating Record

Date	No	Weight Billet (kg)	Weight Charging (kg)	Electric power consumption Melting ('00 kwh)	Electric power consumption Total ('00 kwh)	Weight Billet (Ton)	Weight Charging (Ton)	Billet Melting '00 kwh/ton	Billet Total '00 kwh/ton	Charging Melting '00 kwh/ton	Charging Total '00 kwh/ton	Charging Number
2/8/94	1	33,451	39,620	104	190	33.451	39.620	3.109	5.680	2.625	4.796	3
	22	37,259	40,970	109	178	37.259	40.970	2.925	4.777	2.660	4.345	3
	3	34,567	37,440	96	159	34.567	37.440	2.777	4.600	2.564	4.247	3
	4	33,768	33,510	82	146	33.768	33.510	2.428	4.324	2.447	4.357	2
	5	34,630	31,630	82	148	34.630	31.820	2.368	4.274	2.577	4.651	2
	6	36,876	34,630	89	148	36.876	34.630	2.413	4.013	2.570	4.274	3
	7	39,187	38,740	115	171	39.187	38.740	2.935	4.364	2.969	4.414	2
	8	34,637	35,570	84	154	34.367	35.570	2.425	4.446	2.362	4.329	2
	9	33,998	38,550	103	164	33.998	38.550	3.030	4.824	2.672	4.254	3
	10	31,901	37,670	98	171	31.901	37.670	3.072	5.360	2.602	4.539	3
	11	31,611	40,160	115	211	31.611	40.160	3.638	6.675	2.864	5.254	3
	12	36,032	38,460	100	172	36.032	38.460	2.775	4.774	2.600	4.472	2
	13	37,546	39,440	139	245	37.546	39.440	3.702	6.525	3.524	6.212	3
3/8/94	14	34,202	37,720	93	158	34.202	37.720	2.719	4.620	2.466	4.189	2
	15	37,542	35,350	80	154	37.542	35.350	2.131	4.102	2.263	4.356	2
	16	39,027	38,730	96	166	39.027	38.730	2.460	4.253	2.479	4.286	2
	17	39,286	38,050	100	154	39.286	38.050	2.545	3.920	2.628	4.047	2
	18	32,218		99	160	32.218		3.073	4.966			2
	19	32,787	39,850	88	171	32.787	39.850	2.684	5.215	2.208	4.291	2
	20	32,476	33,220	70	140	32.476	33.220	2.155	4.311	2.107	4.214	2
	21	30,723	40,180	90	158	30.723	40.180	2.929	5.143	2.240	3.932	2
	22	31,712	38,630	112	172	31.712	38.630	3.532	5.424	2.899	4.452	3
	23	29,015		96	145	29.015		3.309	4.997			3
	24	29,096		102	170	29.096		3.506	5.843			4
	25	32,196	38,950	105	170	32.196	38.950	3.261	5.280	2.696	4.365	3
	26	28,838	39,110	115	175	28.838	39.110	3.988	6.068	2.940	4.475	3
	27	36,005	39,450	120	177	36.005	39.450	3.333	4.916	3.042	4.487	4
4/8/94	28	33,540	35,310	96	142	33.540	35.310	2.862	4.234	2.719	4.022	2
	29	32,514		100	160	32.514		3.076	4.921			3
	30	37,495		105	144	37.495		2.800	3.841			5
	31	34,630	38,660	115	161	34.630	38.660	3.321	4.649	2.975	4.165	3
	32	36,860	37,860	110	165	36.775	37.860	2.991	4.487	2.905	4.358	2
	33	32,740	39,720	135	190	32.740	39.720	4.123	5.803	3.399	4.783	2
	34	34,470	38,590	84	163	34.470	38.590	2.437	4.729	2.177	4.224	3
	35	31,589		93	154	31.589		2.944	4.875			3
	36	33,058		113	165	33.058		3.418	4.991			4
	37	33,790		113	162	33.790		3.344	4.794			5
	38	29,370		123	191	29.370		4.188	6.503			4
	39	27,505		110	162	27.505		3.999	5.890			3
	40	30,960		113	164	30.960		3.650	5.297			4
	41	31,900	36,590	86	NA	31.900	36.590	2.696		2.350		3

Figure 8.1.17 The Relation between Billet and Charging Volume



b) The relation between melting time, charging number and melting kWh is presented on Table 8.1.13. The relation is explained in the next revolution formula.

Z = 58.25234 + 0.6405x + 4.941y
Z = power consumption ('00 KWH)
x = melting time (min)
y = charging number (number)

Their relation has a meaning of out probability 0.5%.

As melting time and charging number decrease, power consumption decreases.

Table 8.1.13 The Relation of Charging Number, Melting Time and Melting Power Consumption

	Melting Time	Charging Number	Melting power consumption			Calculation			
40	45	2	100						
	u = X − 45	v = y − 2	w = z − 100	u^2	v^2	w^2	u X v	v X w	w X u
	0	1	4	0.000	1.000	16	0.00	4.00	0.00
	1	1	9	1.000	1.000	81	1.00	9.00	9.00
	−6	1	−4	36.000	1.000	16	−6.00	−4.00	24.00
	−12	0	−18	144.000	0.000	324	0.00	0.00	216.00
	−8	0	−18	64.000	0.000	324	0.00	0.00	144.00
	0	1	−11	0.000	1.000	121	0.00	−11.00	0.00
	4	0	15	16.000	0.000	225	0.00	0.00	60.00
	−10	0	−16	100.000	0.000	256	0.00	0.00	160.00
	26	1	3	676.000	1.000	9	26.00	3.00	78.00
	0	1	−2	0.000	1.000	4	0.00	−2.00	0.00
	0	1	15	0.000	1.000	225	0.00	15.00	0.00
	3	0	0	9.000	0.000	0	0.00	0.00	0.00
	12	1	39	144.000	1.000	1521	12.00	39.00	468.00
	0	0	−7	0.000	0.000	49	0.00	0.00	0.00
	−10	0	−20	100.000	0.000	400	0.00	0.00	200.00
	−5	0	−4	25.000	0.000	16	0.00	0.00	20.00
	0	0	0	0.000	0.000	0	0.00	0.00	0.00
	−3	0	−1	9.000	0.000	1	0.00	0.00	3.00
	−7	0	−12	49.000	0.000	144	0.00	0.00	84.00
	−9	0	−30	81.000	0.000	900	0.00	0.00	270.00
	15	0	−10	225.000	0.000	100	0.00	0.00	−150.00
	3	1	12	9.000	1.000	144	3.00	12.00	36.00
	−6	1	−4	36.000	1.000	16	−6.00	−4.00	24.00
	0	2	2	0.000	4.000	4	0.00	4.00	0.00
	1	1	5	1.000	1.000	25	1.00	5.00	5.00
	0	1	15	0.000	1.000	225	0.00	15.00	0.00
	1	2	20	1.000	4.000	400	2.00	40.00	20.00
	−6	0	−4	36.000	0.000	16	0.00	0.00	24.00
	6	1	0	36.000	1.000	0	6.00	0.00	0.00
	7	3	5	49.000	9.000	25	21.00	15.00	35.00
	2	1	15	4.000	1.000	225	2.00	15.00	30.00
	8	0	10	64.000	0.000	100	0.00	0.00	80.00
	10	0	35	100.000	0.000	1225	0.00	0.00	350.00
	11	1	−16	121.000	1.000	256	11.00	−16.00	−176.00
	15	1	−7	225.000	1.000	49	15.00	−7.00	−105.00
	3	2	13	9.000	4.000	169	6.00	26.00	39.00
	12	3	13	144.000	9.000	169	36.00	39.00	156.00
	1	2	23	1.000	4.000	529	2.00	46.00	23.00
	4	1	10	16.000	1.000	100	4.00	10.00	40.00
	16	2	13	256.000	4.000	169	32.00	26.00	208.00
n = 40 Σ	79	33	92	2787	55	8578	168	279	2375

$\overline{U}$ =	1.9750	Su =	2630.9750	b =	0.6405
$\overline{V}$ =	0.8250	Sv =	27.7750	c =	4.9410
$\overline{W}$ =	2.3000	Sw =	8366.4000	a =	58.252340
$\overline{X}$ =	46.9750	Sx =	2630.9750	bSxz+cSyz =	2408.4125
$\overline{Y}$ =	2.8250	Sy =	27.7750	S.z = Sz − (bSxz + cSyz)=	5957.9875
$\overline{Z}$ =	102.3000	Sz =	8366.4000		
		Suv =	102.8250	Sxy =	102.825
		Svw =	203.1000	Syz =	203.1
		Swu =	2193.3000	Szx =	2193.3

Z = 58.25234 + 0.6405 x + 4.9410 y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark
Revolution	2,408.4125	2	1204.2063	7.4783	F2(0.005) = 6.35 < 7.4783
Rest	5,957.9875	37	161.0267		30
Total	8,366.4000	39			

c) The relation between charging volume, melting time and melting kWh is shown on Table 8.1.14. Their relation is explained in the next revolution formula.

$$Z = -64.1788 + 3.8674x + 0.4073y$$

Z = power consumption ('00 KWH)
x = melting time (min)
y = charging volume (ton)

Their relation has a meaning of out probability 0.5%.

Increasing charging volume and melting time , power consumption increases.

The relation between melting power consumption and charging volume is presented on Figure 8.1.18.

Table 8.1.14 ,The Relation of Charging Volume, Melting Time and Melting Power Consumption

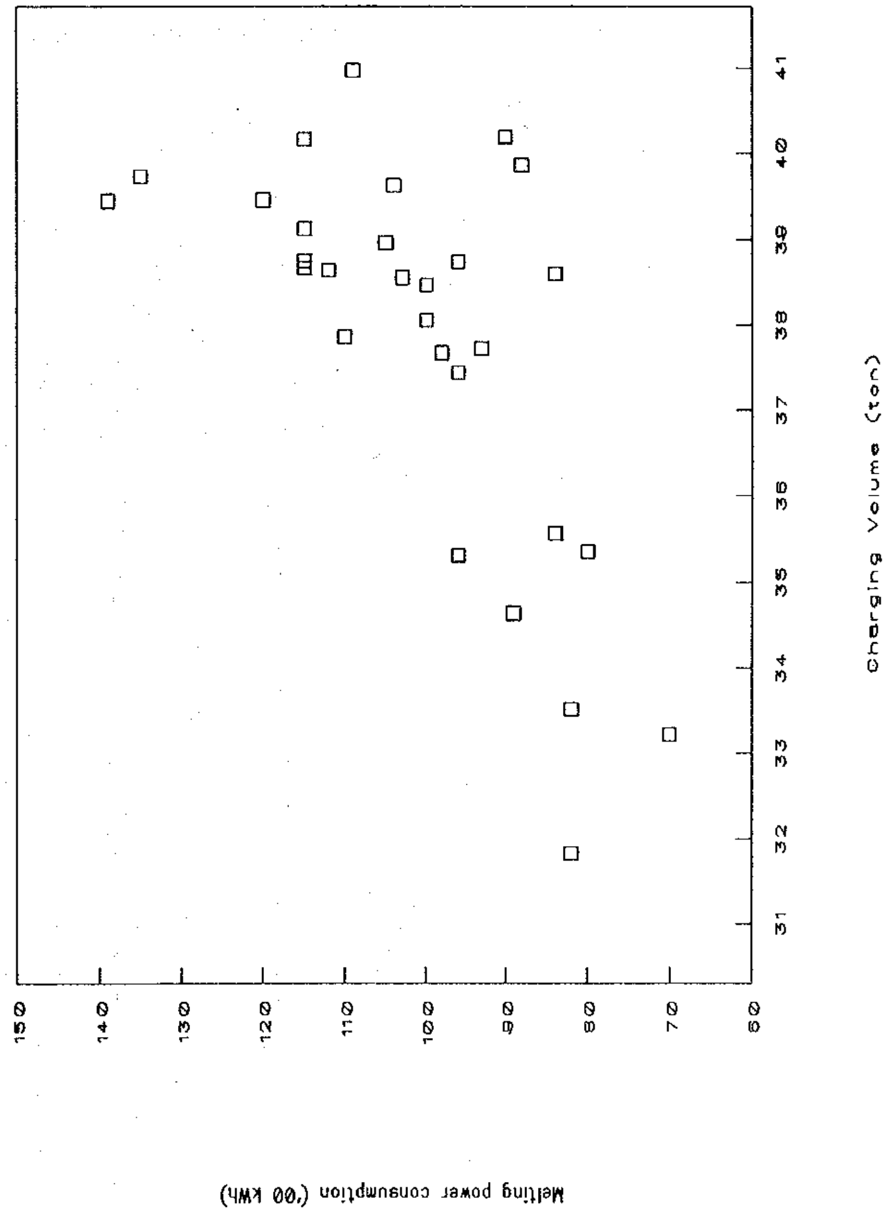
	Charging (Ton)	Melting Time	Melting power consumption	Calculation					
30	35	45	100						
	u = X − 35	v = y − 45	w = z − 100	u^2	v^2	w^2	u X v	v X w	w X u
	4.62	0	4	21.344	0.000	16	0.00	0.00	18.48
	5.97	1	9	35.641	1.000	81	5.97	9.00	53.73
	2.44	−6	−4	5.954	36.000	16	−14.64	24.00	−9.76
	−1.49	−12	−18	2.220	144.000	324	17.88	216.00	26.82
	−3.18	−8	−18	10.112	64.000	324	25.44	144.00	57.24
	−0.37	0	−11	0.137	0.000	121	0.00	0.00	4.07
	3.74	4	15	13.988	16.000	225	14.96	60.00	56.10
	0.57	−10	−16	0.325	100.000	256	−5.70	160.00	−9.12
	3.55	26	3	12.602	676.000	9	92.30	78.00	10.65
	2.67	0	−2	7.129	0.000	4	0.00	0.00	−5.34
	5.16	0	15	26.626	0.000	225	0.00	0.00	77.40
	3.46	3	0	11.972	9.000	0	10.38	0.00	0.00
	4.44	12	39	19.714	144.000	1521	53.28	468.00	173.16
	2.72	0	−7	7.398	0.000	49	0.00	0.00	−19.04
	0.35	−10	−20	0.123	100.000	400	−3.50	200.00	−7.00
	3.73	−5	−4	13.913	25.000	16	−18.65	20.00	−14.92
	3.05	0	0	9.302	0.000	0	0.00	0.00	0.00
	4.85	−7	−12	23.523	49.000	144	−33.95	84.00	−58.20
	−1.78	−9	−30	3.168	81.000	900	16.02	270.00	53.40
	5.18	15	−10	26.832	225.000	100	77.70	−150.00	−51.80
	3.63	3	12	13.177	9.000	144	10.89	36.00	43.56
	3.95	1	5	15.603	1.000	25	3.95	5.00	19.75
	4.11	0	15	16.892	0.000	225	0.00	0.00	61.65
	4.45	1	20	19.803	1.000	400	4.45	20.00	89.00
	0.31	−6	−4	0.096	36.000	16	−1.86	24.00	−1.24
	3.66	2	15	13.396	4.000	225	7.32	30.00	54.90
	2.86	8	10	8.180	64.000	100	22.88	80.00	28.60
	4.72	10	35	22.278	100.000	1225	47.20	350.00	165.20
	3.59	11	−16	12.888	121.000	256	39.49	−176.00	−57.44
	1.59	−8	−14	2.528	64.000	196	−12.72	112.00	−22.26
n = 30 Σ	82.55	16	11	376.8625	2070	7543	359.09	2064	737.59

$\overline{U}$ =	2.7517	Su =	149.7124	b =	3.8674
$\overline{V}$ =	0.5333	Sv =	2061.4667	c =	0.4073
$\overline{W}$ =	0.3667	Sw =	7538.9667	a =	−64.17888
$\overline{X}$ =	37.7517	Sx =	149.7124	bSxz+cSyz =	3573.7770
$\overline{Y}$ =	45.5333	Sy =	2061.4667	S.z = Sz − (bSxz + cSyz) =	3965.1897
$\overline{Z}$ =	100.3667	Sz =	7538.9667		
		Suv =	315.0633	Sxy =	315.06333
		Svw =	2058.1333	Syz =	2058.1333
		Swu =	707.3217	Szx =	707.32166

Z = −64.1788 + 3.8674 x + 0.4073 y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark
Revolution	3,573.7770	2	1786.8885	12.1674	F2(0.005) = 6.49 < 12.1674
Rest	3,965.1897	27	146.8589		29
Total	7,538.9667	29			

Figure 8.1.18 The Relation between Melting Power Consumption and Charging Volume



d) The relation between billet volume, melting time and melting power consumption is shown in Table 8.1.15. Their relation is explained in the next revolution formula.

$Z = 62.76774 - 0.0335x + 0.8616y$

where Z = power consumption ('00 kWH)

x = billet volume (ton)

y = melting time (min)

Their relation has a meaning of out probability 0.5%.

Increasing melting time and decreasing billet volume, power consumption increases.

Relation of billet volume is doubtful, but billet volume contribution is small.

Table 8.1.15 The Relation of Billet Volume, Melting Time and Melting Power Consumption

	Billet (Ton)	Melting Time	Melting power consumption	Calculation					
41	30	45	100						
	u = X − 30	v = y − 45	w = z − 100	u^2	v^2	w^2	u X v	v X w	w X u
~	3.451	0	4	11.909	0.000	16	0.00	0.00	13.80
	7.259	1	9	52.693	1.000	81	7.26	9.00	65.33
	4.567	−6	−4	20.857	36.000	16	−27.40	24.00	−18.27
	3.768	−12	−18	14.198	144.000	324	−45.22	216.00	−67.82
	4.630	−8	−18	21.437	64.000	324	−37.04	144.00	−83.34
	6.876	0	−11	47.279	0.000	121	0.00	0.00	−75.64
	9.187	4	15	84.401	16.000	225	36.75	60.00	137.80
	4.637	−10	−16	21.502	100.000	256	−46.37	160.00	−74.19
	3.998	26	3	15.984	676.000	9	103.95	78.00	11.99
	1.901	0	−2	3.614	0.000	4	0.00	0.00	−3.80
	1.611	0	15	2.595	0.000	225	0.00	0.00	24.17
	6.032	3	0	36.385	9.000	0	18.10	0.00	0.00
	7.546	12	39	56.942	144.000	1521	90.55	468.00	294.29
	4.202	0	−7	17.657	0.000	49	0.00	0.00	−29.41
	7.542	−10	−20	56.882	100.000	400	−75.42	200.00	−150.84
	9.027	−5	−4	81.487	25.000	16	−45.14	20.00	−36.11
	9.286	0	0	86.230	0.000	0	0.00	0.00	0.00
	2.218	−3	−1	4.920	9.000	1	−6.65	3.00	−2.22
	2.787	−7	−12	7.767	49.000	144	−19.51	84.00	−33.44
	2.476	−9	−30	6.131	81.000	900	−22.28	270.00	−74.28
	0.723	15	−10	0.523	225.000	100	10.84	−150.00	−7.23
	1.712	3	12	2.931	9.000	144	5.14	36.00	20.54
	−0.985	−6	−4	0.970	36.000	16	5.91	24.00	3.94
	−0.904	0	2	0.817	0.000	4	0.00	0.00	−1.81
	2.196	1	5	4.822	1.000	25	2.20	5.00	10.98
	−1.162	0	15	1.350	0.000	225	0.00	0.00	−17.43
	6.005	1	20	36.060	1.000	400	6.01	20.00	120.10
	3.540	−6	−4	12.532	36.000	16	−21.24	24.00	−14.16
	2.514	6	0	6.320	36.000	0	15.08	0.00	0.00
	7.495	7	5	56.175	49.000	25	52.46	35.00	37.47
	4.630	2	15	21.437	4.000	225	9.26	30.00	69.45
	6.775	8	10	45.901	64.000	100	54.20	80.00	67.75
	2.740	10	35	7.508	100.000	1225	27.40	350.00	95.90
	4.470	11	−16	19.981	121.000	256	49.17	−176.00	−71.52
	1.589	15	−7	2.525	225.000	49	23.83	−105.00	−11.12
	3.058	3	13	9.351	9.000	169	9.17	39.00	39.75
	3.790	12	13	14.364	144.000	169	45.48	156.00	49.27
	−0.630	1	23	0.397	1.000	529	−0.63	23.00	−14.49
	−2.495	4	10	6.225	16.000	100	−9.98	40.00	−24.95
	0.960	16	13	0.922	256.000	169	15.36	208.00	12.48
	1.900	−8	−14	3.610	64.000	196	−15.20	112.00	−26.60
n = 41 Σ	150.922	71	78	905.590192	2851	8774	216.043	2467	236.359

$\overline{U}$ =	3.6810	Su =	350.0426	b =	−0.0335
$\overline{V}$ =	1.7317	Sv =	2728.0488	c =	0.8616
$\overline{W}$ =	1.9024	Sw =	8625.6098	a =	62.767742
$\overline{X}$ =	33.6810	Sx =	350.0426	bSxz+cSyz =	2028.0534
$\overline{Y}$ =	46.7317	Sy =	2728.0488	S.z = Sz − (bSxz + cSyz) =	6597.5564
$\overline{Z}$ =	101.9024	Sz =	8625.6098		
		Suv =	−45.3097	Sxy =	−45.30973
		Svw =	2351.9268	Syz =	2351.9268
		Swu =	−50.7609	Szx =	−50.76090

Z = 62.76774 + −0.0335 x + 0.8616 y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark	
Revolution	2,028.0534	2	1014.0267	5.8405	F2(0.005) = 5.39 <	5.8405
Rest	6,597.5564	38	173.6199		30	
Total	8,625.6098	40				

e) The relation between charging volume, charging number and total kWh is presented on Table 8.1.16. Their relation is explained in the next revolution formula.

$$Z = -48.1191 + 5.2540x + 6.9895y$$

Z = power consumption ('00 kWh)
x = charging volume (ton)
y = charging number

Their relation has a meaning of out probability 1.0%.

Increasing charging volume and charging number, power consumption increases.

The relation between total power consumption and charging volume is shown in Figure 8.1.19. The relation between total power consumption and charging number is presented in Figure 8.1.20. The relation between oxidizing·Slag off·Refining power consumption and charging volume is shown in Figure 8.1.21.

Table 8.1.16 The Relation of Charging Volume, Charging Number and Total Power Consumption

	Charging (Ton)	Charging Number	Total power consumption	Calculation					
29	35	2	150						
	u = X − 35	v = y − 45	w = z − 150	u^2	v^2	w^2	u X v	v X w	w X u
	4.62	1	40	21.344	1.000	1600	4.62	40.00	184.80
	5.97	1	28	35.641	1.000	784	5.97	28.00	167.16
	2.44	1	9	5.954	1.000	81	2.44	9.00	21.96
	−1.49	0	−4	2.220	0.000	16	0.00	0.00	5.96
	−3.18	0	−2	10.112	0.000	4	0.00	0.00	6.36
	−0.37	1	−2	0.137	1.000	4	−0.37	−2.00	0.74
	3.74	0	21	13.988	0.000	441	0.00	0.00	78.54
	0.57	0	4	0.325	0.000	16	0.00	0.00	2.28
	3.55	1	14	12.602	1.000	196	3.55	14.00	49.70
	2.67	1	21	7.129	1.000	441	2.67	21.00	56.07
	5.16	1	61	26.626	1.000	3721	5.16	61.00	314.76
	3.46	0	22	11.972	0.000	484	0.00	0.00	76.12
	4.44	1	95	19.714	1.000	9025	4.44	95.00	421.80
	2.72	0	8	7.398	0.000	64	0.00	0.00	21.76
	0.35	0	4	0.123	0.000	16	0.00	0.00	1.40
	3.73	0	16	13.913	0.000	256	0.00	0.00	59.68
	3.05	0	4	9.302	0.000	16	0.00	0.00	12.20
	4.85	0	21	23.523	0.000	441	0.00	0.00	101.85
	−1.78	0	−10	3.168	0.000	100	0.00	0.00	17.80
	5.18	0	8	26.832	0.000	64	0.00	0.00	41.44
	3.63	1	22	13.177	1.000	484	3.63	22.00	79.86
	3.95	1	20	15.603	1.000	400	3.95	20.00	79.00
	4.11	1	25	16.892	1.000	625	4.11	25.00	102.75
	4.45	2	27	19.803	4.000	729	8.90	54.00	120.15
	0.31	0	−8	0.096	0.000	64	0.00	0.00	−2.48
	3.66	1	11	13.396	1.000	121	3.66	11.00	40.26
	2.86	0	15	8.180	0.000	225	0.00	0.00	42.90
	4.72	0	40	22.278	0.000	1600	0.00	0.00	188.80
	3.59	1	13	12.888	1.000	169	3.59	13.00	46.67
n = 29 Σ	80.96	15	523	374.337	17	22187	56.32	411	2340.29

$\bar{U}$ =	2.7917	Su =	148.319	b =	5.2540
$\bar{V}$ =	0.5172	Sv =	9.24137	c =	6.9895
$\bar{W}$ =	18.0345	Sw =	12754.9	a =	-48.1191
$\bar{X}$ =	37.7917	Sx =	148.319	bSxz + cSyz =	5606.5642
$\bar{Y}$ =	2.5712	Sy =	9.24137	S.z = Sz - (bSxz + cSyz) =	7148.336
$\bar{Z}$ =	168.034	Sz =	12754.9		
		Suv =	14.4441	Sxy =	14.4441
		Svw =	140.482	Syz =	140.482
		Swu =	880.218	Szx =	880.218

Z = -48.1191 + 5.2540x + 6.9895y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remarks
Revolution Rest	5,606.5642 7,148.336	2 26	2803.2821 274.936	10.196126	
Total	12,754.9	28			

Figure 8.1.19 The Relation between Total Power Consumption and Charging Volume

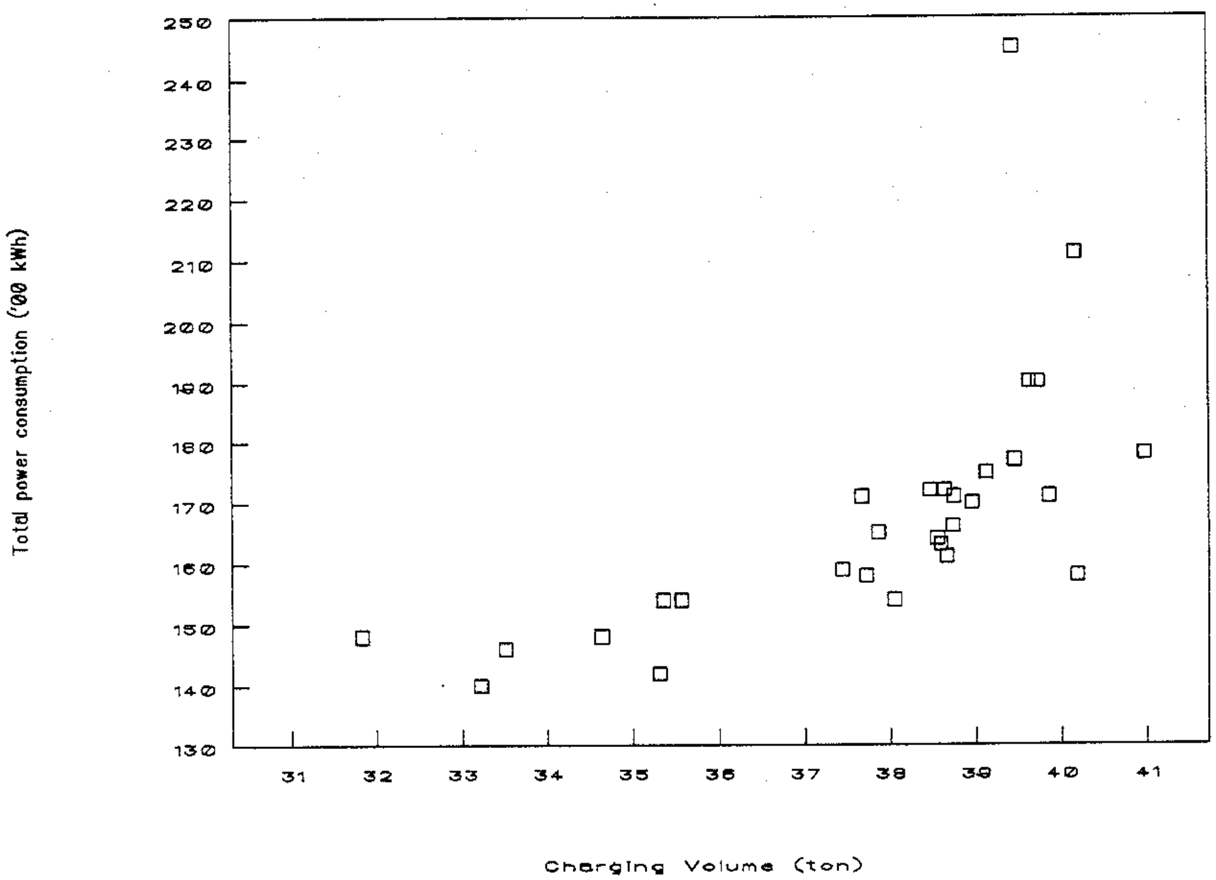


Figure 8.1.20 The Relation between Total Power Consumption and Charging Number

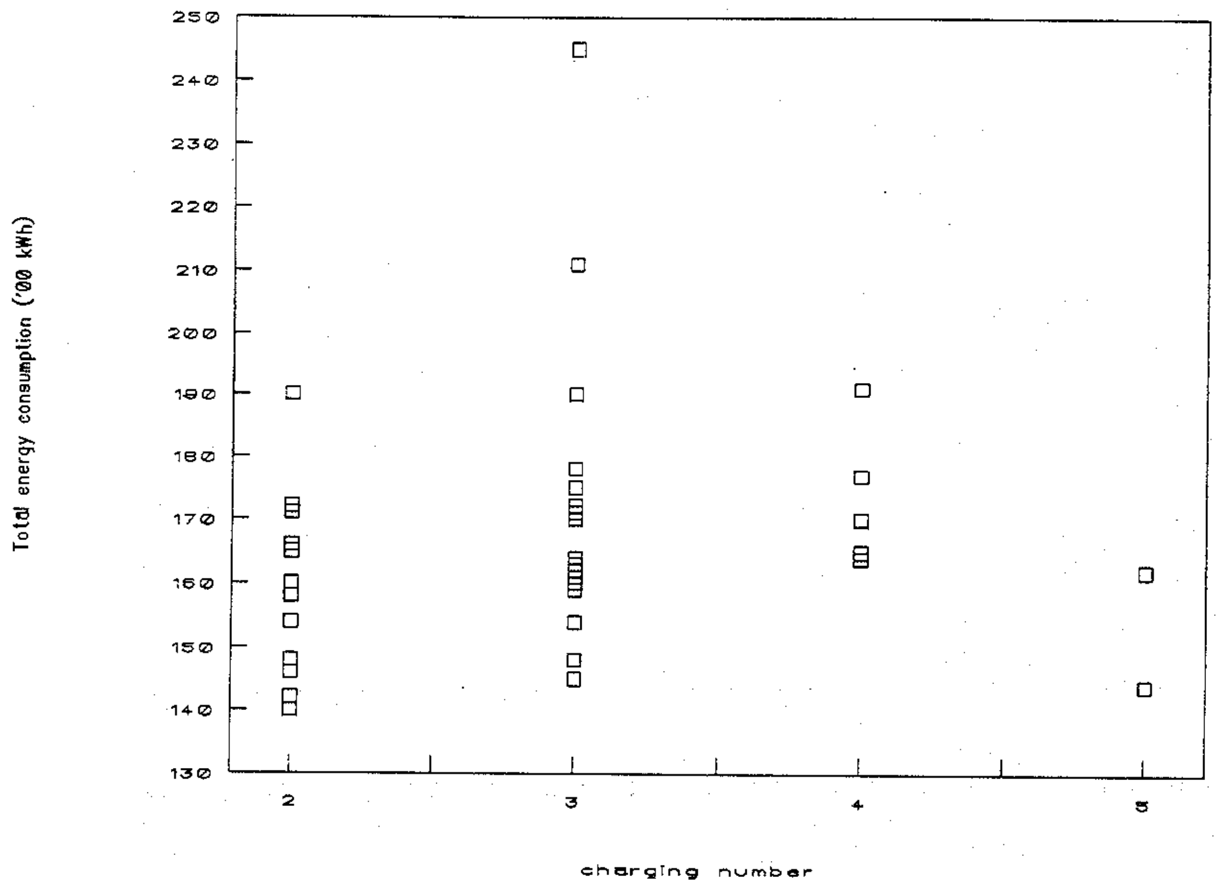
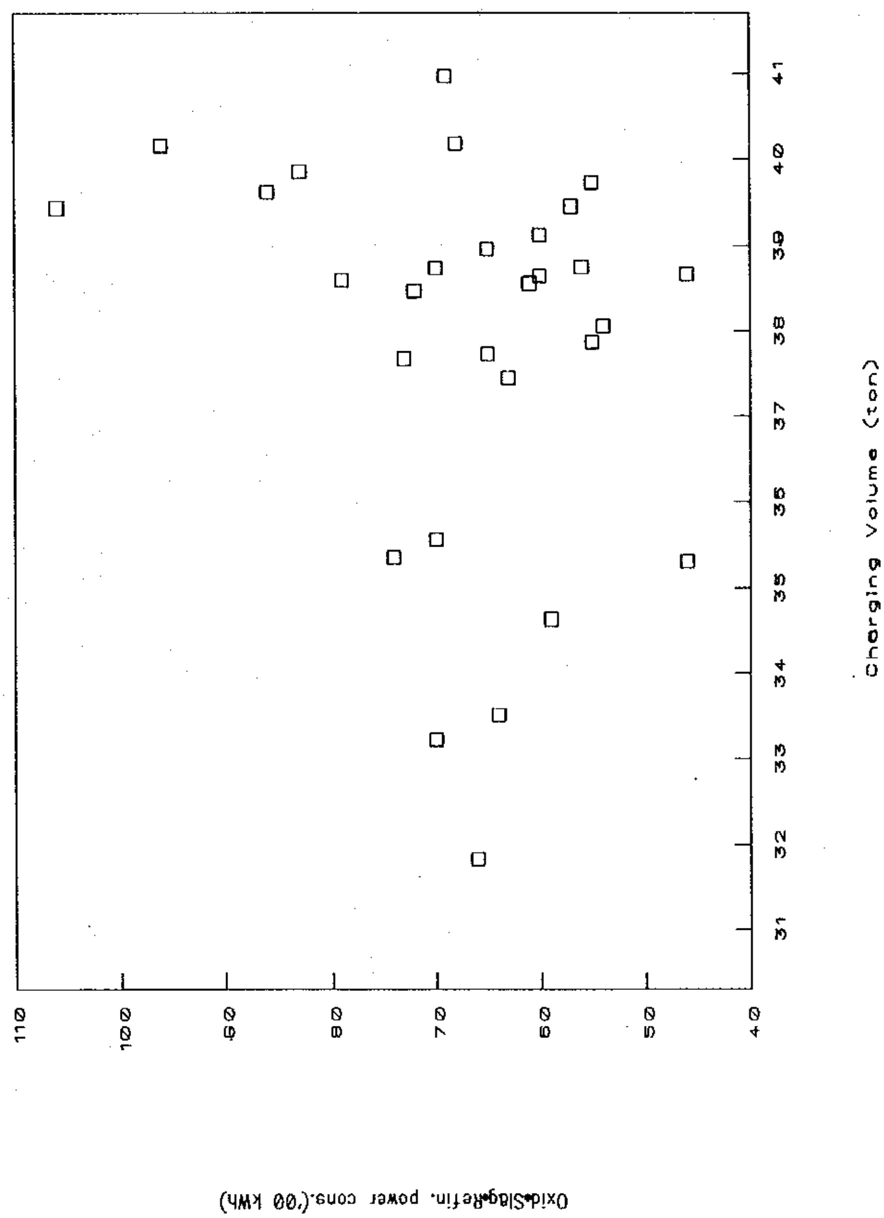


Figure 8.1.21 The Relation between Oxidizing·Slag Off·Refining Power Consumption and Charging Volume



f) The relation of billet volume, charging number and total kWh is shown in Table 8.1.17.

There is no relation.

Scatter diagrams of charging number-billet volume and oxidizing·Slag off·Refining power consumption-billet volume are shown in Figure 8.1.22 and Figure 8.1.23.

Table 8.1.17 The Relation of Billet Volume, Charging Number and Total Power Consumption

	Billet (Ton)	Charging Number	Total ('00 Kwh)			Calculation			
40	30	2	160						
	u = X − 30	v = y − 33	w = z − 160	u^2	v^2	w^2	u X v	v X w	w X u
	3.451	1	30	11.909	1.000	900	3.45	30.00	103.53
	7.259	1	18	52.693	1.000	324	7.26	18.00	130.66
	4.567	1	−1	20.857	1.000	1	4.57	−1.00	−4.57
	3.768	0	−14	14.198	0.000	196	0.00	0.00	−52.75
	4.630	0	−12	21.437	0.000	144	0.00	0.00	−55.56
	6.876	1	−12	47.279	1.000	144	6.88	−12.00	−82.51
	9.187	0	11	84.401	0.000	121	0.00	0.00	101.06
	4.637	0	−6	21.502	0.000	36	0.00	0.00	−27.82
	3.998	1	4	15.984	1.000	16	4.00	4.00	15.99
	1.901	1	11	3.614	1.000	121	1.90	11.00	20.91
	1.611	1	51	2.595	1.000	2601	1.61	51.00	82.16
	6.032	0	12	36.385	0.000	144	0.00	0.00	72.38
	7.546	1	85	56.942	1.000	7225	7.55	85.00	641.41
	4.202	0	−2	17.657	0.000	4	0.00	0.00	−8.40
	7.542	0	−6	56.882	0.000	36	0.00	0.00	−45.25
	9.027	0	6	81.487	0.000	36	0.00	0.00	54.16
	9.286	0	−6	86.230	0.000	36	0.00	0.00	−55.72
	2.218	0	0	4.920	0.000	0	0.00	0.00	0.00
	2.787	0	11	7.767	0.000	121	0.00	0.00	30.66
	2.476	0	−20	6.131	0.000	400	0.00	0.00	−49.52
	0.723	0	−2	0.523	0.000	4	0.00	0.00	−1.45
	1.712	1	12	2.931	1.000	144	1.71	12.00	20.54
	−0.985	1	−15	0.970	1.000	225	−0.98	−15.00	14.77
	−0.904	2	10	0.817	4.000	100	−1.81	20.00	−9.04
	2.196	1	10	4.822	1.000	100	2.20	10.00	21.96
	−1.162	1	15	1.350	1.000	225	−1.16	15.00	−17.43
	6.005	2	17	36.060	4.000	289	12.01	34.00	102.09
	3.540	0	−18	12.532	0.000	324	0.00	0.00	−63.72
	2.514	1	0	6.320	1.000	0	2.51	0.00	0.00
	7.495	3	−16	56.175	9.000	256	22.48	−48.00	−119.92
	4.630	1	1	21.437	1.000	1	4.63	1.00	4.63
	6.775	0	5	45.901	0.000	25	0.00	0.00	33.87
	2.740	0	30	7.508	0.000	900	0.00	0.00	82.20
	4.470	1	3	19.981	1.000	9	4.47	3.00	13.41
	1.589	1	−6	2.525	1.000	36	1.59	−6.00	−9.53
	3.058	2	5	9.351	4.000	25	6.12	10.00	15.29
	3.790	3	2	14.364	9.000	4	11.37	6.00	7.58
	−0.630	2	31	0.397	4.000	961	−1.26	62.00	−19.53
	−2.495	1	2	6.225	1.000	4	−2.50	2.00	−4.99
	0.960	2	4	0.922	4.000	16	1.92	8.00	3.84
n = 40 Σ	149.022	33	250	901.980192	55	16254	100.511	300	945.4

$\overline{U}$ =	3.7255	Su =	346.79128	b =	0.2730
$\overline{V}$ =	0.8250	Sv =	27.77500	c =	3.5958
$\overline{W}$ =	6.2500	Sw =	14691.50000	a =	146.88466
$\overline{X}$ =	33.7256	Sx =	346.79128	bSxz+cSyz =	340.9339
$\overline{Y}$ =	2.8250	Sy =	27.77500	S.z = Sz − (bSxz + cSyz) =	14350.5661
$\overline{Z}$ =	166.2500	Sz =	14691.50000		
		Suv =	−22.43215	Sxy =	−22.43215
		Svw =	93.75000	Syz =	93.75
		Swu =	14.01250	Szx =	14.0125

Z = 146.8846 + 0.2730 x + 3.5958 y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark	
Revolution	340.9339	2	170.4670	0.4395	F2(0.25) = 1.45 >	0.4395
Rest	14,350.5661	37	387.8531		30	
Total	14,691.5000	39				

Figure 8.1.22 The Relation between Charging Number and Billet Volume

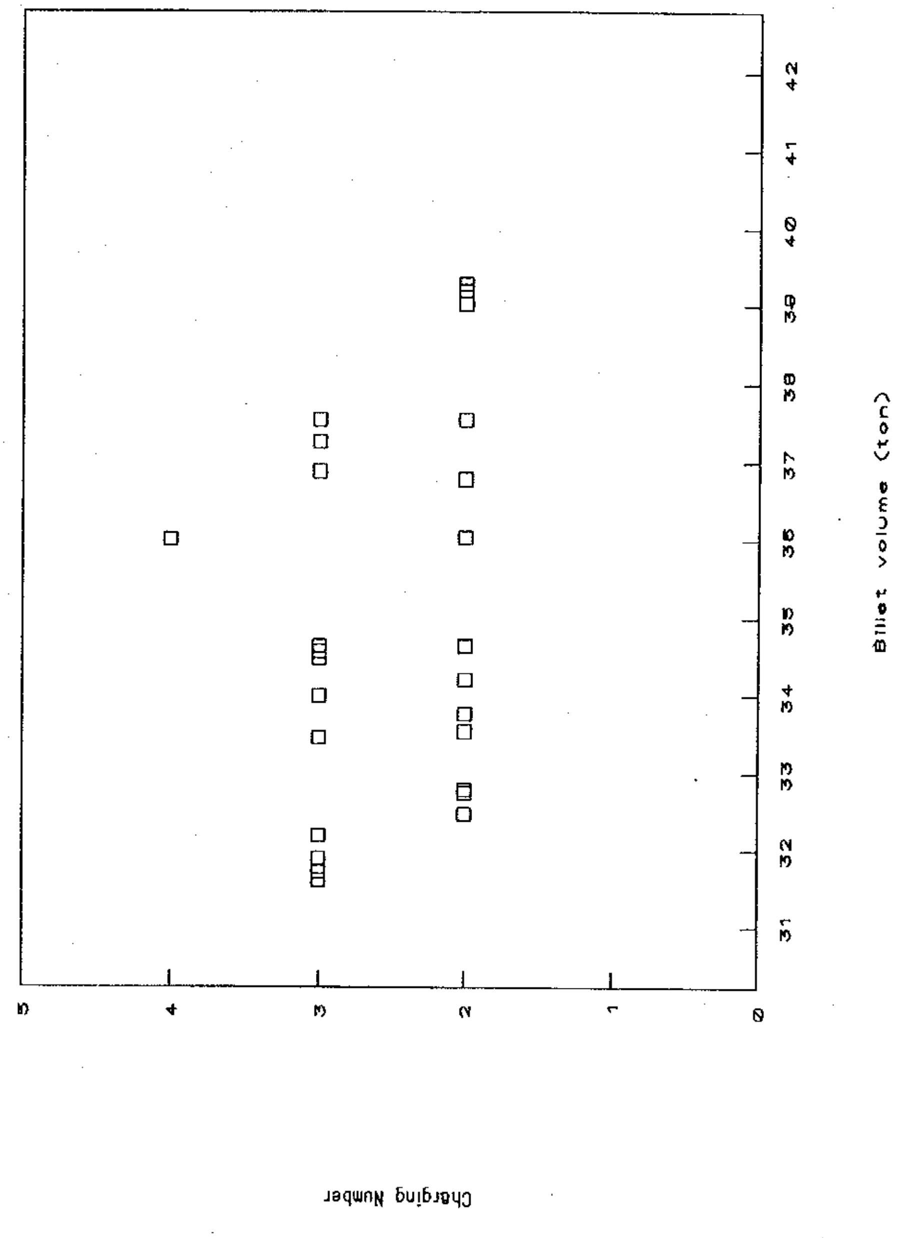
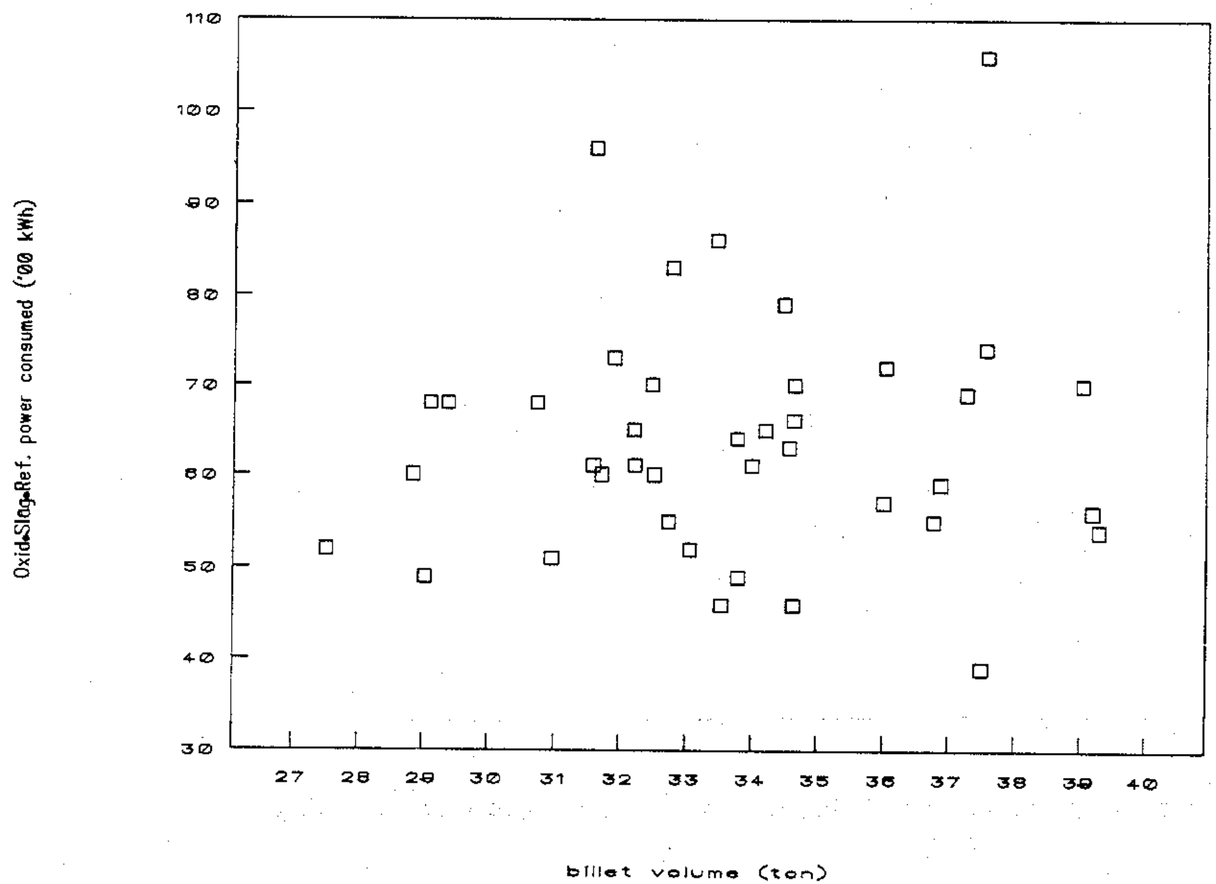


Figure 8.1.23 The Relation between Oxidizing·Slag Off·Refining Power Consumption and Billet Volume



g) The relation between charging number and time period is illustrated in Figure 8.1.24 and Table 8.1.18.

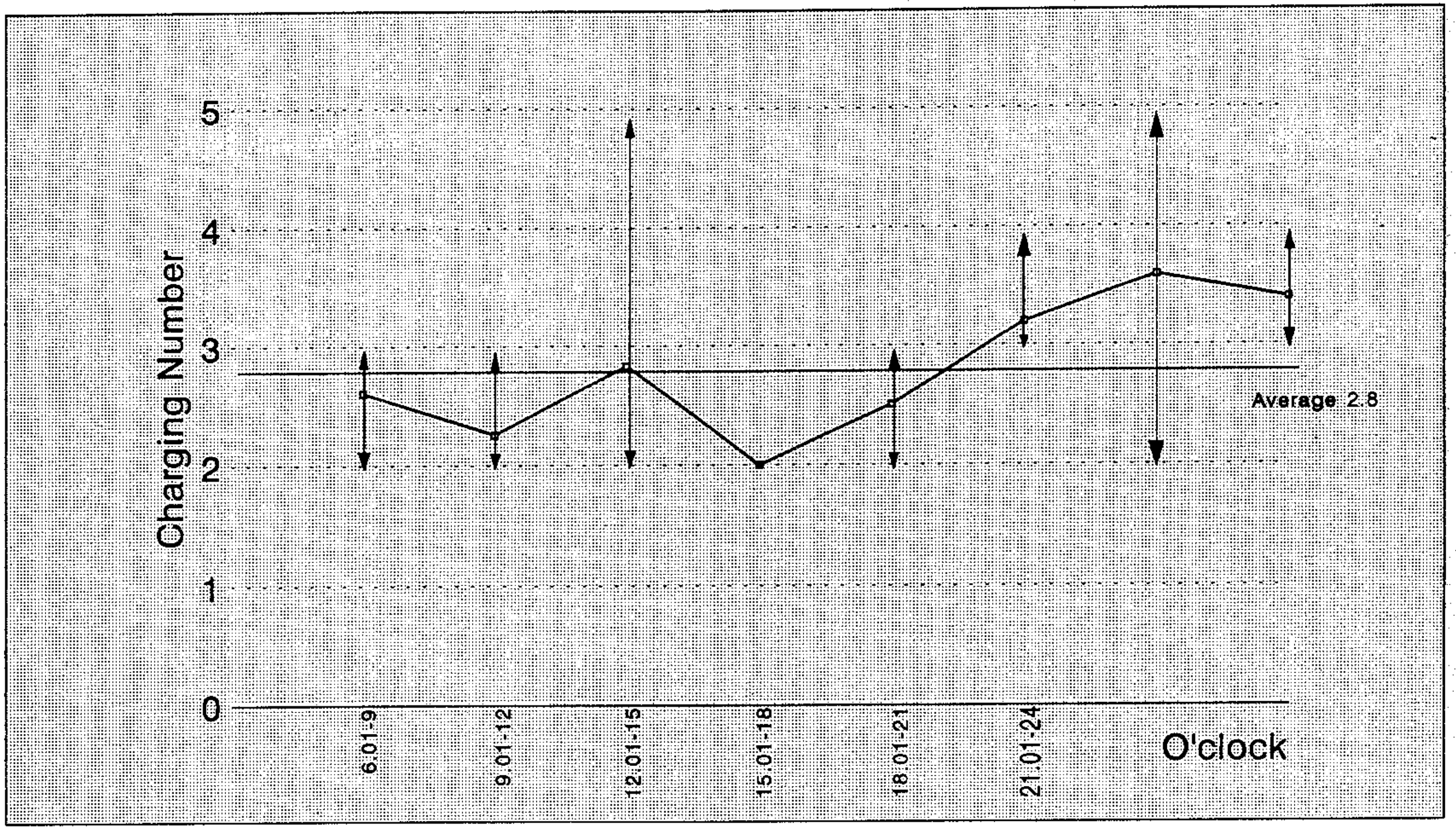
Table 8.1.18 Distribution of Charging Number Each Cycle In One Day

Charging number / Time period		2	3	4	5	Weight Average
06:00	- 9:00	2	3			2.6
09:01	- 12:00	3	1			2.25
12:01	- 15:00	3	2		1	2.83
15:01	- 18:00	6				2.00
18:01	- 21:00	2	2			2.50
21:01	- 24:00		3	1		3.20
00:01	- 03:00	1	1	2	1	3.60
03:01	- 06:00		3	2		3.40
Total		17	16	5	2	2.80

The weight average of charging number is 2.80. The most charging frequent number is 2 times/cycle.

From Figure 8.1.24, charging number increases during off peak period. So if charging number increases, it will occur on increasing power consumption.

Figure 8.1.24 The Relation between Charging Number and Time



h) The relation between melting kWh/billet volume (ton) and billet volume is shown in Table 8.1.19.

That relation is explained in the next revolution formula.

$X = -0.0988y + 6.3792$

where X = melting power consumption/unit ['00 kWH/ton]

y = billet volume (ton)

Their relation has a meaning of out probability 0.5%.

Increasing billet volume/cycle, power consumption unit decreases.

The relation between melting kWh/ton and billet volume ton/cycle is shown in Figure 8.1.25.

Table 8.1.19 The Relation of Melting Power Consumption per Billet Volume and Billet Volume

	Melting '00 Kwh/ton	Billet (Ton)	Calculation		
41	3	33			
	u = X − 3	v = y − 33	u^2	v^2	u X v
	0.109	0.451	0.012	0.203	0.049
	−0.075	4.259	0.006	18.139	−0.317
	−0.223	1.567	0.050	2.455	−0.349
	−0.572	0.768	0.327	0.590	−0.439
	−0.632	1.630	0.400	2.657	−1.030
	−0.587	3.876	0.344	15.023	−2.273
	−0.065	6.187	0.004	38.279	−0.404
	−0.575	1.637	0.330	2.680	−0.941
	0.030	0.998	0.001	0.996	0.030
	0.072	−1.099	0.005	1.208	−0.079
	0.638	−1.389	0.407	1.929	−0.886
	−0.225	3.032	0.050	9.193	−0.681
	0.702	4.546	0.493	20.666	3.192
	−0.281	1.202	0.079	1.445	−0.338
	−0.869	4.542	0.755	20.630	−3.947
	−0.540	6.027	0.292	36.325	−3.256
	−0.455	6.286	0.207	39.514	−2.857
	0.073	−0.782	0.005	0.612	−0.057
	−0.316	−0.213	0.100	0.045	0.067
	−0.845	−0.524	0.713	0.275	0.443
	−0.071	−2.277	0.005	5.185	0.161
	0.532	−1.288	0.283	1.659	−0.685
	0.309	−3.985	0.095	15.880	−1.230
	0.506	−3.904	0.256	15.241	−1.974
	0.261	−0.804	0.068	0.646	−0.210
	0.988	−4.162	0.976	17.322	−4.111
	0.333	3.005	0.111	9.030	1.000
	−0.138	0.540	0.019	0.292	−0.074
	0.076	−0.486	0.006	0.236	−0.037
	−0.200	4.495	0.040	20.205	−0.897
	0.321	1.630	0.103	2.657	0.523
	−0.009	3.775	0.000	14.251	−0.033
	1.123	−0.260	1.262	0.068	−0.292
	−0.563	1.470	0.317	2.161	−0.828
	−0.056	−1.411	0.003	1.991	0.079
	0.418	0.058	0.175	0.003	0.024
	0.344	0.790	0.118	0.624	0.272
	1.188	−3.630	1.411	13.177	−4.312
	0.999	−5.495	0.999	30.195	−5.491
	0.650	−2.040	0.422	4.162	−1.326
	−0.304	−1.100	0.092	1.210	0.334
n = 41 Σ	2.073231	27.922	11.340899	369.058192	−33.182

$\overline{U}$ =	0.0506	Su =	11.23606	b =	−3.0789
$\overline{V}$ =	0.6810	Sv =	350.04263	y =	−0.5516
$\overline{X}$ =	3.0506	Sx =	11.23606	Sxy2/Sx =	106.5127
$\overline{Y}$ =	33.6810	Sy =	350.04263	b' =	−0.0988
		Suv =	−34.59456		
		Sxy =	−34.59456		

y − 33.6810 = −3.0789 (x − 3.0506)

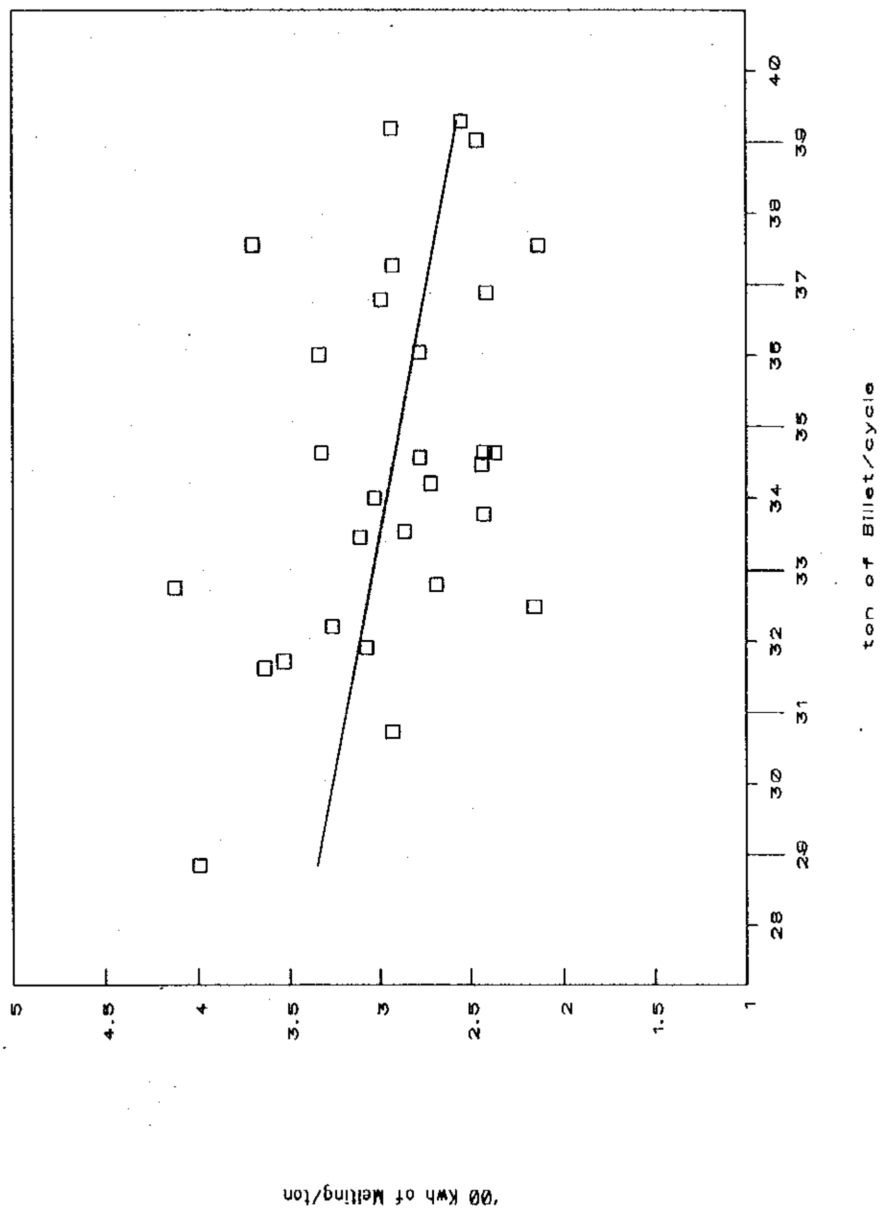
y = −3.0789 x + 43.0734

x − 3.0506 = −0.0988 (y − 33.6810)

x = −0.0988 y + 6.3792

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark
Revolution	106.51271	1	106.51271	17.05743	F'(0.005) = 9.18 < 17.0574
Rest	243.52992	39	6.24436		30
Total	350.04263	40			

Figure 8.1.25 The Relation between Melting Power Consumption per Billet Volume and Billet Volume



i) The relation between total kWh/billet volume (ton) and billet volume is shown on Table 8.1.20.

Their relation is explained in the next revolution formula.

X = -0.487y + 9.9814
where X = total power consumption unit ['00 kWH/ton]
y = billet volume (ton)

Their relation has a meaning of out probability 0.5%.

Increasing billet volume/cycle, total power consumption/ton decreases.

Relation between total kWh/ton and billet volume ton/cycle is shown on Figure 8.1.26.

Table 8.1.20 The Relation of Total Power Consumption per Billet Volume and Billet Volume

	Total	Billet			
	'00 Kwh/ton	(Ton)		Calculation	
40	4	33			
	u = X − 4	v = y − 33	u^2	v^2	u X v
	1.680	0.451	2.822	0.203	0.758
	0.777	4.259	0.604	18.139	3.311
	0.600	1.567	0.360	2.455	0.940
	0.324	0.768	0.105	0.590	0.249
	0.274	1.630	0.075	2.657	0.446
	0.013	3.876	0.000	15.023	0.052
	0.364	6.187	0.132	38.279	2.250
	0.446	1.637	0.199	2.680	0.730
	0.824	0.998	0.679	0.996	0.822
	1.360	−1.099	1.851	1.208	−1.495
	2.675	−1.389	7.155	1.929	−3.715
	0.774	3.032	0.598	9.193	2.345
	2.525	4.546	6.377	20.666	11.480
	0.620	1.202	0.384	1.445	0.745
	0.102	4.542	0.010	20.630	0.464
	0.253	6.027	0.064	36.325	1.526
	−0.080	6.286	0.006	39.514	−0.503
	0.966	−0.782	0.933	0.612	−0.756
	1.215	−0.213	1.477	0.045	−0.259
	0.311	−0.524	0.097	0.275	−0.163
	1.143	−2.277	1.306	5.185	−2.602
	1.424	−1.288	2.027	1.659	−1.834
	0.997	−3.985	0.995	15.880	−3.975
	1.843	−3.904	3.396	15.241	−7.194
	1.280	−0.804	1.639	0.646	−1.029
	2.068	−4.162	4.278	17.322	−8.609
	0.916	3.005	0.839	9.030	2.753
	0.234	0.540	0.055	0.292	0.126
	0.921	−0.486	0.848	0.236	−0.448
	−0.159	4.495	0.025	20.205	−0.717
	0.649	1.630	0.421	2.657	1.058
	0.487	3.775	0.237	14.251	1.837
	1.803	−0.260	3.252	0.068	−0.469
	0.729	1.470	0.531	2.161	1.071
	0.875	−1.411	0.766	1.991	−1.235
	0.991	0.058	0.983	0.003	0.057
	0.794	0.790	0.631	0.624	0.628
	2.503	−3.630	6.266	13.177	−9.087
	1.890	−5.495	3.571	30.195	−10.385
	1.297	−2.040	1.683	4.162	−2.646

n = 40 Σ	38.70852	29.02200	57.67845	367.84819	−23.46906
$\bar{U}$ =	0.9677	Su =	20.21972	b =	−2.5497
$\bar{V}$ =	0.7255	Sv =	346.79128	y =	−0.6157
$\bar{X}$ =	4.9677	Sx =	20.21972	Sxy2/Sx =	131.4468
$\bar{Y}$ =	33.7256	Sy =	346.79128	b' =	−0.1487
		Suv =	−51.55403		
		Sxy =	−51.55403		

y − 33.7256 = −2.5497 (x − 4.9677)

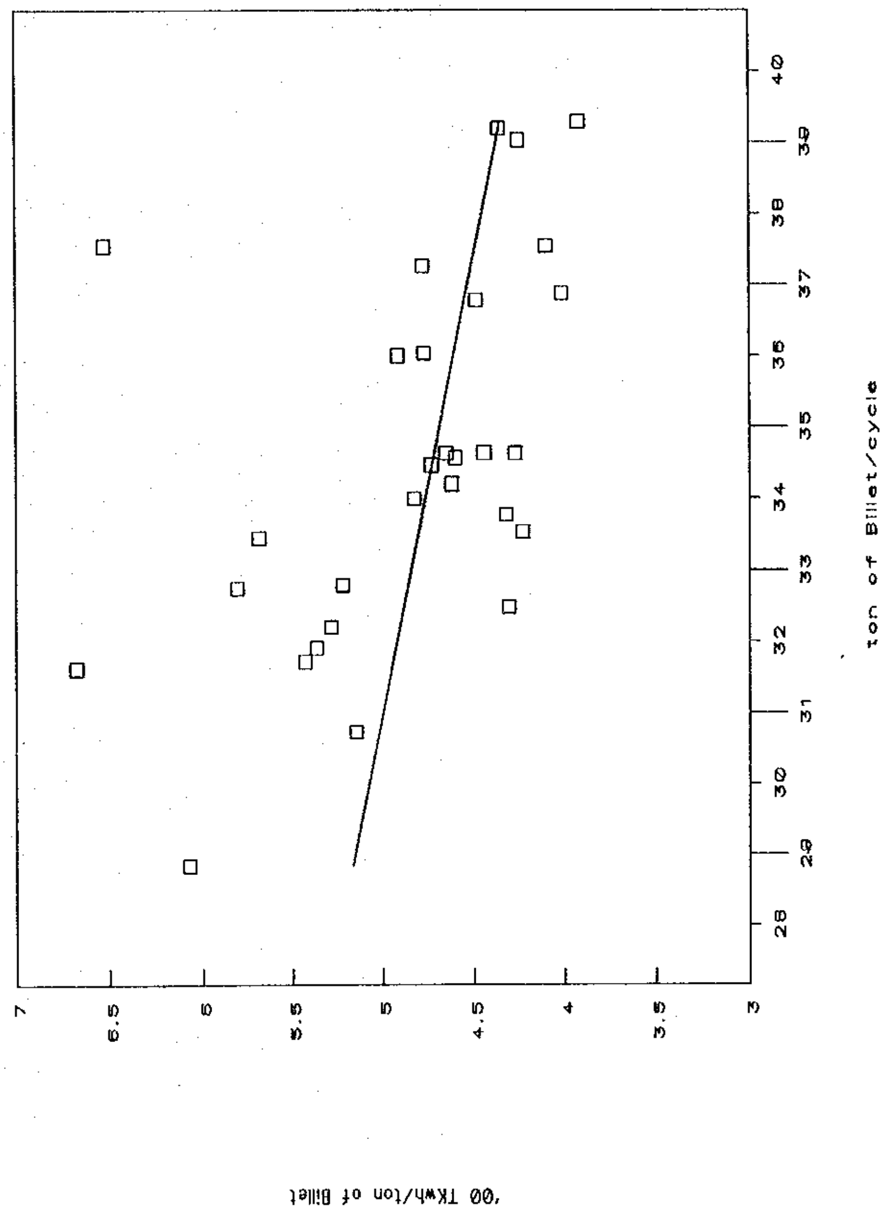
y = −2.5497 x + 46.3917

x − 4.9677 = −0.1487 (y − 33.7256)

x = −0.1487 y + 9.9814

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark
Revolution	131.44682	1	131.44682	23.19530	F'(0.005) = 9.18 < 23.1952
Rest	215.34446	38	5.66696		30
Total	346.79128	39			

Figure 8.1.26 The Relation between Total Power Consumption per Billet Volume and Billet Volume



j) The relation between melting time and oxidizing•Slag off•refining time and total power consumption is shown on Table 8.1.21.

There is no relation.

Forced to do, their relation has a meaning relation of out probability 25%.

Table 8.1.21 The Relation of Melting Time, Oxidizing•Slag Off•Refining Time, and Total Power Consumption

	Melting Time	Oxidizing, Slag, Refining	Total (' 00 Kwh)			Calculation			
40	45	28	150						
	u = X − 45	v = y − 28	w = z − 150	u^2	v^2	w^2	u X v	v X w	w X u
	0	9	40	0.000	81.000	1600	0.00	360.00	0.00
	1	0	28	1.000	0.000	784	0.00	0.00	28.00
	−6	−1	9	36.000	1.000	81	6.00	−9.00	−54.00
	−12	−5	−4	144.000	25.000	16	60.00	20.00	48.00
	−8	−6	−2	64.000	36.000	4	48.00	12.00	16.00
	0	−10	−2	0.000	100.000	4	0.00	20.00	0.00
	4	−7	21	16.000	49.000	441	−28.00	−147.00	84.00
	−10	9	4	100.000	81.000	16	−90.00	36.00	−40.00
	26	6	14	676.000	36.000	196	156.00	84.00	364.00
	0	4	21	0.000	16.000	441	0.00	84.00	0.00
	0	5	61	0.000	25.000	3721	0.00	305.00	0.00
	3	8	22	9.000	64.000	484	24.00	176.00	66.00
	12	5	95	144.000	25.000	9025	60.00	475.00	1140.00
	0	1	8	0.000	1.000	64	0.00	8.00	0.00
	−10	0	4	100.000	0.000	16	0.00	0.00	−40.00
	−5	−2	16	25.000	4.000	256	10.00	−32.00	−80.00
	0	−8	4	0.000	64.000	16	0.00	−32.00	0.00
	−3	−4	10	9.000	16.000	100	12.00	−40.00	−30.00
	−7	−4	21	49.000	16.000	441	28.00	−84.00	−147.00
	−9	20	−10	81.000	400.000	100	−180.00	−200.00	90.00
	15	16	8	225.000	256.000	64	240.00	128.00	120.00
	3	−6	22	9.000	36.000	484	−18.00	−132.00	66.00
	−6	−8	−5	36.000	64.000	25	48.00	40.00	30.00
	0	−1	20	0.000	1.000	400	0.00	−20.00	0.00
	1	−7	20	1.000	49.000	400	−7.00	−140.00	20.00
	0	−5	25	0.000	25.000	625	0.00	−125.00	0.00
	1	−6	27	1.000	36.000	729	−6.00	−162.00	27.00
	−6	−10	−8	36.000	100.000	64	60.00	80.00	48.00
	6	−2	10	36.000	4.000	100	−12.00	−20.00	60.00
	7	−11	−6	49.000	121.000	36	−77.00	66.00	−42.00
	2	−7	11	4.000	49.000	121	−14.00	−77.00	22.00
	8	−6	15	64.000	36.000	225	−48.00	−90.00	120.00
	10	1	40	100.000	1.000	1600	10.00	40.00	400.00
	11	33	13	121.000	1089.000	169	363.00	429.00	143.00
	15	−2	4	225.000	4.000	16	−30.00	−8.00	60.00
	3	−3	15	9.000	9.000	225	−9.00	−45.00	45.00
	12	−11	12	144.000	121.000	144	−132.00	−132.00	144.00
	1	−4	41	1.000	16.000	1681	−4.00	−164.00	41.00
	4	−2	12	16.000	4.000	144	−8.00	−24.00	48.00
	16	−9	14	256.000	81.000	196	−144.00	−126.00	224.00
n = 40 Σ	79	−30	650	2787	3142	25254	318	554	3021

$\overline{U}$ =	1.9750	Su =	2630.9750	b =	0.6232
$\overline{V}$ =	−0.7500	Sv =	3119.5000	c =	0.2585
$\overline{W}$ =	16.2500	Sw =	14691.5000	a =	129.92919
$\overline{X}$ =	46.9750	Sx =	2630.9750	bSxz+cSyz =	1351.9506
$\overline{Y}$ =	27.2500	Sy =	3119.5000	S.z = Sz − (bSxz + cSyz) =	13339.5494
$\overline{Z}$ =	166.2500	Sz =	14691.5000		
		Suv =	377.2500	Sxy =	377.25
		Svw =	1041.5000	Syz =	1041.5
		Swu =	1737.2500	Szx =	1737.25

Z = 129.929195 + 0.6232 x + 0.2585 y

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark	
Revolution	1,351.9506	2	675.9753	1.8750	F2(0.25) = 1.45 <	1.8750
Rest	13,339.5494	37	360.5284		30	
Total	14,691.5000	39				

Table 8.1.22 The Relation between TkWh/t and Charging Volume

	Total '00 Kwh/ton	Charging (Ton)	Calculation		
29	4.5	35			
	u = X − 4.5	v = y − 35	u^2	v^2	u X v
	0.296	4.620	0.087	21.344	1.365
	−0.155	5.970	0.024	35.641	−0.927
	−0.253	2.440	0.064	5.954	−0.618
	−0.143	−1.490	0.020	2.220	0.213
	0.151	−3.180	0.023	10.112	−0.481
	−0.226	−0.370	0.051	0.137	0.084
	−0.086	3.740	0.007	13.988	−0.321
	−0.171	0.570	0.029	0.325	−0.097
	−0.246	3.550	0.060	12.602	−0.873
	0.039	2.670	0.002	7.129	0.105
	0.754	5.160	0.568	26.626	3.891
	−0.028	3.460	0.001	11.972	−0.096
	1.712	4.440	2.931	19.714	7.601
	−0.311	2.720	0.097	7.398	−0.847
	−0.144	0.350	0.021	0.123	−0.050
	−0.214	3.730	0.046	13.913	−0.798
	−0.453	3.050	0.205	9.302	−1.381
	−0.209	4.850	0.044	23.523	−1.013
	−0.286	−1.780	0.082	3.168	0.508
	−0.568	5.180	0.322	26.832	−2.941
	−0.048	3.630	0.002	13.177	−0.172
	−0.135	3.950	0.018	15.603	−0.535
	−0.025	4.110	0.001	16.892	−0.105
	−0.013	4.450	0.000	19.803	−0.059
	−0.478	0.310	0.229	0.096	−0.148
	−0.335	3.660	0.113	13.396	−1.228
	−0.142	2.860	0.020	8.180	−0.406
	0.283	4.720	0.080	22.278	1.338
	−0.276	3.590	0.076	12.888	−0.991
n = 29					
Total	−1.70968	80.96	5.224	374.3344	1.0188

U =	−0.0590	Su =	5.12318	b =	1.1305
V =	2.7917	Sv =	148.31641	y =	0.2101
X =	4.4410	Sx =	5.12318	Sxy2/Sx =	6.5477
Y =	37.7917	Sy =	148.31641	b' =	0.0391
		Suv =	5.79179		
		Sxy =	5.79179		

y − 37.79172 = 1.1305 (x − 4.4410)

y = 1.1305 x + 32.7711

x − 4.441045 = 0.0391 (y − 37.7917)

x = 0.0391 y + 2.9653

Fluctuation	Sum of square	Freedom	Impartial variance	Impartial variance ratio	Remark	
Revolution	6.54765	1	6.54765	1.24701	F'(0.25) =1.38 >	1.2470
Rest	141.76876	27	5.25069		27	
Total	148.31641	28			,	

k) The relation between total kWh/charging volume (ton) and charging volume is shown on Table 8.1.22.

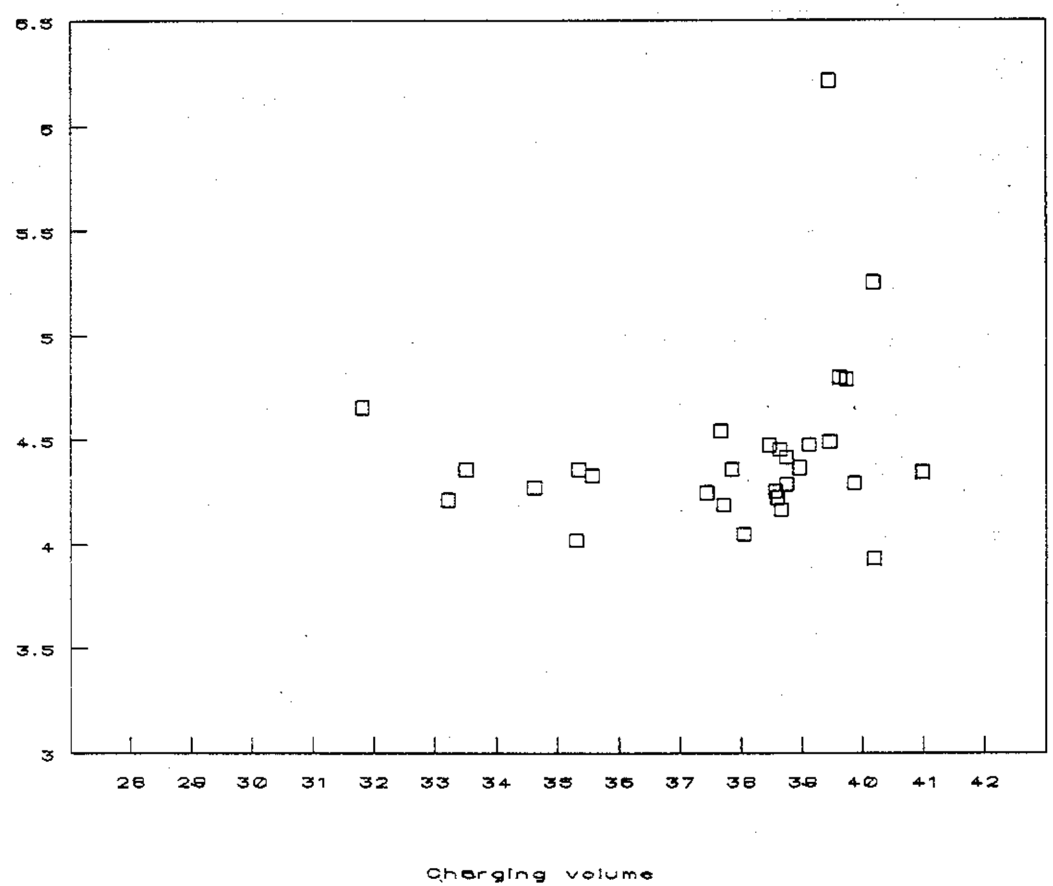
The relation between total kWh/ton and charging volume ton/cycle is shown on Figure 8.1.27.

There is no relation.

They may include many error components.

This case should be checked again by measuring charging volume with accurate scales.

Figure 8.1.27 The Relation between TkWh/t and Charging Volume



1) Delay time

There is quite fluctuation in collecting values. The data are shown in Table 8.1.23.

Table 8.1.23 Delay Time Distribution

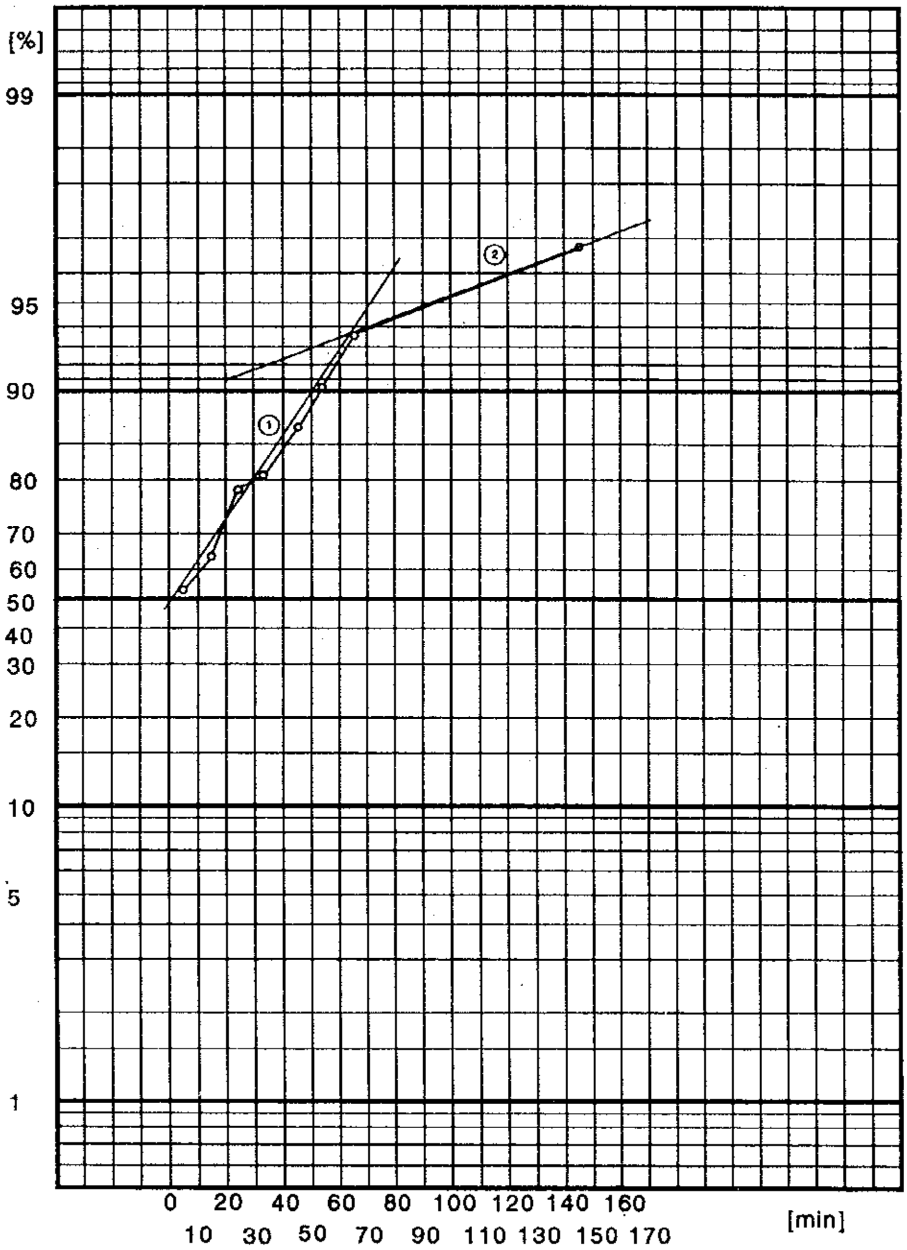
Range time		frequency	sum	%
640.1 ~ 650		1	31	
:				
.				
130.1 ~ 140		1	30	96.8
120.1 ~ 130				
110.1 ~ 120				
100.1 ~ 110				
90.1 ~ 100				
80.1 ~ 90				
70.1 ~ 80				
60.1 ~ 70		1	29	93.5
50.1 ~ 60		1	28	90.3
40.1 ~ 50		2	27	87.1
30.1 ~ 40				
20.1 ~ 30		4	25	80.6
10.1 ~ 20		4	21	67.7
0.0 ~ 10		17		54.8
	4 17			

The percentage of delay time distribution is plotted in probability sheet Figure 8.1.28.

From Figure 8.1.28, the curve is composed of two trends (1), (2). The recommendation of this case is to approach curve No. 1 or to raise the slope precipitously.

Therefore, the factory should use process maintenance (PM) for improving delay time, and good production schedule.

Figure 8.1.28 Delay Time Distribution



m) Scattering diagram between 1st charge volume and 1st charge melting time relation is shown in Figure 8.1.29. Scattering diagram between 2nd charge volume and 2nd charge melting time relation is shown in Figure 8.1.30. There is no relation. Scattering diagram between 3rd charge volume and 3rd charge melting time relation is as shown in Figure 8.1.31.

On twice charge case, charging volume distribution is shown in Figure 8.1.32.

On triple charge case, charging volume distribution is shown in Figure 8.1.33.

Figure 8.1.29 The Relation between 1st Charge Volume and 1st Charge Melting Time

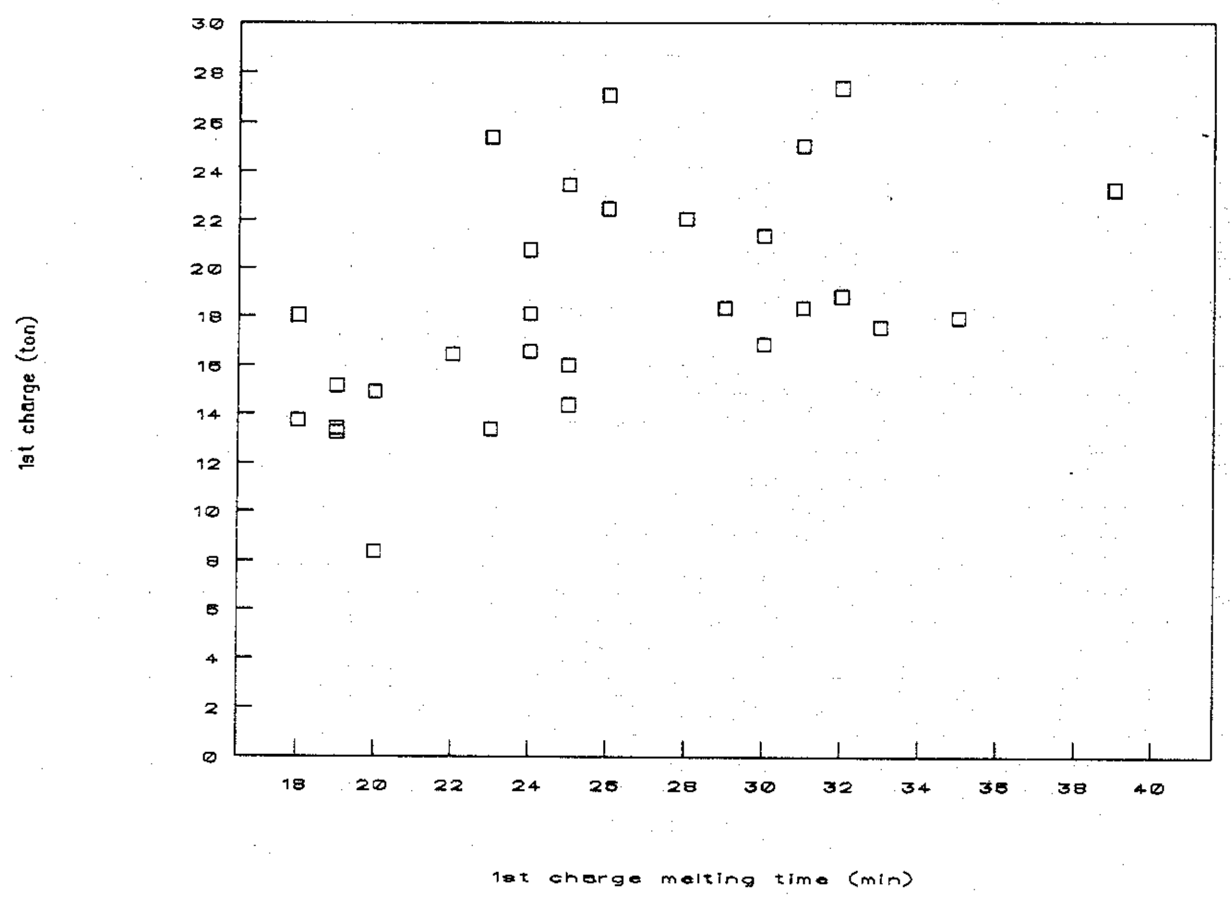


Figure 8.1.30 The Relation between 2nd Charge Volume and 2nd Charge Melting Time

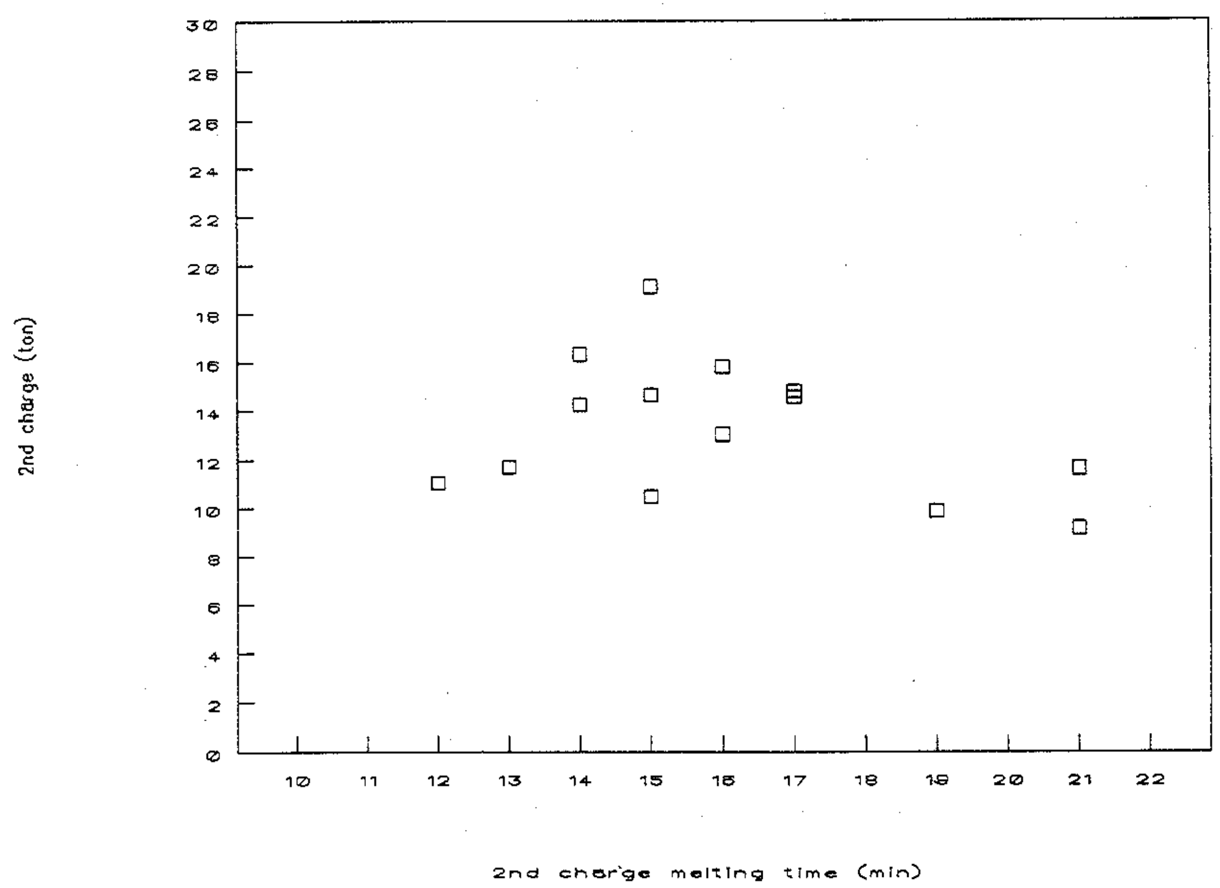


Figure 8.1.31 The Relation between 3rd Charge Volume and 3rd Charge Melting Time

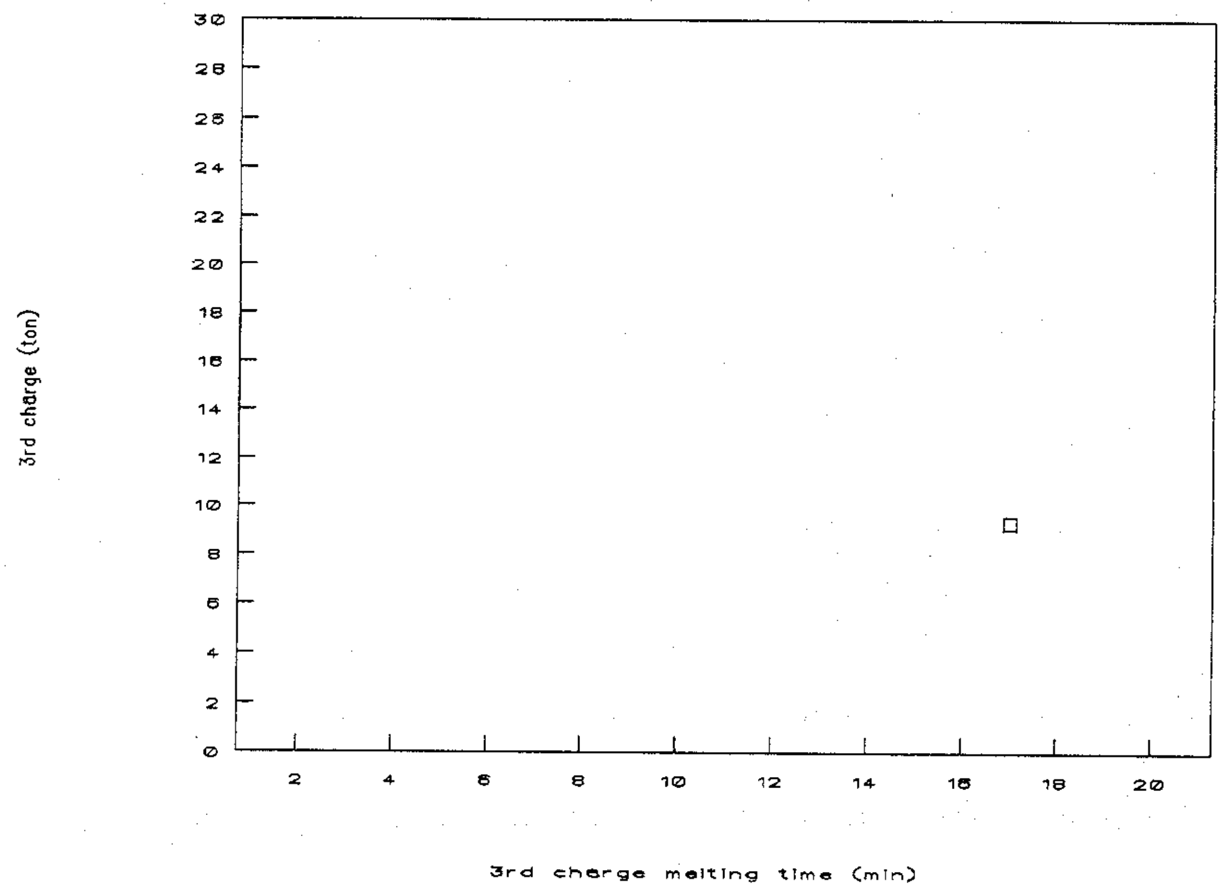


Figure 8.1.32 Twice: 1st and 2nd Charging Volume Distribution

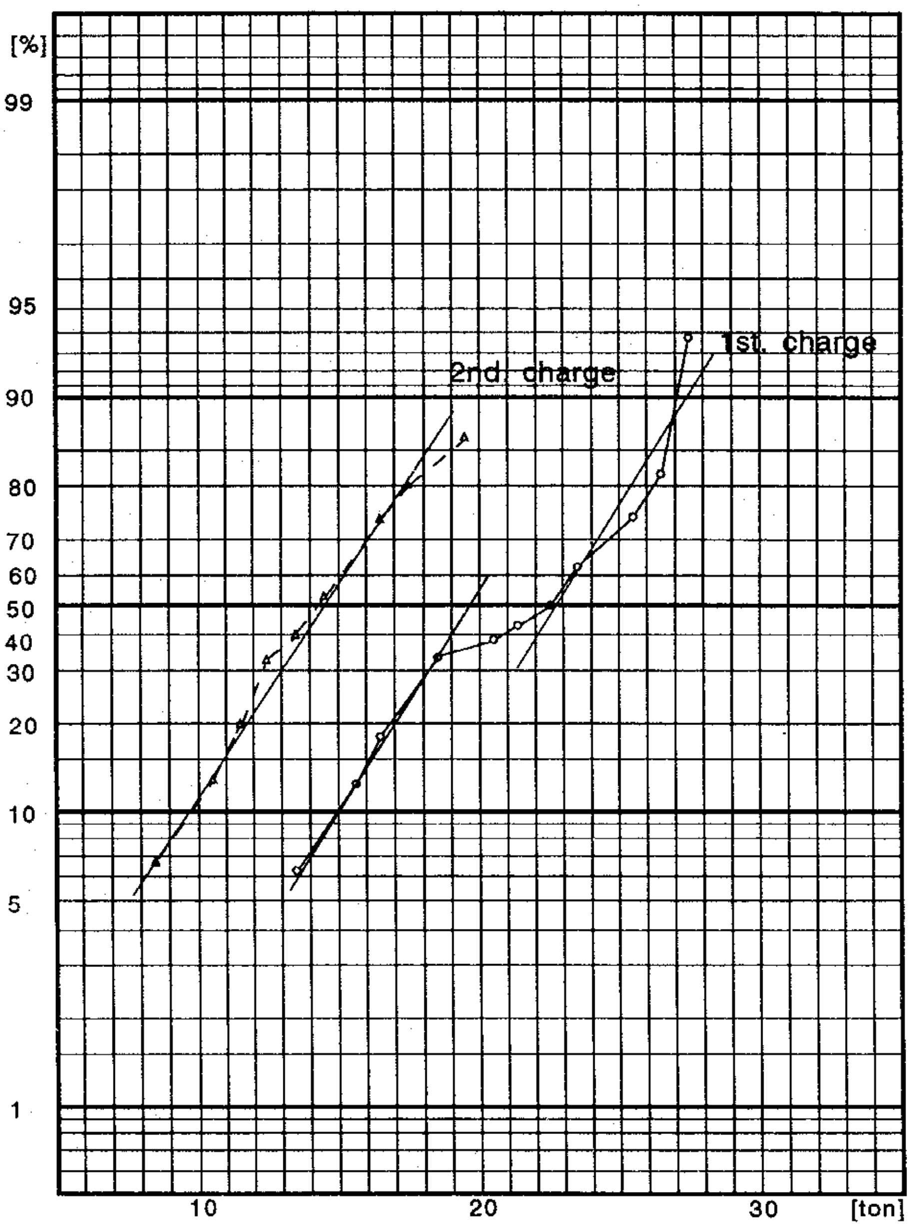
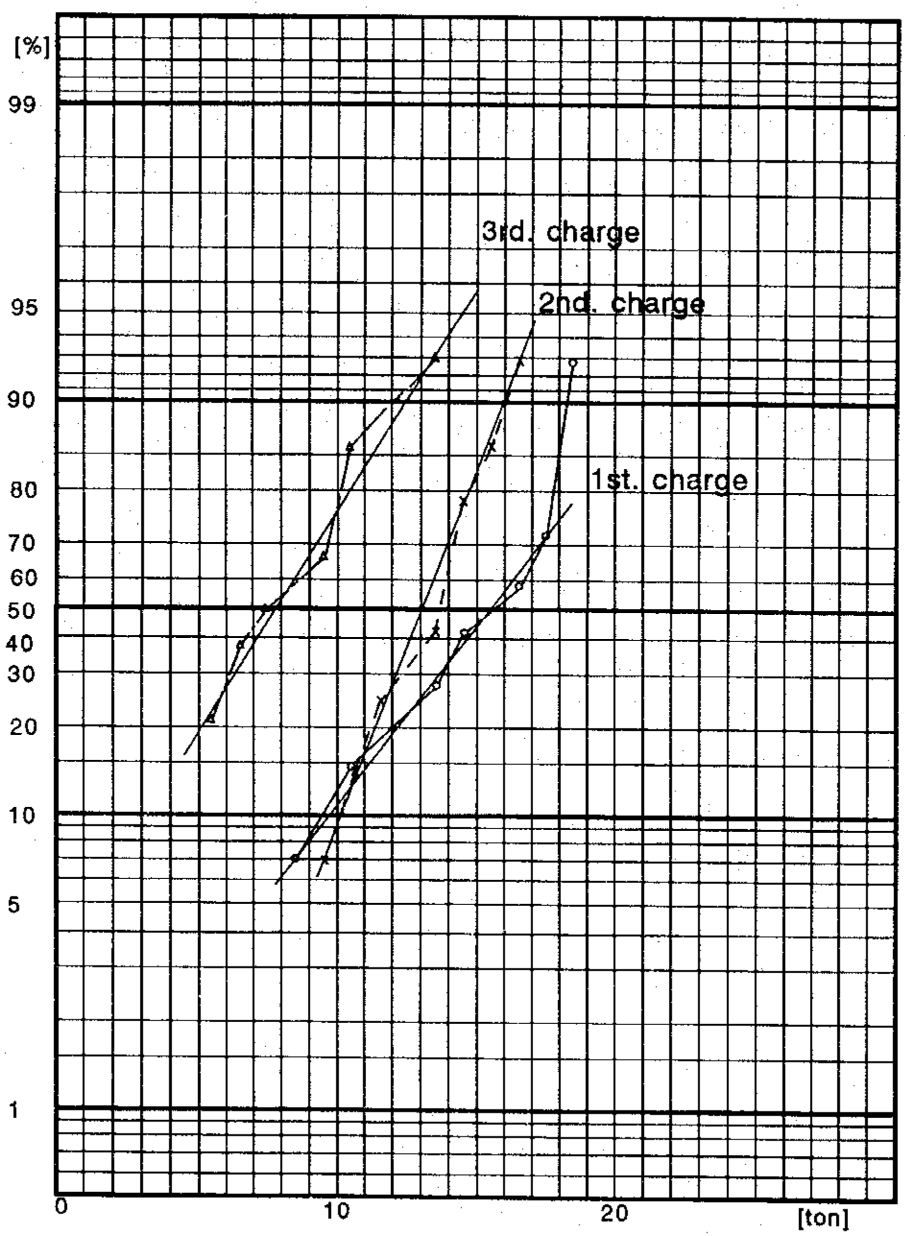


Figure 8.1.33 Triple: 1st, 2nd and 3rd Charging Volume Distribution



It presumes to do no standardization of charging number, and each charging volume, and charging time.

This case is to control and measure charging block weight/unit.

It is necessary to check charging volume of each charging and charging timing (schedule) and charging number.

n) Melting over time cut

There is a lot of over time cut in this factory. So it can be reduced by
1. using observation instrument.
2. having time management.

Data of melting time are plotted in probability sheet. Distribution curve of EAF melting time is shown in melting time distribution Figure 8.1.13.

The comment on this curve is to raise the slope precipitously.

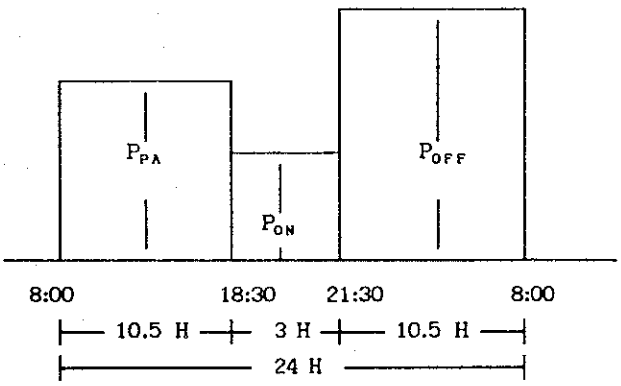
(d) Limit of suppress value of demand

Demand Controller is used for limiting Peak Demand. Pon (on peak demand) and Ppa (partial peak demand) are limited at 12,480 kW and 22,080 kW respectively. The limit of suppress value of demand is to get electric fee reducing.

Electricity fee can be explained by the next formula.

$$Y_1 = 240P_{ON} + 32(P_{PA} - P_{ON}) + 1.03(kWh) \qquad (1)$$

Figure 8.1.34 P_{PA}, P_{ON} and P_{OFF} Period Characteristic



It is possible to think that Steel Products Volume is proportional to Electric Power Consumption (kWh).

Steel Product Volume ~ kWh

If it is assumed that each value of P_{ON}, P_{PA} and P_{OF} is fixed constant load, electric power consumption load is explained in the next formula.

Electric power consumption

$$Y_2 = 10.5P_{PA} + 3P_{ON} + 10.5P_{OF} \qquad (2)$$

Put equation (2) into (1) therefore;

$$Y'_1 = 240P_{ON} + 32(P_{PA} - P_{ON}) + 1.03(kWh)$$
$$Y'_1 = 240P_{ON} + 32(P_{PA} - P_{ON}) + 1.03(3P_{ON} + 10.5P_{OF} + 10.5P_{PA})x30$$
$$= 300.7P_{ON} + 356.45P_{PA} + 324.45P_{OFF} \qquad (3)$$

$$Y_2 = 10.5P_{PA} + 3P_{ON} + 10.5P_{OF}$$

$$Y'_1 = 300.7P_{ON} + 356.45P_{PA} + 324.45P_{OF}$$

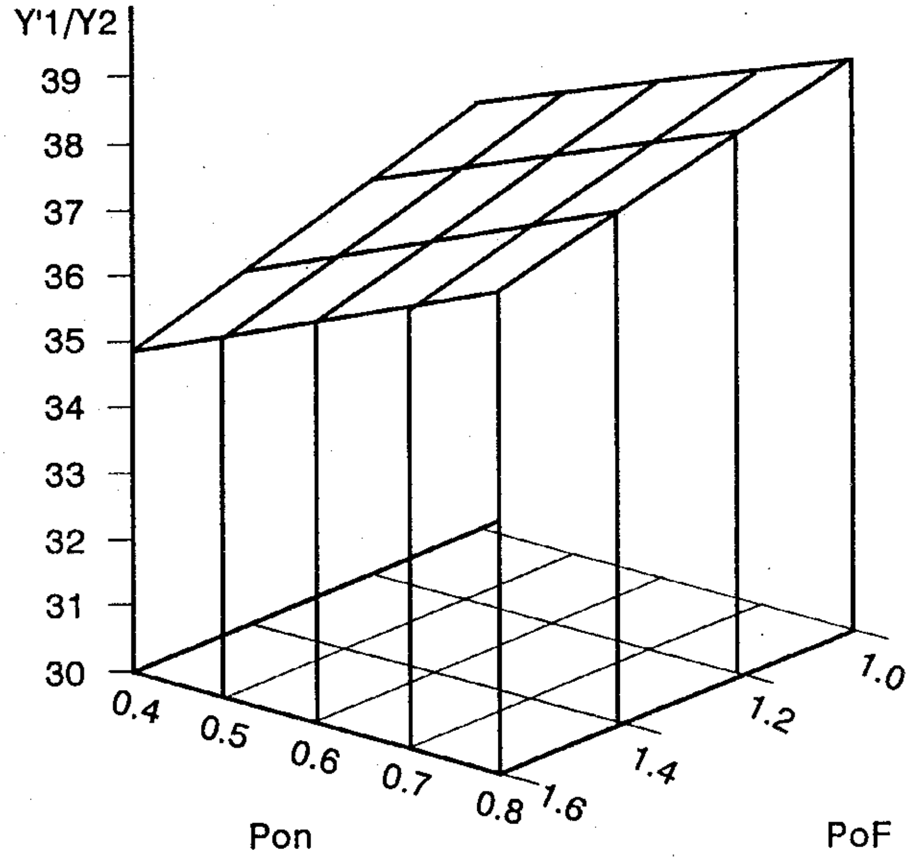
Based on P_{PA} value, $P_{PA} = 1$, changing of P_{ON} and P_{OFF} value, some calculation result is shown in Table 8.1.24.

Table 8.1.24 The Relation of P_{PA}, P_{ON}, P_{OF} and Y'_1/Y_2

P_{PA}	P_{ON}	P_{OF}	Y'_1	Y_2	Y'_1/Y_2
1	0.4	1.0	801.18	22.2	36.09
		1.2	866.07	24.3	35.64
		1.4	930.96	26.4	35.26
		1.6	995.05	28.5	34.94
1	0.5	1.0	831.25	22.5	36.94
		1.2	896.14	24.6	36.43
		1.4	961.03	26.7	35.99
		1.6	1,025.92	28.8	35.62
1	0.6	1.0	861.32	22.8	37.78
		1.2	926.21	24.9	37.20
		1.4	991.10	27.0	36.71
		1.6	1,055.99	29.1	36.29
1	0.7	1.0	891.39	23.1	38.59
		1.2	956.28	25.2	37.95
		1.4	1,021.17	27.3	37.41
		1.6	1,086.06	29.4	36.94
1	0.8	1.0	921.46	22.4	39.38
		1.2	986.35	25.5	38.68
		1.4	1,051.24	27.6	38.08
		1.6	1,116.13	29.7	37.58

The result from Table 8.1.24 can be shown in diagram Figure 8.1.35.

Figure 8.1.35 The Relation between Y'_1/Y_2



$Y_1/Y_2 \sim \dfrac{\text{Electricity fee}}{\text{Product Volume}}$

The result from Table 8.1.24 can be shown in diagram of Figure 8.1.35.

This result shows another idea;

as P_{PA} is basic value,
it is better to decrease P_{ON} value;
it is better to increase P_{OF} value.

It has to select good condition.

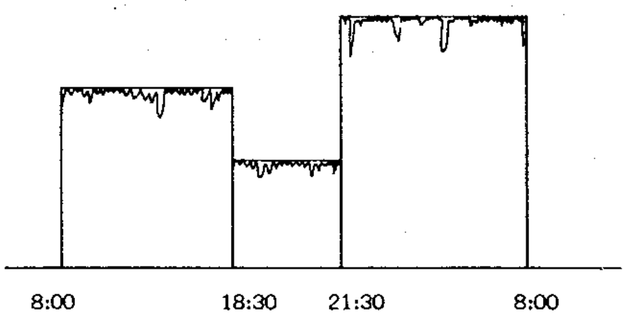
But, actually Y_2 should be explained by the next formula;

$$Y'_2 = K(3P_{ON}k1 + 10.5P_{PA}k2 + 10.5P_{OF}k3)$$

K, k1, k2, k3 = coefficient changing load variance and stopping time.

The above formula Y_2 is special case of K = 1, k1 = 1, k2 = 1, k3 = 1.
Actually load changes and is not always constant as in the following diagram of Figure 8.1.36.

Figure 8.1.36 Actual Load Curve



Therefore, it is necessary to consider K, k1, k2, k3 value charging effect. But the calculation result shows a very important sign. It has to approach k1->1, k2->1, k3->1; it is possible to decrease machine stop time.

(e) Management of Energy Consumption Characteristics

It is necessary to manage using control chart by using the relation of electric energy consumption (kWh), Melting time, Oxidizing·Slag off·Refining time and kWh/ton.

2) EAF Productivity

The principal factor of energy saving in electric furnaces is a shorter production time. The steel production time should be shortened by the following items;

(a) Melting time reducing (But it is not necessary to consider with P_{ON} demand period).

Melting time reducing by
- Maximum Input
- Breaker operating limit
  - reduce breaker trip by finding out the cause of each trip. For example electrode is covered by melting scrap, so it causes the high current in EAF distribution line.
- Charging volume
  - limiting charging volume, and reducing number of charging

(b) Oxidizing, Slag off and Refining time reducing
- minimize composition adjustment time
  - classification of scrap
  - additional material volume
    By accuracy measurement.

(c) Delay time reduction
- good preventive maintenance
  it is necessary to perform total productive maintenance (TPM).
- production schedule

(d) Reduction of fluctuation of each time
- charging volume standardization.
- additional charging timing standardization.
- systematic schedule.
- loss time reduction
  - melting over time cut.
  - Delay time cut.

(2) Electric Power Consumption

1) Arc Furnace

The data collecting from EAF operating record on Aug 2 to 4, 1994, can be summarized in Table 8.1.25;

Table 8.1.25 Power Consumption of Arc Furnace

Electric energy consumption	Range	Average
Melting time ('00kWh/d)	1,316 - 1,496	1,393
Total time ('00kWh/d)	2,123 - 2,270	2,217
Electric power consumption per unit (kWh/t)	461.2 - 495.5	481.6
Billet out (Ton/d)	455 - 465	460

From the above table, the average electric energy consumption per day is 221,700 kWh. The average on melting time period consumption is consumed more than 60 percent of total time.

It is an important item to do arc furnace electric power conservation. How to do electric power conservation has been already explained with (4) a.

2) Power Factor Improvement

The load of each transformer was measured to find the power factor and determine the capacity of the condenser which will be inserted into each MDB to improve the power factor.

The results of the measurement and calculation are as shown in the following Table 8.1.26 and 8.1.27.

Table 8.1.26 Transformer Copper Losses and PF before Improvement

Tr no	Division	Capacity (KVA)	Measuring Apparent Power (KVA)	PF	Transformer Copper Losses (W)
2	EAF Plant	750	382.61	0.690	2,606.31
3	Oxygen Pt.	1000	702.74	0.840	6,558.97
6	CCM	1000	307.32	0.560	1,223.61
7	RM3	1000	678.43	0.510	7,222.46
9	RM2	1000	203.08	0.780	616.61
	Total				18,227.96

Table 8.1.27 Transformer Copper Losses, PF and Condenser Used after Improvement

Tr no	Capacity (KVA)	Apparent Power (KVA)	Target PF	Transformer Copper Losses (W)	Condenser use (Kvar)
2	750	275.00	0.960	1,346.42	200
3	1000	617.47	0.956	5,063.82	200
6	1000	180.59	0.953	422.51	200
7	1000	355.97	0.972	1,988.35	500
9	1000	166.74	0.950	415.67	75
	Total			9,236.77	

The example of these calculations is shown in appendix 8.1.1(a) - 8.1.1(e)

When a condenser is inserted into each MDB, copper loss and apparent power become reducing as shown in the following Table 8.1.28.

Table 8.1.28 Saving from Transformer Copper Losses

Tr no	Condenser use (Kvar)	Saving energy (kWh/y)	Saving expense (Bt/y)	Investment (Bt)
2	200	9,071.18	13,643	52,900
3	200	10,765.07	16,191	52,900
6	200	5,767.97	8,675	52,900
7	500	37,685.58	56,679	108,000
9	75	1,446.73	2,176	21,650
Total*1)	1,175	63,289.80	95,188	266,700

*1) excluding Tr No. 9 because of high investment comparing with saving energy and expense.

The reduction of loss and release from payment of the Bt/year penalty result in savings of 95,188 Bt/year.

The condensers necessitate expenditure without Transformer No. 9, which is 266,700 Bt/year.

3) Line Loss Reduction

After providing capacitor to improve the power factor, the electric power distribution line loss is reduced. Specification of each distribution line is shown in Table 8.1.29 and Table 8.1.30.

Table 8.1.29 Specification of Distribution Line

Tr no	Type of conductor	Diameter (sq.mm)	Distance (m)-*2)	Quantity (line/phase)	Line Temp. (°C)
3 1)	Copper	50	120	3	33
2)	Copper	185	40	3	33
6	Copper	240	200	3	33
7	Copper	185	150	4	33

*2) Distance from transformer to MDB
*3) to calculate 2 lines losses for transformer No.3

Table 8.1.30 Saving from Line Losses

Tr no	Ia (A)	Ib (A)	Saving Energy (kwh/y)	Saving Expense (Bt/y)
3 1)	48.97	25.94	593.93	893
2)	1,008.37	899.23	6,125.46	9,213
6	438.10	257.44	14,074.54	21,168
7	1,064.38	558.47	67,948.85	102,186
Total			88,742.78	133,460

Remark : Ia = current before improvement
Ib = current after improvement

The example of line loss calculation is shown in Appendix 8.1.2(a)-(d).

This table above shows line loss reduction when the power factor is improved. Total electric energy saving is 88,742.78 kWh/y and saving expense is 133,460 Bt/y.

Table 8.1.31 Total Saving after Using Condenser

Tr No.	Condenser use (kvar)	Saving Tran. loss (kWh)	Saving Line loss (kWh)	Saving Total loss (kWh)	Saving Expense (Bt/y)	Invest-ment (Bt)	Pay-back period (y)	IRR *4) (%)
2	200	9,071.2	-	9,071.2	13,643	52,900	3.88	22.8
3	200	10,765.1	6,719.4	17,484.5	26,297	52,900	2.01	48.8
6	200	5,768.0	14,074.5	19,842.5	29,843	52,900	1.77	55.7
7	500	37,685.6	67,942.9	105,628.4	158,865	108,000	0.68	147.1
T	1,100	63,289.8	88,736.8	152,026.6	228,648	266,700	1.17	85.6

*4) life time of condenser is 10 years.

The total saving after power factor improvement is shown in Table 8.1.31. Total electric energy saving is 152,026.6 kWh/y and saving expense is 228,648 Bt/y. The investment for new condenser is 266,700 Baht. Therefore, this expense can be recovered within 1.2 years.

4) Integration of Transformer Load

As shown in Table 8.1.5, Tr4 3000 kVA and Tr5 1000 kVA have small load. They can be integrated to allow the load for oxygen plant to be supplied from the transformer for Dust Collector as shown in Table 8.1.32.

Table 8.1.32 Rating of Transformer Loads

Tr no	Division	Rating Capacity (kVA)	Apparent Power (kVA)	PF
	Before integrated			
4	Dust Collector	3,000	1,257.50	0.90
5	Oxygen Plant	1,000	485.80	0.85
	After integrated			
4	Dust Collector & Oxygen Plant	3,000	1,741.41	0.89

The result of transformer integration becomes as follows;

Energy saving = 2,324.32 kWh/y
Saving expense = 3,486 Bt/y, calculation is shown in Appendix 8.1.3.

5) Transformer Tap Changing

Table 8.1.33 Transformer Tap Changing : Tr No. 6 (CCM)

No.		Sec. voltage before (V)	Sec. voltage after (V)	Saving energy (kWh/y)	Saving expense (Baht/y)
1	Transformer losses	405	395	861.69	1,293
2	Motor losses	405	395	526.62	790
	Total			1,388.31	2,083

The example of these calculations is shown in Appendix 8.1.4.

The secondary voltage of the transformer is rather a high level of 405 volt for motor. Taps should be changed to lower the secondary voltage down to the normal level of 395 volt for motor load. Then, the power losses (Iron loss) in transformer and induction motor could be reduced and the power factor of induction motors should be increased. From Table 8.1.33, energy saving for the reduction of transformer losses is 861.69 kWh/y and 1,293 Baht/y of expense. Energy of 526.62 kWh/y and expense of 790 Baht/y will be saved for the reduction of motor losses.

As previously described in Table 8.1.5 and 8.1.6, the low voltages of 368 and 363 volt cause low efficiency operating.

Therefore, it is necessary to adjust transformer tap.

6) Peak Demand and Load Curve Analysis

<1>Peak Demand

Data of peak demand (Partial, On and Off peak), energy consumption, percent of load factor and Electric cost are shown in Table 8.1.34. On peak and partial peak period are controlled by demand controller which can be adjustable. The average peak demand in one month is 14,526 kW on peak, 22,666 kW partial peak and 22,518 kW off peak. On peak demand in November '93 is quite high and too low in February '94. Then these are needed to improve.

<2>Load Curve Analysis

The graph of Figure 8.1.37 shows relationship of peak demand (kW), energy consumption (kWh) and percent of load factor (%LF) of factory in one year. In the month in which energy consumption was low but peak demand was high, therefore the percentage of load factor would become low, such as in February 1994 the energy consumption was 5,708,000 kWh, 22,425 kW of peak demand and 34.9 percent of load factor, etc. It means that peak demand controlling was not appropriate which effects an increase in electric price of average energy consumption (Baht/kWH). On another side, in the month which energy consumption was high, peak demand was low. Then it would make percent of load factor increase, such as in July 1993, energy consumption was 9,244,400 kWH, 22,500 kW of peak demand and 56.3% percent of load factor, etc. It showed that peak demand was very good and it would have effected to decrease the price of average energy consumption (Baht/KWH). In second case, it was good benefit for factory, if engineer could control peak demand in minimum value while the production capacity was not changing, to set the target of peak demand of EAF and another load in the factory by setting operation system and appropriate Schedule of machines operating. Unnecessary machines should be stopped during on peak period. Electric machines should be started according to the priority of important machines. Therefore this factory should have low peak demand and high percent of load factor.

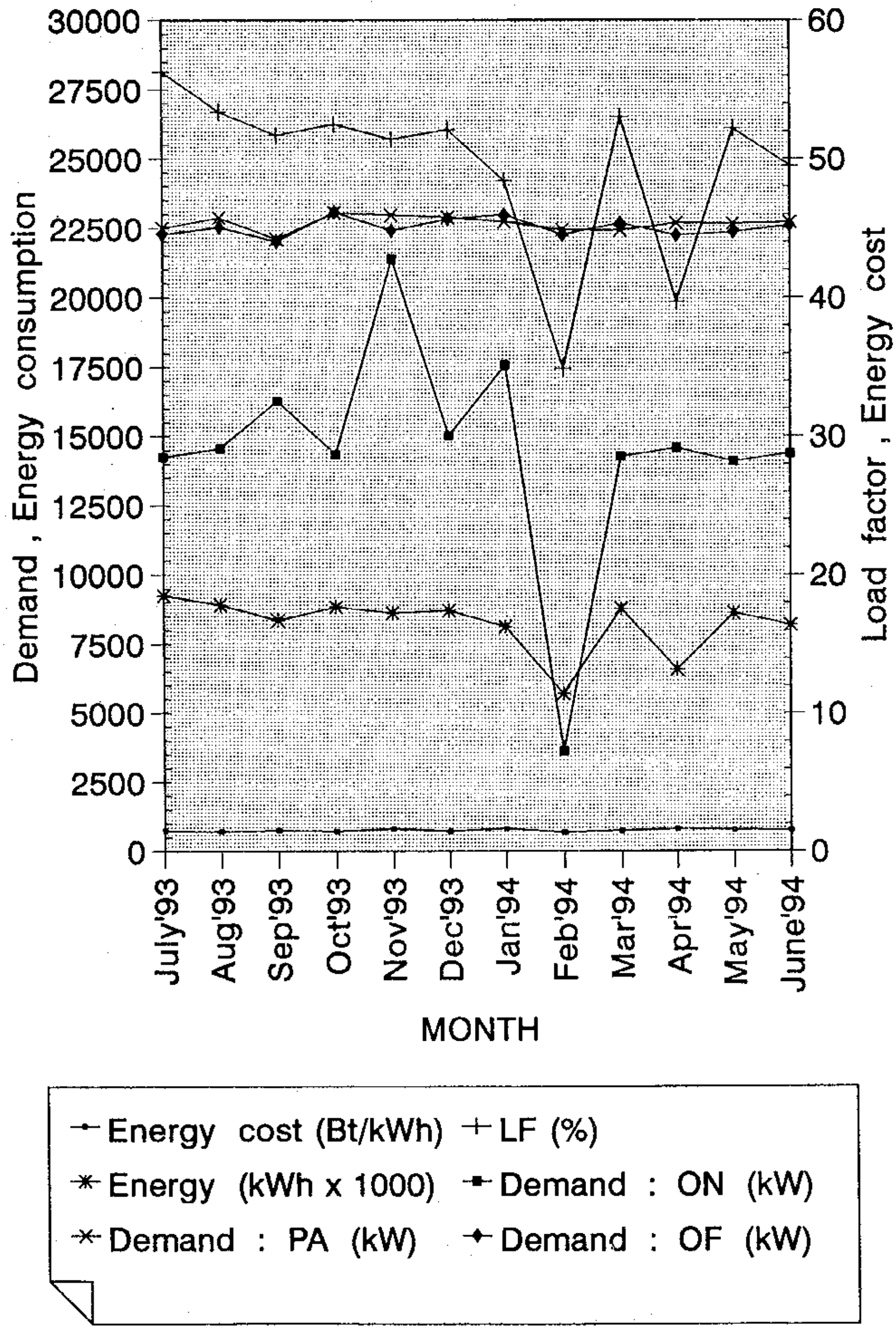
Table 8.1.34 Electrical Demand, Energy Consumption, Energy Cost, Baht/Unit and LF in 1 Year

Table 8.1.34 Electrical Demand, Energy Consumtion, Energy Cost, Baht/Unit and LF in 1 year

Month	Demand			Demand charge			Energy	Energy charge	FT	VAT	Total charge	Baht/Unit	LF
	ON(KW)	PA(KW)	OF(KW)	ON(B)	PA(B)	OF(B)	KWh	Baht	Baht	7%	Baht		(%)
July'93	14,240	22,500	22,270	3,417,600	264,320	0.00	9,244,400	9,521,731.94	299,518.56	883,364.99	13,503,170.50	1.461	56.3
Aug'93	14,560	22,880	22,530	3,494,400	266,240	0.00	8,915,200	9,182,655.97	−165822.72	835,909.47	12,777,473.25	1.433	53.4
Sep'93	16,262	22,099	22,022	3,902,880	186,784	0.00	8,348,300	8,598,748.88	−155278.38	819,924.69	12,533,134.50	1.501	51.7
Oct'93	14,343	23,059	23,079	3,442,320	278,912	0.00	8,839,000	9,104,169.90	−164405.4	828,289.50	12,660,996.50	1.432	52.5
Nov'93	21,389	22,964	22,406	5,133,360	50,400	0.00	8,613,000	8,871,390.05	−160201.8	909,015.30	13,894,948.25	1.613	51.4
Dec'93	15,014	22,886	22,829	3,603,360	251,904	0.00	8,711,000	8,972,330.10	−162024.6	828,588.65	12,665,569.50	1.454	52.1
Jan'94	17,568	22,733	22,982	4,216,320	165,280	0.00	8,123,000	8,366,689.95	561,299.30	970,720.00	13,309,589.25	1.639	48.4
Feb'94	3,629	22,425	22,253	870,960	601,472	0.00	5,708,000	5,879,239.95	394,422.80	506,753.37	7,746,094.75	1.357	34.9
Mar'94	14,266	22,406	22,676	3,423,840	260,480	0.00	8,780,000	9,043,400.00	312,568.00	853,102.95	13,040,288.00	1.485	53.0
Apr'94	14,573	22,676	22,233	3,497,520	259,296	0.00	6,571,000	6,768,129.90	23,655.60	690,095.43	10,548,601.50	1.605	39.7
May'94	14,093	22,656	22,349	3,382,320	274,016	0.00	8,627,000	8,885,809.90	822,153.10	874,299.94	13,364,299.00	1.549	52.2
June'94	14,380	22,713	22,598	3,451,200	266,656	0.00	8,201,000	8,447,030.00	229,628.00	810,856.06	12,394,514.00	1.511	49.5
Total	174,317	271,997	270,227	41,836,080	3,125,760	0.00	98,680,900	101,641,326.54	1,835,512.46	9,810,940.35	148,438,679.00	1.504	49.7

$$\%LF = \frac{\text{Energy consumption (KWH)} \times 100}{\text{Maximum peak demand (KW)} \times 730 \text{ (H/M)}}$$

Figure 8.1.37 The Relation of Demand and Energy Consumption



7) Air Compressor

There are 5 of air compressor used in EAF section. The load of each unit is presented in Table 8.1.26. In order to reduce input power and increase the efficiency of air compressor, the following items are important.

1. Maintenance of air leakage from clearance, hole, pipe, etc..
2. Suppress same time driving number of air compressor to use air tank effectively.

8) Mechanical losses of machine

Many machines, located in factory, have mechanical friction loss.

The important thing for this case is periodical good maintenance such as supply lubrication. Good lubrication reduces mechanical friction.

9) Lighting

It is better to replace low efficiency lamps for lighting of the whole factory by high efficiency lamps such as 18, 36 watts fluorescent lamps. Another thing is to switch off lamps in unnecessary area such as air compressor room in oxygen plant, etc.

(3) Others

The other things which should be considered are the presented as following items;

1) Arrangement of many materials in factory.

2) Elimination of scrap and remaining material - all parts in factory.

3) Good Maintenance such as;

- good lubrication

4) Good production schedule to reduce over stuck cold billet.

5) Working record of electric energy consumption.

6) Working record analysis.

7) Productivity and melting time, billet weight, kWh, etc., energy consumption control

- using control chart

8) Demand limit over all factory

- simulation of Pon - Ppa - Pof value to limit power demand.

9) Installation of instrumentation for measuring electric power, kWh, PF, weight, time control (melting, oxidizing, slag off, refining, etc.)

10) Continuous casting

- Reduce wait time of adjustment of composition.
- Reduce fail time loss
- Good preventive maintenance
- Less Reheating
  Final target. But it includes solving problems, apparatus, production schedule, etc.
- Less stop of beating billet shooting.
- Less stop of billet rolling.

11) Improvement by all member participation.

8.1.3.5 Total effect

From the result of energy audit in a factory, a possibility to reduce energy costs can be identified as the following :

Item	Installation Costs (Baht)	Energy Savings (Baht/year)	Payback Period (year)
1. Heat Energy			
1.1 Results of Oxygen Reduction in Furnace	100,000	476,582	0.2
1.2 Changing to substitute "A" Heavy oil for Diesel fuel reheating of Electric Arc Furnace Body	300,000	1,934,774	0.15
Sub Total	400,000	2,411,356	0.17
2. Electric Energy			
2.1 Power Factor Improvement	228,648	266,700	1.17
2.2 Tranformer Tap changing	2,083	–	–
Sub Total	230,731	266,700	0.86
Total	630,731	2,678,056	0.24

Appendix 8.1.1 (a)

POWER FACTOR CORRECTION

DATA OF TRANSFORMER

Transformer name	TR.2 (EAF PLANT)	
Capacity of Transformer	750.00	kVA
Efficiency (eff)	98.53	%
Rated sec. voltage	400.00	V
Rated current (Ir)	1082.53	A
Iron Losses (at 75 deg. C)	1530	W
Copper Losses (at 75 deg. C)	9680	W (at full load)

BEFORE IMPROVEMENT			AFTER IMPROVEMENT		
Active Power	264.00	kW	Active Power	264.00	kW
Apparent Power	382.61	kVA	Apparent Power	275.00	kVA
Reactive Power	276.94	kVar	Reactive Power	77.00	kVar
Power Factor	0.690		Power Factor	0.960	
Actual sec. voltage	390.00	V	Actual sec. voltage	390.00	V
Actual current (Ia)	566.41	A	Actual current (Ib)	407.11	A
Iron Losses	1530	W	Iron Losses	1530	W
Copper Losses	2606.31	W	Copper Losses	1346.42	W
Efficiency of trans.	98.46	%	Efficiency of trans.	98.92	%

Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh
To use capacitor	200	kVar

FORMULA

Copper loss reduction = kVA x (1−eff) x % CU loss x [(Ia/Ir)^2 − (Ib/Ir)^2] x Work hour per year

SAVING

Energy saving	9071.18	kWh/year
Money saving	13643	Baht/year

Printed Date 06/09/94
Printed Time 11:38:36

Appendix 8.1.1 (b)

POWER FACTOR CORRECTION

DATA OF TRANSFORMER

Transformer name	TR.3 (OXYGEN + CCM COOLING WATER)	
Capacity of Transformer	1000.00	kVA
Efficiency (eff)	98.48	%
Rated sec. voltage	400.00	V
Rated current (Ir)	1443.38	A
Iron Losses (at 75 deg. C)	1950	W
Copper Losses (at 75 deg. C)	13500	W (at full load)

BEFORE IMPROVEMENT			AFTER IMPROVEMENT		
Active Power	590.30	kW	Active Power	590.30	kW
Apparent Power	702.74	kVA	Apparent Power	617.47	kVA
Reactive Power	381.30	kVar	Reactive Power	181.14	kVar
Power Factor	0.840		Power Factor	0.956	
Actual sec. voltage	400.00	V	Actual sec. voltage	400.00	V
Actual current (Ia)	1014.32	A	Actual current (Ib)	891.24	A
Iron Losses	1950	W	Iron Losses	1950	W
Copper Losses	6558.97	W	Copper Losses	5063.82	W
Efficiency of trans.	98.58	%	Efficiency of trans.	98.83	%

Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh
To use capacitor	200	kVar

FORMULA

Copper loss reduction = kVA x (1−eff) x % CU loss x [(Ia/Ir)^2 − (Ib/Ir)^2] x Work hour per year

SAVING

Energy saving	10765.07	kWh/year
Money saving	16191	Baht/year

Printed Date	06/09/94
Printed Time	11:26:45

Appendix 8.1.1 (c)

POWER FACTOR CORRECTION

DATA OF TRANSFORMER

Transformer name	TR.6 (CCM)	
Capacity of Transformer	1000.00	kVA
Efficiency (eff)	98.48	%
Rated sec. voltage	400.00	V
Rated current (Ir)	1443.38	A
Iron Losses (at 75 deg. C)	1950	W
Copper Losses (at 75 deg. C)	13500	W (at full load)

BEFORE IMPROVEMENT			AFTER IMPROVEMENT		
Active Power	172.10	kW	Active Power	172.10	kW
Apparent Power	307.32	kVA	Apparent Power	180.59	kVA
Reactive Power	254.61	kVar	Reactive Power	54.71	kVar
Power Factor	0.560		Power Factor	0.953	
Actual sec. voltage	405.00	V	Actual sec. voltage	405.00	V
Actual current (Ia)	438.10	A	Actual current (Ib)	257.44	A
Iron Losses	1950	W	Iron Losses	1950	W
Copper Losses	1223.61	W	Copper Losses	422.51	W
Efficiency of trans.	98.19	%	Efficiency of trans.	98.64	%

Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh
To use capacitor	200	kVar

FORMULA

Copper loss reduction = kVA x (1−eff) x % CU loss x [(Ia/Ir)^2 − (Ib/Ir)^2] x Work hour per year

SAVING

Energy saving	5767.97	kWh/year
Money saving	8675	Baht/year

Printed Date 06/09/94
Printed Time 11:33:13

Appendix 8.1.1 (d)

POWER FACTOR CORRECTION

DATA OF TRANSFORMER

Transformer name	TR.7 (RM3 PLANT)	
Capacity of Transformer	1000.00	kVA
Efficiency (eff)	98.48	%
Rated sec. voltage	400.00	V
Rated current (Ir)	1443.38	A
Iron Losses (at 75 deg. C)	1950	W
Copper Losses (at 75 deg. C)	13500	W (at full load)

BEFORE IMPROVEMENT			AFTER IMPROVEMENT		
Active Power	346.00	kW	Active Power	346.00	kW
Apparent Power	678.43	kVA	Apparent Power	355.97	kVA
Reactive Power	583.57	kVar	Reactive Power	83.65	kVar
Power Factor	0.510		Power Factor	0.972	
Actual sec. voltage	368.00	V	Actual sec. voltage	368.00	V
Actual current (Ia)	1064.38	A	Actual current (Ib)	558.47	A
Iron Losses	1950	W	Iron Losses	1950	W
Copper Losses	7222.46	W	Copper Losses	1988.35	W
Efficiency of trans.	97.42	%	Efficiency of trans.	98.87	%

Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh
To use capacitor	500	kVar

FORMULA

Copper loss reduction = kVA x (1−eff) x % CU loss x [(Ia/Ir)^2 − (Ib/Ir)^2] x Work hour per year

SAVING

Energy saving	37685.58	kWh/year
Money saving	56679	Baht/year

Printed Date 06/09/94
Printed Time 11:34:59

Appendix 8.1.1 (e)

POWER FACTOR CORRECTION

DATA OF TRANSFORMER

Transformer name	TR.9 (RM2 PLANT)		
Capacity of Transformer	1000.00	kVA	
Efficiency (eff)	98.48	%	
Rated sec. voltage	400.00	V	
Rated current (Ir)	1443.38	A	
Iron Losses (at 75 deg. C)	1950	W	
Copper Losses (at 75 deg. C)	13500	W	(at full load)

BEFORE IMPROVEMENT			AFTER IMPROVEMENT		
Active Power	158.40	kW	Active Power	158.40	kW
Apparent Power	203.08	kVA	Apparent Power	166.74	kVA
Reactive Power	127.08	kVar	Reactive Power	52.06	kVar
Power Factor	0.780		Power Factor	0.950	
Actual sec. voltage	377.00	V	Actual sec. voltage	377.00	V
Actual current (Ia)	311.00	A	Actual current (Ib)	255.35	A
Iron Losses	1950	W	Iron Losses	1950	W
Copper Losses	616.61	W	Copper Losses	415.67	W
Efficiency of trans.	98.41	%	Efficiency of trans.	98.53	%

Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh
To use capacitor	75	kVar

FORMULA

Copper loss reduction = kVA x (1−eff) x % CU loss x [(Ia/Ir)^2 − (Ib/Ir)^2] x Work hour per year

SAVING

Energy saving	1446.73	kWh/year
Money saving	2176	Baht/year

Printed Date 06/09/94
Printed Time 11:50:42

Appendix 8.1.2 (a)

LINE LOSSES REDUCTION

DATA OF CONDUCTOR

Type of conductor (THW,TW ect.)	THW	
Conductor materials	Annealed Copper	
Cross section area of conductor	50.00	sq.mm
Quantity of conductor	3.00	line/phase
Distance of conductor (L)	120.00	m
Temp. of conductor (tw)	33.00	deg. C
Temp. coefficient at 20 deg. C (Tc)	0.00393	
Max.resistance at 20 deg. C (Rt)	0.379	Ohm/km/Conductor
Current before improvement (Ia)	48.97	A
Current after improvement (Ib)	25.94	A
Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh

FORMULA

Line losses saving = 3 x (Ia^2−Ib^2) x Rt x [1 + Tc (tw−20)] x L x work hour / 10^6

SAVING

Energy saving	593.93	kWh/year
Money saving	893	Baht/year

Printed Date	13/09/94
Printed Time	15:19:05

Appendix 8.1.2 (b)

LINE LOSSES REDUCTION

DATA OF CONDUCTOR

Type of conductor (THW,TW ect.)	THW	
Conductor materials	Annealed Copper	
Cross section area of conductor	185.00	sq.mm
Quantity of conductor	3.00	line/phase
Distance of conductor (L)	40.00	m
Temp. of conductor (tw)	33.00	deg. C
Temp. coefficient at 20 deg. C (Tc)	0.00393	
Max.resistance at 20 deg. C (Rt)	0.0972	Ohm/km/Conductor
Current before improvement (Ia)	1008.37	A
Current after improvement (Ib)	899.23	A
Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh

FORMULA

Line losses saving = 3 x (Ia^2-Ib^2) x Rt x [1 + Tc (tw-20)] x L x work hour / 10^6

SAVING

Energy saving	6125.46	kWh/year
Money saving	9213	Baht/year

Printed Date 13/09/94
Printed Time 15:20:21

Appendix 8.1.2 (c)

LINE LOSSES REDUCTION

DATA OF CONDUCTOR

Type of conductor (THW,TW ect.)	THW	
Conductor materials	Annealed Copper	
Cross section area of conductor	240.00	sq.mm
Quantity of conductor	3.00	line/phase
Distance of conductor (L)	200.00	m
Temp. of conductor (tw)	33.00	deg. C
Temp. coefficient at 20 deg. C (Tc)	0.00393	
Max.resistance at 20 deg. C (Rt)	0.074	Ohm/km/Conductor
Current before improvement (Ia)	438.10	A
Current after improvement (Ib)	257.44	A
Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh

FORMULA

Line losses saving = 3 x (Ia^2−Ib^2) x Rt x [1 + Tc (tw−20)] x L x work hour / 10^6

SAVING

Energy saving	14074.54	kWh/year
Money saving	21168	Baht/year

Printed Date 13/09/94
Printed Time 15:24:57

Appendix 8.1.2 (d)

LINE LOSSES REDUCTION

DATA OF CONDUCTOR

Type of conductor (THW,TW ect.)	THW	
Conductor materials	Annealed Copper	
Cross section area of conductor	185.00	sq.mm
Quantity of conductor	4.00	line/phase
Distance of conductor (L)	150.00	m
Temp. of conductor (tw)	33.00	deg. C
Temp. coefficient at 20 deg. C (Tc)	0.00393	
Max.resistance at 20 deg. C (Rt)	0.0972	Ohm/km/Conductor
Current before improvement (Ia)	1064.38	A
Current after improvement (Ib)	558.47	A
Work hour	7200.00	h/y
Electricity price	1.504	baht/kWh

FORMULA

Line losses saving = 3 x (Ia^2-Ib^2) x Rt x [1 + Tc (tw-20)] x L x work hour / 10^6

SAVING

Energy saving	67942.85	kWh/year
Money saving	102186	Baht/year

Printed Date 13/09/94
Printed Time 15:26:47

Appendix 8.1.3

TRANSFORMER REMOVE

DATA OF TRANSFORMER

Transformer name	TR.5 (OXYGEN)		Transformer name	TR.4 (DUST)	
Capacity of Transformer	1000.00	kVA	Capacity of Transformer	3000.00	kVA
Efficiency (eff)	98.48	%	Efficiency (eff)	98.8	%
Iron Losses (at 75 deg. C)	1950	W	Iron Losses (at 75 deg. C)	4150	W
Copper Losses (at 75 deg.C)	13500	W	Copper Losses (at 75 deg.C)	32400	W

LOAD OF TRANSFORMER

Transformer name	TR.5 (OXYGEN)		Transformer name	TR.4 (DUST)	
Active Power	412.93	kW	Active Power	1131.75	kW
Apparent Power	485.80	kVA	Apparent Power	1257.50	kVA
Reactive Power	255.91	kVar	Reactive Power	548.13	kVar
Power Factor	0.85		Power Factor	0.90	

FORMULA

Iron loss = kVA x (1−eff) x % Iron loss x hour per year

Copper loss = kVA x (1−eff) x % Copper loss x (kVA actual/kVA rated)^2 x working hour per year

Work hour	7200.00	h/y
Electricity price	1.50	baht/kWh

Transformer name	TR.5 (OXYGEN)		Transformer name	TR.4 (DUST)	
Iron loss (1)	16805.59	kWh/y	Iron loss (2)	35806.95	kWh/y
Copper loss (1)	22568.17	kWh/y	Copper loss (2)	40370.68	kWh/y

Remove the transformer TR.5 (OXYGEN) out of system and transfer the load to transformer TR.4 (DUST)
Then the load of transformer TR.4 (DUST) is as following :−

Active Power	1544.68	kW
Apparent Power	1741.41	kVA
Reactive Power	804.04	kVar
Power Factor	0.89	
Copper loss (3)	77420.13	kWh/y

SAVING

Energy saving = Iron loss (1) + Copper loss (1) − Copper loss (3)
= 2324.32 kWh/year
= 3486 Baht/year

Appendix 8.1.4

TRANSFORMER TAP CHANGING

1) REDUCTION OF TRANSFORMER LOSSES

DATA OF TRANSFORMER

Name of transformer	TR.6 (CCM)	
Capacity of transformer	1000	kVA
Efficiency of transformer	98.48	%
Iron losses (at 75 degree C)	1950	W
Copper losses (at 75 degree C)	13500	W (at full load)
Actual Sec. voltage before tap changging (V actual)	405.00	V
Sec. voltage after tap changging (V rated)	395.00	V
Working hour of transformer	8760.00	h/y
Electricity price	1.50	baht/kWh

~~Press "Enter" to continue....~~

FORMULA

Reduction of Iron losses = kVA x (1−eff) x % Iron loss x [(V actual/V rated)^2 − 1] x Work hour per year

SAVING

Energy saving	861.69	kWh/year
Money saving	1293	Baht/year

2) REDUCTION OF MOTOR LOSSES

Average load	=	Energy consumption (kWh/y) / Hour per year	
	=	63.40	kW
% of motor per total load	=	30.00	% of average load
	=	19.02	kW

Efficiency of motor (Average)	80.00	%
Iron losses of motor	30.00	% of tatal losses
Actual voltage at motor before tap changging (V actual)	405.00	V
Voltage at motor after tap changging (V rated)	395.00	V
Working hour of motor	7200.00	h/y
Electricity price	1.50	baht/kWh

FORMULA

Reduction of Iron losses = % of motor (kW) x (1/eff−1) x (% Iron loss) x [(V actual/V rated)^2 − 1] x Working hour

SAVING

Energy saving	526.62	kWh/year
Money saving	790	Baht/year

Technical Data of Transformer

Rated Primary Voltage : 11 kV, 12 kV
Secondary Voltage : 400/230 V, 416/240 V

Capacity (kVA)	No Load Losses Po (W)	Load Losses at 75 deg.C Pk (W)	Total Losses at 75 deg.C (W)	Impedance at 75 dec.C Un (%)	Efficiency P.F. 1 1/2 Load (%)	Efficiency P.F. 1 Full Load (%)	Voltage Regulation (%)
50	190	1050	1240	4	98.22	97.58	2.16
100	320	1750	2070	4	98.51	97.97	1.81
160	460	2350	2810	4	95.35	98.27	1.54
250	650	3250	3900	4	98.84	98.46	1.37
315	770	3900	4670	4	98.9	98.54	1.31
400	930	4600	5530	4	98.97	98.64	1.22
500	1100	5500	6600	4	99.02	98.7	1.17
630	1300	6500	7800	4	99.08	98.78	1.1
800	1600	11000	12600	6	98.92	98.45	1.55
1000	1950	13500	15450	6	98.95	98.48	1.52
1250	2300	16400	18700	6	98.99	98.53	1.48
1500	2800	19800	22600	6	98.98	98.52	1.49
2000	3250	24000	27250	6	99.08	98.66	1.37
2500							
3000							

Rated Primary Voltage : 22 kV, 24 kV
Secondary Voltage : 400/230 V, 416/240 V

Capacity (kVA)	No Load Losses Po (W)	Load Losses at 75 deg.C Pk (W)	Total Losses at 75 deg.C (W)	Impedance at 75 dec.C Un (%)	Efficiency P.F. 1 1/2 Load (%)	Efficiency P.F. 1 Full Load (%)	Voltage Regulation (%)
50	210	1050	1260	4	98.15	97.54	2.16
100	340	1750	2090	4	98.46	97.95	1.81
160	480	2350	2830	4	98.69	98.26	1.54
250	670	3250	3920	4	98.83	98.46	1.37
315	800	3900	4700	4	98.89	98.53	1.31
400	960	4600	5560	4	98.96	98.63	1.22
500	1150	5500	6650	4	99	98.69	1.17
630	1350	6500	7850	4	99.06	98.78	1.1
800	1600	11000	12600	6	98.92	98.44	1.55
1000	1950	13500	15450	6	98.94	98.47	1.52
1250	2300	16400	18700	6	98.98	98.63	1.48
1500	2800	19800	22600	6	98.98	98.52	1.49
2000	3250	24000	27250	6	99.08	98.66	1.37
2500							
3000							

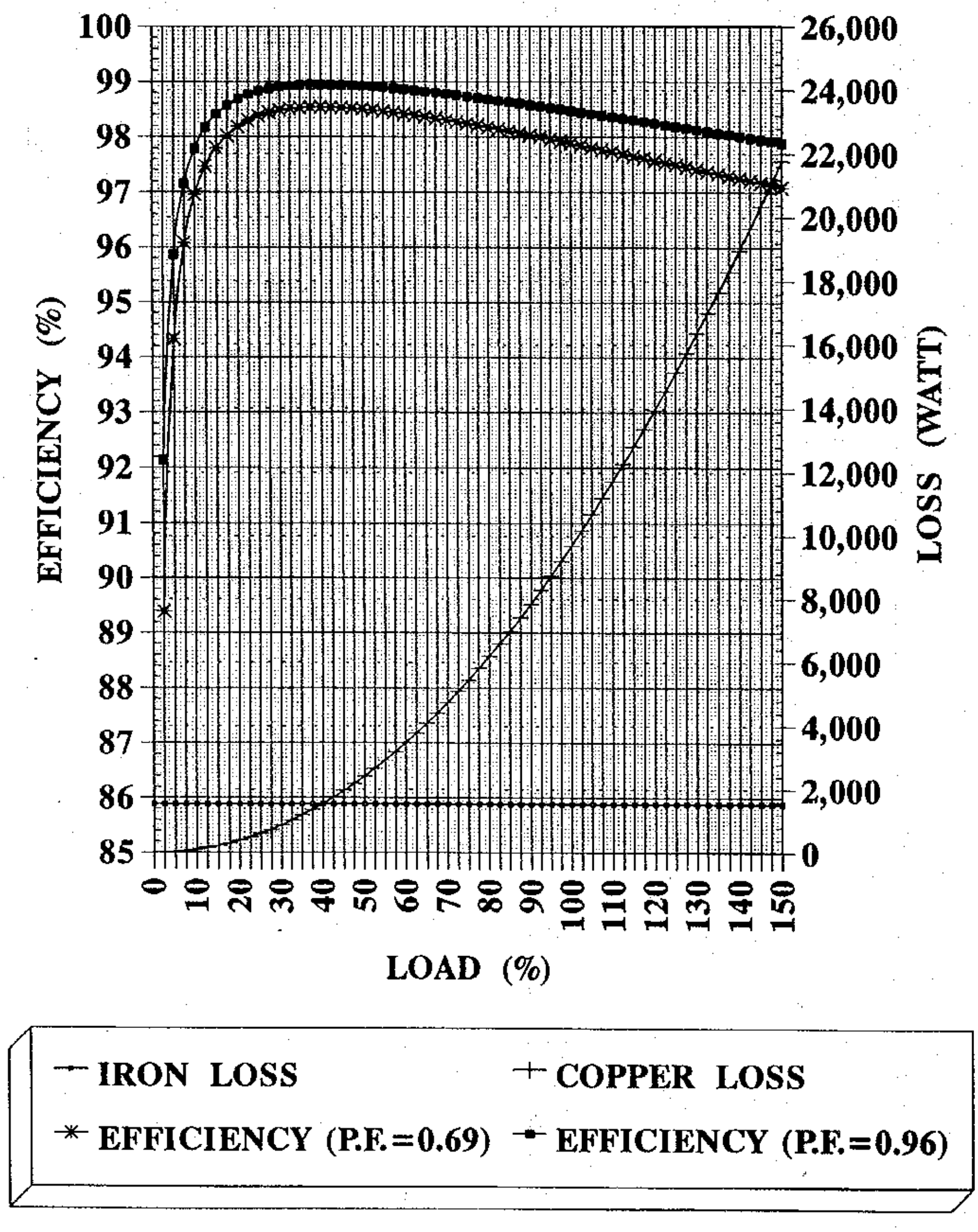
Rated Primary Voltage : 33 kV
Secondary Voltage : 400/230 V

Capacity (kVA)	No Load Losses Po (W)	Load Losses at 75 deg.C Pk (W)	Total Losses at 75 deg.C (W)	Impedance at 75 dec.C Un (%)	Efficiency P.F. 1 1/2 Load (%)	Efficiency P.F. 1 Full Load (%)	Voltage Regulation (%)
50	230	1050	1280	4	98.07	97.5	2.16
100	350	1750	2100	4	98.45	97.94	1.81
160	500	2350	2850	4	98.66	98.25	1.54
250	700	3250	3950	4	98.8	98.44	1.37
315	850	3900	4750	4	98.85	98.51	1.31
400	1000	4600	5600	4	98.94	98.62	1.22
500	1200	5500	6700	4	99.98	98.68	1.17
630	1400	6500	7900	4	99.05	98.76	1.1
800	1700	11000	12700	6	98.9	98.44	1.55
1000	2000	13500	15500	6	98.94	98.47	1.52
1250	2350	16400	18750	6	98.98	98.52	1.48
1500	2850	19800	22650	6	98.97	98.51	1.49
2000	3300	24000	27300	6	98.08	98.65	1.37
2500							
3000							

CHARACTERISTIC OF TRANSFORMER

TR.2 EAF PLANT

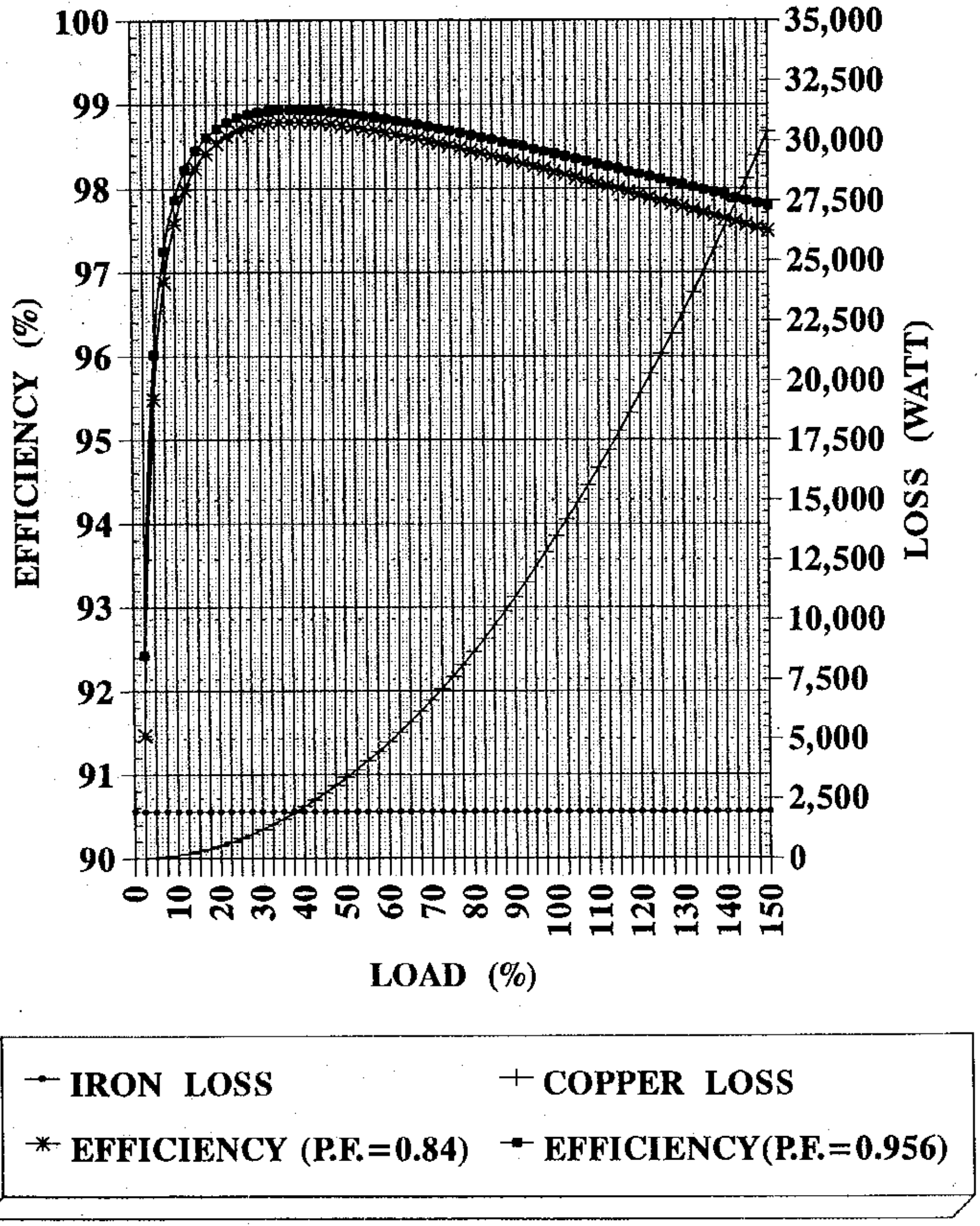
(750 KVA 12 KV/400-230 V)



CHARACTERISTIC OF TRANSFORMER

TR.3 OXYGEN & CCM COOLING WATER

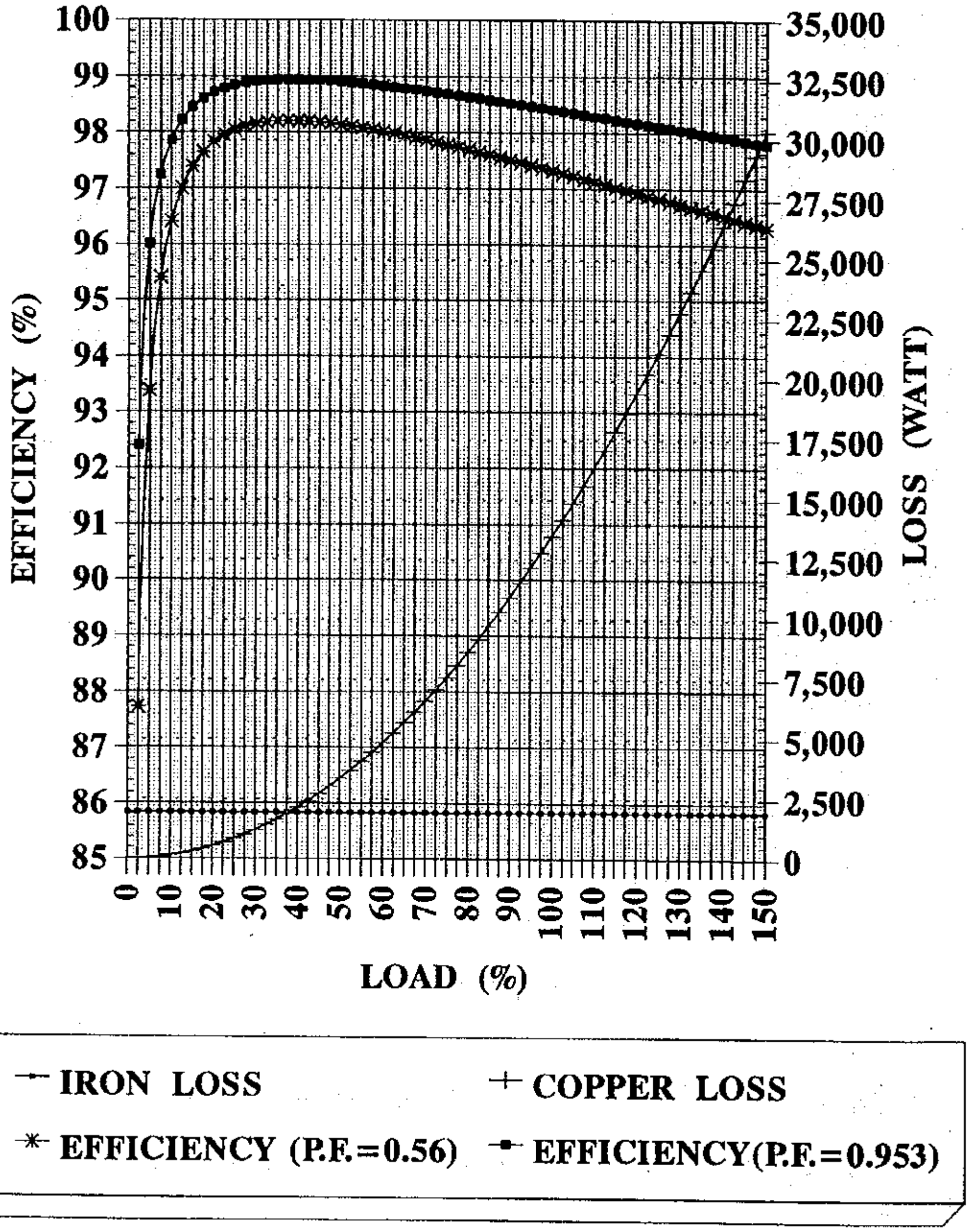
(1000 KVA 12 KV/400-230 V)



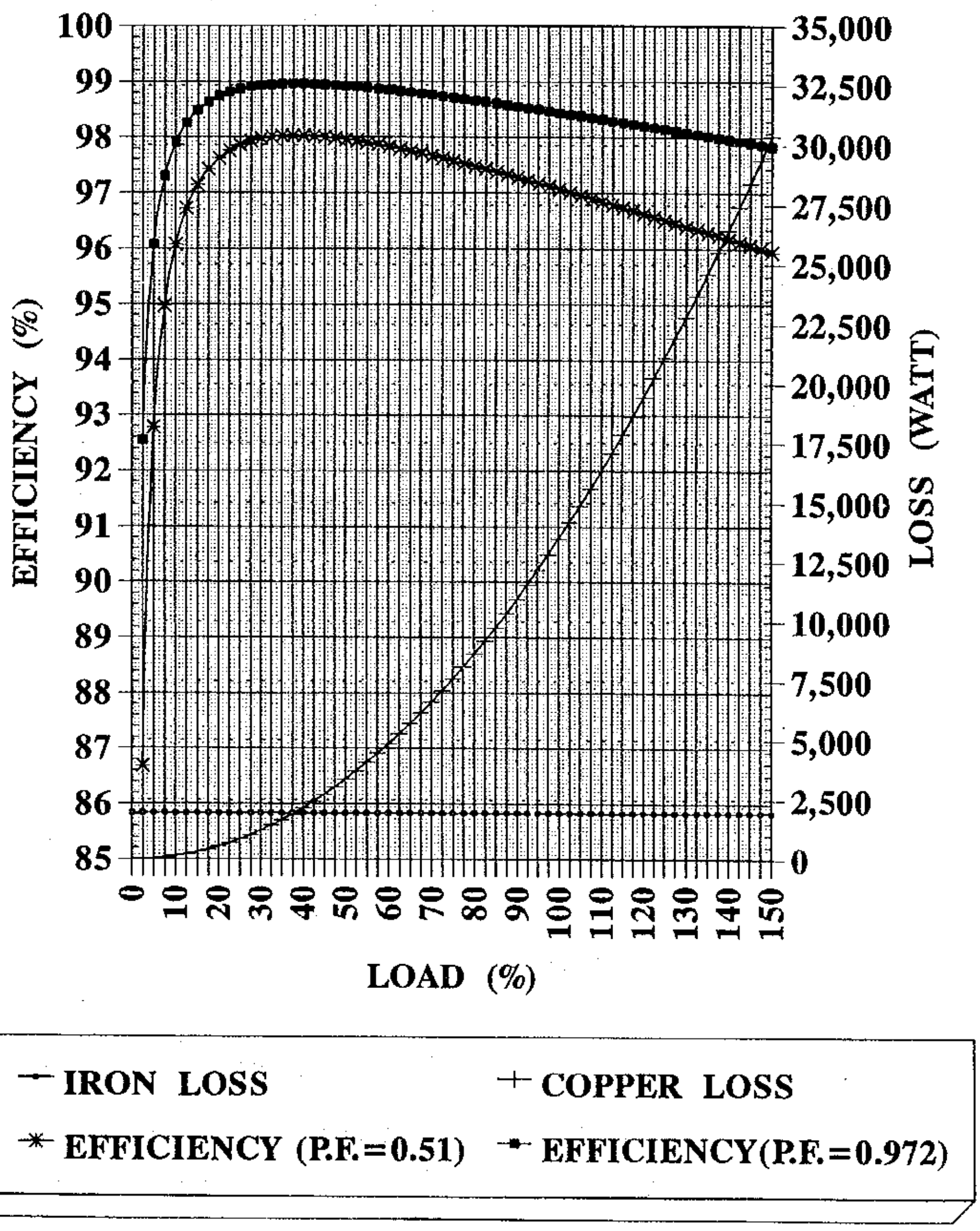
CHARACTERISTIC OF TRANSFORMER

TR.6 CCM

(1000 KVA 12 KV/400-230 V)



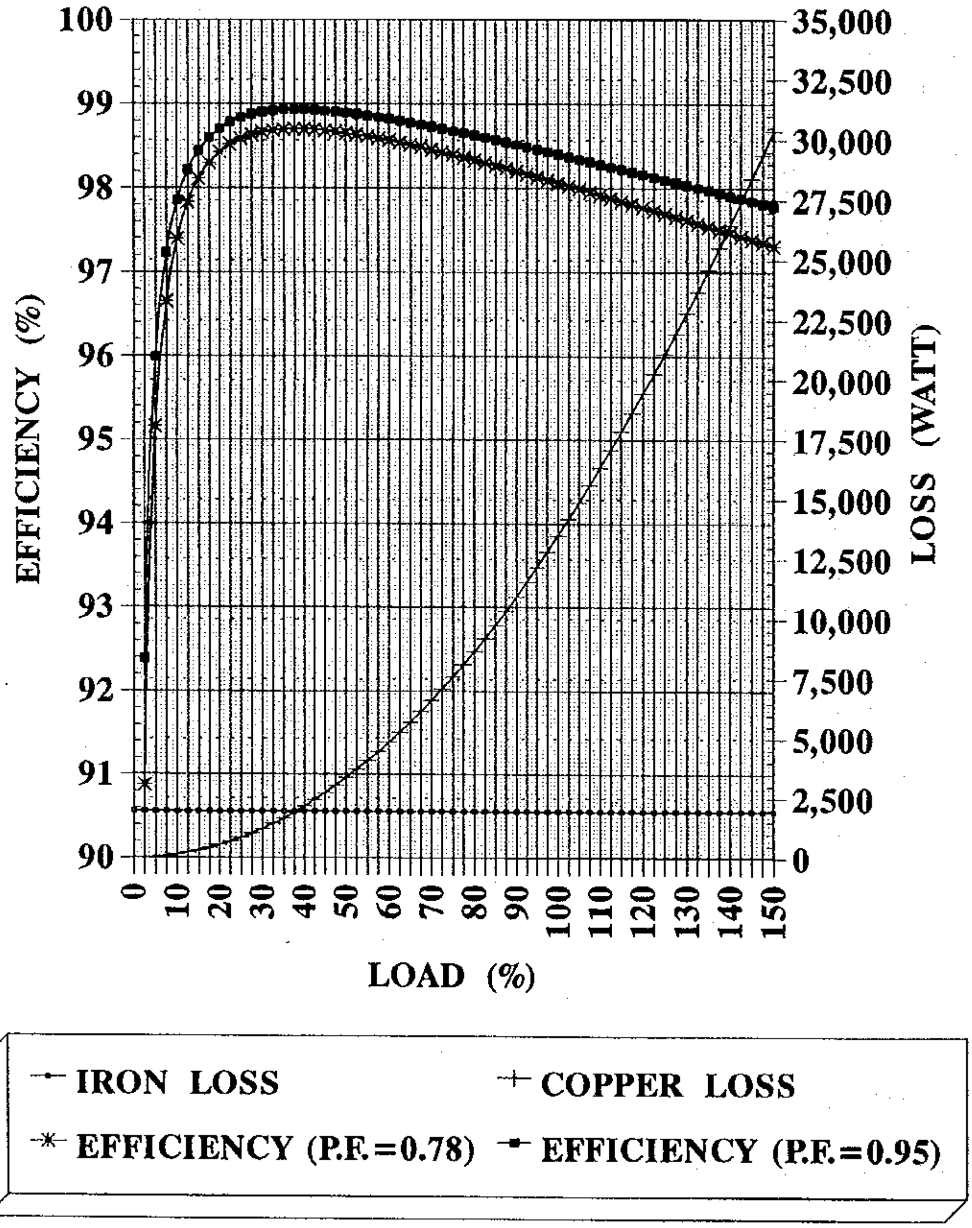
CHARACTERISTIC OF TRANSFORMER
TR.7 RM#3 PLANT
(1000 KVA 12 KV/400-230 V)



CHARACTERISTIC OF TRANSFORMER

TR.9 RM#2 PLANT

(1000 KVA 12 KV/400-230 V)



8.2 Results of Study at the Paper Factory

8.2 Results of Study at the Paper Factory

8.2.1 Factory outline

(1) Factory Name :
Z Co., Ltd.

(2) Type of Industry :
Paper Mill

(3) Major product name and production capacity :

Printing and writing paper	: 26,000 tons/Yr	Maximum Actual product in 1993
Chip board	: 15,000 tons/Yr	

(4) Number of employees on the payroll : 400

(5) Factory address :
In Bangkok

(6) History

Z Co., Ltd., the first private company that operates on paper production, was established in 1954. The first factory is located in Bangkok. Later on, the enterprise was expanded by opening a new factory by starting the production of the chip board with its capacity of 10 tons/day. Then, the machine was added to produce the printing & writing paper with its capacity of 15 tons/day. Furthermore, the two more machines are added for operating. Up to the present, the factory has four paper machines to produce the chip board and the printing & writhing with the production capacities of annual 26,000 tons and 15,000 tons respectively in 1993.

(7) Study period

July 18, 1994 to July 21, 1994

(8) Members of study group.

JICA

1.	Mr. Norio Fukushima	Deputy Leader
2.	Mr. Mitsuo Iguchi	Energy Management Expert
3.	Mr. Yukio Nozaki	Heat Expert
4.	Mr. Akira Koizumi	Process. Heat expert
5.	Mr. Toshio Sukimoto	Electric. Expert

6. Mr. Shosuke Noguchi — Electric. Expert

DEDP MEMBERS

1. Mr. Danai Egkamol — Mechanical Engineer
2. Mr. Kittipong Rattanapisutikul — Mechanical Engineer
3. Mr. Chatree Peamparvut — Technician Heat
4. Mr. Somchart Tanglikhosit — Technician Heat
5. Mr. Suthat Chobchuen — Electrical Engineer
6. Mr. Thamasak suwanatep — Technician Electric.
7. Mr. Pittaya Kruakhuanpet — Technician Electric.

(9) Interviewees

1. Mr. A — Chief Engineer
2. Mr. B — Engineer
3. Mr. C — Engineer
4. Mr. D — Engineer (pm/5)
5. Mr. E — Chief of Dep. stocking prep. (pm6)
6. Mr. F — Electrical Engineer
7. Mr. G — Chief of Dep. paper M/C (pm/6)

(10) Results of production

Table 8.2.1 Results of Production

Name of product	Unit	1990	1991	1992	1993
1) Printing and Writing Paper	ton	23,880	25,200	25,000	26,000
2) Chip board	ton	7,200	15,000	15,200	15,500
Total		31,080	40,200	40,200	41,500

(11) Results of Sales amount

Table 8.2.2 Results of Sales Amount

Name of product	Unit	1990	1991	1992	1993
1) Printing and Writing Paper	ton	23,700	25,200	25,000	26,000
2) Chip board	ton	7,200	15,000	15,200	15,500
Total		30,900	40,200	40,200	41,500

(12) Results of energy consumption

Table 8.2.3 Results of Energy Consumption

Kind of Energy	Unit	1990	1991	1992	1993
Fuel oil	Kl	1,770	–	6,318	7,235
Saw dust	ton	12,701	–	14,024	13,112
Coal	ton	5,189	–	1,439	–
Electricity	MWh	–	–	43,012	44,231
Total	Mcal	–	–	149,544,000	136,618,000
River water	Mton	1.6	1.92	2.0	2.1

(13) Results of unit energy consumption

Table 8.2.4 Results of Unit Energy Consumption

Kind of Energy	Unit	1990	1991	1992	1993
Fuel	ton eq.	9,013	–	11,256	10,790
- Fuel oil					
- Saw dust					
- Coal	ton/t-Paper	0.29	–	0.28	0.26
Electric power	Mwh	–	–	43,012	44,231
	MWh/t-paper	–	–	1.07	1.066
Total	Mcal/t-paper	–	–	3,720	3,292

Figure 8.2.1 Production of Z Co.

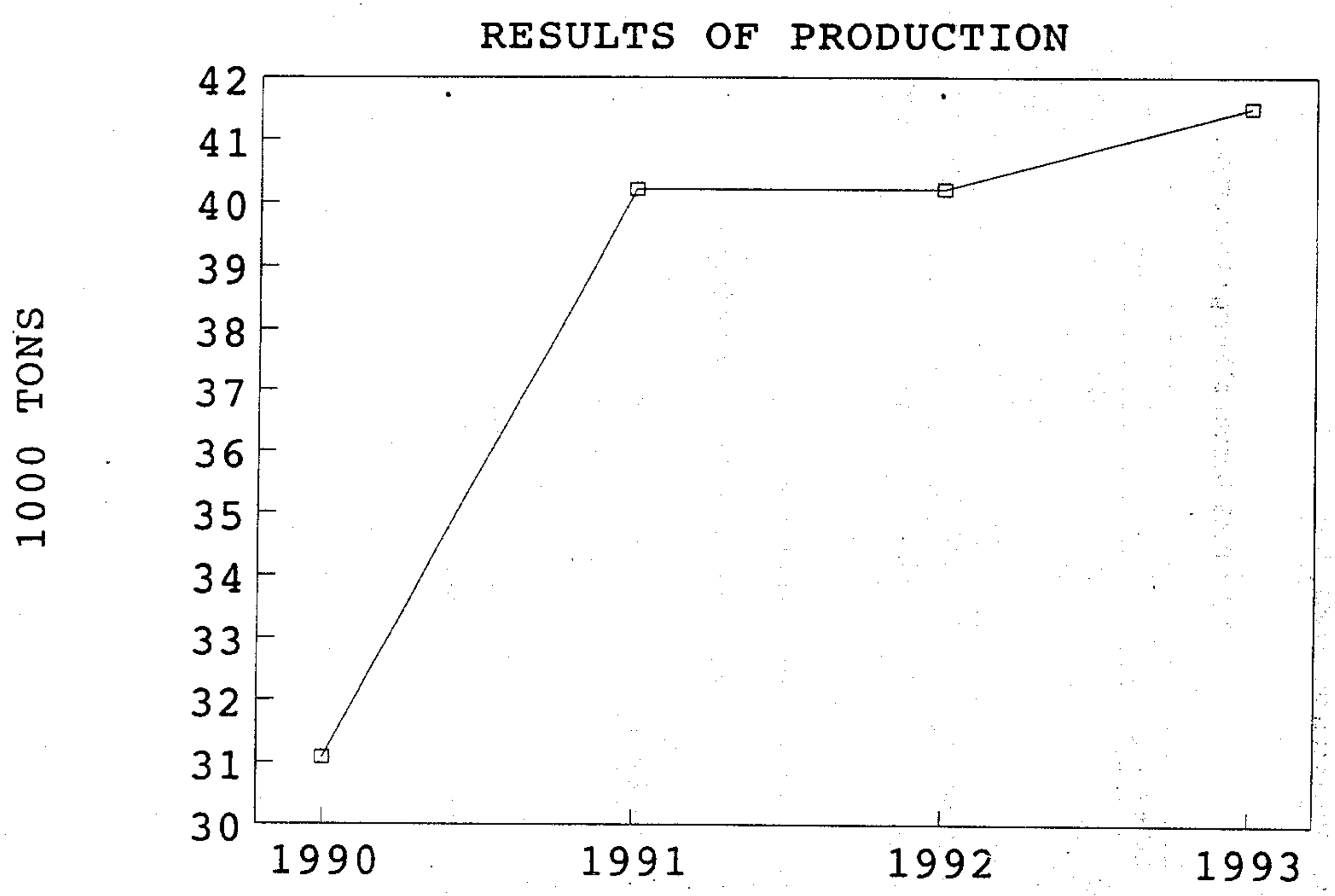
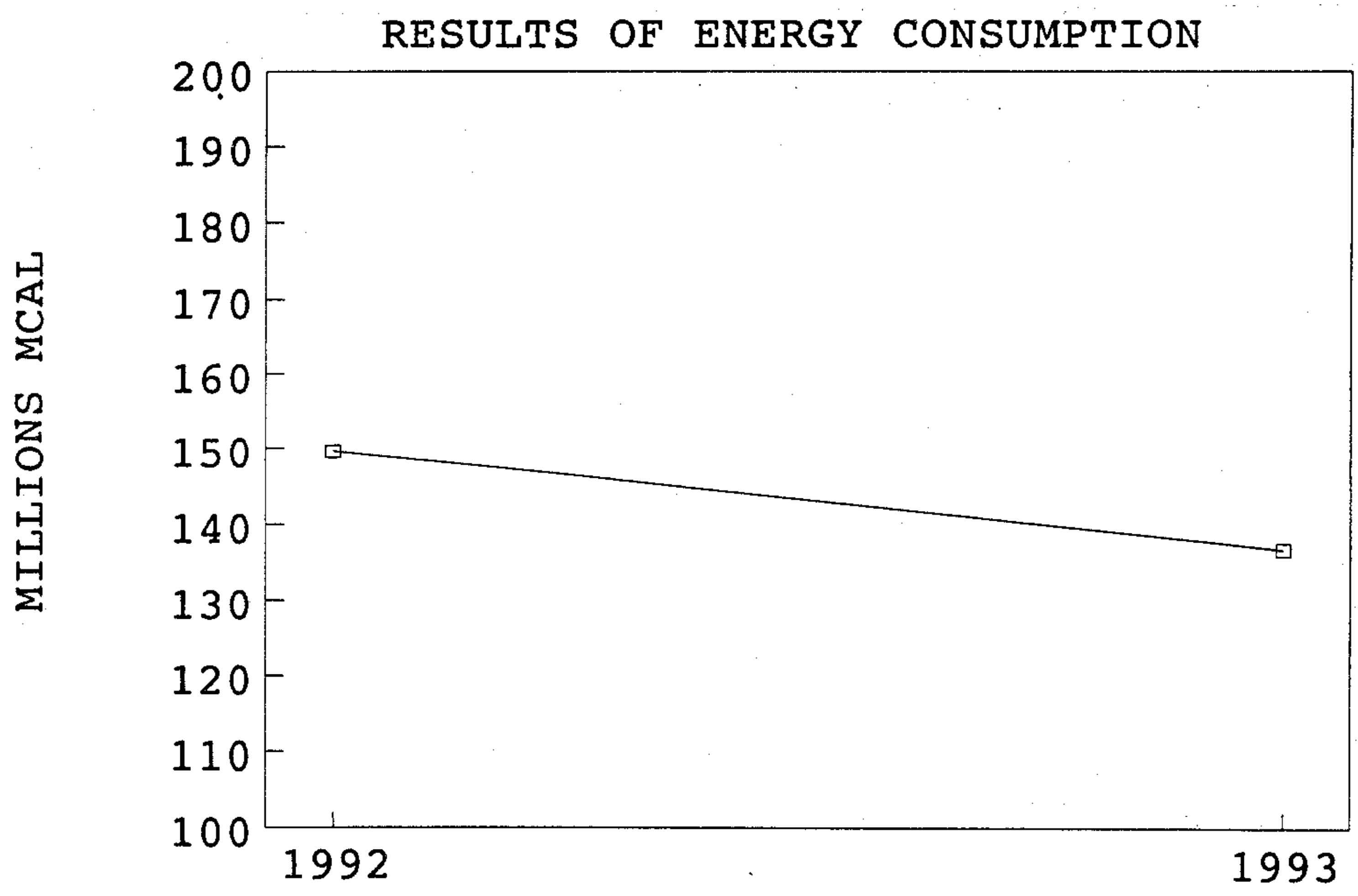


Figure 8.2.2 Energy Consumption of Z Co.



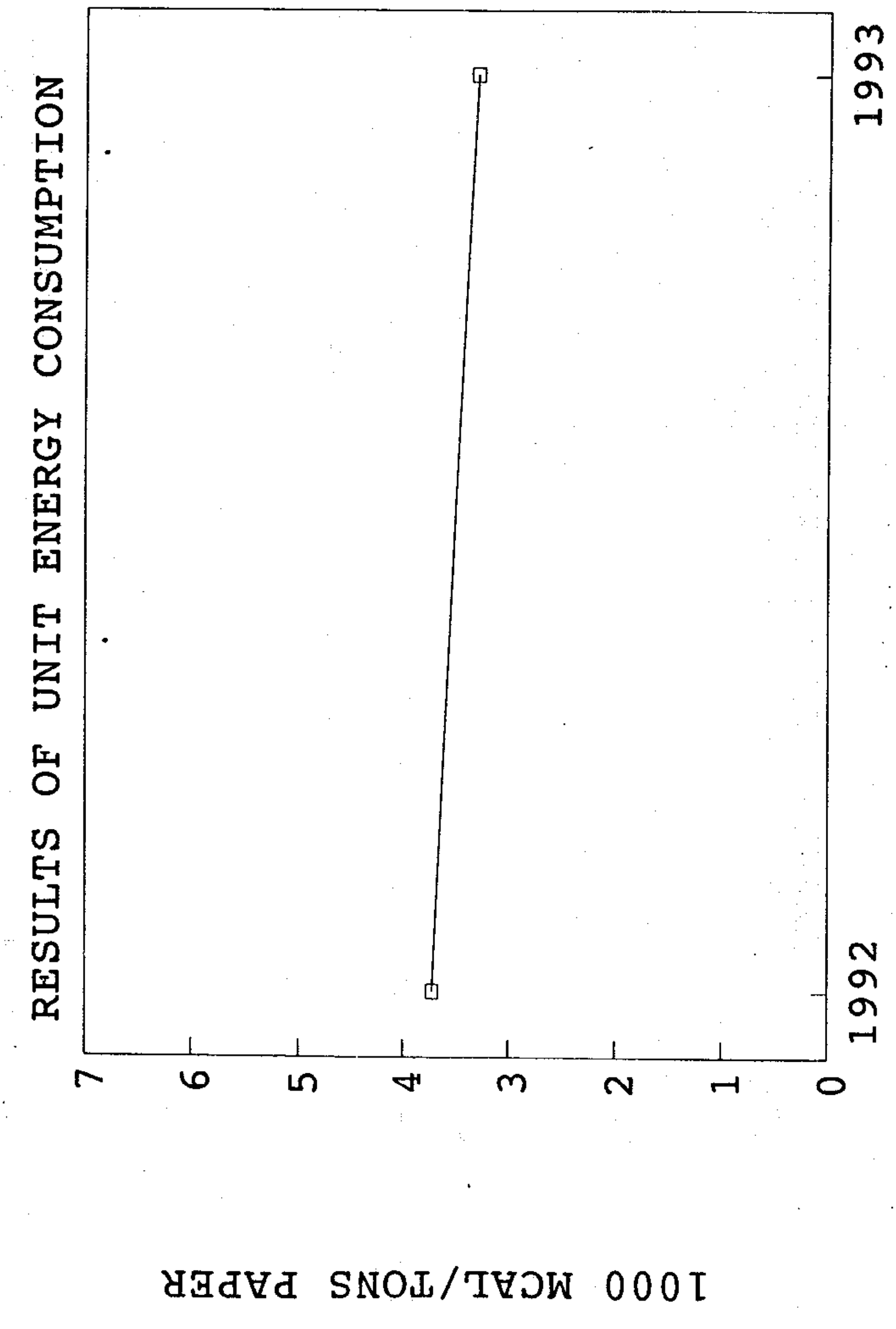


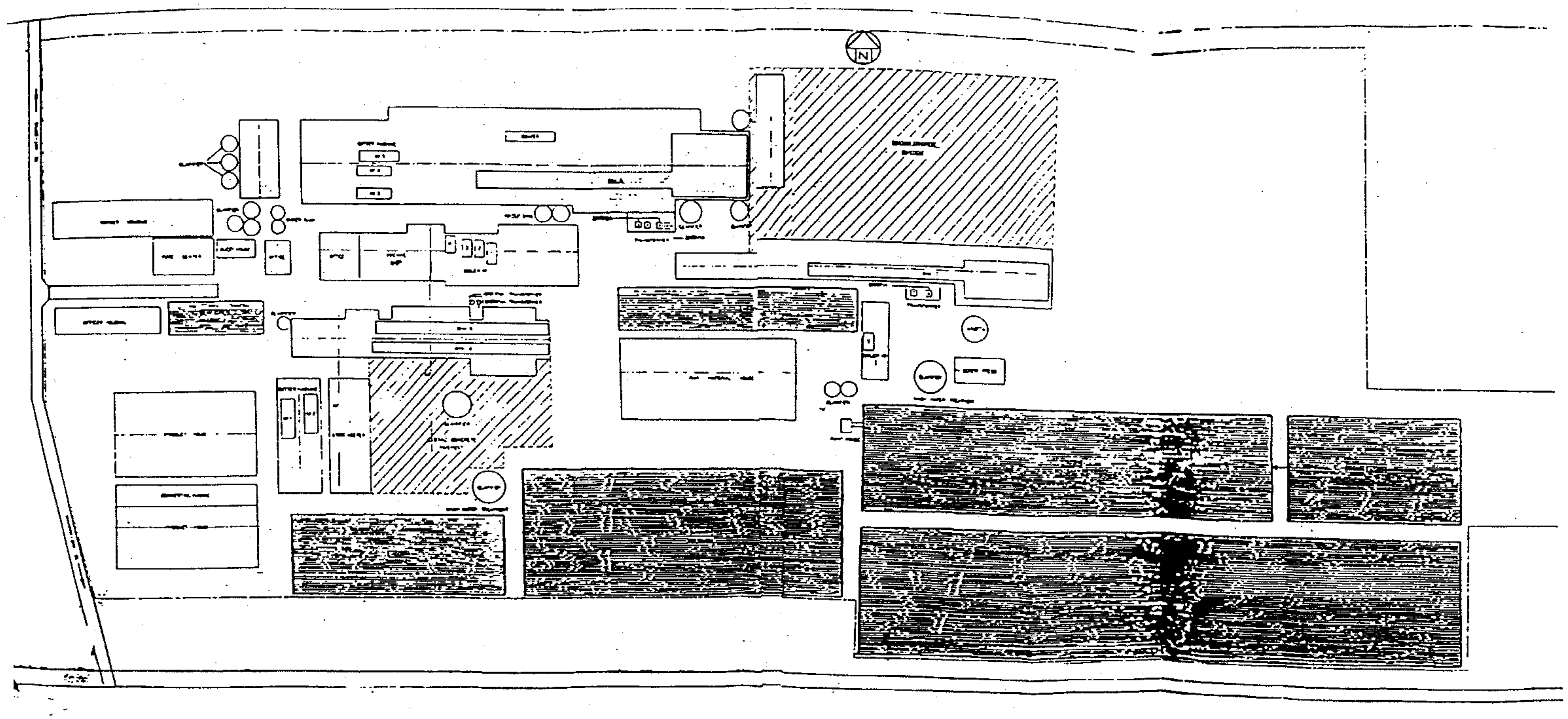
Figure 8.2.3 Unit Energy Consumption of Z Co.

(14) Energy Prices

Fuel oil	3,040	Baht/kl
Sawdust	140	Baht/m^3
Electricity	1.57	Baht/kw-h

(15) Layout of factory

Figure 8.2.4 Layout of Factory



(16) Production process

Figure 8.2.5 Pm # 4 Process

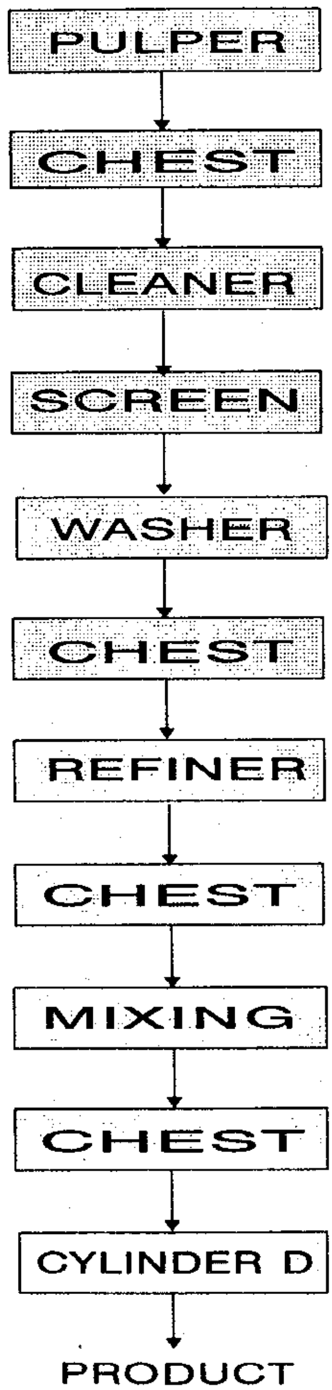


Figure 8.2.6 PM # 5 Process

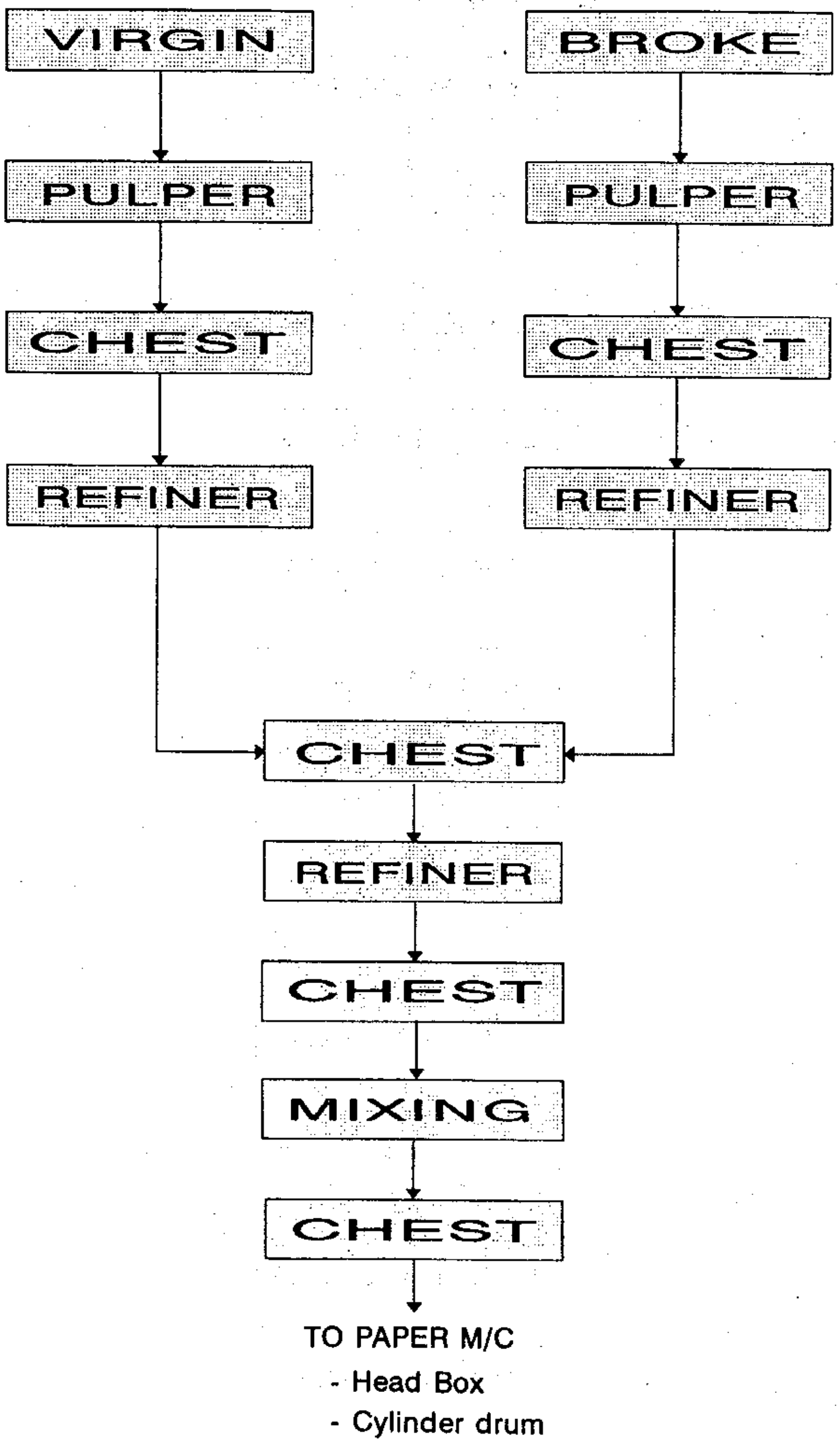
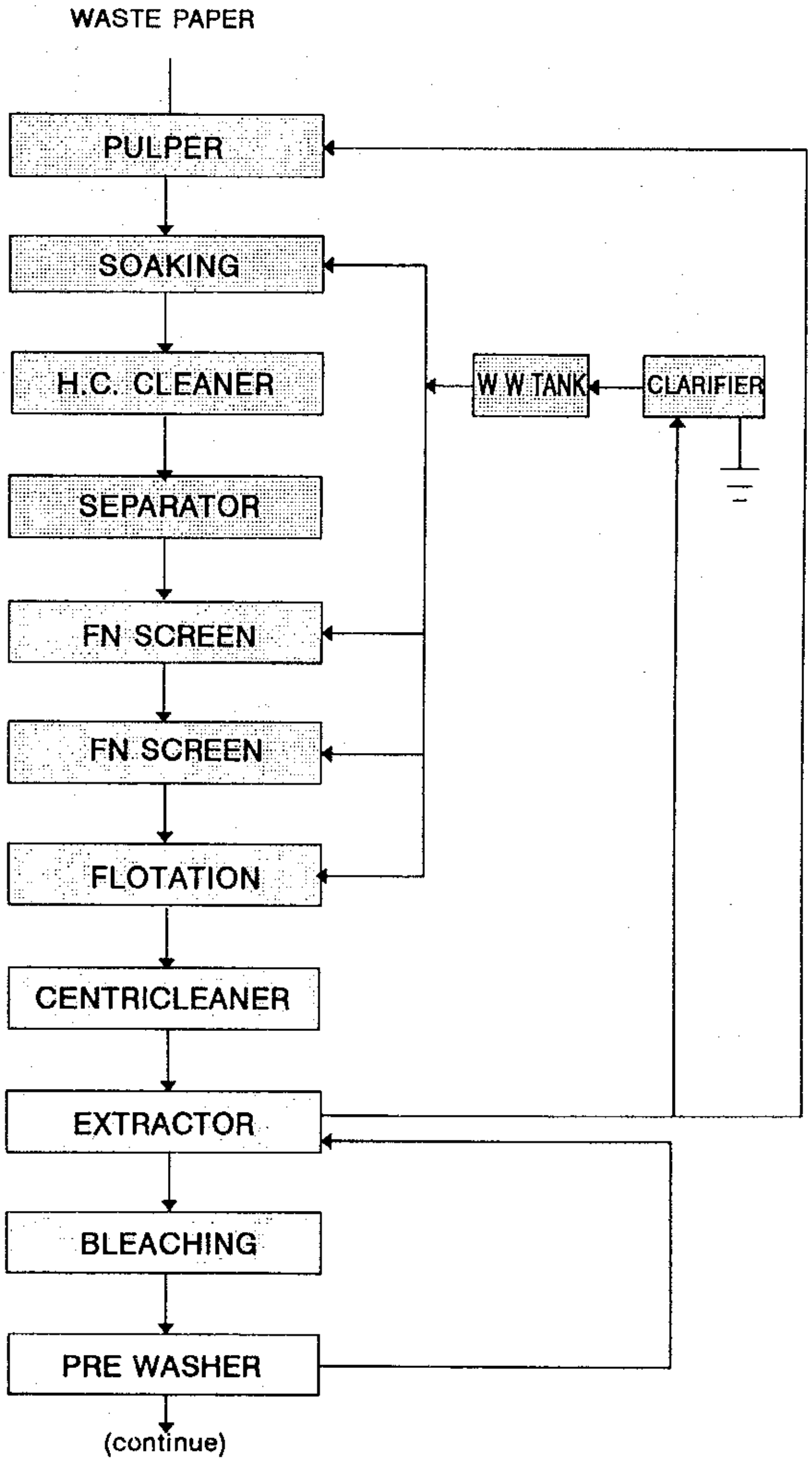


Figure 8.2.7 PM # 6 Process



(continue)

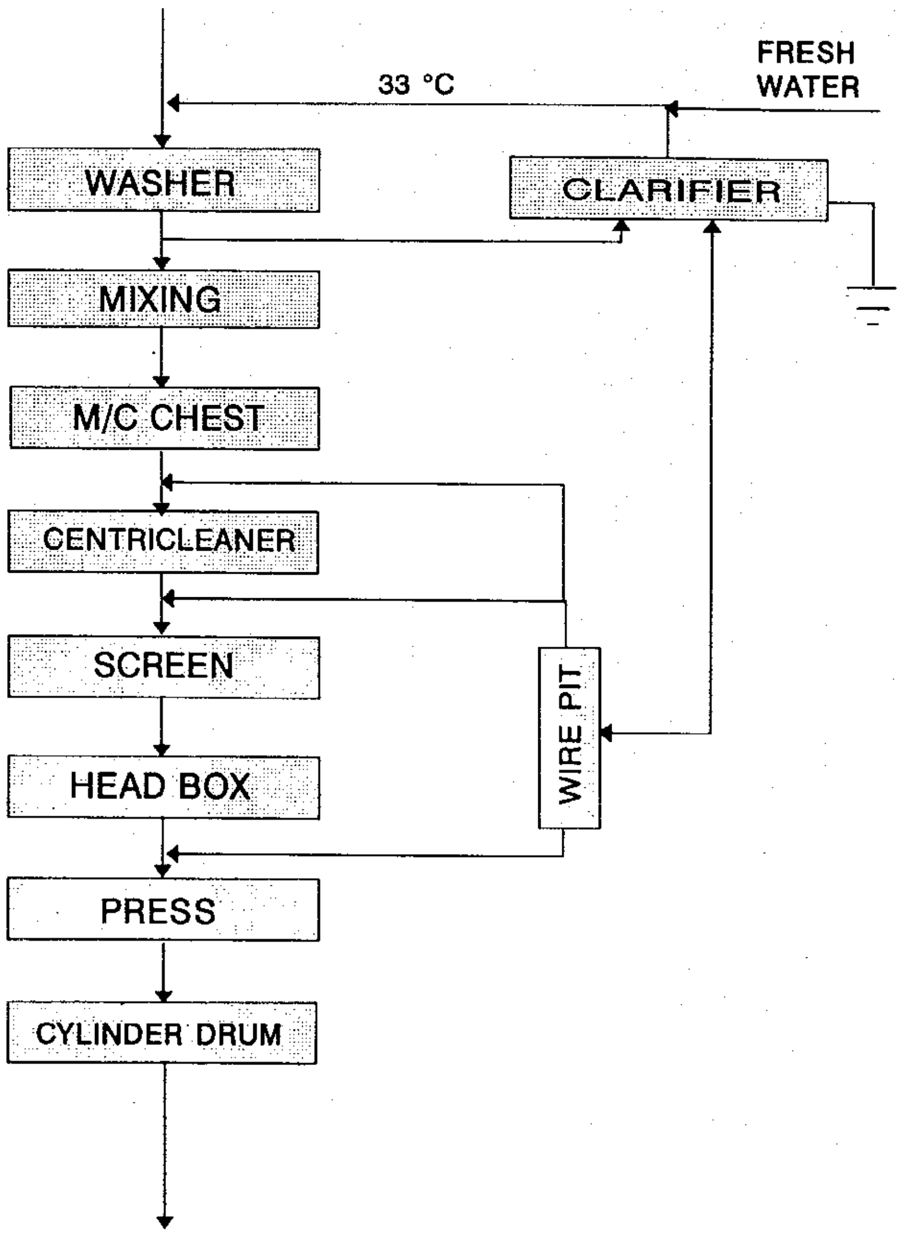
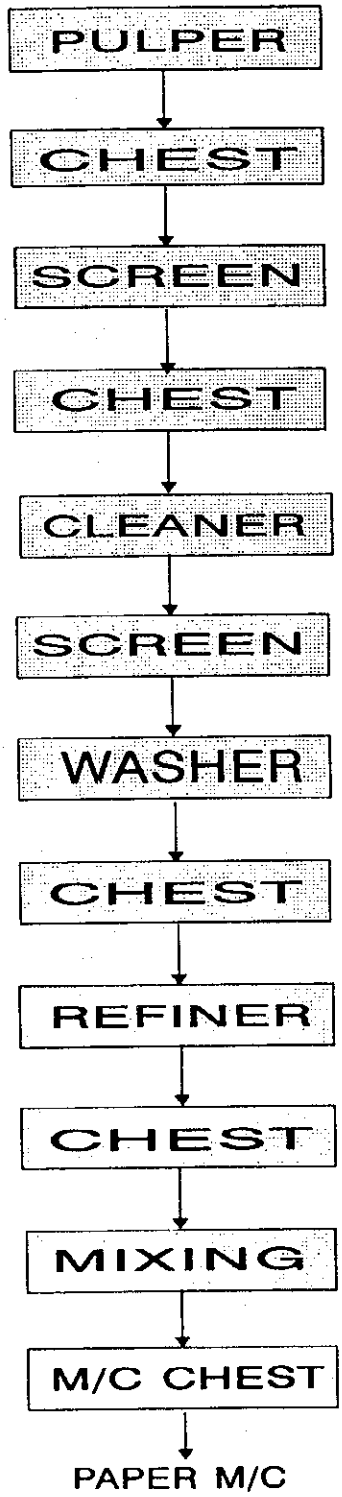
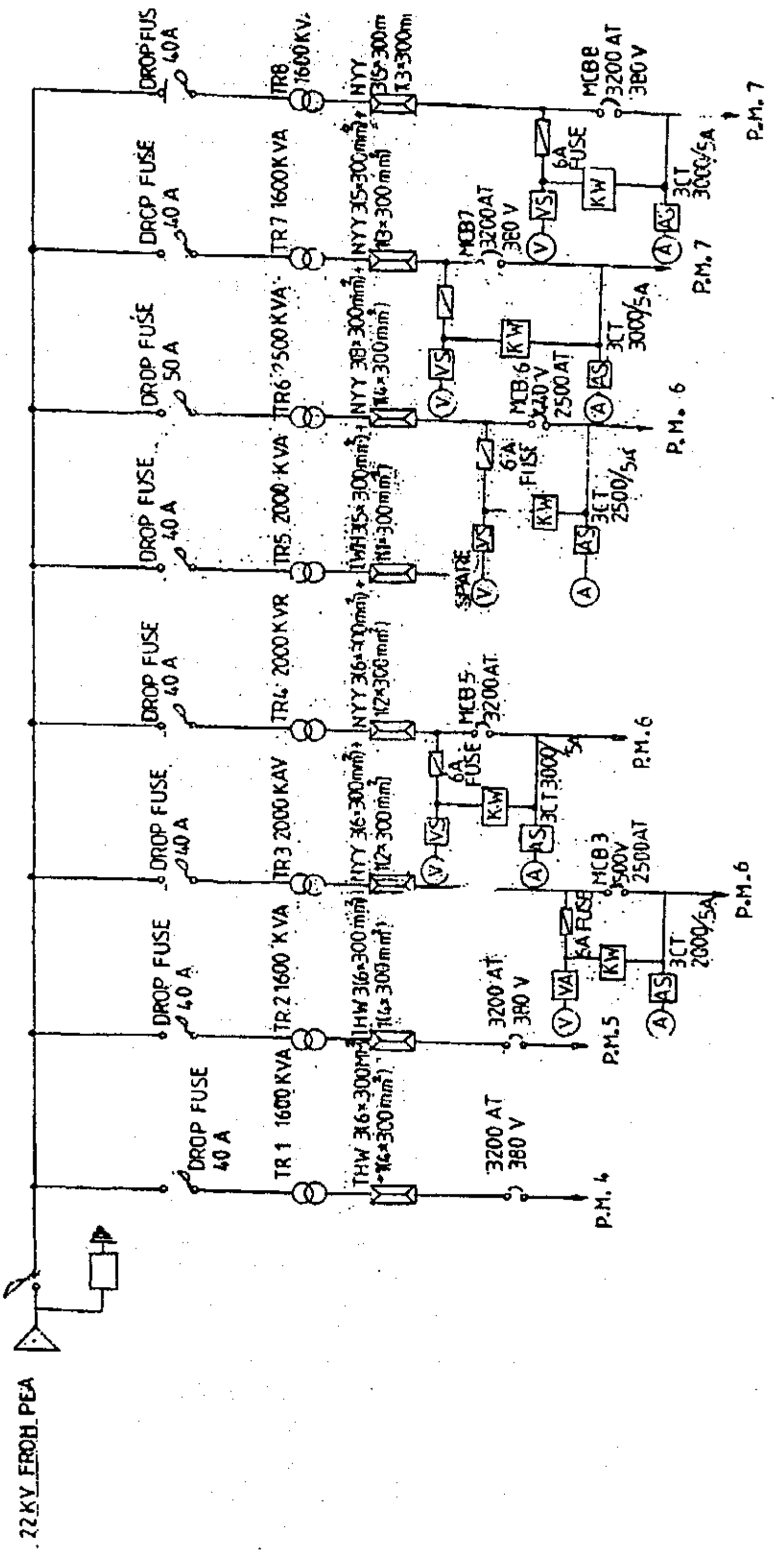

FRESH
WATER
33 °C
WASHER
CLARIFIER
MIXING
M/C CHEST
CENTRICLEANER
SCREEN
HEAD BOX
WIRE PIT
PRESS
CYLINDER DRUM

Figure 8.2.8 PM # 7 Process



(17) Electric power one line diagram

Figure 8.2.9 Electric Power One Line Diagram



8.2.2 Situation of energy management

(1) Setting the Target for Energy Management

The general situation of energy management for implementing energy conservation has not yet been operated seriously. However, the factory has set the policy to reduce the unit energy consumption 10% by the end of this year, through comparison with energy consumption of the previous year. The reason for setting the policy and target above is that the factory has realized the high value of energy cost in production costs and increasing competition in this pulp and paper manufacturing industry.

In implementing to achieve reducing energy consumption as said above, the executive must give the importance towards that target and transfer that policy to employee and personnel perceptions. Measures and points found to be improved for energy efficiency in various parts should be set and let to be known. Should give the opportunity to get their comments and ideas including proposed measures and methodologies. To make the purpose as above successful the following items should be done:

1) The managing of paper machine should be introduced of Unit Energy Consumption (Steam Unit, Electric Unit, etc.)

2) But paper machine has no steam flow meter. Without steam flow meter, machine cannot do daily management. From the unit energy consumption we can estimate the product cost.

   Daily management of unit energy and utilities consumption is needed.

   Each paper machine should be provided with a steam flow meter.

If paper moisture increases 1% by steam charge control, products yield will increase by 1%; Unit of Steam consumption and Unit of electric consumption will decrease by 1%.

3) Unit management is daily cost managing. Company should thoroughly carry out unit management for not only steam and electricity but also water, chemicals and other materials.

(2) Systematic Action

To implement systematic action on energy conservation, the work plan should be set up obviously and predominantly, then assigned to the persons in charge for practical operation. Towards this, there must be the joint meeting to plan for implementing energy conservation, the evaluation for investment cost and the feasibility. The previous implementation should be evaluated on their results as well.

The joint meeting to formulate the energy saving plan should be mutual collaboration among members of sections and of related parts, to get relative effects and results but does not incur any problems to any sections for implementing. Each production field should have circle movements such as 4S campaign, QC Circle Energy Saving Group, etc.

(3) Data-Based Management

To implement energy conservation as planned in that target, and to evaluate energy savings or implementing results, it is necessary to collect the data on energy consumption and production/outputs as data-base to analyse the marginal unit energy consumption ratio or to analyse energy consumption trend at abnormal conditions to search for those causes, as an example.

For the general situation of data and their analyses for this factory, they are not managed seriously. Data for energy consumption have been collected in total for the whole factory, but not collected separately for each part consumption. Besides, the data collected may not be utilized for analysing, such as : to indicate the trend of annual unit energy consumption since data collected by the surveying team, got from the person in charge, are not available in some period (of 1991).

In addition, the statistics of data on energy consumption situation as analysed in various forms should be disseminated to motivate or encourage the staff awareness and understanding on current situation, such as the trend of increasing energy prices that impact directly to the production costs, including the proportion of the energy costs. These will figure out the staff perception to see and aware of using energy more efficiently.

(4) Education and Training of Employees

In addition to the various implementations above, still it is necessary to provide knowledge and to organize the training courses for the staff concerned. Also, sending staff or employees to be trained in the courses provided by the external organizations if seeing that such those courses will be beneficial to give them knowledge and understanding to apply in practical work. This will enhance their capabilities to implement the target to achieve finally.

(5) Equipment Management

In case the machines and equipment are not running well as usual, the energy will be lost or consumed more wastefully. Thus, in the Paper Factory, to run the machines continuously without stopping frequently will have an effect on reducing largely energy losses.
To achieve the above target, management on planning for the good maintenance or machine improvement as their usual conditions will help to reduce or alleviate such problems.

8.2.3 Problems in the use of energy and countermeasures

8.2.3.1 Production and maintenance system

(1) Continuous operation of paper-machine

The pulp and paper industry as Process Industry (Installation Industry) is required to ensure efficient operation, depending on the control method which provides continuous operation. An improvement of the operation efficiency will lead to the effective use of energy and lowering of the unit consumption.

From the viewpoint of operation efficiency the energy conservation measures can be reduced to the following points :

a. Prevention of paper breaking
b. Prevention of accident stop by machine trouble
c. Prevention of electric failure regardless of the inside or outside
d. Prevention of quality deviation of purchase materials that are raw materials, sub-materials, instruments, tools and etc.

The Process Industry (Installation Industry) cannot enjoy continuous operation without an effective maintenance division of machinery and electricity. Preventive maintenance (PM) is to prevent accident in advance and to make a repair and improvement by a planned equipment maintenance based on the past experience with equipment failure and by checking the operation through a daily equipment inspection on patrol. It is intended to eliminate the operation shutdown by the maintenance division.

Paper-making process is the process that consumes a lot of energy both electrical energy and steam. To operate the machine efficiently will have an effect on and be necessary for energy efficiency. The continuous operation of the machine with minimum stopping will have a direct effect on its efficiency. Since to operate machine continuously will make it operate effectively and reduce heat losses, stop operating at each time will decrease its production efficiency. The pulp and paper industry is Process Industry which has to operate machines without stop for a long term.

There are many times machine stops. These many stops cause waste of energy, a decrease in yield and cost up. The causes for paper machine being unable to operate continuously may be the following :-

a. Paper Break

In this factory as statistics recorded, paper break occurs 3-6 times a day. Each time of paper break means time loss or waste in production, waste of energy and reduction of machine efficiency. The main cause that affects the paper break may be, for example: dust and dirts from outside enter with fresh air and intervention in the pulp, then makes it break easily. According to the factory situation, saw dust is consumed partly as one type of energy and the saw dust to the factory situation, saw dust is consumed partly as one type of energy and the saw dust storage is located close to the paper machine. Furthermore, there is no hood inside the paper machine, then dirts mixed with fresh air go into machine easily. The other causes to make paper break frequently are such as : the screens or filters work badly and get failure then let dirts mixed with the pulp, incorrect roll crowing, surface is not in parallel with bad contact, the paper thickness is not uniform and no formation, using the dirty felt, etc. These causes must be made aware of mostly in operating the paper machine to prevent the paper break or to minimize it. For the good statistics to be considered through the sample in case of Japan, the occurrence of paper break in machine operation will be only 0.1-0.2 times a day. For this factory, one major of paper breaking is dust from saw dust fuel. There are effects of dust and recommendation to reduce this problem as the following:

(Present Situation)

1) Finished paper are covered with dust.

2) Paper machine room floor are also covered with dust. These dusts are effects of saw dust and etc.

(Effects of dust)

1) Saw dust must bring about the paper break. These dusts are circulating from the finish room and the machine room to cause these paper breaks again, resulting in energy loss.

2) Dust included in finish paper will cause printing troubles, so-called snow-fall:

(Recommendations)

The paper machine room and Finish room should be perfectly prevented from saw dust as follows.

1) The machine room and the Finish room should be prevented from the inflow of outside air. More machine hoods have to be provided.

2) The boiler room should be moved to another place.

(Measurement of Paper breaking)

Paper breaking in the paper machine will lead to a waste of energy and reduced yield, causing costs to be increased. It also results in a considerable labor consumption. Paper breaking used to be considered as a matter of course. However, after a detailed analysis of the paper breaking is carried out, the problem will be greatly reduced as a result of improved operator skill, improved equipment ranging from material treatment to paper making process, and introduction of the instrumentation control.

Figure 8.2.10 shows a chart for the characteristic factors which cause paper breaking. Table 8.2.5 illustrates the outline list showing causes for paper breaking and their remedies. Means to eliminate the possibility of paper breaking can be summarized as follows.

Figure 8.2.10 Cause and Effect Diagram of Paper Breaking