(c) Calculation of heat balance

a. Heat balance at preliminary heating

First of all, the heat quantity required for heating up of the charged 2,000 kg treated water was calculated by summing up the enthalpy difference between the hot water which has flowed into the jacket, and the warm water which has flowed out of the jacket using computer. As a result, 110 M cal was obtained.

On the other hand, the heat loss based on natural convection and radiation from the exposed surface of the reactor are obtained as shown Table 5-6-10

As for the average temperature difference between the surface temperature and the air temperatue, the figures calculated by the computer based on measured results were used in the same way as the heat quantity for heating.

Table 5-6-10 Displated heat from the reactor surface

	Jacket kcal	Exposeat point kcal	Total kcal
Heat loss by natural convestion	20.8	10.8	31.6
Heat loss by radiation	11.5	4.4	15.9
Total	32.3	15.2	47.5

The total quantity of heat dissipation during this period was 47.5 M cal, and the total of this value and 112 M cal which is the aforementioned heat quantity required for heating the treated water (i.e. 160 M cal) is the heat output.

The heat quantity difference of 50 M cal betweeen input and output can be attributed to steam condensation heat which might flow in together with the hot water, which could not be measured. If we calculate backwards from this figure, it is estimated that about 100 kg of steam condensed.

b. Heat balance after starting of polymerization reaction

When the polymerization raction begins, the generation of reaction heat exceeds the heat required for raising the temperature of the raw materials which have been charged, and cooling load will generate.

The cooling load is defined as the portion of polymerization heat which was not utilized to heat the raw material plus the heat required to cool the raw material to normal temperature after completion of reaction, minus the heat lost from outside of reactor walls.

As for the heat transfer between the reactor and the atmosphere, since the average temperature difference between the surface temperature of the jacket and the air temperature is only 0.16°C, this heat transfer shall be neglected.

If the heat quantity dissipated from the exposed portion at the top of the reactor is calculated in the same way as the aforementioned calculation, the heat dissipation due to natural convection is 31 M cal, and the heat dissipation due to radiation is 14 M cal.

That is, a total of 45 M cal is dissipated as cooling effect.

Thus, the cooling load will be as follows:

Reaction heat	894 M cal
Heat used for raising raw material temp.	−431 M cal
Heat dissipated to atmosphere	−45 M cal
Cooling load to normal temperature	545 M cal
Total	963 M cal

The heat quantity taken away by the cooling water is obtained as 778 M cal from the integrated value of the computer based on measured results in the same way is.

The differnce of 185 M cal between this value and the cooling load is believed to be taken away by the reflux condenser.

We summarize the above results as shown in Table 5-6-11.

Table 5−6−11 Heat Balance of Reactor

1. Preheat step

Heat input			Heat output		
Item	Mcal	%	Item	Mcal	%
Heat of hot water Heat of steam	110 50	69 31	Heat for preheating Surface heat loss	112 48	70 30
Total	160	100	Total	160	100

2. Reaction and cooling step

Heat input			Heat output		
	Mcal	%	Item	Mcal	%
Heat of polymerization Heat of polymer emulsion	894 545	62 38	Surface heat loss Heat for water and monomer heating Heat removed by water Heat removed at condenser	45 431 778 185	3 30 54 13
Total	1,439	100	Total	1,439	100

D) Problems and Their Solutions

As it is clear from the heat balance, the problems which arise in the preliminary heating process are the large heat dissipation from the surface.

About 30% of the heat quantity is dissipated from the surface.

However, in the reaction and the cooling process, the surface dissipation of the exposed portion is contributing to the cooling.

Thus, it is not necessarily suitable to conduct insulation to prevent heat dissipation.

About this heat dissipation, most of the heat is dissipated from the jacket portion.

And the long heating time is the cause for the large heat dissipation.

In order to prevent this, it is preferable to adopt a heater which can be mounted to the water supply line, and which enables supplying and heating of water at a same time, and prevent heat dissipation from the jacket portion.

Since the temperature raising limit is 80°C and rather low, it would be possible to utilize the waste heat of the boiler or oil heater.

Through such countermeasures, for one batch operation, it would be possible to economize on about 40 M cal of heat.

In addition, the operating time of one batch operation can be shortened by 1 – 1.5 hours.

We study the outline of the new heat exchanger which will be necessary for this as follows: The necessary heat quantity shall be 112 M cal in 0.5 hours.

The steam pressure used for heating is 5 kg/cm^2 · G, and the temperature is 160°C. In case of steam-water, the overall heat transfer coefficient of multi-tubular heat exchanger is given as 1,000 – 3,500 $kcal/(m^2 \cdot h\ °C)$ in general.

In this case, 2,000 $kcal/(m^2 \cdot h \cdot °C)$ shall be adopted.

If we assume that the treated water is heated from 25°C to 81°C, the required heat transfer area can be obtained as follows:

$$A = \frac{112 \times 10^3 \times 2}{2000 \times \dfrac{(160-25)-(160-81)}{2.3\log\dfrac{(160-25)}{(160-81)}}} = 1.07\ m^2$$

If we use the safety factor 75%, 1.43 m^2 will be required as the heat transfer area. If pipes of 2 inch are used, a length of 10m will be required.

The fabrication and installation expenses of this heat exchanger shall be about U$S4,000.

If we assume the number of annual reactor operation to be 100 times, the amount of steam saved will be 8 t/y . Since the time of use is short and the unit cost of natural gas is low, it is difficult to recover the fund only by fuel saving. However, as it helps to shorten the operation time, it is recommended that proper consideration be given as occasion arises.

The temperature control of the reactor has major influence on the polymerization degree, etc.

Currently, only one temperature indicator used, and temperature of two points, the top and bottom of the reactor, is measured by manual changeover, and an operator records the readings.

From the standpoint of heat control and quality control, the installation of an automatic recorder is desirable.

5.6.3.4 Furnace

(1) Outline of furnace operation

In the manufacture of acrylic plates, prepolymerized methyl methacrylate and polymerization catalyst mixtures are poured into a mold consisting of 2 glass plates, sealed by spacers in metal frames. Several tens of these molds are placed in the furnace, and the contents are polymerized.

Heating is necessary when starting the polymerization, but when the reaction starts, polymerization heat is generated, and suitable temperature control which maintains constant temperature by cooling is required.

The temperature inside of the furnace is not necessarily constant, and a specific temperature control program is set depending on the type and thickness of the acrylic plates.

Since such heating pattern, inside structure of the furnace, operating conditions, etc. are the company's secret, on this occasion, the survey was restricted to the measurement of only the outside conditions.

(2) Heat balance

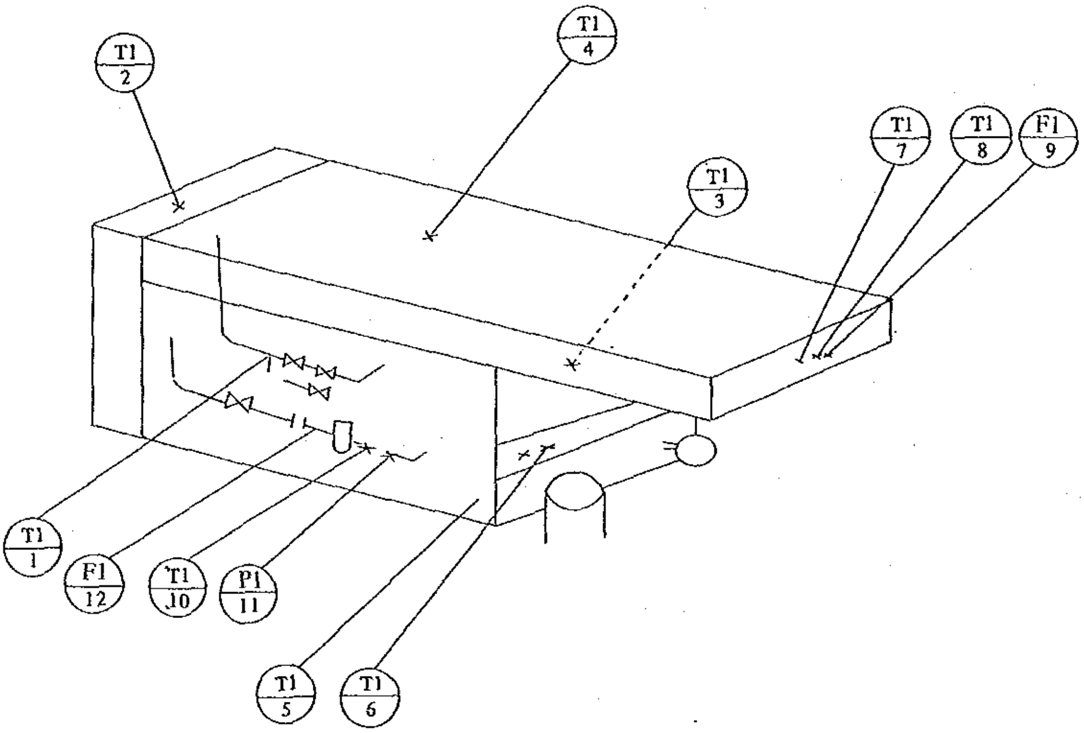
a) Measuring point and measured value

In order to obtain the heat balance, we used the measuring instrument that we brought, and measured from 11:00 a.m. October 27 to 1:00 p.m. October 28.

The furnace exterior temperature, exhaust air temperature from furnace, and the air flow were measured until the temperature of the furnace contents reached the highest point after starting the operation.

In addition, we measured the amount of steam condensate by the weight method, and calculated the heat quantity that entered the furnace.

The measurement points were as shown in Figure 5-6-13.



TI 1	Inlet temperature of steam for heating
TI 2	Surface temperature of the door of furnace
TI 3	Surface temperature of the back wall of furnace
TI 4	Surface temperature of furnace roof
TI 5	Dry bulb temperature of intake air (room temperature)
TI 6	Wet bulb temperature of intake air
TI 7	Dry bulb temperature of exhaust air
TI 8	Wet bulb temperature of exhaust air
FI 9	Linear velocity of exhaust air (the central value of exhaust duct)
TI 10	Condensate temperature
PI 11	Inner tube pressure of condensate
FI 12	Flow of condensate

Figure 5–6–13 Schematic Diagram of Furnace's Measuring Point

b) Heat balance

Dimensions of furnace which were our subject of measurement, the weight of the contents and the measured value of temperature, etc. were as shown below.

a. Exterior surface area of the furnace

Front, back, and sides	33.16 m^2
Roof	9.95 m^2

b. Cross section of exhaust duct

$1.85 \times 0.41 = 0.76\ m^2$

c. Furnace insulation material

The thickness of the mineral wool was 75 mm and the total volume was 3.14 m^3.

The specific gravity and specific heat were deemed as 0.12, 0.2 [kcal/kg °C], respectively.

d. Weight of furnace contents

Total weight of glass plates:	4690 kg
Total weight of iron parts:	4090 kg
Total weight of acrylate:	300 kg

The specific heat of the acrylate and the polymerization heat per cycle were given as 0.35 kcal/(kg°C), 15041 kcal, respectively.

e. Temperature

Room air temperature	28.0°C
Average air temp. at furnace outlet	45.2°C
Average furnace side wall temp.	32.3°C
Average furnace roof temp.	33.2°C

As for the heat input, it consists of the condensation heat calculated from the measured amount of steam condensate and the polymerization heat.

As for the heat output, it consists of the heat quantity required for raising the temperature of glass, iron parts, acrylate and furnace materials, and the heat quantity taken away by the exhaust air, and the heat escaping from the surface of the furnace.

Among the heat input, the amount of steam condensate totalled 474 kg, and the pressure of the condensate at the trap fluctuated within the range of 2.5 – 7 kg/cm^2 · G during operation.

Since the average pressure was in the region of 5 kg/cm^2 · G, the furnace heating quantity by steam was obtained by setting the latent heat of condensation as 500 kcal/kg.

$474 \times 500 = 237{,}000$ kcal.

The polymerization reaction heat 15,041 kcal is added to this, and the total heat input during the process is 252.0 M cal.

The calculation of heat output was done on the following preconditions.

The temperatures of the furnace and the furnace contents are 25°C when starting the operation, and during the polymerization the polymerization heat is cooled off, and maintained at about 50°C, and finally after being heated to about 120°C, it is cooled by the room temperature air.

All of the heating is done by steam heated air in aerofin heaters.

The heat quantity which should be calculated as heat output is as the total of the following three.

1. Heat quantity taken away by the exhaust air (Figure 5-6-14)
2. The amount of heat lost from the surface of the furnace
3. Heat quantity required to raise the content of the furnace from 25°C to the maximum temperature (120°C)

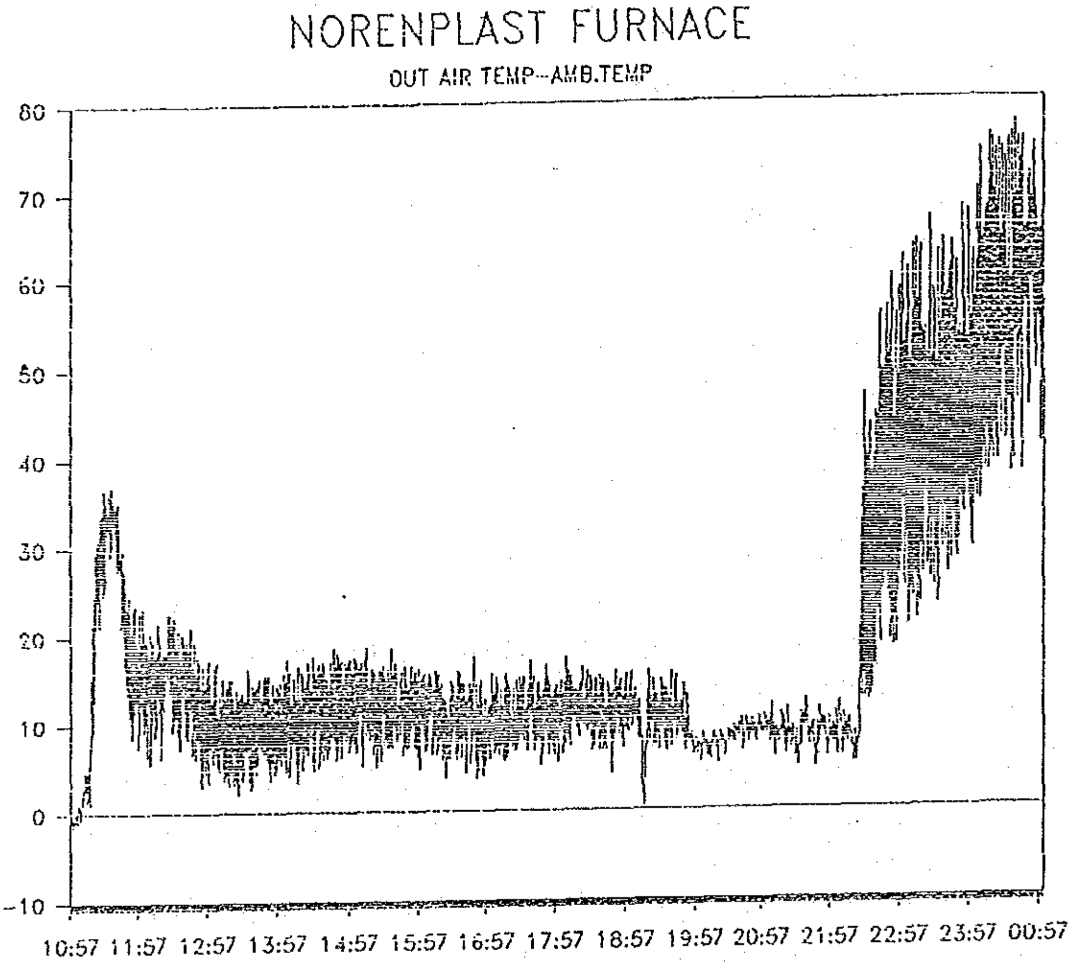


Figure 5–6–14 Difference Out Air Temperature and Ambient Temperature

Since the wind speed at the center of the exhaust duct outlet is measured, the average velocity is calculated in the following way.

First of all, the average value of measuring data during the process is calcuated by computer.

By using these data and velocity distribution data of Rothfus et. al., the average velocity was calculated.

The average value of the central velocity was 0.124 m/s, and Remax calculated by the equivalent diameter of the exhuast duct is 5570.

From this figure, the mean value of the average wind velocity of the exhaust duct is obtained as 0.09 m/s, and the total wind volume during the period is 3,447 m^3.

If we use 0.24 kcal/kg · °C for the specific heat of the air, the total heat quantity of raising the air temperature from the average outside air temperature (28.0°C) to the average exhaust temperature of 45.2°C is as follows:

$$3{,}447 \times \frac{273}{318.2} \times \frac{29}{22.4} \times 0.24 \times (45.2 - 28.0) = 15{,}805 \text{ kcal}$$

As for the heat quantity dissipated from the sides of the furnace by natural convection, if we use the euqation which we used in the previous paragraph, and use 3.2 kcal/m^2·h°C) as the overall heat transfer coefficient in the calculation, the following is obtained.

$$33.16 \times 3.2 \times 4.3 \times 14 = 6{,}388 \text{ kcal}$$

The heat quantity dissipated from the roof of the furnace by natural convection is as follows when 4.2 kcal/(m^2·h°C) is used for the overall heat transfer coefficient.

$$9.95 \times 4.2 \times 5.3 \times 14 = 3{,}101 \text{ kcal.}$$

In a similar way, by using equation of the previous paragraph, the quantity of radiation heat is calculated by using 0.85 as emissivity.

The quantity of radiation heat from the sides of the furnace will be as follows:

$$33.16 \times 4.88 \times 0.85 \times \left[\left(\frac{32.3 + 273}{100}\right)^4 - \left(\frac{28.0 + 273}{100}\right)^4\right] \times 14 = 9{,}228 \text{ kcal}$$

The quantity of radiation heat from the roof of the furnace is

$$9.95 \times 4.88 \times 0.85 \times \left[\left(\frac{33.2 + 273}{100}\right)^4 - \left(\frac{28.0 + 273}{100}\right)^4\right] \times 14 = 3{,}363 \text{ kcal}$$

The total heat quantity dissipated from the surface of the furnace is 22.1 Mcal.

The heat quantity required for raising the contents temperature of the furnace from 25°C to 120°C is as follows:

The heat quantity required for raising the temperature of the glass plates is

$$4{,}690 \times 0.18 \times (120 - 25) = 80{,}119 \text{ kcal.}$$

The heat quantity required for raising the temperature of the iron parts is

$$4{,}090 \times 0.11 \times (120 - 25) = 42{,}741 \text{ kcal.}$$

The heat quantity required for raising the temperature of the acrylate is

$$300 \times 0.35 \times (120 - 25) = 9{,}975 \text{ kcal.}$$

The heat quantity required for raising the furnace insulation material is as follows if we assume its average temperature to be 80°C.

$$377 \times 0.2 \times (80 - 25) = 4{,}147 \text{ kcal}$$

We summarize the above as shown in Table 5-6-12.

Table 5–6–12 **Heat Balance of Furnace**

Heat input			Heat output		
Item	Mcal	%	Item	Mcal	%
Heat of steam Heat of polymerization	237 15	94 6	Heat removed by air Surface heat loss Heat of acryl plate Heat of furnace etc. Others	16 22 10 127 78	6 9 4 50 31
Total	252	100	Total	252	100

d) Problems and their solutions

i) According to the heat balance, heat quantity used for raising the temerature of the acrylic product is merely 4% of the total heat input, and the heat quantity used for raising the temperature of the glass plates and iron frames is about 13 times more.

In the polymerization of acrylic plates, the surface smoothness is an important factor. In addition, in order to advance the uniform reaction, certain amount of heat capacity will be required for the glass plates.

However, it is preferable to make the iron frames as light as possible.

ii) Aerofin heaters

Aerofin heater which is used as heat exchangers for steam and air, large transfer resistance on the air side in comparison with the heat transfer resistance for the condensation heat transfer of the steam side. Thus, this point is compensated by the increase in heat transfer area by fins and it is believed that this usage in this factory is proper.

However, it is desirable to select structures and materials which will heighten the fin efficiency as much as possible. Because depending on the shape, thickness, and metal materials of the fins, the increase in fin area will not contribute 100% to the heat transfer.

Since the interior of the furnace was not checked, we have not confirmed it, but judging from the observations made from the outside, we believe a considerable amount of dust may adhere to the heat transfer surface.

The overall heat transfer coefficient obtained from the measured heat transferred is rather low as 10.6 kcal/($m^2 \cdot h \cdot ^\circ C$)

Since the adherence of dust will increase the heat transfer resistance, it can be anticipated that the heat transfer efficiency will be improved by cleaning the heat transfer surface.

If wind velocity is increased, the heat transfer coefficient of the air side can be made larger, even though the pressure loss will become large, and the required power will increase. Since we have not made observation of the internal structure, a quantitative study will be impossible, but we believe it would be desirable to select optimum wind velocity for both heat transfer efficiency and the amount of power.

iii) Steam pressure

The heating at the time of starting the polymerization is about 50°C as temperature inside of the furnace, and it does not require steam such as high pressure of 5 – 6 $kg/cm^2 \cdot G$.

The amount of condensate during this time is about 130 kg.

If the pressure of the steam is reduced to about 2 $kg/cm^2 \cdot G$, the vaporization latent heat per 1 kg of steam will become larger, so about 3.5% of steam amount can be saved for one operation. If proportional calculation is made for annual production quantity of acrylic plates, the annual savings of steam will be

$$130 \times 0.035 \times \frac{492.5t}{0.3\ t} = 7{,}470 \text{ kg/y}$$

By switching the steam pressure during the process, an effect of 60 U$S/y can be anticipated. Thus, the establishment of a fine control system is desirable.

5.6.3.5 Power Receiving and Distributing and Electrical Facilities

(1) Outline of electric power receiving equipment and load

Power is received by 380V aerial wire, and at the receiving point, accounting service integrating wattmeter and integrating reactive power meter, etc. are installed. From this receiving point the power is connected to the distribution panel of utility room via underground cable having a length of about 150m.

The load consists of the motors for driving the agitators of several reactors, refrigerator, air compressors, and water pumps.

The average power consumption on the day we measured was 145 kW. The peak demand for 30 minutes during the peak period was 179 kW. The average consumption by plants were as follows:

Acrylic plate factory	40 kW
Polyurethane factory	26 kW
Utility room	23 kW

Load factor (mean power/maximum power) and power factor were 81%, 90%, respectively, and they were good figures.

(2) Contents of measurement

The following measurements were done by using the watt-power factor meter (PFM-1000, PFMA-5210, PFM-1000P), AC clip on power meter, 12 point recorder.

(1) Load condition of whole factory

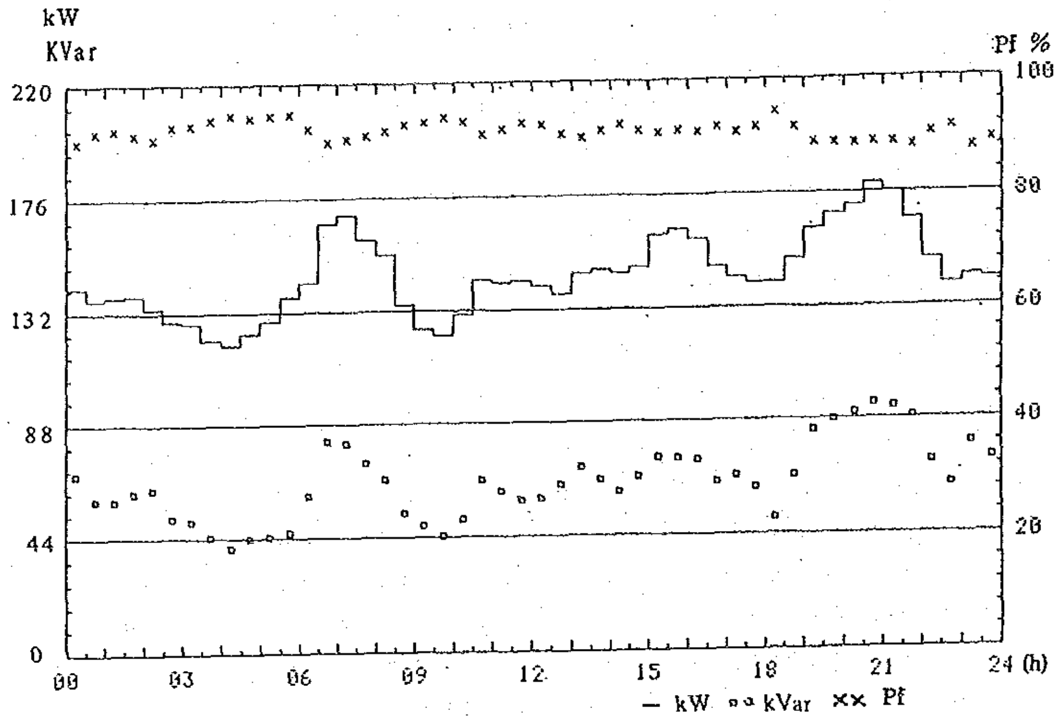


Figure 5–6–15 Total Load Condition of Factory

(2) Load condition of furnace for acrylic plate

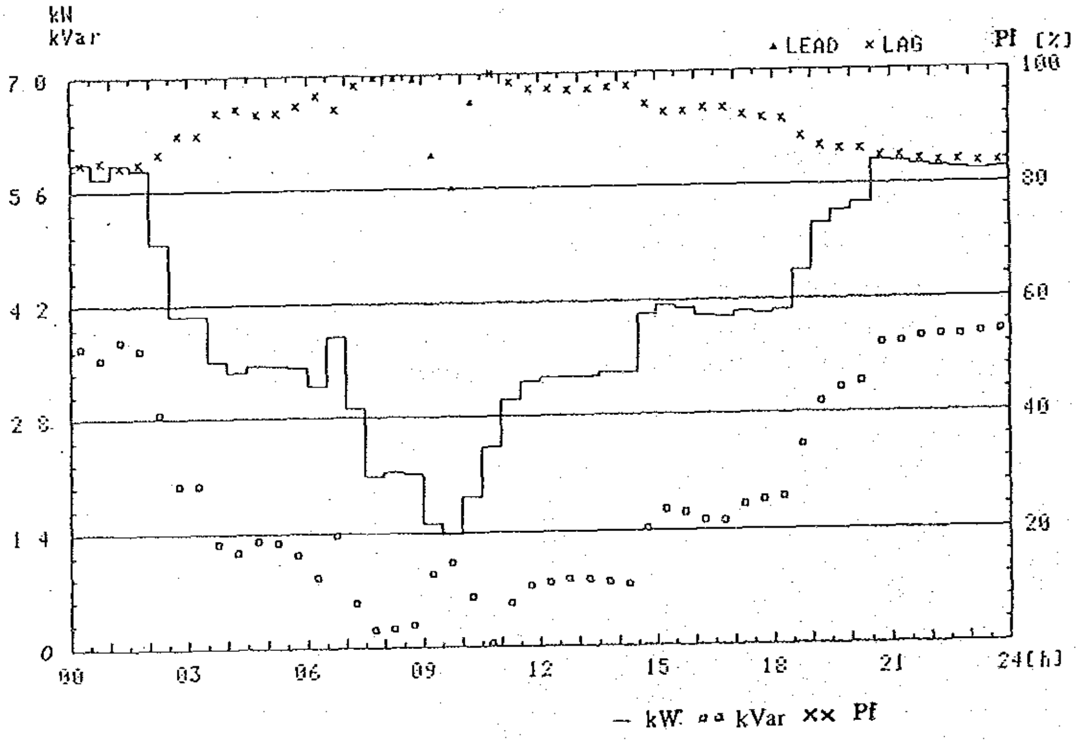


Figure 5–6–16 Load Condition of Furnace at Acryl Plate Factory

(3) Conditions of power consumption by plants

Table 5–6–13 Consuming Power of Main Factory (1988-10-27)

Factory	Consuming power			Power factor	Remarks
	Ave.	Peak			
		In all day	In peak hour		
	kW	kW	kW	%	
Emulsion	6	13	2.9	50	P.F. lead at light load
Finishing and leather	26	34	30	81	
Acryl plant reactor	4.5	9	2.1	43	Work time: 6H ~ 21H
Acryl plate furnace	40	58.8		92	
Power station	23	32.6	29	72	

(4) Power consumption of main motors

Table 5–6–14 Consuming Power of Motor

Factory	Equipment	Rating		Actual		Load (B)(A) X 100	Remarks
		CV	kW (A)	kW (B)	Cos φ		
Acryl plate	Furnace No. 7	18 cv (4 x 4.5)	13.2	9.5	% 62	% 72	
	Furnace No. 4	12 cv (4 x 3)	8.8	7.9	73	90	
Cooling tower	Pump	20	14.7	10.5	90	71	
Depoly-merization	Metal bath	10	7.4	5.7	88	77	
Power station	Ammonia compressor	30	22.1	14	77	63	
	Air compressor (un-load)	15	11	8 (2)	74 (28)	72 (18)	Pressure 6 – 8 kg/cm²
	Air compressor	75	55.2	15	40	27	
	Vacuum pump	7.5	5.5	4.3	78	78	Pressure –65 mmHg
	Vacuum pump	10	7.4	7.7	87	104	
	Cooling water pump	7.5	5.5	3.0	61	55	Pressure 2.5 kg/cm² (out door)

(3) Problems in electric management and their solutions

(1) Preparation of one-line diagram

Although there is a drawing showing the layout of the wiring in the factory, there is no one-line diagram. In order to grasp the whole electrical system easily, it is necessary to prepare a one-line diagram like the one shown in Figure 5-6-3.

In addition, since the indication of digital voltmeter for monitoring the receiving voltage is about 4% lower than the actual voltage, repairing is necessary.

(2) Power control at the peak time

From Figure 5-6-15 we see that on the day of our measurement, the power consumption during the peak time (17:00 – 21:00) reached maximum and exceeded the contract demand of 168 kW.

According to the actual records of the period between April and September, the power consumption at the peak time accounted for 17.3% of the total consumption. This value is approximately equal to the ratio of the peak time versus the whole day or 24 hours (16.7%).

It may be said that the personnels are not conscious of aiming at power savings during the peak time. The energy charge of the electric power during the peak time will cost 1.54 times in comparison with the charge during the daytime off peak time. Therefore, it is necessary to decrease both the electric power (kW) as well as the amount of power used (kWh) during the peak time.

(1) Plan and execute a production schedule so that the production of acrylic plates having large load will be less during the peak time.

(2) Among various operations at the factories, check the work which can be shifted to time zones other than the peak, and decreases the load of the peak time.

Install a demand controller which will alarm when it predicts that load will exceed a set value.

In case of the alarm, move the work which is not in a hurry to some other time zone, and make efforts to decrease the peak power consumption.

(3) Improvement of cooling water system

The refrigerating unit consists of two 30 kW ammonia compressors, 7.5 kW pumps for cooling, and four cooling water circulating pumps. During the day time, the operation is in about a constant state.

The temperature of the cooling water sent out is –3°C, the cooling water returned is 3°C, and the amount of water is about 290 ℓ/min. Thus, the cooling heat quantity can be expressed as follows:

$$\{3 - (-3)\}\ ^\circ\mathrm{C} \times 290\ell/\mathrm{min} \times 1\ \mathrm{kg/l} \times 1\ \mathrm{kcal/kg} \times 60\ \mathrm{min/h} \fallingdotseq 100{,}000\ \mathrm{kcal/h}$$

In relation to this load, the power consumption of the ammonia compressor is 14 kW, and it may be at approximately proper level.

Besides the above, formation of ice was seen at the top of the cooling water tank, and dews formed on the piping to the plant. Thus, it is necessary to perform insulation work for them.

In case water flow changes greatly such as the circulation pump for cold water and outdoor cooling water pump, it is recommendable to control the flow by revolution control.

This effect is as shown in Figure 5-6-17. If the amount of flow decreases by 20%, the power consumption will become almost half. However, by the reduction in flow, the pressure will also change (It is proportional to the square of the revolutiuon speed). Thus, it shall be within the permissible range of pressure change.

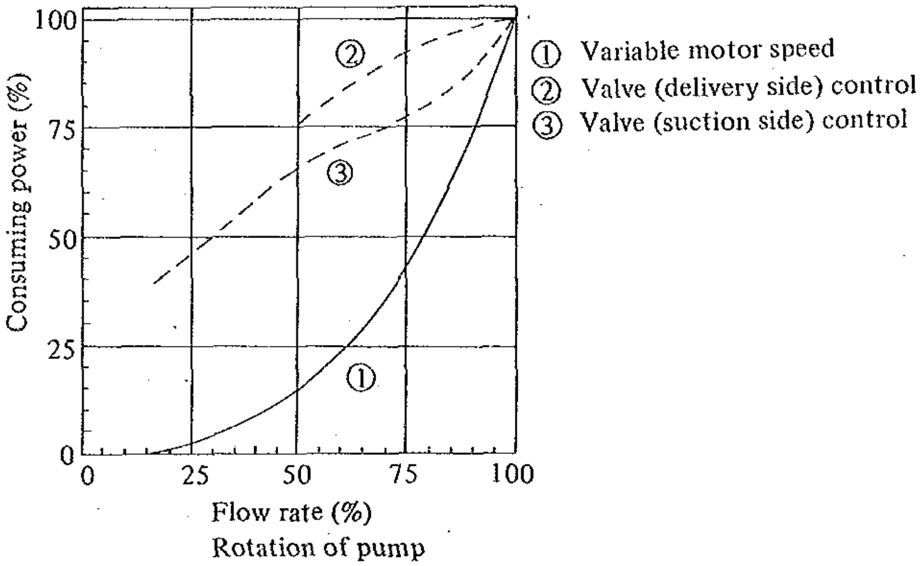


Figure 5–6–17 Power Consumption vs Flow rate

(4) Others

There are certain motors having light load. If the load of the motor is light, the efficiency will become low, and the power factor will drop. Thus, the following measures are considered.

a) Capacity of 75 CV air compressors seems to be excessive for the current load. If this is exchanged to 30 – 40 CV, the no-load loss at the time of UN-LOAD can be reduced.

b) It is believed that the load fluctuation of the boiler is great. However, the power consumption at the boiler room is about 5 kW and it is almost constant for 24 hours. The controlling of the combustion air is done by the choking of the dampers, but it is preferable to change this to revolution control by inverter.

c) There were some motors with loose sagging drive belt, and some motors lacking some belts. It is necessary to maintain them properly.

5.6.3.6 Summary

The following are the effects of the aforementioned improvement that can be estimated quantitatively.

Item		Possible annual amount of saving	%
Improvement of boiler air ratio	Gas	13,400 Nm^3	2.2
Improvement of oil heater air ratio		3,900	0.6
Heat insulation of boiler		2,900	0.5
Improvement of reactor heating method		2,800	0.5
Change of steam pressure		2,600	0.4
Total		25,600	4.2

5.7 Results of Survey of Plastic Factory

5. Survey of Use of Energy in Model Factories

5.7 Results of Survey of Plastic Factory

5.7.1 Outline of the Factory

(1) Name of the factory : Plastimet S.A.I.C.

(2) Type of product : Plastic

(3) Location of the factory : Pampa 515-Bella Vista (1661), Prov. Buenos Aires

(4) Summary

The factory was built 24 years ago to produce plastic products with only one machine. However, it has been developed to be able to manufacture and sell plastic manufacturing machines and testing equipment besides the plastic products by steadily strengthening its production facilities and securing its technical power until today.

A great variety of hoses in many sizes ranging from ordinary water hoses to medical hoses are manufactured by the factory as specialized plastic hoses manufacturer. It holds the greater part of the hose market shares in the Argentine Republic.

A considerable volume of scraps are generated at this factory due to the many frequencies to switch the manufacturing condition to the types of products and other causes. Although the scraps are regenerated for use, it is needless to say that it consumes an excessive amount of energy. The improvement of product yield is the basis for promoting the energy conservation.

All the energies required for the factory are supplied by electric power, and the electric power cost is very high. Therefore, considerable economic effects are expected to be obtained by the promotion of the energy conservation.

(5) Number of employees : 80

(6) Survey period : October 31 to November 5, 1988

(7) Survey members

Name	Assignment
Issei Furugaki	Group leader and energy management
Teruo Nakagawa	Heat management
Toshio Sugimoto	Electric power receiving and distributing equipment
Naoshi Honda	Heat management
Keiji Sawada	Plastic process
INTI members	
Mr. E. M. Leikis	Chief
Mr. M. A. Silvosa	Heat using equipment, process
Mr. A. Berset	Heat using equipment
Mr. A. A. Monzon	Heat using euipment, mobile unit driving
Mr. M. A. Bermejo	Electric receiving and distributing equipment
Mr. A. D. Verghelet	Electric receiving and distributing equipment
Mr. O. W. Fuentes	Heat using equipment
Mr. P. L. Cozza	Electric receiving and distributing equipment

(8) Interviewed
Mr. Horacio Lercari
Mr. Frino
Mr. P. Minaudo

(9) Production

Table 5–7–1 Production (t)

Year	1983	1984	1985	1986	1987
Irrigation hose	855	489	524	892	803
Crystal tube	160	91	99	149	121
Pressure tube	68	37	41	94	103
Others	117	67	73	113	160
Total	1,200	684	737	1,248	1,187

(10) Energy consumption

Table 5–7–2 Energy Consumption

Year	1983	1984	1985	1986	1987
Elect. Power MWh	997.6	541.9	591.7	1,241.7	–
Energy/production Power kWh/t	831	792	803	995	–

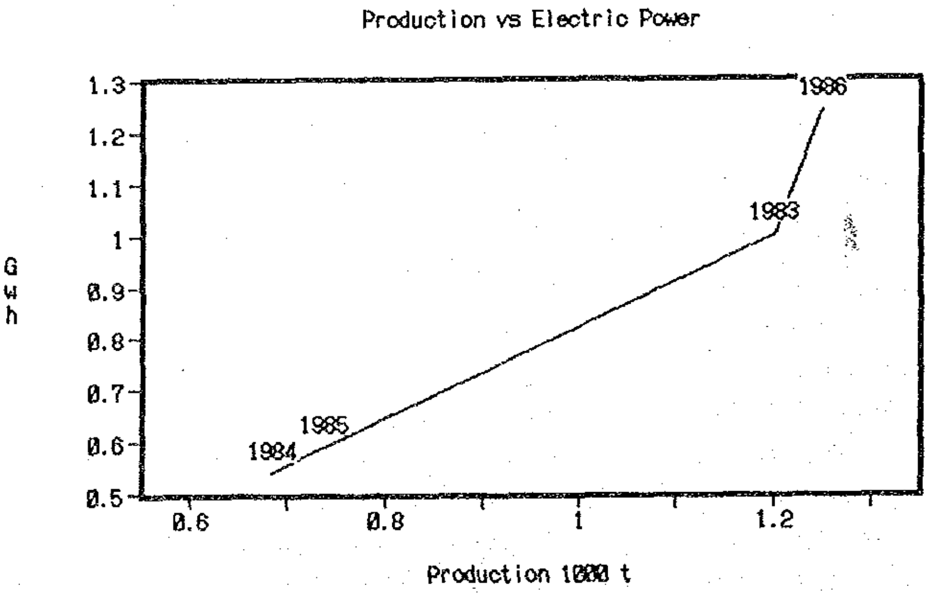


Figure 5–7–1 Production and Energy Consumption

Electric power unit price 0.1U$S/kWh

(11) Factory layout

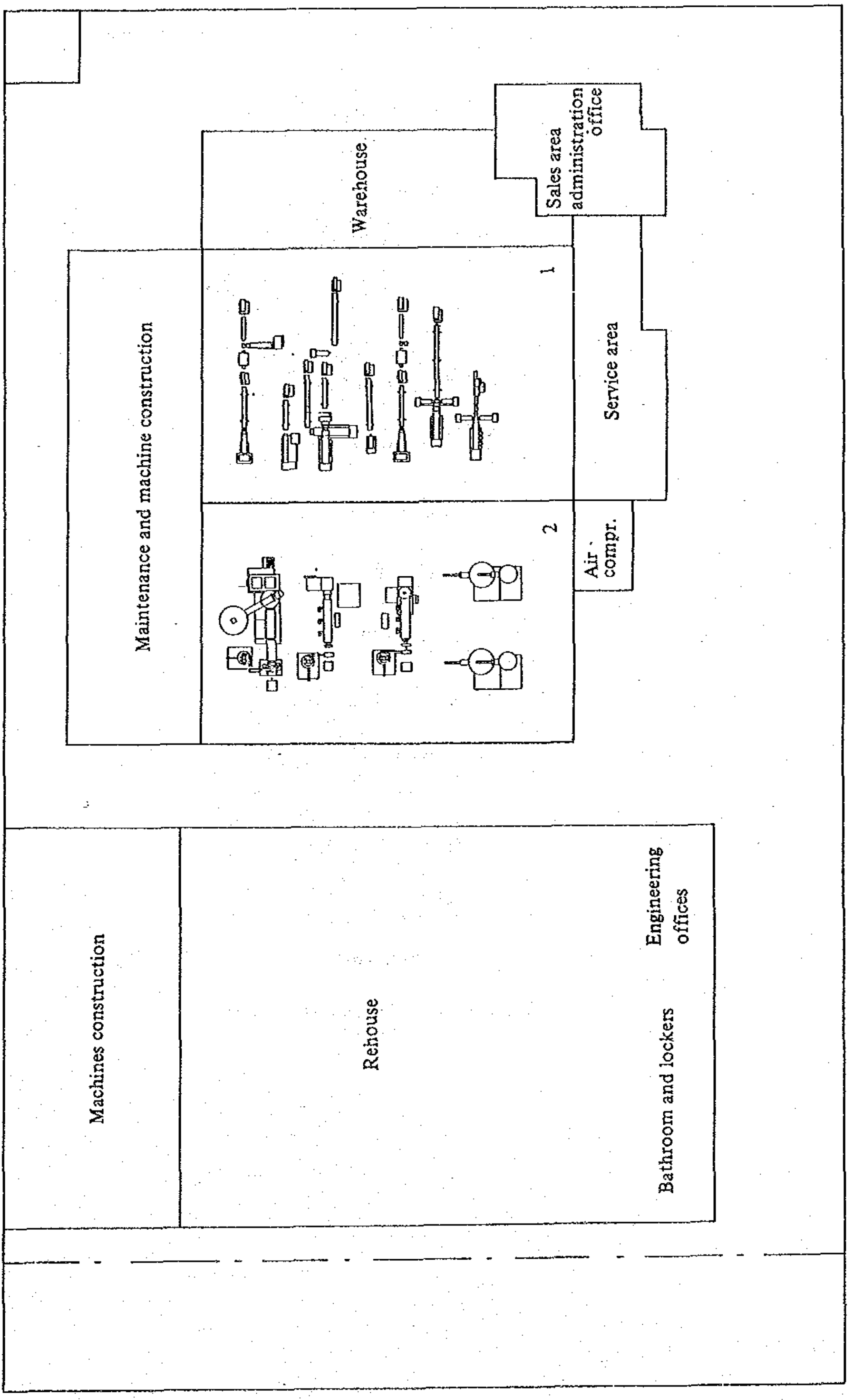


Figure 5–7–2 Factory Layout

(12) Production process

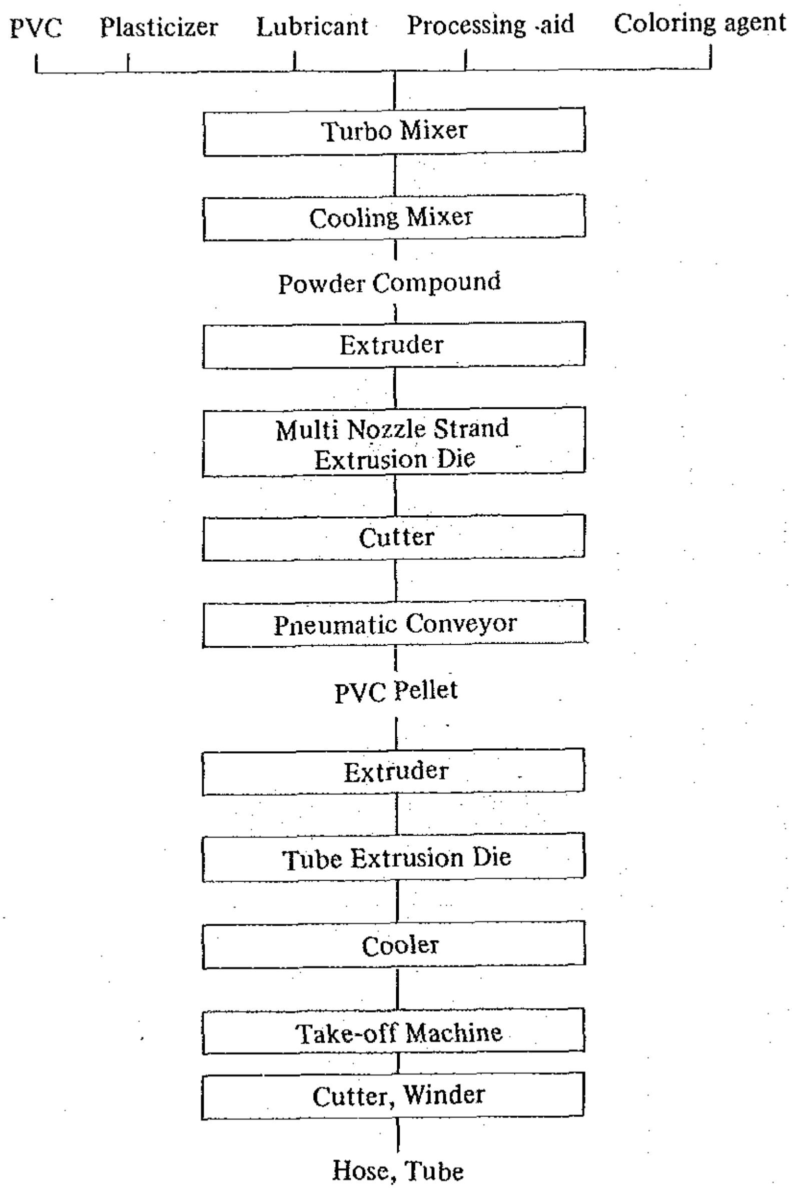


Figure 5–7–3 Production Process

(13) One line diagram

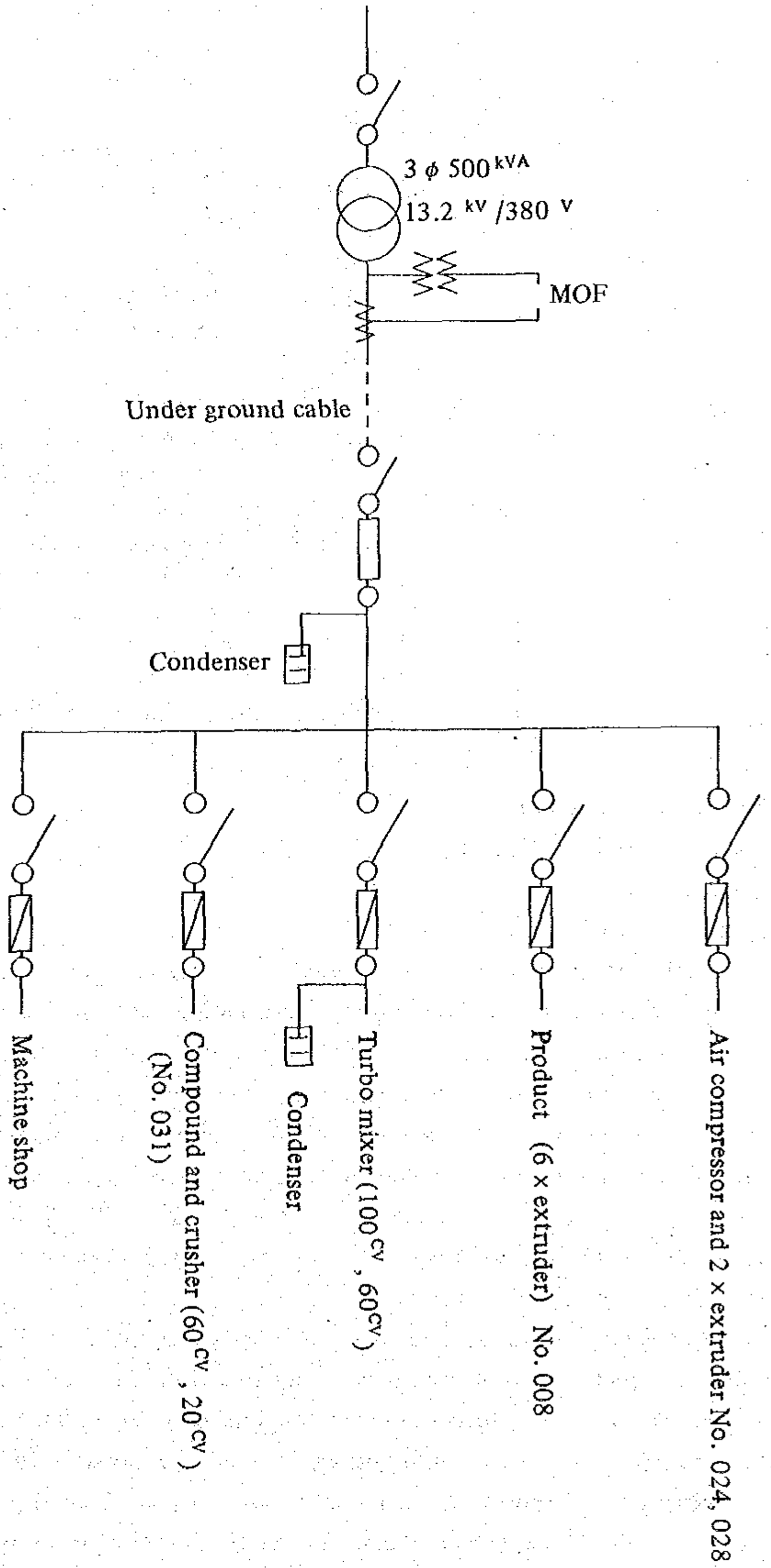


Figure 5–7–4 One Line Diagram

(14) Major energy consuming equipment

Table 5–7–3 Major Energy Consuming Equipment

Name	Number	Specification
Turbo mixer	2	(TM 001) 160 1, cooling mixer 380 1 50 CV, 65 kg/batch (TM 002) 350 1, cooling mixer 500 1 100 CV, 120 kg/batch
Compound extruder	3	120 φ x 1 36 rpm (EX 031) 100 CV (AC), 168 kg/h temperature control P 100 φ x 2
Hose extruder	13	102 φ x 1 37 rpm (EX 024) 40/26 CV (AC), 87 kg/h temperature control P 75 φ x 2 multicolored hose 60 φ x 4 braided hose, medical tube (EX 008) 23.3 kW (DC), 29 kg/h temp. control ON-OFF 40–60 rpm 45 φ x 1 30 φ x 5 multicolored coextrusion

(15) Factory operating time

24 h/d X 250 d/y = 6,000 h/y

5.7.2 Energy Management

(1) Energy conservation target

No specific target has been set for reducing energy consumption. As electric power is the only energy source of the factory despite its high cost, it is desired to reduce the cost by establishing a target for saving electric power consumption. Electric power is expected to be saved by both more strict operation management and the improvement of equipment. In any case, the first step necessary for energy conservation is to clearly grasp the present condition as explained in the following paragraph.

For the power saving at the factory it is required to first decrease the number of defectives and then reduce the energy consumption per unit product.

(2) Determining energy consumption

To improve the operation and equipment, it is essential to collect the process data on production, quality, and electric power, and thus accurately determine the facts about the factory. Without data which shows the relationship of operating conditions with production, quality, and energy consumption, it won't be possible to determine what is to be emphasized and how to make the improvement plan. Several points of equipment to be improved will be explained later in this report. It is also necessary to fully recognize the facts about the factory to evaluate the forecasted effect of improvement and determine if the plan can be carried out or not. It requires some measuring instruments. The installation of the minimum number of necessary measuring instrements is indispensable, and further improvement of operation can be expected from the constant notice of the employees on the values obtained by measurement.

(3) Engineer education and employee training

We were greatly impressed by the high consciousness of the employees toward the electric power conservation who make it a rule to put out lights carefully without fail in offices. In the factory, however, quite different scenes were observed. It is therefore desirable that the high consciousness toward the electric power conservation will be achieved in all the operator just as in offices.

Electricity is usually difficult for the general employees other than electricity specialists to understand. However, as the factory uses electric power as its main energy, it is necessary to educate the employees so that they can have the minimum knowledge about electricity. In this case, it is anticipated that the employees' interest in the energy conservation will be increased without fail if the forecasted effect of measures to save energy is expressed by the actual values of electric power cost.

5.7.3 Problems with Use of Energy and Remedial Measures

The following three types of energies are required for extrusion molding.

(1) Heat energy for melting the resin supplied

(2) Mechanical energy for shearing and mixing resin

(3) Mechanical energy to press and extrude resin

These energies are given to the three equipment; cylinder heater, cooling blower and driving motor.

The survey was made to mainly investigate the points mentioned below.

Difference of the electric power consumption by type of the driving motors

Difference of the electric power consumption depending on the cylinder heater temperature controlling method.

Other problems related to voltage variation, heater radiation and powder compound cooling

5.7.3.1 Difference of the Electric Power Consumption by the Type of the Driving Motors

Results of the measurement of the electric power consumption for the driving motors are shown in Table 5-7.4.

Table 5–7–4 Electric Power Consumption by Each Extruder

Extruder	Motor	Power consumption	Production	Unit rate cons
Ex 008	DC 23.3 kW	6.08 kWh/h	29 kg/h	0.21 kWh/kg
Ex 024	AC 40/26 CV	13.4 kWh/h	87 kg/h	0.15 kWh/kg
Ex 031	AC 100 CV	21.7 kWh/h	168 kg/h	0.13 kWh/kg

The survey results show that the efficiency of AC motor is excellent. However, attention should be paid to the AC motor that controls the r.p.m. by secondary resistance, or primary voltage or eddy current coupling, because in the case of square torque-load characteristic its efficiency decreases as increasing of the speed change range as shown in Figure 5-7-5.

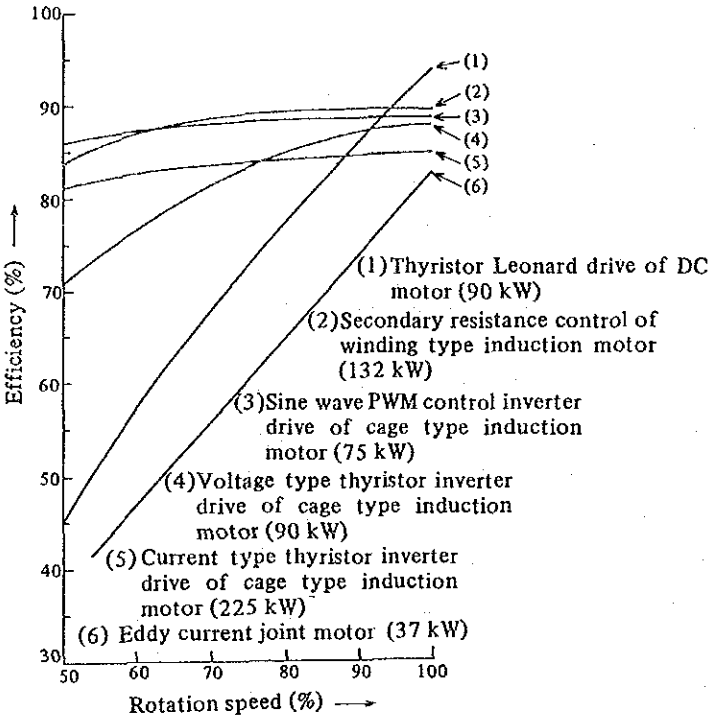


Figure 5–7–5 Comparison of the Efficiencies of Various Rotation Control Systems for Small and Medium Capacity Machines

As one of the above examples, the difference of power consumption in the extrusion moldings using an eddy current coupling motor and a DC motor respectively is shown in Table 5-7-5. It can be seen from the table that the difference of power consumption becomes larger as the load decreases.

Table 5–7–5 Comparison of Power Consumption between DC Motor and AC Motor with Eddy-Current Coupling

Screw speed (rpm)	Pressure at screw tip (kg/cm²)	Feed opening not cooled			Feed opening cooled		
		Throughput (kg/hr)	Power consumption of motor (kW)		Throughput (kg/hr)	Power consumption of motor (kW)	
			DC Motor	AC motor with eddy-current coupling		DC Motor	AC motor with eddy-current coupling
20	100	3.00	1.501	2.476	4.52	1.992	2.858
40	100	6.60	1.811	2.476	9.27	2.200	2.858
60	100	10.20	2.071	2.591	13.86	2.588	3.048
80	100	13.80	2.536	2.667	18.84	2.976	3.048

Moreover, it was found by the measurement of voltage variations in the survey that voltage greatly varied from 340V to 375V as shown in Figure 5-7-6. Therefore, the rotating speed of the motor also varies and the variance influences the dimensions of products obtained by extrusion molding, causing the increase of defectives.

AC motor is directly influenced by the voltage variations, but the voltage of DC motor is more stable because it uses the voltage stabilizer and thus the precision of the dimensions of products obtained by extrusion molding is high.

Considering the electric power consumption and voltage variations, it is advisable to employ DC motor as far as possible.

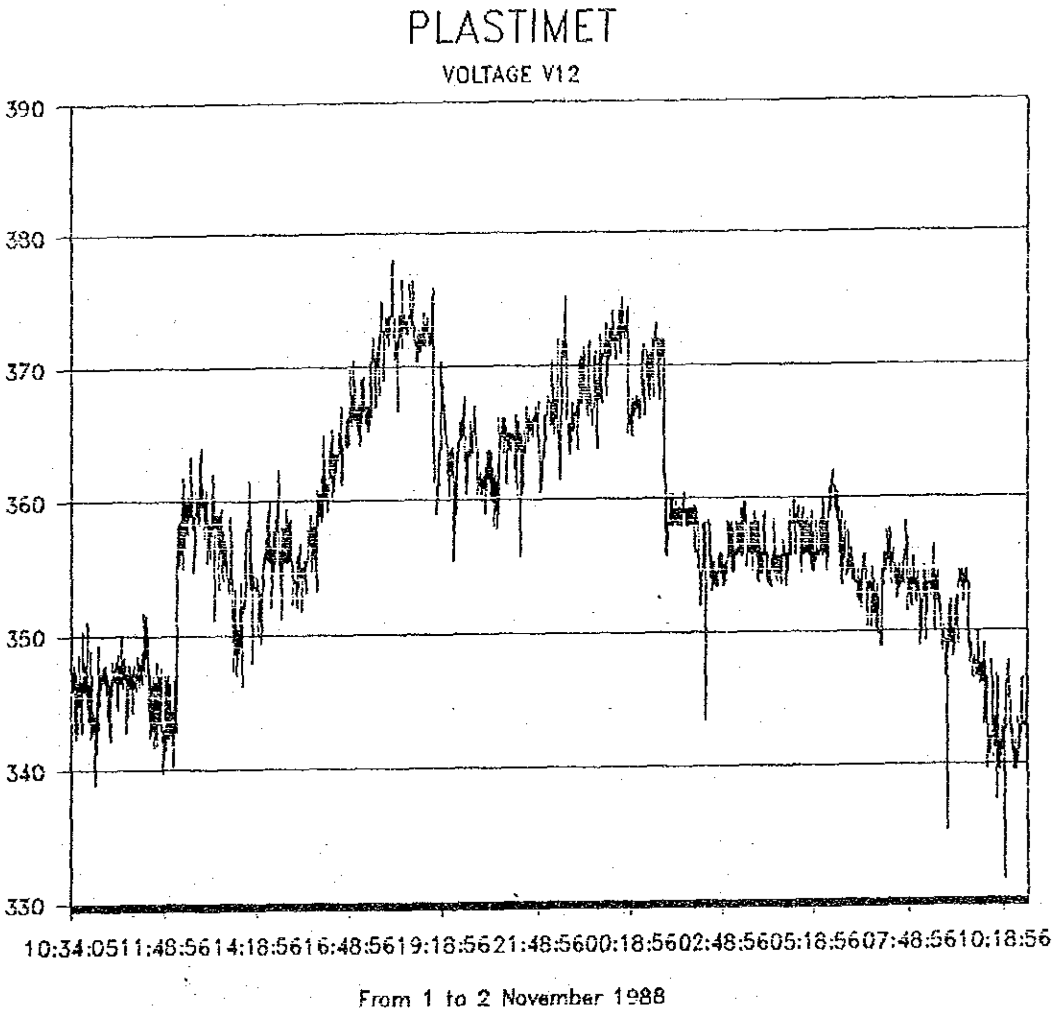


Figure 5–7–6 Voltage Variation of Power Supplied to Plastiment Factory

5.7.3.2 Difference of the Electric Power Consumption Depending on the Cylinder Temperature Controlling Method

(1) Temperature variations of extruder

The cylinder temperature variations of the three extruders surveyed are shown in Figure 5-7-7, Figure 5-7-8, Figure 5-7-9 and Table 5-7-6.

Table 5–7–6 Temperature Variance of Extruder Cylinder

Extruder	Temp. control	Temp. variance
Ex 008	ON-OFF	6 – 20 °C
Ex 024	P	1.5 – 2.5°C
Ex 031	P	1.5 – 2.5°C

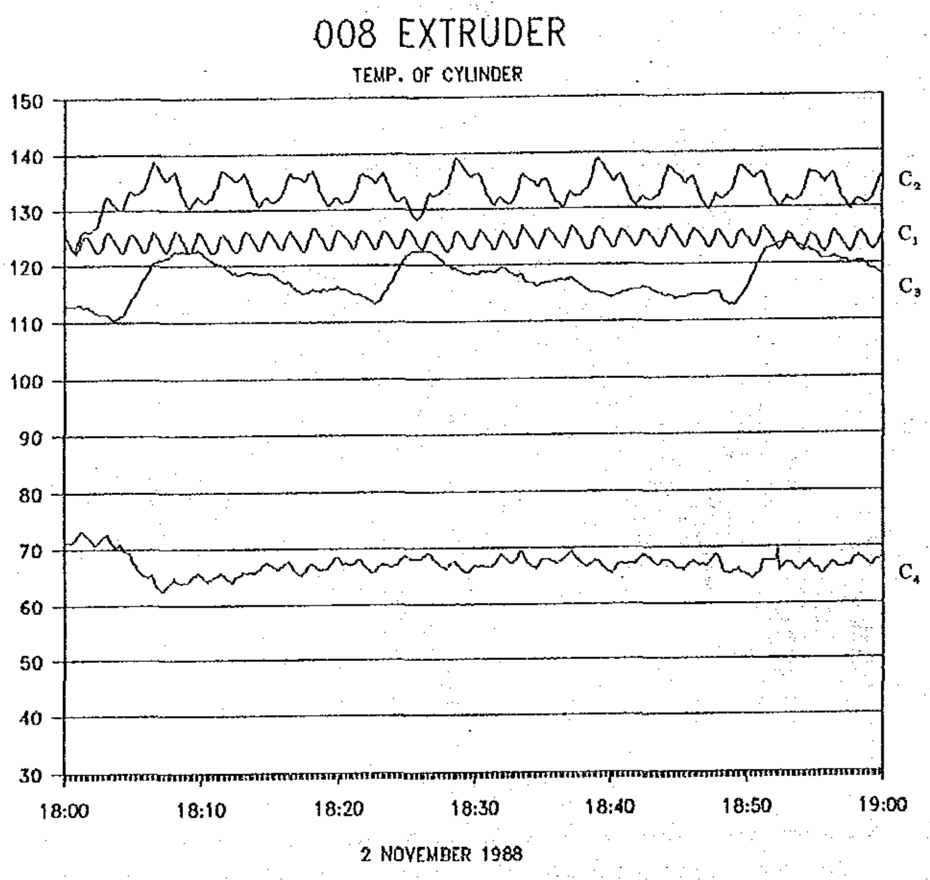


Figure 5–7–7 Temperature Variance of Extruder Cylinder

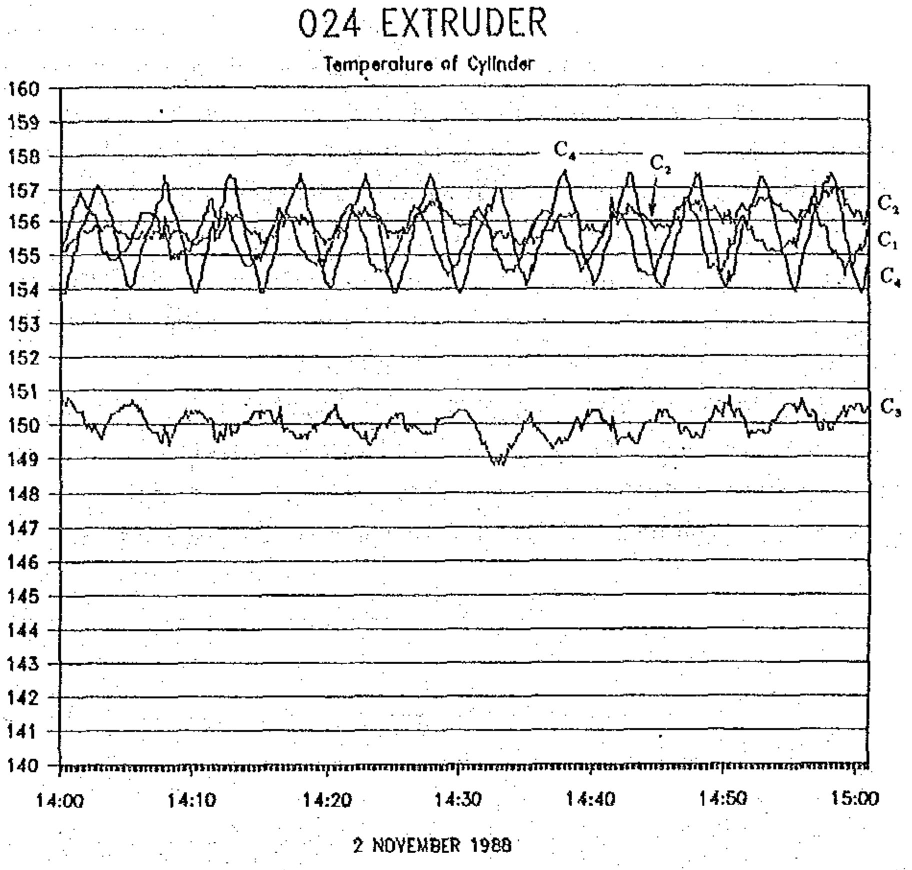


Figure 5–7–8 Temperature Variation of Extruder Cylinder

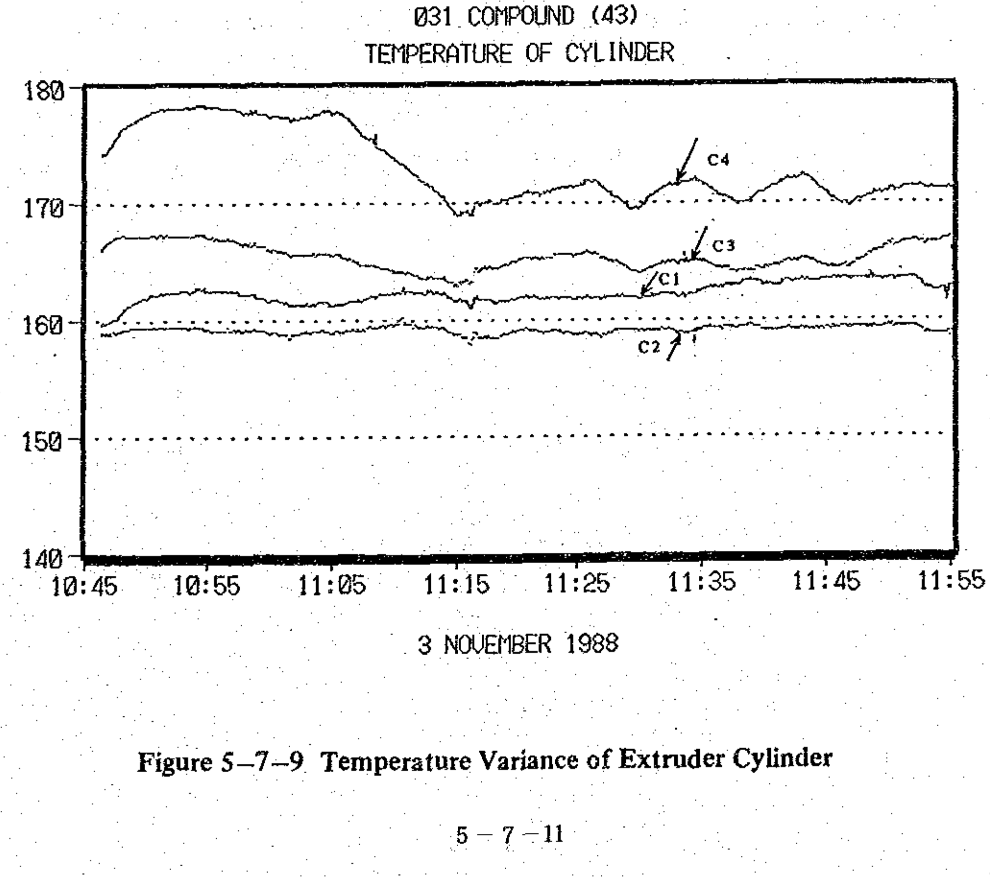


Figure 5–7–9 Temperature Variance of Extruder Cylinder

For all the extruders, the temperature control precision was not good, and the temperature variations were large especially for Ex 008 whose temperature was controlled by on-off control. In case of P control, the ordinary precision is 0.5°C. Such inferior temperature control precision is considered to be probably caused by the use of incomplete controlling devices and the insufficient maintenance of blowers.

(2) On-off operation of heater and blower

Except for PID control, the switching of heater and blower should be performed conversely for P control and on-off control. But it was made clear by the visual survey that the switching of heater and blower was independent.

For example, Cl heater repeated on-off while Cl blower of Ex 024 was operated continuously as shown in Figure 5-7-10. This means that perfect temperature control cannot be made because heating and cooling are conducted at the same time. As shown in Figure 5-7-11 and Figure 5-7-12, this also applies to Ex 008 and Ex 031.

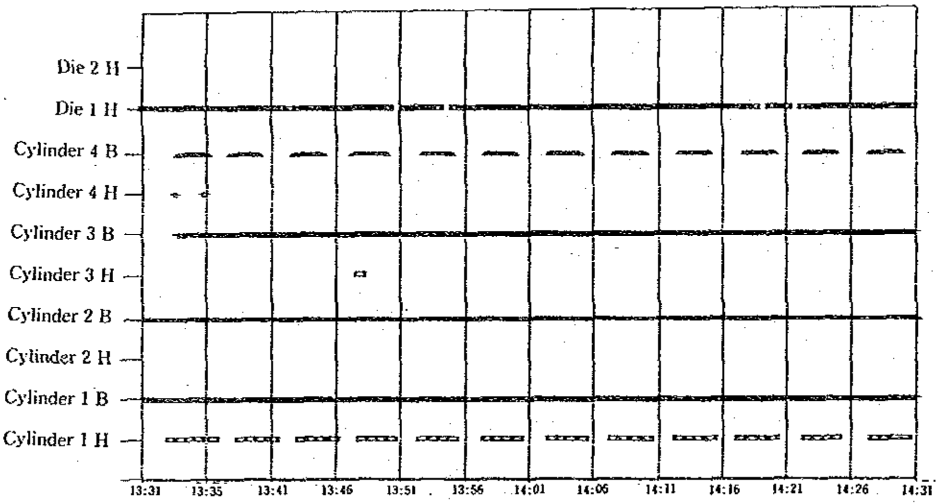


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Figure 5-7-10 024 Extruder

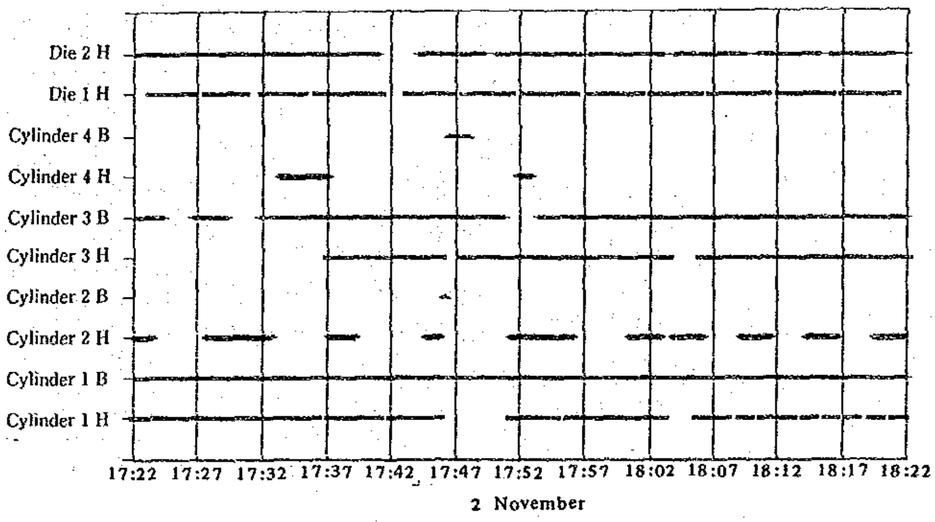


Figure 5–7–11 008 Extruder

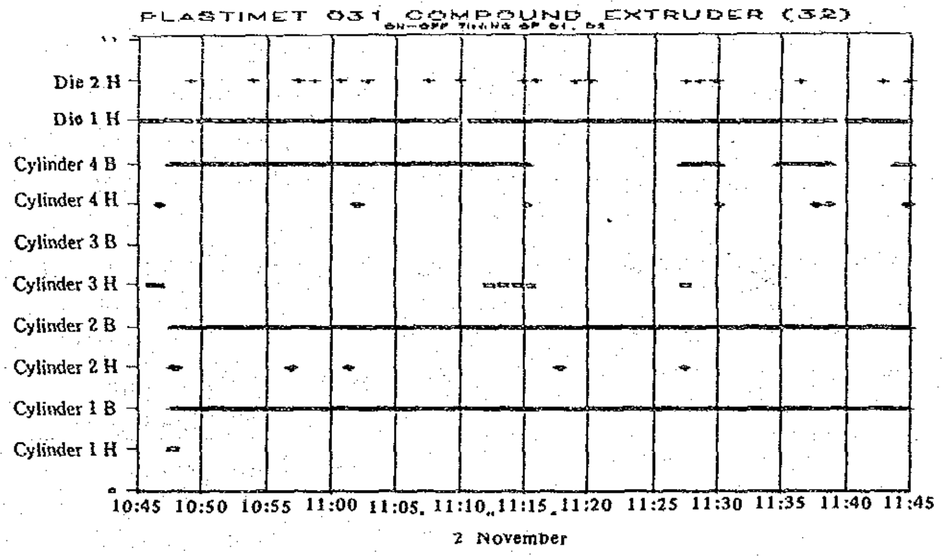


Figure 5–7–12 031 Compound Extruder

It seems to be a phenomenon caused by the insufficient maintenance of equipment. Therefore, it is necessary to periodically clean and maintain the contact points, etc. of the control devices.

(3) Temperature control method

Of the automatic temperature control devices for extruder, the temperature stability and energy conservation effect are high in the order of PID control and P control, and are most inferior in case of the on-off control. Therefore, PID control system has recently been adopted rapidly.

Table 5-7-7 shows the power consumption measured by an integrating meter in both cases that a 50 mm extruder was controlled by PID control system and P control system. PID control made it possible to save electric power by 75.6%.

Table 5–7–7 Comparison of Power Consumption between P & PID Control System (1)

	Proportional control				PID Control			
	Heater		Blower		Heater		Blower	
	ON time	Power	ON time	Power	ON time	Power	ON time	Power
C1	0.4 h	4 kWh	0.6 h	0.38 kWh	0.22 h	2.2 kWh	0 h	0 kWh
C2	0.2 h	2 kWh	0.8 h	0.51 kWh	0 h	0 kWh	0.5 h	0.32 kWh
C3	0.26 h	2.6 kWh	0.74 h	0.47 kWh	0 h	0 kWh	0.5 h	0.32 kWh
C4	0.29 h	2.9 kWh	0.71 h	0.45 kWh	0.04 h	0.4 kWh	0.01 h	0.01 kWh
Total		11.5 kWh		1.81 kWh		2.6 kWh		0.65 kWh
	13.31 kwh				3.25 kwh			
Ratio	100%				24.4%			

Note:

Heater	C1, C2, C3, C4	10 kw
Blower	C1, C2, C3, C4	0.64 kw
Cylinder Diameter		50 mm

For another example, the power consumption measured by an integrating meter in both cases that a 40 mm extruder was controlled by PID control system and P control system when LDPE (Melt Index = 2.3) resin was extruded is shown in Table 5-7-8. In this case, power consumption was aved by 60 – 75% at the screw speed of 20 – 60 rpm.

Table 5–7–8 Comparison of Power Consumption between P & PID Control System (2)

Screw speed (rpm)	Screw tip pressure (kg/cm²)	Throughput (kg/h)	Resin temperature (°C)	Power consumption (kW)	
				PID Heating PID Cooling	P Control
20	100	3.00	200	Heater 0.683 Blower 0.001 Total 0.684	Heater 2.518 Blower 0.098 Total 2.616
40	100	6.60	202	Heater 1.286 Blower 0.003 Total 1.289	Heater 3.178 Blower 0.103 Total 3.281
60	100	10.20	208	Heater 0.883 Blower 0.003 Total 0.886	Heater 2.643 Blower 0.091 Total 2.734
80	100	12.80	211	Heater 1.359 Blower 0.011 Total 1.370	Heater 2.261 Blower 0.059 Total 2.320

Note: Temperature C1 = 165°C, C2 = 180°C, C3 = 190°C, H = 190°C
Band Heater C1, C2, C3 = 1.96 kW H = 0.9 kW
Power Consumption for Die Adapter are included

Table 5-7-9 shows the estimated values of power consumption in the case that all the automatic temperature control systems for extruders of the factory are changed to PID control system using the data on the screw speed of 40 r.p.m. mentioned in Table 5-7-8.

Table 5–7–9 Estimation of Power Saving in the case of PID Control

Extruder	Control	Power consumption (kWh/h)			PID control	Saving
		Total (A)	Motor (B)	Heater, blower (C = A-B)	Heater, blower (D = C x 0.39)	
EX 024	P	19.3	13.4	5.9	2.3	3.6
EX 008	ON-OFF	9.1	6.1	3.0	1.2	1.8
EX 031	P	27.1	21.7	5.4	2.1	3.3
				14.3	5.6	8.7

Annual Saving 8.7 kW x 6,000 h/y = 52,200 kWh/y

For EX 008 controlled by the on-off control system, the actual saving is expected to be larger than the estimated value. As it is possible to save the power of about 16, 000 kWh/y per one extruder, the power of 160,000 kWh/y can be saved by adopting the PID control system for 10 extruders excluding small-sized 6 extruders. At the same time, as the temperature stability increases when PID control system is used, the extrusion irregularity decreases. Furthermore, the precision of the molded product dimensions is improved, the generation of defectives decreases, and the electric power for regeneration can be sharply reduced.

The expense required for the exchange of control units for 10 extruders is about U$S 18,000, and it can be recovered in 1.1 year.

(4) Mounting of heater

As the flanges and dies of extruder are not insulated, the heat radiation of extruder is large.

In addition, the heater was not attached closely to the metallic surface of flanges or dies that are frequently removed. This makes the heat transmission from the heater worse and causes the irregularity of die temperature. As a result, many defectives are likely to be generated, and the life of the heater is shortened by the increased wasteful heat radiation.

The thermal picture at this section is shown in Figure 5-7-13.

5.7.3.3 Powder Compound Temperature Management

(1) Results of the measurement of powder compound temperature

When the powder compound discharged from a cooling mixer is stored without being properly cooled, it causes deterioration due to self-heat generation. Namely, if resin is stored at 50 – 60°C for a long time, double bond is formed by leaving the hydrochloric acid gas from vinyl chloride. Since the double bond is liable to combine with oxygen and the temperature rising due to the heat of reaction accelerate the generation

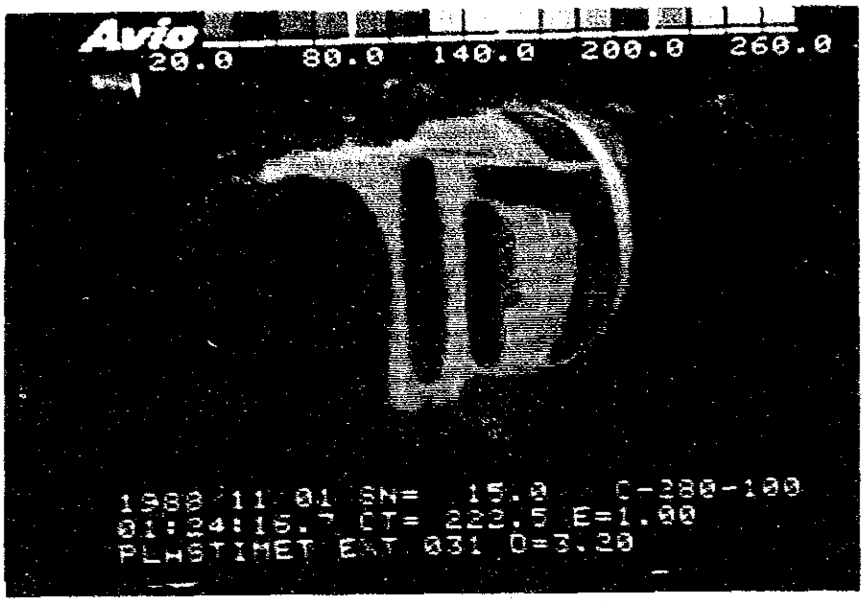


Figure 5–7–13 Infrared Image of Heater at Die Flange

of double bond causing the deterioration of powder compound. Accordingly, the powder compound discharged from a cooling mixer must be cooled up to a proper temperature. In general, the proper temperature is about 35 – 40° C.

If the powder compound is matured for several hours while it is quietly stirred at about 40° C after discharge, its physical properties are greatly improved.

The results of measurement of powder compound temperature conducted at the factory are shown in Figure 5-7-14. When 6 hours elapsed after discharge, the center section reached 83° C. It is supposed that the powder compound was probably discharged at around 60° C.

Table 5-7-10 shows the temperature of powder compound in the chute discharged by two operating mixers. The discharge temperatures are not uniform, but any of them exceeds the proper temperature, and the powder compound is liable to deteriorate if it is stored for a long time.

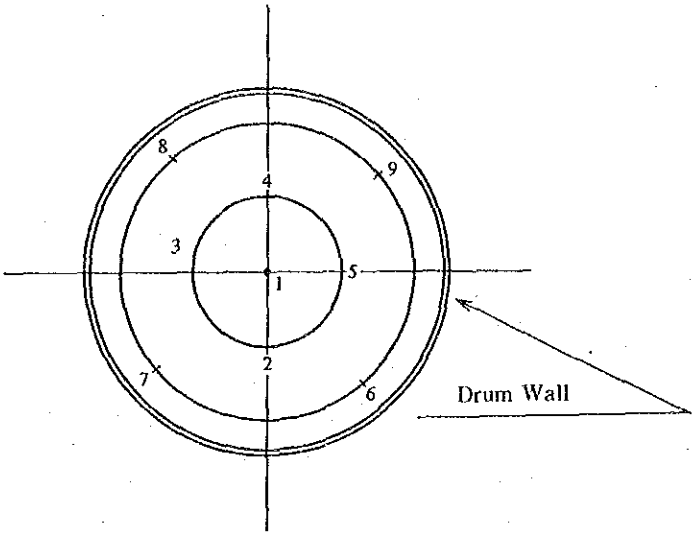
It is desirable that the discharge temperature will be measured and managed in the proper range.

(2) Powder extrusion

The powder extrusion method in which the compound manufacturing process is omitted is now being employed for the extrusion of PVC.

The merit of this method is featured by the achievement of sharp energy conservation and cost reduction through the omission of the compound manufacturing process. In addition, as the physical property changes of resin due to thermal hysteresis are few, it is possible to obtain uniformly extruded products.

On the other hand, however, it is necessary to change the design of screws such as C/R and others because sufficient mixing by extruder is required due to its small thermal hysteresis. Moreover, as the surface area of the material used is large, the material is liable



Measuring point		1	2	3	4	5	6	7	8	9
A	Compound temperature 6 hrs. after discharge	83	81	82	79	76	44	51	51	42
B	Compound temperature right after discharge	58	58	58	56	58	57	53	54	57

Figure 5–7–14 Heat Generation of Powder Compounds in Storage

Table 5–7–10 Temperature of Powder Compound under Discharge

Cooling mixer	Discharging temperature (°C)		
TM 001	63	50	53
TM 002	50	48	51

to absorb moisture. Therefore, the storing of the material for a long time has some problems.

Therefore, the application of the powder extrusion method should be made in consideration of the merits and demerits mentioned above.

5.7.3.4 Power Receiving and Distributing and Electrical Facilities

(1) Outline of electric power receiving facilities and load facilities

Electricity is received by a private transformer (500 kVA) at a low voltage of 380V from an aerial line of 13.2kV. A supply watt-hour meter and a reactive volt-ampere-hour meter are installed at the electricity receiving point.

The electric power receiving contract is concluded for 280 kW (peak demand 168 kW).

On the day when the measurement was performed, the electric power consumption was 145 kW, the power-factor was about 90%, and the load factor (average electric power/

maximum electric power) was 83.6%. All these values were good.

(2) Measurement

The following measurements were performed by use of watt-power factor meter (PFM-1000, PFMA-5210 and PFM-1000 P), AC clip-on power meter, 12-point recorder, frequency meter and lux meter.

1) Load condition of the factory

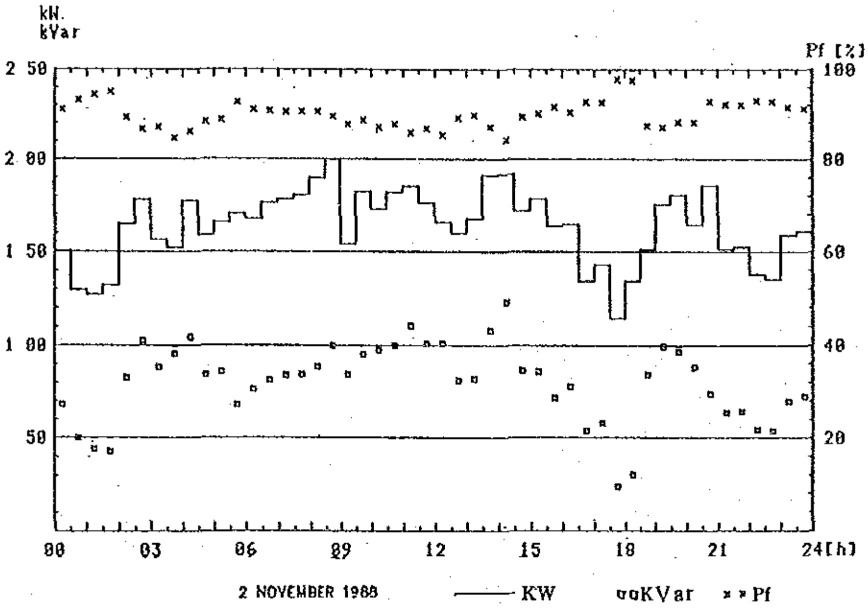


Figure 5–7–15 Total of Factory

2) Load condition of compound crusher branch

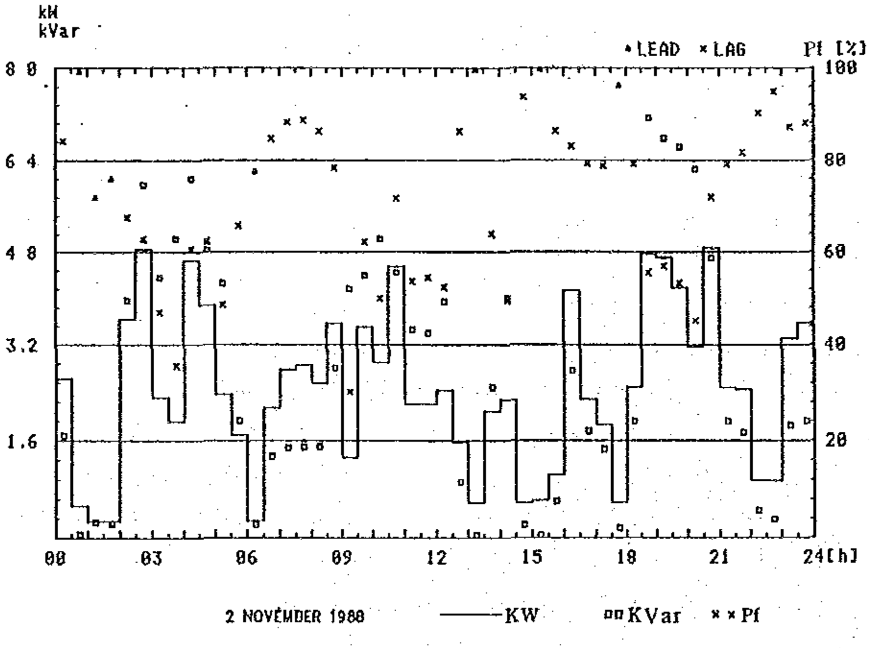


Figure 5–7–16 Compound Line

3) Illuminance in the factory

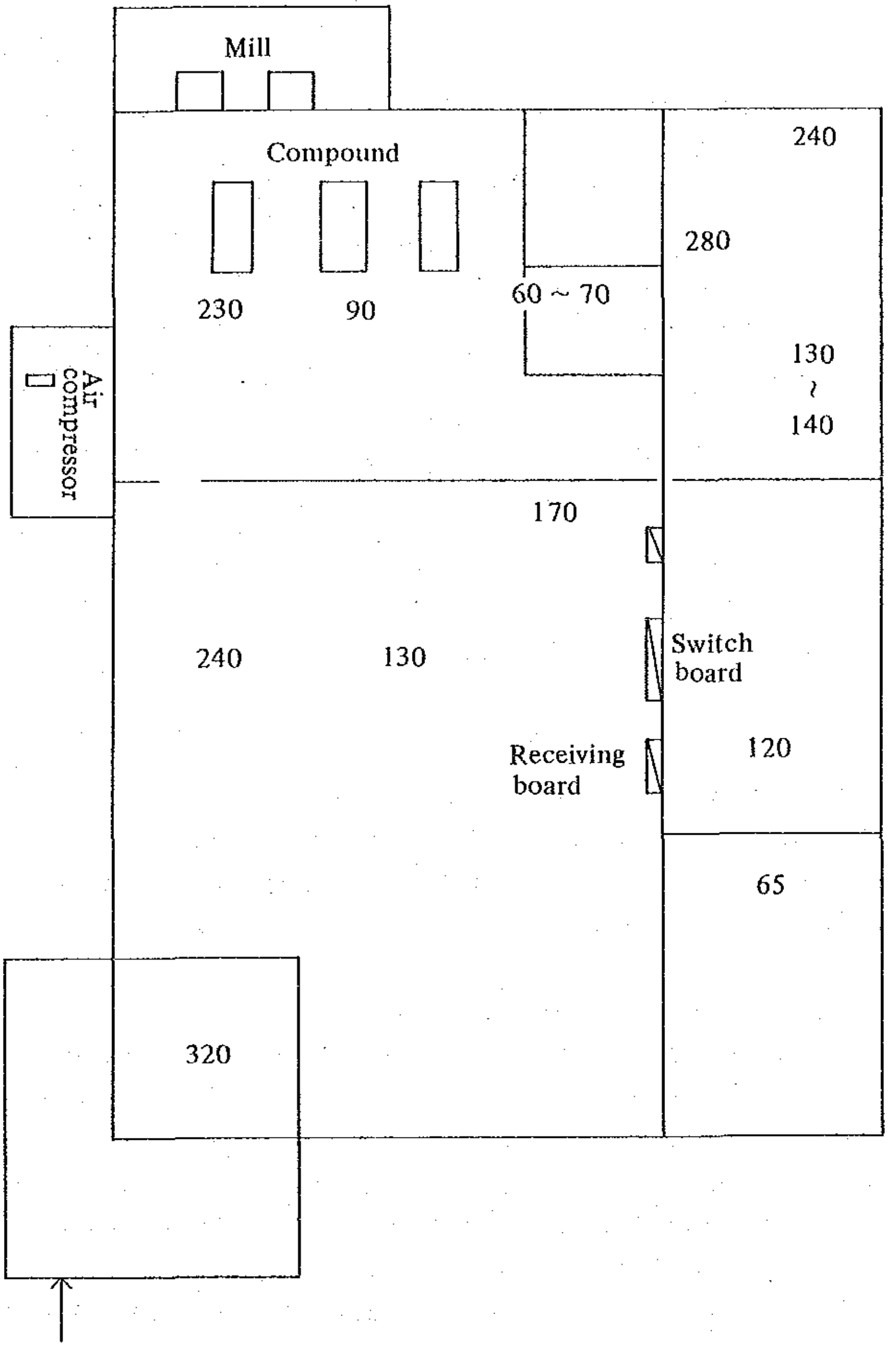


Figure 5-7-17 Illuminance in the Factory

4) Load condition of main motors

Table 5–7–11 Load Condition of Motors

Machine	Rating		Actual				Remark
	CV	kW (A)	kW (B)	Cos φ	Load (B)/(A) x 100	Voltage	
Turbo mixer	100	73.6	45	% 82	% 61	V 352	
Turbo mixer (no-load)	100	73.6	10	24	41	350	
Turbo mixer	50	36.8	15	85	41	350	
Turbo mixer (no-load)	50	36.8	3.3			362	
Extruder (024)	26	19.1	19.5	87	100	352	Motor 8 ~ 10 kW
Extruder (no-load)			8	82	V		(by recorder)
Extruder 008 (DC)		23.3	11.5	89	49	355	Motor 5 ~ 7 kW
Extruder (no-load)			6	85	26		(by recorder)
Compound (031)	100	73.6	27.8	91	36.8	362	Motor 22 kW (by recorder)
Compressor		10	10	77	100	395	
Compressor (un-load)			9.3	85			
Machine shop			5 ~ 7	20 ~ 40			6H ~ 8H Working

(3) Insufficient preparation of drawings and data

It is necesssary to prepare one line diagram like Figure 5-7-4 so that the outline of the electric system can be grasped easily. The factory has no ledger for listing motors, machinery and their specifications. Such a ledger must be prepared to take measures for trouble and purchase spares.

(4) Large variations of power supply voltage

As shown in Figure 5-7-6, the variations of power supply voltage are large to such a degree that the voltage becomes in some cases lower than the rated voltage (380V) by 40V. As the voltage variations exert an influence on the motor efficiency and rotating speed, it is necessary to install a voltmeter to grasp the condition of the voltage variations.

As one of measures for the voltage variations, it is advisable to install a power factor improving condenser at the switch where the crusher and mixer are connected. (10 kVar and 6 kVar are good for mixers of 100 cv and 60 cv, and 6 kVar is good for crusher of 60 cv)

Another measure is to request the electric power company to change the tap of transformer to the voltage of about 360 – 400V.

(5) Too high compressed air pressure and air leakage at several spots

One of the two air compressors was operated, and the power consumption was 100 kW (at load time). Of the 10-minute operation, the load condition continued only for 2 minutes (25%) probably due to the light load. The control range of outlet air pressure was so wide as 7.5 – 9.5 kg/cm^2, and the value was too high.

On the other hand, the leakage of compressed air was found at 5 spots in the factory

(2 spots in the extruding factory and 5 spots in the machine factory).

Compressed air was used not only for extrusion but also for the processing and testing of products and machining. The required pressure is said to be 5 kg/cm^2. A thin-vinyl tube (the inner diameter: about 8 mm) of 20m or so in length was used for a part of the piping. Therefore, it is considered necessary to take the following measures.

a) The air pressure should be lowered to such a degree that the operation is not hindered by it. If the outlet air pressure is lowered by about 1.5 kg/cm^2, the power consumption can be saved by about 9%. In this case, the saved power consumption is 1,555 kWh/y if the power used is 3 kW on the average.

b) Air leakage is checked periodically for necessary repair. In a factory where an compressed air is not used at night, a main stop valve must be installed and closed without fail.

(6) The loads of main motors for production equipment are shown in Table 5-7-11.

a) Some motors have a light load, as their capacity is too large. If possible, such motors had better to be replaced with those of adequate capacity.

b) Mixer of 100 cv was sometimes rotating without load. No-load operation must be avoided as far as possible because no-load power reaches 10 kW.

c) Since the crushers of 60 cv and 20 cv are included in the compound machine branch, the power used varies very much. As seen from Figure 5-7-16 and Table 5-7-11, it is found that the maximum power used for crushers is about 30 kW, the operation often stops, and the variations of the branch voltage are large to such an extent that the voltage is sometimes lowered to 340V.

To avoid such unfavorable events, it is desirable that the voltage is stabilized by a condenser after changing the crushers circuit from the compound machine branch to the mixer branch.

d) The illuminance in the factory is as shown in Fugure 5-7-17. Some places were slightly dark, but the factory illumination is considered generally good. However, unnecessary electric lamps were lit up in the machining room. Therefore, it seems better to train the employees to make it a rule to put off lights partially when no workers are found there. As the factory has high ceilings, the use of high-pressure sodium vapor lamps leads to the saving of the power for illumination. The same illumination as mercury lamps can be obtained by highpressure sodium vapor lamps with the power of less than half for mercury lamps.

5.7.3.5 Summary

The following are the effects of the aforementioned improvement that can be estimated quantitatively.

Item		Possible annual amount of saving	%
Improvement of controlling method	Electric power	160,000 kWh	12.9
Lowering of compressed air pressure		1,600	0.1
Total		161,600	13.0

5.8 Results of Survey of Cast Steel Factory

5. Survey of the Use of Energy in Model Factories

5.8 Results of Survey of Cast Steel Factory

5.8.1 Outline of the Factory

(1) Name of the factory: CADAFE S.R.L.

(2) Type of product: Iron and steel (cast steel)

(3) Location of the factory: Aguero 4860 – Villa Dominico (1874)
Prov. Buenos Aires

(4) Summary:

The factory is equipped with electric arc furnaces and induction furnaces and produces 40 to 50 tons of special cast steel and spheroidal graphite cast iron products per month.

The factory was founded 40 years ago, and produced only carbon steel products with electric arc furnaces. However, as a result of study on the induction furnace which was introduced in around 1980, the factory began to produce alloy cast steel and spheroidal graphite cast iron in around 1986. Since then, importance has been transferred to the small-scale production of a variety of special products.

The factory has been authorized by Lloyd, Meehanite Corp. and is supplying its products to domestic big enterprises such as petroleum, iron and steel, tire industries, etc.

Only three factories including this factory produce special iron and steel products, each having a similar production capacity. The total production of cast steel in Argentina in 1987 was 30,000 tons/year, about 4% of which was produced by the factory.

The operational factor of the factory is about 90% as one-shift operation at present.

The factory is equipped with an atomic emission spectroscopy made by Baird Co., the only one in the country.

As one of the energy conservation measures, the factory is equipped with condensers for power factor inprovement.

(5) Number of employees: 98, of which 3 are engineers

(6) Survey period: November 7 to 11, 1988

(7) Survey members

Name	Assignment
Mitsuo Iguchi	Chief
Isamu Taki	Melting with electric furnace, cast steel process
Shoji Nakai	Heat management
Yukio Nozaki	Heat management
Teruo Nakagawa	Heat management
Toshio Sugimoto	Electrical management
INTI members	
Mr. Jorge A. Fiora	Chief
Mr. Marcelo A. Silvosa	Unit operation, process
Mr. Alberto Berset	Heat using equipment
Mr. Anibal A. Monzon	Heat using equipment, mobile unit driving

Mr. Miguel A. Bermejo	Electric power receiving and distributing equipment
Mr. Arturo D. Verghelet	Electric power receiving and distributing equipment
Mrs. Maria L. Gomez	Heat using equipment

(8) Interviewed

Mr. Juan Lo Forte	Factory Manager
Ing. Jose Lopez	Subsecretary Industrial Association of Avellaneda
Ing. Alberto Outeirino	Chief of Engineer
Ing. Olivieri	Production Manager
Mr. N. Cuesta	Maintenance supervisor

(9) Production

Table 5–8–1 **Production**

Year	1983	1984	1985	1986	1987
Molten metal (ton)	1,190	1,473	922	1,360	1,202

(10) Energy consumption

Table 5–8–2 **Energy Consumption**

Year	1983	1984	1985	1986	1987
Natural gas m^3	87,460	106,785	81,867	110,957	101,795
Elect. power MWh	1,295.6	1,549.2	1,003.7	1,590.3	1,234.4
Energy/molten metal					
Natural gas m^3/t	73.5	72.5	88.8	81.6	84.7
Power kWh/t	1,089	1,052	1,089	1,169	1,027

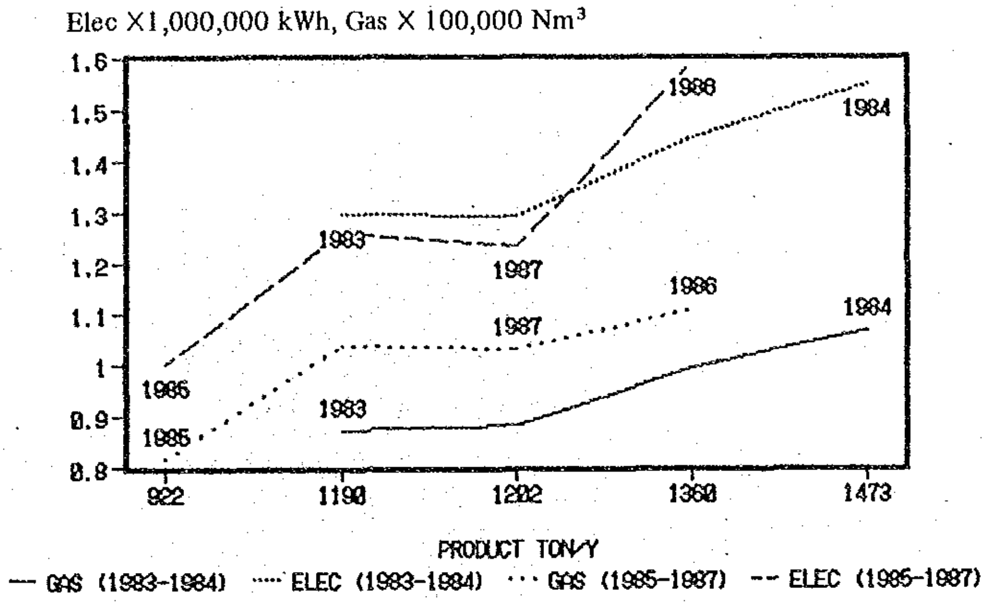


Figure 5–8–1 Production and Energy Consumption

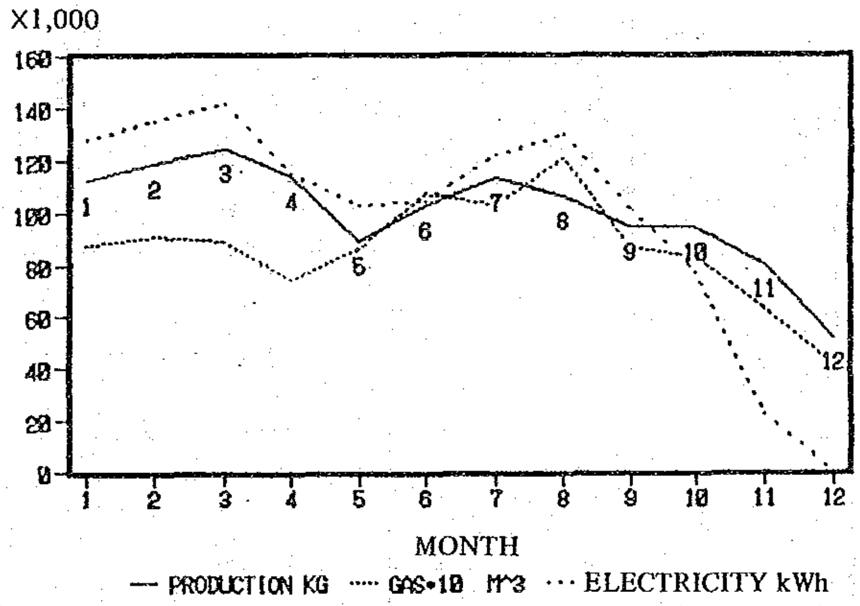


Figure 5–8–2 Monthly Production and Energy Consumption in 1987

Electric power unit price 0.07 U$S/kWh

Natural gas unit price 0.08 U$S/Nm³

(11) Factory layout

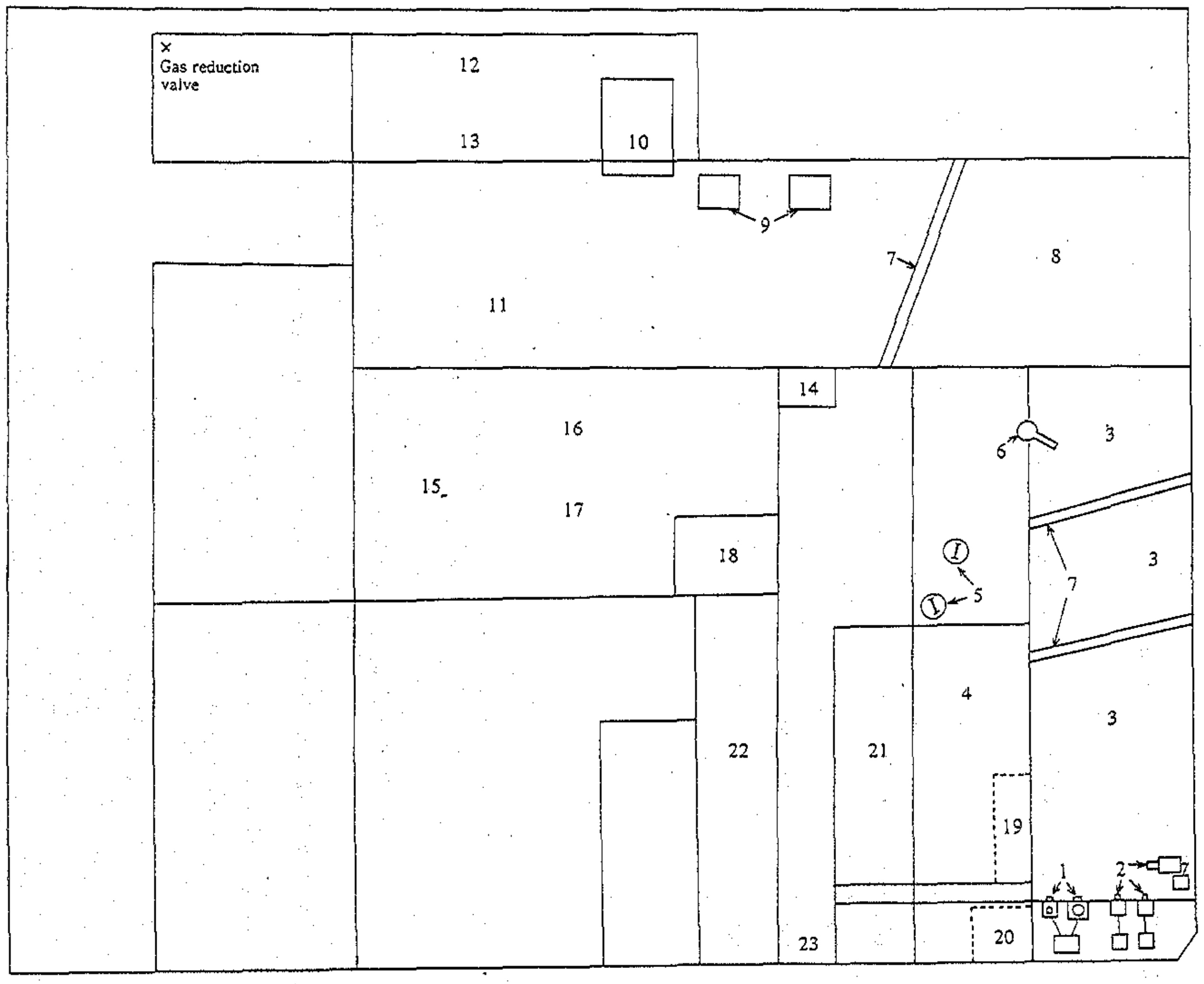


Figure 5–8–3 Factory Layout

Size; 1/500
Factory Layout of CADAFE Foundry

No.	Articles
1	High frequency induction furnaces
2	Girod single phase arc furnaces
3	Moulding shop
4	Core room
5	Sand mill for green sand
6	Sand screw mixer for chemical binder
7	Over head cranes
8	Bur-removing shop
9	Shot blasting machines
10	Annealing furnace
11	Finished products area
12	Shell core room (new installed)
13	Miscellaneous materials store room
14	Compressor room
15	Tools store room
16	Castings stock room
17	Melting materials stock room
18	Quality control room
19	Sand testing room
20	Spectorography equipment
21	Free space for truck
22	Office
23	Main gate

(12) Production process

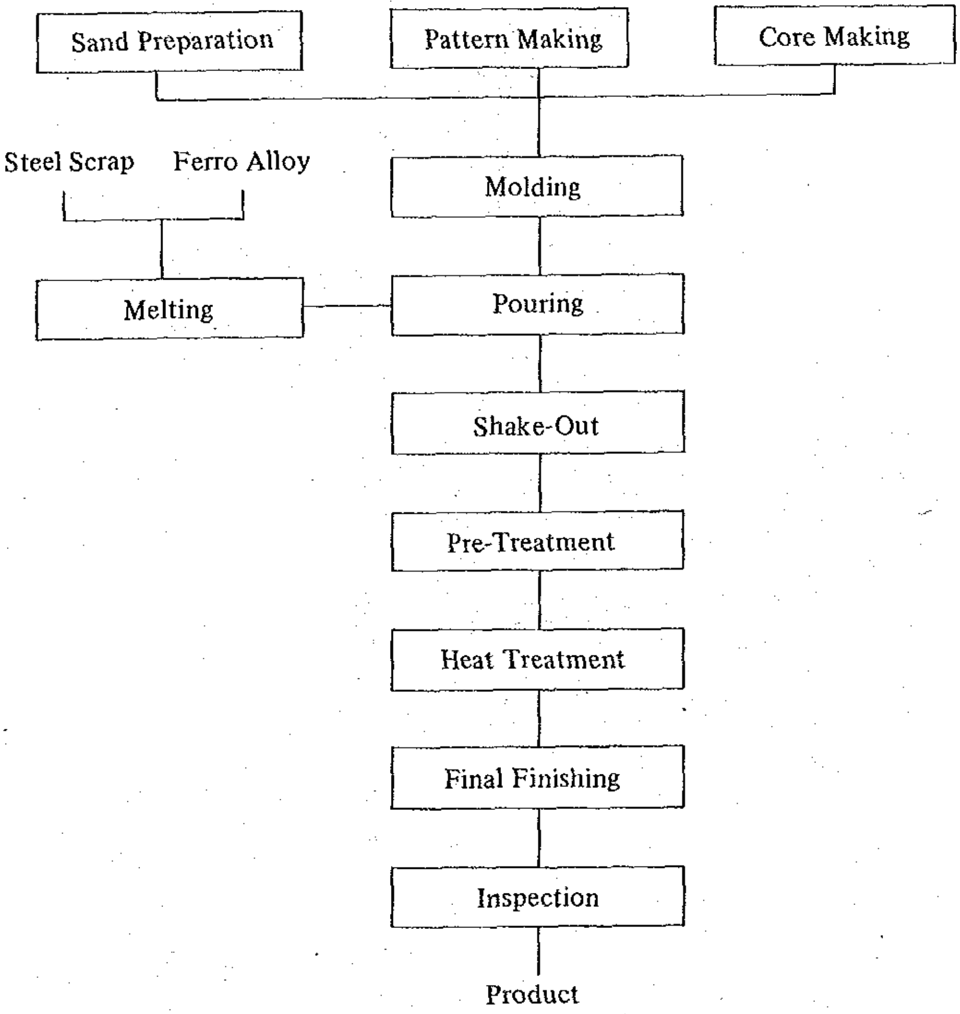


Figure 5–8–4 Production Process

(13) One line diagram

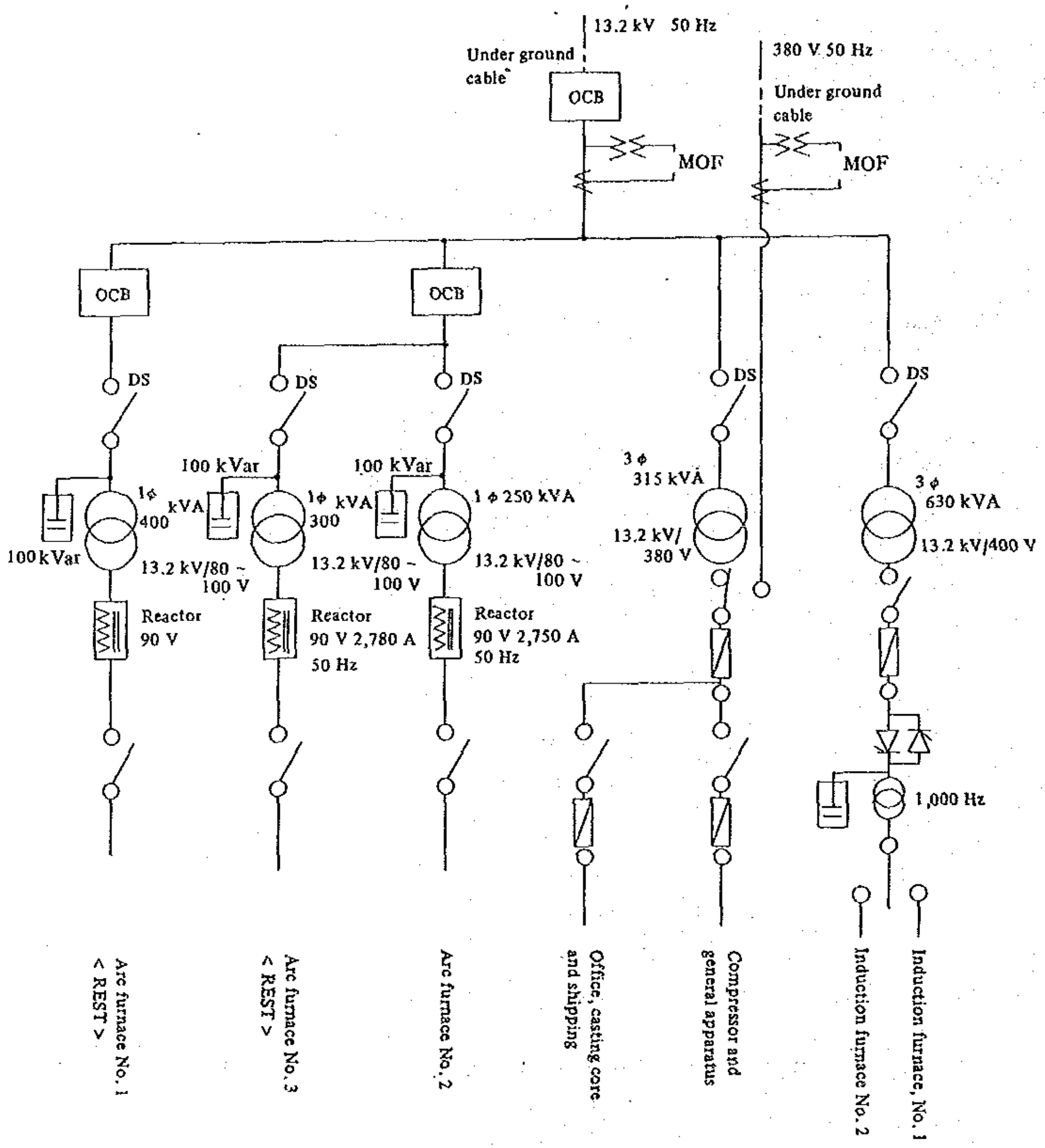


Figure 5–8–5 One Line Diagram

(14) Major equipment

Table 5–8–3 Major Energy Consuming Equipment

Name	Number	Specification
Arc furnace	3	Girod type, single phase 400 kVA 750 kg 250 kVA 250 kg 300 kVA 250 kg
High frequency Induction furnace	2	400 kVA 350 kg 1,000 Hz 400 kVA 800 kg 1,000 Hz
Annealing Furnace	1	shuttle type, 800,000 kcal/h 10 toncharge
Air compressor	4	60 cv (2) 30 cv (1) 52 cv (1)

(15) Factory operating time

9.5 h/d X 250 d/y = 2,375 h/y

5.8.2 Energy Management

(1) Energy conservation target

Although the factory managers take a great interest in energy conservation, the factory does not have a concrete energy conservation target for reducing energy consumption.

In general, casting industry is one of the energy-intensive industries. Above all, cast steel industry ranks one of the top energy-intensive industries because of high temperature melting, indispensability of high temperature annealing for the sake of homogeniing metal structure, etc. The above trend is further intensified in the factory by the fact that importance has been transferred to the small-scale production of variety of special products. As can be seen from Figure 5-8-1, the gas consumption rate for the same level of production has increased since 1985.

The factory has paid nearly U$S 100,000 per year as energy cost, most of which is electricity cost. Energy conservation not only conforms to the policy of the country, but also serves as a useful means of cutting down the production cost. In order to systematically promote energy conservation, it is necessary to determine the target of energy conservation or energy consumption per each process and each type of steel, instructing all the factory employees concerned to make efforts for realizing the target.

(2) Determining energy consumption

To improve the productivity and product quality as well as energy consumption, it is essential to grasp the actual circumstances of the factory as correctly as possible by collecting and processing the data on these factors and operational conditions and completing the statistical data to be used for comparative investigation. If variations from data values are found, or if deviations occur from the planned values or design values, clues to improvement may be found by immediately tracking down the cause and taking necessary steps.

The factory keeps a daily record of electric power consumption in the whole factory. However, in order to examine the cause of a variation, if any, and take an appropriate step, it is necessary to record electric power consumption, type of steel, molten quantity, melt temperature and operating time per each batch with respect to electric arc furnaces and induction furnaces which occupy the most part of electric power consumption. The fuel gas consumption is grasped only once a month with slip sheet, and the daily or monthly consumption is not examined. Under such circumstances, if an abnormality is found in energy consumption, it is too late to determine the cause and take an appropriate remedial step for it. If a daily report on the actual energy consumption is kept and given to the operators, energy conservation can be made by the operators automatically.

(3) Engineer education and employee training

Even though the employees want to make improvements, they won't be able to do so unless they know how. It is therefore important to educate the employees. Fortunately, the factory is in an advanced state in this respect.

The Soceity of Casting Engineers in which the engineers of the factory participate as the directors is extending positive actions such as publication of engineering journals and holding lectures and educational visits, greatly contributing to the upgrade of the engineers. Further, the information exchange among the three enterprises with similar activities has been made since one year before.

Only daily instruction and guidance of foremen are made for the employees in the factory except for special technicians who are trained for welding and testing. However, endeavor is concentrated on the simplification and standardization of casting jobs, which will help the upgrade of the employees.

(4) Equipment management

Insufficient maintenance was noted for the equipment other than those such as electric furnaces that are periodically repaired. The electric arc furnace was causing gas leakage at the door brick owing to insufficient maintenance. The compressed air leakage and the trouble of the air control device of the annealing furnace must be repaired as soon as possible. Arrangement of design calculation data, drawings, renovation records and electric one line diagrams for major equipment is necessary for formulating the future improvement plan and for taking a promt action in case of accident.

5.8.3 Problems with Use of Energy and Remedical Measures

5.8.3.1 Electric-Arc Furnace

(1) Heat balance

(a) Range of heat balance calculation

Heat balance calculation is made for the equipment ranging from the transformer to the furnace body. As all the electric-arc furnaces are acid furnaces that are not used for smelting such as desulphurization and dephosphorization, the factors relating to the heat balance are as follows.

Heat input

Making electric power

Heat of electrode oxidation

Heat of oxidation of iron and other elements contained

Heat of slag formation

Heat output

Heat retained by molten steel

Heat retained by slag

Heat of limestone decomposition

Heat of resistance loss of secondary circuit and electrode

Transformer loss

Water cooling loss

Heat released from furnace surface and openings

Others

The object of heat balance calculation is Arc Furnace No. 2

(b) Results of measurement

Table 5-8-4 shows the operation records of the arc furnace. Figure 5-8-6 and Figure 5-8-7 show the temperature distribution in the outer walls of the arc-furnace body and the sectional view, respectively, during the above operation period. On November 9, 1988, six batches of steel grade 0022 (carbon steel) each with a charged weight of 300 kg were molten during 10.5 hours. Of the 6 batches, 3 batches in Table 5-8-4 was the ones whose electric power consumption could be measured.

In spite of the small difference in tapping temperature shown in Table 5-8-4, the period of time and electric power consumption rquired for melting the same quantity of steel vary widely. The batch which required the maximum amount of electric power was the batch No. 3 operated in the minimum operating time causing a big difference as compared with the other two.

Table 5–8–4 Operation Data in Arc Furnace No. 2

9 Nov. 1988

	No. of melting	1	2	3	Average
a	Steel grade	0022	0022	0022	
b	Charged weight (kg)	300	300	300	300
c	Power on (o'clock: m)	5;00	7;10	9;15	
d	Power off (o'clock: m)	7;00	9;00	10;40	
e	Operation hours (hr: m)	2;00	1;50	1;25	1;45
f	Power consumption (kWh)	310	250	370	310
g	P C/charge ton (kWh/t)	1,033	833	1,233	1,033
h	Tap temperature (°C)	1,670	1,650	1,650	1,657
j	Additional materials				
	Fe-Si (kg)	1.8	1.8	1.8	1.8
	Fe-Mn (kg)	3.5	3.5	3.5	3.5
	Aluminum (kg)	0.3	0.3	0.3	0.3
	Lime (kg)	0.2	0.1	0.1	0.13
	Sand (kg)	2.0	2.0	2.0	2.0
k	Slag (kg)	25	25	25	25

Chemical analysis are not checked

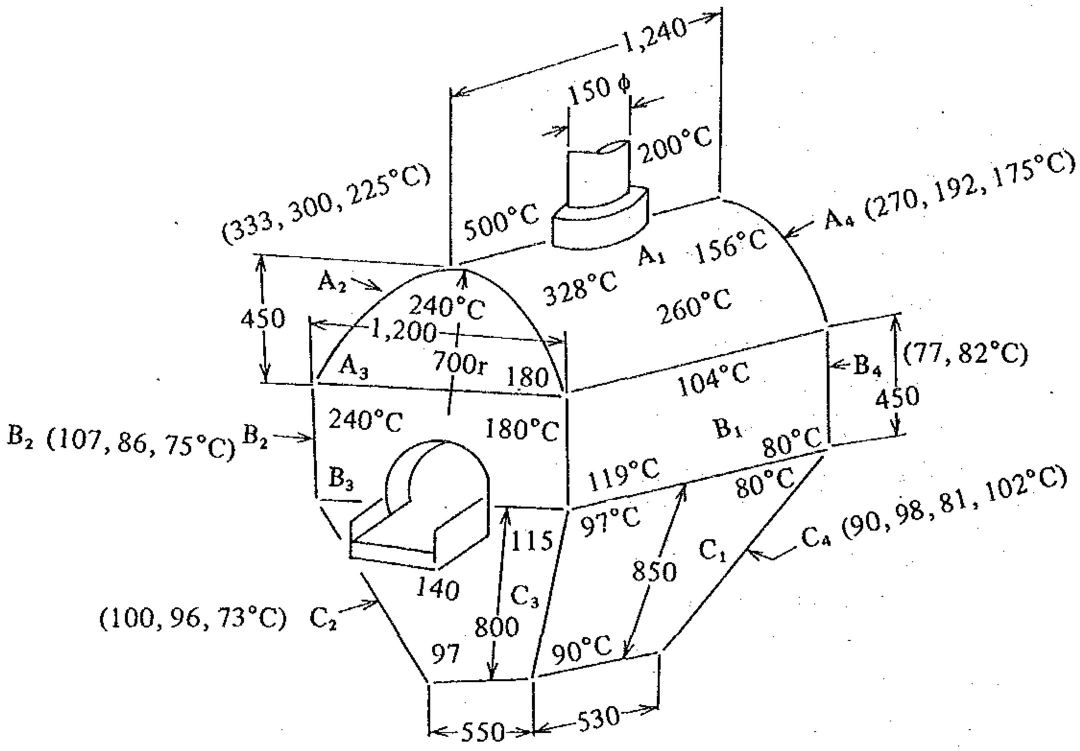


Figure 5–8–6 Surface Temperature of No. 2 Arc Furnace
Note: Surface temperature of Arc furnace are checked by Radiation pyrometer.

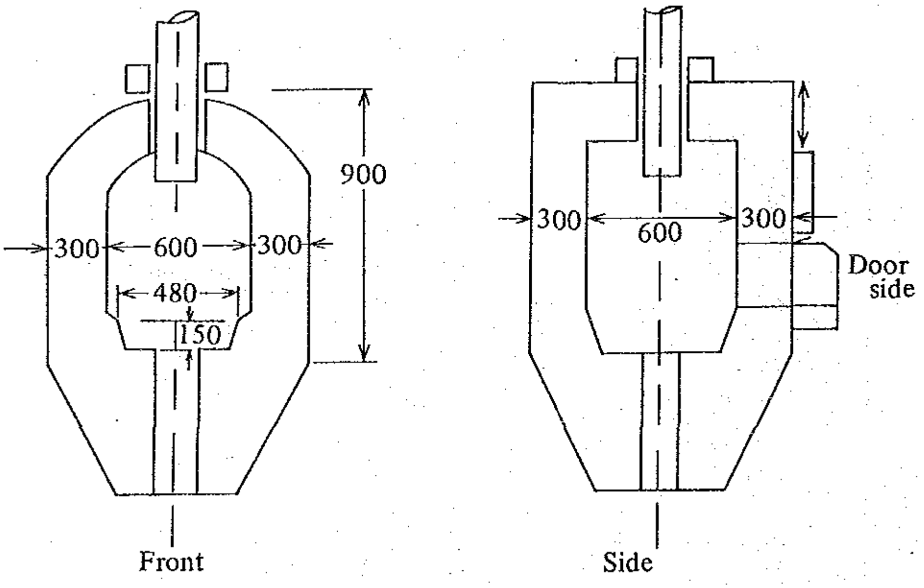


Figure 5–8–7 Front and Side View of No. 2 Arc Furnace

The difference might be due to some abnormality in the operation of the batch, but in the heat balance calculation, the average of the three batches was used. The electric power consumption was in the range of 833 to 1,233 kWh/t per ton of charge which was in the higher level.

(c) Heat balance calculation

The heat balance per ton of steel output is calculated. The ratio of steel output to charged quantity is taken as 0.95.

Heat input

c-1) Heat quantity of input electric power

Electric power = 1,033 x 860 ÷ 0.95 = 935,140 kcal/t of steel output .... (1)

c-2) Heat of electrode oxidation

The data on the consumption of electrode oxidation was not available, and the heat was calculated from the following regression equation which was based on the actual results in Japan:

$y = 0.0058 \times x + 1.55 = 7.54$ kg/t of charge

where, y = Electrode consumption, kg/t

x = Electric power consumption, kWh/t

Heat of electrode oxidation = 7.54 x 8,080 x 0.99 ÷ 0.95

= 63,490 kcal/t of steel output. .... (2)

where, 0.99: Electrode purity

c-3) Heat of oxidation of C, Si, Mn and Fe

c-3-1) Heat of oxidation of Carbon

Because it is an acid furnace, the oxidation of C, Si, Mn, Fe, etc. is slight in principle, but this was taken into account in calculating heat input since the charge inlet is always kept open during operating the furnace. The calculation was made on the basis of the assumption that carbon content decreased from 0.2 ~ 0.3% to 0.15 ~ 0.25% by 0.05% during operation.

Heat of carbon oxidation = 0.05/100 x 8,080 x 1,000 ÷ 0.95

= 4,250 kcal/t of steel output .... (3)

c-3-2) Heat of Si oxidation

Assuming the charged quantity of FeSi as 1.8 kg including Si of 75%, Si charged quantity of 1.35 kg is obtained, that is, 4.74 kg/t of molten steel (1.35 kg ÷ 0.300 ÷ 0.95 ≒ 4.7 kg/t).

Heat of Si xoidation = 4.74 X 7,460

= 35,360 kcal/t of steel output .... (4)

c-3-3) Heat of Mn oxidation

Assuming the charged quantity of FeMn as 3.5 kg including Mn of 75%, Mn charged quantiy of 2.625 kg is obtained, that is, 9.2 kg/t of molten steel 2,625 ÷ 0.3 ÷ 0.95 = 9.2 kg/t

Heat of Mn oxidation = 9.2 kg/t X 1,680

= 15,460 kcal/t of steel output .... (5)

c-3-4) Heat of Fe oxidation

Assuming FeO in slag as 25%

Heat of Ferrum oxidation =

$$25/0.3 \times \left[\frac{FeO}{100} \times \frac{55.8}{55.8 + 16} \times 1{,}150 \right] \div 0.95$$

= 19,600 kcal/t of steel output .... (6)

where 1,150 kcal/t: Heat of Fe oxidation at FeO formation.

Total heat of oxidation = 4,250 + 35,360 + 15,460 + 19,600

= 74,670 kcal/t of steel output .... (3) ~ (6)

c-4) Heat of slag formation

Heat of reaction for SiO_2 and CaO is calculated by the following equation:

$SiO_2 + 2CaO = Ca_2SiO_4 = 492$ kcal/kg.SiO_2

Assuming SiO_2 in slag as 35%, heat of slag formation is

$$25/0.3 \times 492 \times \frac{35}{100} \div 0.95$$

= 15,100 kcal/t of steel output .... (7)

Total heat input = (1) ~ (7)

= 935,140 + 63,490 + 4,250 + 35,360 + 15,460

+ 19,600 + 15,100 = 1,088,400 kcal/t of steel output

Heat output

c-5) Heat retained by molten steel

= 1,000 x 343 = 343,000 kcal/t of steel output .... (1)

c-6) Heat retained by slag

= Slag quantity (kg/t) x Specific heat x (1,550°C – 20°C) ÷ 0.95

= 25/0.3 x 0.28 x 1,530 ÷ 0.95

= 37,580 kcal/t of steel output .... (2)

c-7) Heat of limestone decomposition

= Quantity of limestone used per ton of molten steel (kg/t)

$\times \frac{(CaO)}{100} \times$ Heat of $CaCO_3$ decomposition ÷ 0.95

$= 0.13/0.3 \times \frac{56}{100} \times 760 \div 0.95 \fallingdotseq 190$ kcal/t of steel output ... (3)

c-8) Heat of resistance loss of secondary circuit and electrode

Resistance loss = combined resistance of secondary conductor
with electrode (Ω) x [average current (A)]^2 x
current flow hour (h) x 10^{-3} x 860 ÷ steel output

c-8-1) Resistance of secondary conductor $= 1.72 \times 10^{-6}\ \Omega \cdot \mathrm{cm}\ (20^\circ\mathrm{C})$

Temperature coefficient of resistance $= 0.0039$

Conductor dimensions (mm) 100 mm x 10 mm x 6,000 mm (2 pcs.)

Temperature 60°C

Resistance of secondary conductor at 20°C

$$= 1.72 \times 10^{-6} \times 600 \times \frac{1}{10 \times 1} = 103.2 \times 10^{-6}\ \Omega$$

Resistance of secondary conductor at 60°C

$$= 103.2 \times 10^{-6} \times [1 + 0.0039 \times (60 - 20)] = 119 \times 10^{-6}\ \Omega$$

Total resistance of bus bars including 2 pcs. each for positive and negative one $= 119 \times 10^{-6} \times 2 \times 1/2 = 119 \times 10^{-6}\ \Omega$ .... ⓐ

c-8-2) Resistance of electrode $7 \times 10^{-6}\ \Omega\mathrm{m}\ (1000^\circ\mathrm{C})$

Dimensions of exposed electrode 150ϕmm x 800 mm x 1 pce.

Resistance of electrode $= 7 \times 10^{-6} \times 0.8 \times \dfrac{1}{0.15^2 \times \pi/4} = 317 \times 10^{-6}\ \Omega$. ⓑ

Combined resistance $=$ ⓐ $+$ ⓑ

$$= 119 \times 10^{-6} + 317 \times 10^{-6} = 436 \times 10^{-6}\ \Omega$$

Average current during arc-furnace operation

$$= 177 \div 90 \times 10^3 = 1.97 \times 10^3\ \mathrm{A}$$

Resistance loss $= 436 \times 10^{-6} \times (1.97 \times 10^3)^2 \times \dfrac{315}{60} \times 10^{-3} \times 860 \div 0.9 \div 0.95$

= 8,940 kcal/t of steel output .... (4)

c-9) Heat of resistance loss of transformer and reactor

Assuming the reactor loss is same as the transformer loss, and setting iron loss of 250 kVA transformer and copper loss at rated output as 1 kW and 2.5 kW, respectively,

the heat loss of transformer and reactor

$$= [1 + 2.5 \times (\frac{177}{250})^2] \times 2 \times \frac{315}{60} \times 860 \div 0.9 \div 0.95$$

= 23,800 kcal/t of steel output .... (5)

c-10) Heat taken away by cooling water

$14.4 \times 315 \div 0.9 \div 0.95 = 5{,}303$ kg/t of steel output .... (6)

Heat loss due to cooling water = cooling water rate per ton of molten steel (kg/t) x 1 (kcal/kg· °C) x [outlet temp. – inlet temp. of cooling water (°C)] kcal/t $= 5{,}305 \times 1 \times (72 - 22)$

= 265,250 kcal/t of steel output

c-11) Heat released from furnace outer walls

The heat released is calculated from the surface temperature as shown in Figure 5-8-6.

Furnace outer wall heat loss $18{,}565 \times \dfrac{315}{60} \div 0.9 \div 0.95$

= 114,000 kcal/t of steel output .... (7)

c-12) Released heat loss from furnace opening

Area of opening: 350 mm x 220 mm = 0.077 m^2

In-furnace temp.: 1,500°C

Emissivity: 1

Correction factor due to the shape of opening and wall thickness: 0.5

$$\text{Radiation heat loss} = 4.88 \times 1 \times \left[\left(\frac{1{,}500 + 273}{100} \right)^4 - \left(\frac{20 + 273}{100} \right)^4 \right] \times 0.5$$

$$\times 0.077 \times \frac{315}{60} \div 0.9 \div 0.95$$

$$= 113{,}920 \text{ kcal/t of steel output} \quad \dots\dots\dots\dots\dots\dots \quad (8)$$

c-13) Hot gas blowoff from opening

In case of arc-furnace door being open, the difference in specific gravity between the hot gas in the furnace and the air outside the furnace causes hot gas blowoff and cold air suction, the quantity of which is given by the following equation.

$$Q = \frac{2}{3} W \sqrt{\frac{2g}{r_0}(r_0 - r_1)\, Hm^3}$$

where,

Q :	Suction air rate	m^3/s
W :	Width of opening	0.35 m
g :	Gravitational acceleration	9.8 m/s^2
r_0 :	Specific gravity of air outside furnace	kg/m^3
r_1 :	Specific gravity of gas in furnace	kg/m^3
Hm :	Boundary height of suction and exhaust	m
R_0 :	Gas constant of air	29.2 kgfm/(kg°C)
P_0 :	Pressure	10,330 kgf/m^2
t_1 :	Gas temp. in furnace	°C
t_0 :	Air temp. outside furnace	°C
H :	Height of opening	0.22 m

$$r_1 = \frac{P_0}{R_0\,(t_1 + 273)} \qquad r_0 = \frac{P_0}{R_0\,(t_0 + 273)}$$

$$Hm = \frac{H}{1 + \left(\frac{t_1 + 273}{t_0 + 273} \right)^{1/3}}$$

Setting t_1 = 1,000°C and t_0 = 20°C, the following values are obtained:

r_1 = 0.28 kg/m^3

r_0 = 1.21 kg/m^3

Hm = 0.0836 m

Q = 0.0219 m^3/s = 0.0265 kg/s

The heat quantity taken away by the hot blowoff gas from furnace opening is calculated as follows using a specific heat of 0.22 kcal/kg.

$0.0265 \times 3{,}600 \times 0.22 \times (1{,}000 - 20) = 20{,}570$ kcal/h

$$\text{Hot gas loss} = 20{,}570 \times \frac{315}{60} \div 0.9 \div 0.95$$
$$= 126{,}310 \text{ kcal/t of steel output} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

d) Heat balance table and its evaluation

The heat balance for the Arc furnace No. 2 is shown in Table 5-8-5, from which the thermal efficiency is calculated as follows.

$$\text{Thermal efficiency} = \frac{\text{effective heat}}{\text{heat input}} = \frac{(6)+(7)+(8)}{(5)} = \frac{343.0+37.6+0.2}{1{,}088.4} = 35.0\%$$

Table 5–8–5 Heat Balance of Arc Furnace

Heat input		Mcal/t	%
1)	Heat of electric power	935.1	85.9
2)	Oxidation heat of electrode	63.5	5.8
3)	Oxidation heat of C, Si, Mn & Fe	74.7	6.9
4)	Slag formation heat	15.1	1.4
5)	Total	1,088.4	100.0
Heat output			
6)	Heat of molten steel	343.0	31.5
7)	Heat of slag	37.6	3.5
8)	Decomposition heat of lime stone	0.2	0.0
9)	Heat loss of secondary circuit and electrode	8.9	0.8
10)	Transformer loss	23.8	2.2
11)	Heat loss by cooling water	265.3	24.4
12)	Radiation heat loss from wall surface	114.0	10.5
13)	Radiation heat loss from opened charging hole	113.9	10.5
14)	Convection heat loss from opened charging hole	126.3	11.6
15)	Others	55.4	5.1
16)	Total	1,088.4	100.0

The thermal efficiency of basic arc furnace is usually about 70% for large-scale furnace and 50% or higher for small-scale furnace. As compared with the above, the thermal efficiency of the present furnace is quite low. In Table 5-8-5 it is noted that the cooling water heat loss is 24% and the radiation and convection heat loss ratio from opened charging hole is about 22%. In addition, "15) others" whos also high percentage, in which the heat used for warming the initial furnace body is included. In order to reduce these losses, it is necessary to thoroughly investigate the records of melting work for improvement from the viewpoint of energy conservation.

With regard to the electric power consumption for basic arc furnace in Japan, the following regression equation has been formulated for carbon steel from statistical data:

$$\text{Electric power consumption} = \frac{399}{0.88 \times C + 2.44} + 574 \ \text{kWh/t of charge}$$

where, C : Furnace capacity (t)

Therefore, in case of 300 kg furnace

$$\text{Electric power consumption} = \frac{399}{0.88 \times 0.3 + 2.44} + 574$$

$$\doteqdot 721.6 \ \text{kWh/t of charge}$$

In the present investigation, despite the acid furnace requiring less operating hour, the power consumption is 933 to 1,233 kWh per ton of charge with an average of 1,033 kWh/t, which is much higher than the standard value of 721.6 kWh/t of charge in Japan.

As the countermeasure, "Heat output 10) through 15)" in Table 5-8-5 must be reduced. Its details will be explained below.

(2) Charged raw material

The raw materials used at present include pig iron, recovered scrap, machined scrap, etc. Limestone and silica sand are used as slag formation agent.

The machined scrap is unsuitable for melting because a considerable amount of machine oil is attached to it. The silica sand contains moisture. Machine oil and moisture which cause hydrogen-gas defect to castings need to be completely removed prior to application.

Since the arc furnace is an acid furnace lined inside with silica (SiO_2), the reaction by basic slag for dephosphorization or desulphurization cannot be expected. In addition, as vigorous boil smelting by oxgen is difficult, the removal of contained hydrogen and impurities cannot be expected. Hence, strict selection of the material to be charged to the furnace is the only way of obtaining a quality product.

Pig iron as a major raw material should be subjected to shot blasting prior to use when contaminated with rust. If care is given to the above points in operation, the yield and energy consumption will be improved.

(3) Reducing heat loss from opened door

As described above, since the released heat loss from opened charging hole in Arc furnace No. 2 during operation is so large as about 22% as shown in Table 5-8-5, it is most effective for improvement to reduce the loss.

Furnace operation with the cover kept open lowers in-furnace atmosphere temperature, and delays rise in molten metal temperature. This accelerates the oxidation of Si, Mn, Fe, etc., causing inferior products due to the mixing of these oxides in the cast steel products.

The door and the surrounding of the opening should be repaired to completely close the door and prevent the gas leakage. It is also necessary, as the case may be, to renovate the surrounding of charging the opening into water-cooled construction to prevent deformation.

The material was charged in the furnace little by little with the door kept open.

It is imperative to charge raw material in larger lot as far as possible to decrease the number of times of opening the door and to shorten the door opening hours by rapid operation.

(4) Improvement of other operation method

The furnace body which is always inclined to the rear during operation, makes it difficult to keep the depth of melt bath and melt temperature uniform and to separate by flotation the slag and non-metallic inclusion in steel bath, accelerating the convection of infurnace atmosphere with outside air. The furnace should be kept horizontal as are as possible.

The high position of the material charge opening requires physical strength for workers. Lowering the height by about 300 to 500 mm facilitates material charging, intermediate check for temperature and slag in the furnace, leading to shortened operating time.

(5) Expected effect of improvement

The above-mentioned countermeasures will shorten the furnace operating time, and greatly lower power consumption. It is recommended that the above description be summarized in an operating manual as operational standard for education and training for the employees and for stabilizing operation procedures. Also, the melting time and power consumption should be recorded and analyzed for confirmation of the effect of the improvement.

As a result of these improvements, the power consumption of about 700 kWh per ton of charge, and the energy conservation of 25% are expected.

According to the energy flow charge of the company, 60% of the tatal consumption is occupied by melting, 54% of which is occupied by arc furnaces. Since about 32% of the total electric power is consumed by arc furnaces and it is possible to save the power by about 8.1%, its effect on economical efficiency is very large.

5.8.3.2 High Frequency Induction Furnace

(1) Heat balance

a) Range of heat balance calculation

The range of heat balance calculation for high frequency furnaces is from the transformer to the furnace body.

Use of the slag forming agent is neglected because of its small percentage less than 1.5% of molten steel and the small values of slag formation heat and limestone decomposition heat.

b) Result of measurement

Table 5-8-6 and Figure 5-8-8 show the operation records of high frequency induction furnace No. 1 and the temperature distribution in the outer walls of the furnace body, respectively.

Table 5–8–6 Operation Data in High Frequency Induction Furnace No. 1

9 Nov. 1988

	No. of melting	1	2	3	4	Total/Average
a	Iron and steel grade	13MnSc	13MnSc	SAE0036	E-4	
b	Charged weight (kg)	300	300	295	272	1,167
	Pig iron (kg)	–	–	–	–	
	Ductile scrap (kg)	–	–	SAE 45	22	67
	Steel scrap (kg)	Mn 300	Mn 300	250	250	1,100
c	Power on time (o'clock)	6:35	7:45	8:50	9:50	
d	Power off time (o'clock)	7:40	8:45	9:40	10:50	
e	Powered time (hr m)	1:05	1:00	0:50	1:00	3:55
f	Power meter reading					
	initial (a) (kWh)	547.2	548.4	549.7	551.0	
	final (b) (kWh)	548.4	549.7	551.0	552.4	
g	Power consumption (kWh) (b-a) x 200	240	260	260	280	1,040
h	P C/charged ton (kwh/t)	800	867	881	1,029	891
i	Tap temperature (°C)	1,500	1,480	1,635	1,680	1,574
j	Additional materials					
	Fe-Si (kg)	0.5	0.5	0.5	1.0	2.5
	Fe-Mn (kg)	5.0	5.0	4.0	5.0	19.0
	Fe-Cr (kg)	–	–	–	10.0	10.0
	Fe-Mo (kg)	–	–	–	3.0	3.0
	Aluminum (kg)	0.3	0.2	0.3	0.2	1.0
	Carburizer (kg)	–	–	0.3	0.6	0.9

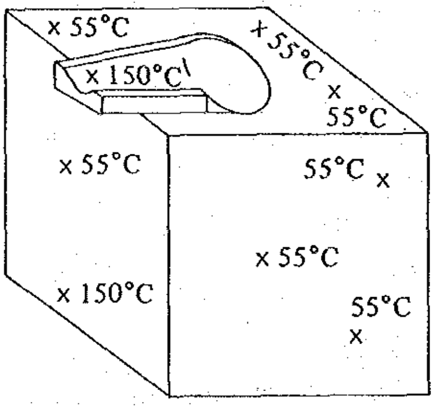


Figure 5–8–8 Surface Temperature of No. 1 High Freq. Induction Furnace

Note: Surface temperature of furnace are checked by radiation pyrometer.

c) Heat balance calculation

The heat balance per ton of steel output is calculated . The yield of steel output to charged quantity is taken as 100%.

Heat input

c-1) Heat quantity of making electric power

Electric power consumption = 1,040 ÷ 1,167 = 891.1 kWh/t

Heat input to molten steel = 891.1 x 860

= 766,350 kcal/t of steel output

Heat output

c-2) Heat retained by molten steel = 327 x 1000

= 327,000 kcal/t of steel output

c-3) Heat loss of secondary circuit

Secondary electric power could not be measured, so it was estimated from other examples.

Average power consumption = 270 kWh/h

Circuit loss = 270 x 0.115 = 30.0 kWh/h

Heat loss of secondary circuit $= 30.0 \times \frac{235}{60} \div 1.167 \times 860$

$\doteq$ 86,590 kcal/t of steel output.

c-4) Heat loss of transformer

Average power consumption	270 kWh/h
Average power factor	90%
Average apparent power	270/0.9 = 300 kVA
Transformer capacity	630 kVA
Iron loss, presumed	1.9 kW
Copper loss during rated operation, presumed	6.9 kW

Heat loss $= [1.9 + 6.9 \times (\frac{300}{630})^2] \times \frac{235}{60} \div 1.167 \times 860$

= 10,000 kcal/t of steel output

c-5) Heat taken away by cooling water

Cooling water flow rate	2.59 m^3/h
Cooling water inlet temp.	37.5 °C
Cooling water outlet temp.	71.3 °C

Heat taken away by cooling water = $2{,}590 \times (71.3 - 37.5) \times \frac{235}{60} \div 1.167$

= 293,810 kcal/t of steel output.

c-6) Heat released from furnace outer walls

Outer side wall 1,450 kcal/h + outer upper wall 440 kcal/h

= 1,890 kcal/h.

Heat released from the surface = $1{,}890 \times \frac{235}{60} \div 1.167$

= 6,340 kcal/t of steel output

c-7) Heat released from furnace opening

Surface temp. (°C)	500 °C	1,000 °C	1,570 °C
Emissivity	0.8	0.8	0.16 (molten steel)

Area of opening (m^2)	0.096	0.096	0.096	D = 350 m/m
Released heat (kcal/h)	1,660	10,630	10,490	

The released heat differs depending on the processes of temperature rising or molten steel retention, but it is taken as the average of the above three conditions.

$$\text{Released heat} = 7{,}590 \times \frac{235}{60} \div 1.167$$

$$= 25{,}470 \text{ kcal/t of steel output}$$

d) Heat balance table and its evaluation

The heat balance for high frequency induction furnace is shown in Table 5-8-7, from which the thermal efficiency is calculated as follows.

$$\text{Thermal efficiency} = \frac{\text{Heat retained by molten steel}}{\text{Total heat input}} = \frac{327.0}{766.4} = 42.7\%$$

Table 5–8–7 Heat Balance of Induction Melter

Heat input	Mcal/t	%
1) Heat of electric power	766.4	100.0
Heat output		
2) Heat of molten steel	327.0	42.7
3) Heat loss of Secondary circuit	86.6	11.3
4) Transformer loss	10.0	1.3
5) Heat loss by cooling water	293.8	38.3
6) Radiation heat loss from wall surface	6.3	0.8
7) Radiation heat loss from open hole	25.5	3.3
8) Others	17.2	2.8
9) Total	766.4	100.0

The above efficiency is low as compared with the usual thermal efficiency of high frequency induction furnace of 60 – 65%.

As seen clearly from the above table, the coil cooling loss, resistance loss of secondary circuit and loss from material charging openings occupy a large percentage.

(2) Raw material dimensions and charging method

The raw materials used at present include recovered sprue and feeder, conventional steel scrap, press ingot, etc. The recovered material generally makes many large voids in furnace because of its large dimensions. The penetration depth of current decreases with the increase in frequency, and is only about 0.08 cm at normal temperature and 1.6 cm at 1,200 °C both for 1,000 Hz. This results in the ineffective utilization of induction current energy.In particular, the press crap now in use is suspended at the furnace opening because of its execessive dimensions.

It is said that the favorable dimensions of charged material are one third or less of the furnace diameter and one sixth or less of the furnace plane area.

The most favorable charged materials are turnings, punchings and steel plate. The sprue and feeder of cast steel should be cut off to the above dimensions prior to charging.

As a method of charging, turnings and punchings should at first be charged on the furnace botton in the depth of 100 to 150 mm, and steel plates and cast-steel scraps are charged thereupon in a longitudinal direction so as to minimize the dead space. On completion of the initial charge, the furnace cover should be placed to wait for melt down. When a steel bath is formed on the hearth, additional steel scraps should be charged to densify the space.

Steel smelting by oxidation and reduction cannot be attained by a high frequency induction furnace alike the acid arc-furnace. Therefore, it is necessary to use the raw material with clear composition and without impurities attached thereto or mixed therein.

If foreign matters such as sand are attached to the charged material, it will increase electrical power loss and accelerate furnace erosion due to the increased slag amount, and therefore foreign matters need to be removed by shot blasting, etc.

(3) Pretreating of ferro-alloy

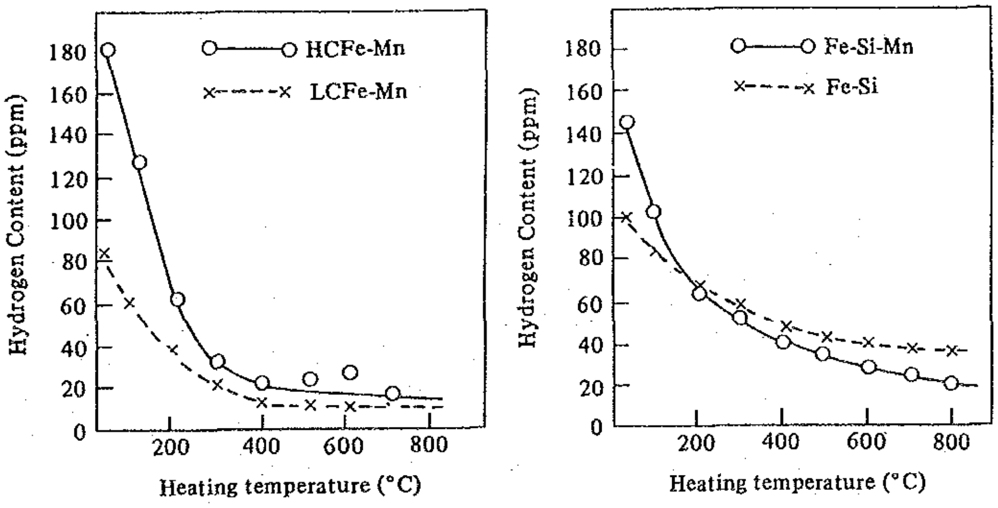
As shown in Table 5-8-8, ferro-alloys usually contain moisture and a considerable amount of hydrogen, which causes blow holes of castings.

Since a large amount of ferro-chromium, ferro-silicon, ferro-manganese, etc. are charged depending on the steel grade, the ferro-alloy should be dried and preheated prior to charging to prevent the increase in hydrogen contained in molten steel. Heating at about 600 °C for 3 hours can decrease hydrogen content to 4 ppm or less.The effect of heating temperature on hydrogen content in ferro-alloys is shown in Figure 5-8-9.

Table 5–8–8 Hydrogen Content in Ferro-Alloy

Ferro-alloy	75% FeSi	LCFeCr	HCFeMn	LCFeMn	SiMn	SiCr	Ni
H (ppm)	9.8 – 17.6	4.3 – 6.0	7.6 – 18.1	8.2	14.4	6.0 – 9.4	0.2
Size (mm)	40 – 60	100 – 150	60 – 100	25 – 40	40 – 60	40 – 60	t = 10

Note; H; Hydrogen LC; Low carbon HC; High carbon t; Thickness



(a) (b)

Figure 5–8–9 Heating Temperature Acted on Hydrogen Contents of Ferro Alloy

(4) Reducing heat loss

As can be seen from Table 5-8-7, a large amount of heat is released from coil cooling and furnace opening.

Intensified coil cooling cools furnace walls but decreases electric power loss of coil, showing an example of the increase in efficiency of 0.8 to 0.9% due to the temperature drop of 10 °C. In general, it is more advantageous to lower the temperature by increasing the cooling water flow rate.

The above relationship depends on the furnace design, but the optimum condition should be found by varying the cooling water flow rate.

Since the heat released from furnace openings is proportionate to the 4th power of absolute temperature, the furnace cover should be placed during melting as far as possible.

The difference in power loss between the conditions with and without a cover depends on the surface state of molten steel, but it is said to be about 300 kW/m^2. The operating time of the furnace seems to be very long. Because of the fixed loss involved, it is effective for electric power conservation to shorten the operating time. Wasteful overheating should be avoided by improving the temperature control for molten steel and work arrangement in addition to shortening melting time by improving the method of charging raw material. In high frequency induction furnaces, overheating of 60 to 90 °C sometimes occurs even in 2 to 3 minutes, resulting in unfavorable increase in power consumption of 10 to 40 kWh/t.

The electric consumption for high frequency induction furnace No. 1 is 894.3 kWh/t in this factory, the standard electric consumption for general high frequency induction furnaces is as shown in Table 5-8-9. The table indicates 45 minutes of melting time with 750 kWh/t of power consumption for melting 300 kg at 1,000 Hz and 300 kW. The transformer of the factory has a capacity of 630 kVA, which is higher than the above example. Endeavor should be made to attain a target of 720 kWh/t in power consumption at a thermal efficiency of 55% to obtain the power saving ratio of 5.4% to the total power consumption.

Table 5–8–9 Equipment Capacity, Standard Melting Time and Power Unit Consumption of High Freq. Induction Furnace in Steel Melting

Melting capy (kg)	Frequency (Hz)	Electric source capacity (kW)	Melting time (min)	Power unit consumption (kWh/t)
50	3,000	50	50	900
		100	25	
100	3,000	50	120	780
		100	40	
150	3,000	100	70	760
	1,000	150	45	
300	1,000	150	100	750
		300	45	
500	1,000	150	140	720
		300	80	
1,000	1,000	300	170	750
		600	80	680
2,000	1,000	600	170	750
		1,100	80	650

Note; Japan Steel Foundrymen Society, 1980

5.8.3.3 Ladle

(1) Improvement of ladle lining

At present, molding sand for core is used for the ladle lining for cast steel. The ladle is used for receiving molten metal without drying.In addition,the initial melt is returned again into the melting furnace for heating after reception by the ladle.The above procedure may be taken for drying and preheating the ladle,but it is not suitable for any of the factors of prolonged melting time, and cast steel quality such as gas absorption in molten steel from ladle lining, electric consumption.

Also the ladle lining is replaced with new sand everytime after use. It is recommended that the ladle be lined inside with firebrick, the inside of which is coated with refractory mortar for durability, and that the ladle lined in the above be kept red-out for 2 to 3 hours before melt reception. The above improvement can decrease slag inclusion, deterioration in product quality due to hydrogen absorption and heat loss.

(2) Preventing heat release from ladle

The heat of melt in a ladle is released from its top surface and the circumference of the body. It is better to cover the top with molten slag and fix a cover to the ladle to prevent heat release. With the above improvement of the ladle, it is possible to lower the temperature of the melt output.

(3) Changing ladle capacity

It is desirable to replace the ladle now in use having an insufficient capacity with a tea pot ladle of 500 kg so that the molten steel in the induction furnace and the arc furnace can be received at one time only. Preheating the ladle and a cover fixing can limit the temperature drop of molten metal, shorten the melting time, decrease the number of ladle workers from 5 to 2, and shorten the time required for casting, leading to various advantages.

Figure 5-8-10 shows the dimensions for 500 kg ladle.

The ladle should be lined inside with chamotte brick of about 70 mm in thickness and equipped with a cover of about 3 to 5 mm in thickness lined inside with chamotte mortar to prevent heat loss.

The ladle must be completely dried in any case prior to use, since insufficient drying will cause an increase hydrogen gas in molten steel, blow holes and pin holes.

The method of drying the ladle includes heating from the upper side, heating from the side or the position upside-down, etc., as shown in Figure 5-8-11. From the standpoint of energy conservation, the upside-down system using solid fuel would be useful.

The temperature of the ladle at the time of receiving molten steel should be higher. It is preferable to continue heating of the ladle until immediately before receiving melt and to keep it red-hot when molten metal is introduced.

(4) Molding sand

New sand and used sand in the ratio of 50:50 are used for facing sand for casting. However, only new sand is usually used for cast steel to prevent thermal penetration of molding sand to the surface of casting. The casting with thermal penetration requires additional hour for annealing because of its lowest heat conductivity.

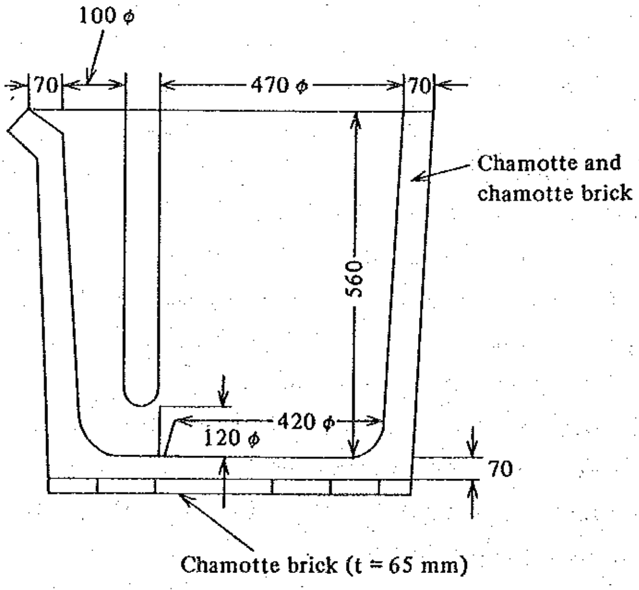


Figure 5–8–10 Tea-Pot Ladle for Steel Casting

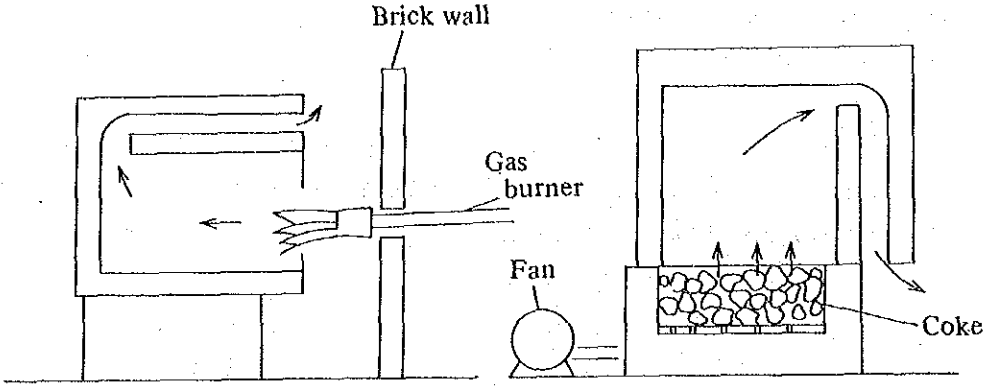


Figure 5–8–11 Heating Process of Tea-Pot Ladle

5.8.3.4 Annealing Furnace

(1) Heat balance

A) Basis of heat balance

The heat balance calculation in non-steady state was carried out as follows on the basis of the data for 4 hours and 45 minutes from loading at 14:00, November 8, to the completion of uniform heating at 18:45 on the same day.

1)	Type of fuel		Natural gas	
2)	Fuel consumption	(Ff)	440.47	Nm^3
3)	Heating value of fuel (lower value)	(Hl)	8,545	$kcal/Nm^3$
4)	Specific heat of fuel	(Cp)	0.39	$kcal/(Nm^3 \cdot {}^\circ C)$
5)	Fuel temperature	(Tf)	34.52	°C
6)	Air temperature (standard)	(To)	29.02	°C
7)	Temperature of combustion air	(Ta)	36.63	°C
8)	Specific heat of combustion air	(Cpa)	0.31	$kcal/(Nm^3 \cdot {}^\circ C)$
9)	O_2 (%) in dry exhaust gas	(O_2)	10.27	%
10)	CO_2 (%) in dry exhaust gas	(CO_2)	5.55	%
11)	CO (%) in dry exhaust gas	(CO)	0.13	%
12)	Temperature of dry exhaust gas	(Tg)	414.50	°C
13)	Specific heat of dry exhaust gas	(Cpg)	0.33	$kcal/(Nm^3 \cdot {}^\circ C)$
14)	Quantity of theoretical combustion air	(Ao)	9.55	Nm^3/Nm^3
15)	Quantity of theoretical wet exhaust gas	(Go)	10.57	Nm^3/Nm^3
16)	Air ratio	(m)	2.75	
17)	Quantity of actual wet exhaust gas	(G)	27.28	Nm^3/Nm^3
18)	Quantity of charged steel	(Sw)	2,870	kg
19)	Temperature of steel before charge	(Tsa)	40.0	°C
20)	Heat content of steel before charge	(Hsa)	0	kcal/kg
21)	Temperature of steel heated	(Tsb)	815	°C
22)	Heat content of steel heated	(Hsb)	128.34	kcal/kg
23)	Carrier weight	(Kw)	1,275	kg

24)	Temperature of carrier before charge	(Tka)	47.87	°C
25)	Heat content of carrier before Charge	(HKa)	0	kcal/kg
26)	Temperature of carrier heated	(Tkb)	815	°C
27)	Heat content of carrier heated	(HKb)	128.34	kcal/kg

28) Temperature of outer wall surface

Side wall temperature		
Left-hand	at charge	74.43 °C
	at finishing	121.80 °C
	average	103.83 °C
Right-hand	at charge	69.28 °C
	at finishing	117.40 °C
	average	97.48 °C
Rear wall temperature		
	at charge	66.35 °C
	at finishing	62.05 °C
	average	64.08 °C
Ceiling temperature		
	at charge	98.70 °C
	at finished	128.20 °C
	average	107.11 °C
Door temperature		
	at charge	63.05 °C
	at finished	111.55 °C
	average	86.38 °C

29) Temperature of inner surface at each part of furnace at charge

Side wall temperature	136.17 °C
Rear wall temperature	128.50 °C
Ceiling temperature	140.75 °C
Door temperature	102.80 °C

B) Heat input

Calculation is made for 1 ton of charged steel.

(1) Combustion heat of fuel

$Hf = Hl \times Ff \div Sw = 8{,}545 \times 440.47 \div 2.87 = 1{,}311{,}434$ kcal/t

(2) Sensible heat of fuel (Qf)

$Qf = Cp \times (Tf - To) \times Ff \div Sw$

$= 0.39 \times (34.52 - 29.02) \times 440.47 \div 2.87$

$= 329$ kcal/t

(3) Sensible heat of combustion air (Qa)

$Qa = Cpa \times m \times Ao \times (Ta - To) \times Ff \div Sw$

$= 0.31 \times 2.75 \times 9.55 \times (36.63 - 29.02) \times 440.47 \div 2.87$

$= 9{,}509$ kcal/t

(4) Total heat input (Qi)

$Qi = Hf + Qf + Qa = 1{,}311{,}434 + 329 + 9{,}508$

$= 1{,}321{,}272$ kcal/t

C) Heat output

Calculation is made for 1 ton of charged steel.

(1) Heat content of steel (Qs)

$Qs = (Hsb - Hsa) \times 1{,}000 = (128.34 - 0) \times 1{,}000$

$= 128{,}340$ kcal/t

(2) Heat required for carrier heating (QK)

$Qk = (Hkb - Hka) \times Kw \div Sw = (128.34 - 0) \times 1{,}275 \div 2.87$

$= 57{,}015$ kcal/t

(3) Heat storaged in furnace body (Qh)

$Qhn = V \times \rho \times c \times [(t_1 + t_2)/2 - (t_3 + t_4)/2] \div Sw$

where, Qhn : Storaged heat kcal

V : Volume m^3

ρ : Density kg/m^3, $1{,}800\ kg/m^3$

c : Specific heat kcal/(kg.°C), 0.23 kcal/(kg.°C)

t_1 : Temperature of inner surface of furnace body at finishing °C

t_2 : Temperature of outer surface of furnace body at finishing °C

t_3 : Temperature of inner surface of furnace body at charge °C

t_4 : Temperature of outer surface of furnace body at charge °C

$Qhn = 1{,}264{,}224 \div 2.87 = 440{,}496$ kcal/t

Table 5–8–10 Heat Storaged in Furnace Wall

Part	Temperature (°C)				Volume (m^3)	Heat storage (kcal)	%
	Starting time		Heating end time				
	Inside	Surface	Inside	Surface			
Side	136.17	71.86	815	119.60	4.38	658,752	52.14
Back	128.50	66.35	815	62.05	1.69	238,654	18.93
Ceiling	140.75	98.70	815	128.20	2.01	292,809	23.12
Door	102.80	63.05	815	111.55	0.47	74,007	5.81
Total					8.55	1,264,224	100.00

(4) Heat storaged in truck brick (Qd)

$Qd = V \times \rho \times c \times (t_1 - t_2) \div Sw$

where,	Qd	Storaged heat	kcal
	V	: Volume	m^3
	ρ	: Density	kg/m^3 , 1,800 kg/m^3
	c	: Specific heat	kcal/(kg.°C), 0.23 kcal/(kg.°C)
	t_1	: Temperature at finishing	°C, 750 °C
	t_2	: Temperature at charge	°C, 53.45 °C

$Qd = 0.779 \times 1,800 \times 0.23 \times (750 - 53.45) \div 2.87$
$= 78,272$ kcal/t

(5) Heat taken away by exhaust gas (Qg)

$Qg = \Sigma\ [G \times Cpg \times (Tg - To) \times Ff) \div Sw$
$= 1,591,918.28 \div 2.87 = 554,675$ kcal/t

(6) Heat radiated from furnace body (Qr)

$Qr = 33,640.81 \times 4.75 \div 2.87 = 55,677$ kcal/t

Table 5–8–11 Heat Radiation from Annealing Furnace

Part	Temperature (°C)	Surface area (m^2)	Heat loss [kcal/(m^2 · h)]	Heat loss (kcal/h)
Side wall	100.66	14.37	907.51	13,040.92
Back wall	64.08	5.10	366.95	1,871.45
Ceiling	107.11	14.37	1,145.33	16,458.39
Door	86.38	3.15	720.65	2,270.05
Total				33,640.81

(7) Other heat loss (Qm)

$Qm = Qi - (Qs + Qk + Qh + Qd + Qg + Qr)$
$= 1,321,272 - (128,340 + 57,015 + 440,496 + 78,272 + 554,675$
$+ 55,677) = 6,797$ kcal/t

(8) Total heat output (Qo)

$Qo = Qs + Qk + Qh + Qd + Qg + Qr + Qm$
$= 128,340 + 57,015 + 440,496 + 78,272 + 554,675 + 55,677 + 6,797$
$= 1,321,272$ kcal/t

D) Heat balance table

The above calculation results are summarized in Table 5-8-12.

Table 5-8-12 Annealing Furnace Heat Balance

Heat Input			Heat Output		
Item	kcal/t	%	Item	kcal/t	%
Combustion heat of fuel	1,311,434	99.26	Heat content of steel	128,340	9.71
Sensible heat of fuel	329	0.02	Heat content of supporting rail	57,015	4.32
Sensible heat combustion air	9,509	0.72	Heat storaged in furnace wall	440,496	33.34
			Heat storaged in truck	78,272	5.92
			Heat taken away by exhaust gas	554,675	41.98
			Heat loss from furnace surface	55,677	4.21
			Other heat loss	6,797	0.52
Total	1,321,272	100.00	Tofal	1,321,272	100.00

As can be seen from the results of heat balance calculation, heat storaged in furnace body of 33% and heat taken away by exhaust gas of 42% make a total of about 75% of the total heat output. This percentage is high, even though the actual heat storage is lower than the calculated value because the inner temperature of brick at charge; is anticipated to be higher than the average temperature of inner and outer surfaces. The attempt to reduce the heat storage and the heat taken away by exhaust gas will be effective in fuel saving.

In order to reduce the heat storaged in furnace body, it is necessary to lighten and thermally insulate the truck as well as the side walls of furnace body, and at the same time, to prevent heat radiation from the furnace at empty condition. In addition, the improvement of air ratio and the waste heat recovery from exhaust gas are effective in reducing the heat taken away by exhaust gas.

(2) Light weight heat insulation of furnace body

(A) Heat storaged in furnace body at present condition

As shown in Table 5-8-10, the heat storaged in furnace body is calculated as 1,264,224 kcal, 52% of which is occupied by the heat in both side-walls.

Since the furnace of batch system such as the annealing furnace with a truck undergoes repeated heating and cooling during a short period of time, heat is consumed by reheating the once cooled furnace walls at every reheating. As the furnace walls are more than four times as heavy as the charged material to be treated, they lose a great deal of storaged heat. Regarding the existing furnaces of batch operation system, a veneering method in which ceramic fiber is lined inside the furnace is adopted as a simplified method with remarkable effect in reducing heat storage loss. This is due to the heat capacity of ceramic fibers that is extremely low as compared with that of the conventional and existing chamotte brick.

(B) Light weight heat insulation and their effect

a. Brick temperature after veneering

Heat transfer to the furnace wall inner surface includes radiation from flame, radition from combustion gas, radiation from the surface of solid in the furnace, and convection of in-furnace gas. These heat transfer rates are much higher than those through furnace wall or from outer surfaces and therefore, the inner surface temperature of the furnace wall can be regarded as being almost equal to the atmospheric temperature in the furnace. Considering the furnace wall consisting of a bilayer as shown in Figure 5-8-12, the heat flown through the wall per unit area and unit time (kcal/m²·h) is expressed by the following equation.

$$Q_2 = \frac{(t_1 - t_3)}{[(l_1/\lambda_1) + (l_2/\lambda_2)]} = \frac{(t_1 - t_2)}{(l_1/\lambda_1)} \quad [\mathrm{kcal}/(\mathrm{m}^2 \cdot \mathrm{h})]$$

$$Q_1 = 4.88 \times 0.8 \times (\frac{t_3 + 273}{100})^4 - (\frac{t_0 + 273}{100})^4 + 2.2 \times (t_3 - t_0)^{1.25}$$

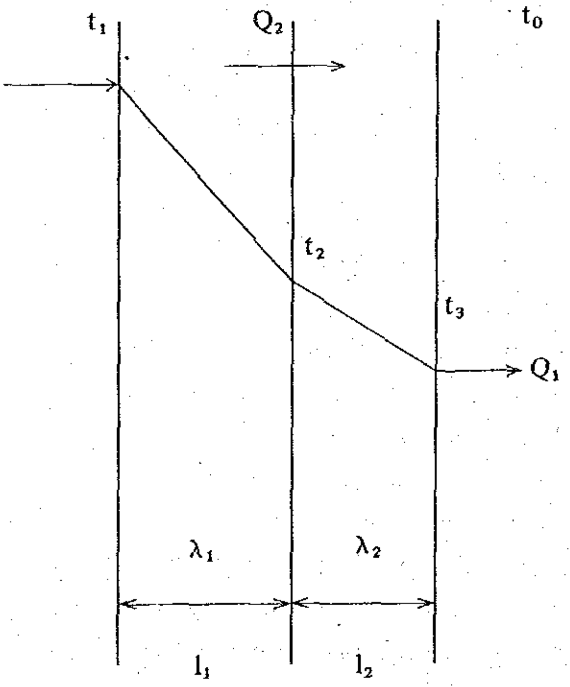


Figure 5–8–12 Heat Transfer through Wall

where, Q_2 : Heat transferred through wall kcal/(m^2.h)
t_1 : Temperature of inner surface of furnace wall °C
t_2 : Boundary temperature between existing brick and ceramic fiber °C
t_3 : Temperature of outer surface of furnace wall °C
t_0 : Atmospheric temperature C
λ_1 : Heat conductivity for existing brick kcal/(m·h·°C)
0.22 kcal/(m.h.°C)
λ_2 : Heat conductivity for existing brick kcal/(m.h.°C)
0.54 kcal/(m.h.°C)
l_1 ; Thickness of ceramic fiber m , 0.1m
l_2 : Thickness of existing brick m , 0.425m
Q_1 : Heat released by radiation and convection from outer surface of furnace wall [kcal/(m^2·h)]

The surface temperature t_3 which equalizes the heat conducted through the furnace wall after lightening and thermal insulation to the heat radiated from the outer surface of the furnace wall is obtained, followed by obtaining the boundary temperature t_2.

b. Improvement plan

The upper part of inside both side wall (10.31 m^2) over the truck surface level is coated with ceramic fibers of 100mm in thickness by veneering, which is carried out by bonding ceramic blocks to the existing bricks with adhesive mortar. It is recommended, however, that surface preparation be performed prior to coating to remove surface unevenness with mortar or the like depending upon the surface condition of adhesiveness. Further, the ceramic fiber is protected by coating its surface with coating material.

c. Effect of improvement

Trial calculation was made on the side-wall surface temperature after improvement and the boundary temperature between the ceramic fiber and chamotte brick each at the time of charging and finishing using the above heat transfer calculation. The results are shown in Table 5-8-13.

Table 5–8–13 Temperature of Side Wall (°C)

	Inner wall temp.	Boundary temp.	Surface temp.
Charging time	136.2	100.5	38.4
Heating end time	815.0	546.9	80.6

The above results are used for calculating the storaged heat after lightweight heat insulation.

The density and specific heat of the ceramic fiber were regarded as 200 kg/m^3 and 0.20 kcal/(kg·°C), respectively.

Ceramic fiber portion:

$10.31 \times 0.1 \times 200 \times 0.2 \times [(815.0 + 546.9)/2 - (136.2 + 100.5)/2] \div 2.87$

$= 8{,}083$ kcal/t

Existing brick portion:

$10.31 \times 0.425 \times 1800 \times 0.23 \times [(546.9 + 80.6)/2 - (100.5 + 38.4)/2] \div 2.87$

$= 154{,}353$ kcal/t

Total 162,437 kcal/t

The decrease in storaged heat amounts to 67,094 kcal/t, which is corresponding. 29% is for the heat in furnace side walls and 15% to the total storaged heat, and is converted into a reduction of fuel by 10.2 Nm^3/t.

The effective heat ratio in converting into fuel basis was calculated as follows on the basis of the condition obtained after the improvement of air ratio:

(1) Heating value of fuel	8,545 kcal/Nm^3
(2) Sensible heat of exhaust gas	1,952 kcal/(Nm^3 – fuel)

$$\text{Effective heat ratio} = \frac{(1) - (2)}{(1)} = 0.772$$

In addition, the effect of decrease in heat released from the furnace body by ceramic fiber lining can be expected.

d. Economic effect

Premise

Insulation material cost	Dimensions (mm)	Unit cost
Insulating firebrick	65 x 114 x 230mm	0.3 U$S
Fiber 1400	100 x 300 x 300mm	19.0 U$S
Natural gas		0.08 U$S/Nm^3
Charged material to be treated	Estimated on the basis of gas consumption 717	

Cost and effect

Surface area of side walls in furnace	3,965 x 1,300 x 2 = 10.31 m^2
Fiber cost	19.0 x 10.31 ÷ 0.09 = 2,177 U$S
Fuel reduction	10.2 Nm^3/t
Profit	0.08 x 10.2 x 717 = 585 U$S/y
Expense recovery period	2,177 ÷ 585 = 3.7 years

(3) Light weight heat insulation of truck

In the case of a batch-system annealing furnace, a truck is cooled by atmosphere during extraction, and requires a great deal of heat for reheating. Reduction in heat required for reheating can be made by lightening the truck.

A) Heat storaged in truck at present condition (H_1)

The heat storaged in truck brick, that is, the heat required for heating the truck brick up to the heating temperature can be calculated by the following equation.

$H = V \cdot \rho \cdot c \cdot (t_1 - t_2)$

where, H : Storaged heat kcal

V : Volume of brick at upper layer of truck m^3 , 0.779

ρ : Density of brick at upper layer of truck kg/m^3 , 1,800 kg/m^3

c : Specific heat of brick at upper layer of truck kcal/((kg·°C), 0.23 kcal/(kg·°C)

t_1 : Temperature of brick at upper layer of truck at heating end °C

Presumed as 750 average

t_2 : Temperature of brick at upper layer of truck at the time of charging °C

H_1 : 0.779 x 1800 x 0.23 x (750 – 53.45) = 224,642 kcal

Thus, the heat storaged in truck at present condition is 224,642 kcal, that is, 78,272 kcal per ton of charged steel.

B) Light weight heat insulation and their effects

a. Improvement plan

The number of used rails of carrier is reduced from 34 to 17 by half, the rail loads are supported by chamotte bricks at both ends, and non-loaded portions are changed to insulating firebrick.

In other words, one layer of conventional chamotte brick is left on both sides of the longitudinal direction of truck, and all the inner bricks are changed to insulating firebricks.

b. Effect of improvement

1. Heat storage of the portion subjected to load (H2a)

Volume of conventional bricks laid in longitudinal direction of truck (V_1)

V_1 = 4.18 x 0.114 x 0.23 x 2 = 0.22 m^3

Heat storaged in this portion (H2a)

H2a = 0.22 x 1,800 x 0.23 x (750 – 53.45) = 63,442 kcal

2. Heat storage of the portion not subjected to load (H2b)

Representing the total volume of truck brick with V, the brick volume of this portion (V_2)

$V_2 = (V - V_1)$ = 0.779 – 0.22 = 0.559 m^3

Heat storaged in this portion (H2b)

H2b = 0.559 x 630 x 0.23 x (750 – 53.45)

= 56,420 kcal

In the above calculation, the density and specific heat of the insulating firebrick were regarded as 630 kg/m^3 and 0.23 kcal/(kg·°C), respectively.

3. Heat storaged in truck after improvement (H_2)

H2 = H2a + H2b = 63,442.1 + 56,420 = 119,862 kcal

Thus, the heat storaged in truck after improvement in 119,862 kcal, that is, 41,746 kcal per ton of charged steel

4. Effect of decrease in storaged heat

The decrease in heat storaged in truck due to the above improvement is 36,508 kcal per ton of charged steel that equals to a reduction by 47%. Further, the heat required for heating the carrier is also halved, to 28,508 kcal/t resulting in the total fuel reduction of 9.9 Nm^3/t.

In calculating the conversion into fuel, an effective heat ratio is regarded as 0.772.

c. Economic effect

The premise is same as that used in the light weight heat insulation of the furnace body.

Volume of insulating firebrick	0.559 m^3
Brick cost	0.3 x [0.559 ÷ (0.065 x 0.114 x 0.23)] = 98.4 U\$S
Fuel reduction	9.9 Nm^3/t
Profit	0.08 x 9.9 x 717 = 568 U\$S/y
Expense recovery period	98.4 ÷ 568 = 0.2 year

(4) Improvement of air ratio

The heat taken away by exhaust gas is so large as 554,675 kcal/t, 42% to the heat input. As one of the means for reducing the loss due to exhaust gas, the decrease in exhaust gas quantity is effective, which can be attained by properly adjusting the amount of combustion air.

The annealing furnace is using a combustion control system of on-off control. Figure 5-8-13 shows O_2 concentration in exhaust gas as the combustion characteristics after reaching the prescribed temperature. As can be seen from the figure, O_2 concentration in exhaust gas is 7.2 to 7.5% during combustion, but is 19.0 to 19.8% at the time of combustion stoppage, which is much higher than the former. The result of investigation have proved that one side of the air control damper mechanism was fixed at a degree of opening of 45 degrees, while the other side was fixed to only 15% closing even at the time of combustion stoppage, thereby depriving the heat of furnace of owing to the unnecessary air introduced into the furnace.

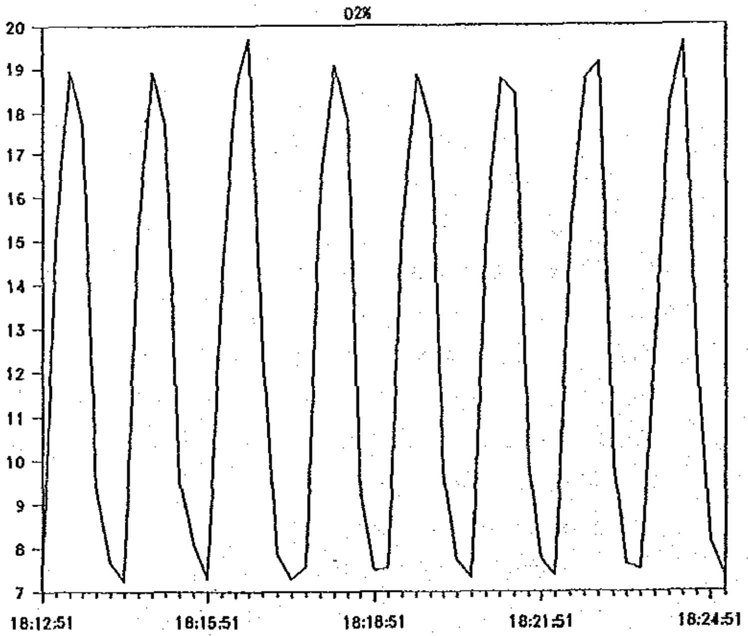


Figure 5–8–13 O_2 % in the Exhaust Gas

An improved air ratio of 1.5 is obtained by arranging the control mechanism, cutting off unnecessary air at combustion stoppage and reducing O_2 concentration in exhaust gas to 7.0% on the average. Hence, heat loss due to exhaust gas can be reduced by about 43%.

Table 5-8-14 shows the data relating to reducing heat loss due to exhaust gas by improving air ratio.

Table 5–8–14 Reducing the Exhaust Gas Heat Loss by Improving Air Ratio

Item	Unit	Present	Improved
Oxygen in exhaust gas	%	10.27	7.0
Air ratio		2.75	1.50
Theoretical combustion air	Nm^3/Nm^3	9.55	9.55
Theoretical exhaust gas	Nm^3/Nm^3	10.57	10.57
Actual amount of air	Nm^3/Nm^3	26.26	14.33
Actual amount of exhaust gas	Nm^3/Nm^3	27.28	15.345
Exhaust gas temperature	°C	414.5	414.5
Heat taken away by exhaust gas	$kcal/Mn^3$	3,614	1,952

The fuel reduction rate (S) obtained by reducing air ratio is calculated by the following equation.

$$S = 1 - \frac{Hi - Qga}{Hi - Qgi} = 1 - \frac{1,321,272 - 554,675}{1,321,272 - 554,675 \times (1,952/3,614)}$$

$$= 0.25$$

where, Hi : Heat input kcal/t
Qga : Heat taken away by exhaust gas at present condition kcal/t
Qgi : Heat taken away by exhaust gas after improvement kcal/t

The fuel curtailment ratio by reducing air ratio is 25% leading to a fuel saving of 38.4 Nm^3 per ton of charged steel.

(5) Recovery and utilization of waste heat in exhaust gas

As one of the other methods of reducing heat taken away by exhaust gas it is possible to lower the exhaust gas temperature by recovering waste heat from the gas.

With regard to the furnace, the double-cylinder type air preheater which was used as a preheating equipment for combustion air in the past is left as it is without being used at the present time. Investigation will be made on the fuel conservation by reuse of the above preheater.

In case of ON-OFF combustion control system as used for the present furnace, the air amount and exhaust gas amount are different depending upon the time of ON and OFF. However, the fuel conservation will be studied assuming constant air ratio for convenience, and the condition after decrease in heat capacity of furnaceand truck,and air ratio improvement.

The heat transfer area of heat exchanger is assumed as 1.08 m^2/pc x 6 pcs = 6.48 m^2.

Table 5–8–15 Calculation Data of Heat Recovery

Item	Unit	Data
Fuel gas after improvement	Nm^3/h	57.4
Air ratio		1.5
Theoretical combustion air	Nm^3/Nm^3	9.55
Theoretical exhaust gas	Nm^3/Nm^3	10.57
Actual amount of air	Nm^3/h	822.3
Actual amount of exhaust gas	Nm^3/h	880.8
Ambient temperature	°C	29.02
Exhaust gas temperature	°C	414.5
Overall heat transfer coefficient K	kcal/(m^2 h°C)	15
Heat transfer area A	m^2	6.48

We set the air outlet temperature for the heat exchanger as Y, and the exhaust gas outlet temperature as X. Heat quantity transferred from exhaust gas side of heat exchanger to air side (Q).

$$Q = K \times A \times 1/2\ [(X - 29.02) + (414.5 - Y)]$$
$$= 15 \times 6.48 \times 1/2\ [(X - 29.02) + (414.5 - Y)] \qquad (1)$$

Heat quantity obtained by preheated air (Q)

$$Q = A \times Cpa \times (Y - 29.02)$$
$$= 822.3 \times 0.31 \times (Y - 29.02) \qquad (2)$$

Heat quantity given by exhaust gas (Q)

$$Q = G \times Cpg \times (414.5 - X) \times \eta$$
$$= 880.8 \times 0.33 \times (414.5 - X) \times 0.95 \qquad (3)$$

where, η: Heat transfer efficiency in exhaust gas side . . . 0.95

The above equations (1), (2) and (3) are solved as follows:

Q = 27,426 kcal/h

X = 315.2 °C

Y = 136.6 °C

The fuel conservation rate (S) by air preheating is calculated as follows:

$$S = \frac{P}{F - Q + P}$$

where, P : Heat quantity brought by preheated air kcal/h, 27,426 kcal/h

F : Heat input by fuel : kcal/h

Q : Heat quantity taken away by exhaust gas kcal/h

$$Q = 0.33 \times 880.8 \times (315.2 - 29.02)$$
$$= 83{,}182 \text{ kcal/h}$$

$$S = \frac{27{,}426}{8{,}545 \times 57.4 - 83{,}182 + 27{,}426} \times 100 = 6.3\%$$

Therefore, the saved fuel amounts to 3.6 Nm^3 per hour, that is, 6.0 Nm^3 per ton of charged steel.

As calculated above, a fuel conservation of 64.5 Nm^3 per ton of charged steel is brought by the synthetic effect of improvement including light weight heat insulation for furnace body and truck, improvement of air ratio, and waste heat recovery from exhaust gas. Based on charged material to be treated of 717 t/y, the yearly fuel conservation amount of money becomes as follows:

717 t/y X 64.5 Nm^3/t X 0.08 U$S/$Nm^3$ = 3,700 U$S/y

(6) Improvement of working procedure

A) Closing doors of furnace when empty

At present, the doors are kept full open during the empty period of the furnace from the time of taking out the treated material from furnace after annealing to the time of loading the material to be treated. The above procedure results in cooling of the furnace walls still remaining warm, necessitating heat required for heat storage in the furnace in the next batch operation. It is recommended, therefore, that the doors be closed every time immediately after taking out the treated material as a customary procedure.

B) Confirmation of seal between truck and furnace

Insufficient seal was found for the sand-seal which was used between the truck and furnace. At the time of investigation, the pressure in the furnace was +0.21 mm Aq on the average, but fluctuation of the iner pressure of furnace and infiltration of cold air at negative pressure was found. In view of the above, it is recommended that the sand-seal be inspected at every time of completing annealing work, and the sand for sealing be periodically replenished.

C) Removing sprue runner for loaded material

In case of charging the material to be treated, the sprue runner at the time of casting is left unremoved. The heat required for reheating the runner as high as the annealing temperature is quite wasteful. It is recommended that the runner be removed for the product without a danger of damage.

D) Intensifying equipment maintenance

Damage to the burner tiles which were seen on the furnace will cause unstable combustion. The damaged burner tiles need to be replaced as quickly as possible. As described above, cold air intrusion was observed during combustion stoppage on account of the incompleteness in the link rod mechanism of the air control valve for the air-to-fuel ratio control device. Therefore, it is recommended that the above contorl device be periodically inspected and adjusted so as to maintain the proper air amount, that is, about 4.0% in oxygen concentration at all times during operation.

5.8.3.5 Power Receiving and Distributing and Electrical Facilities

(1) Outline of electric power receiving and load equipment

Electric power is received through the underground cable of 13.2kV, and an integrating watt meter and a reactive volt-ampere hour meter are installed for trading at the point of power reception. The substation is equipped with 5 sets in total of transformers, of which the transformer of 315 kVA for power-driven equipment for general use can receive 380 V as an emergency power source.

The loads include 3 sets of arc furnaces, 2 sets of high frequency induction furnaces, and motors for air compressors, sand mills, ventilation fans, etc.

Average electric power consumption on the measurement day (November 9) was 583 kW, but the load during peak hours (from 5:00 p.m. to 9:00 p.m.) was not high. As for the load by each equipment, the loads of the arc furnaces, induction furnaces and general equipment were about 170 kW, 270 kW and 100 kW (of which 50 kW is for air compressors) respectively, with an overall load factor of 85.4% and a power factor of about 85%.

(2) Contents of measurement

The following measurements were made by use of watt-power factor meter (PFM-1000, PFMA-5210, PFM-1000 P), AC clip-on power meter, multipoint recorder (12 points), integrating wattmeter, etc.

1. Load condition for whole factory (Calculated from each data)

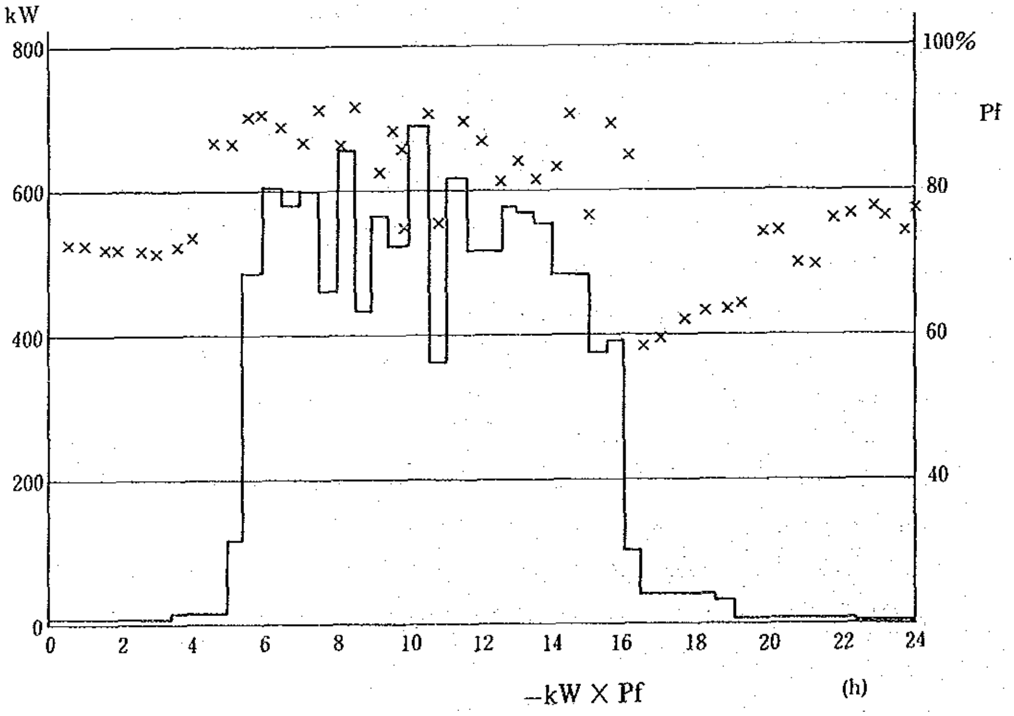


Figure 5–8–14 Total Power of Factory

2. Load condition for arc furnaces

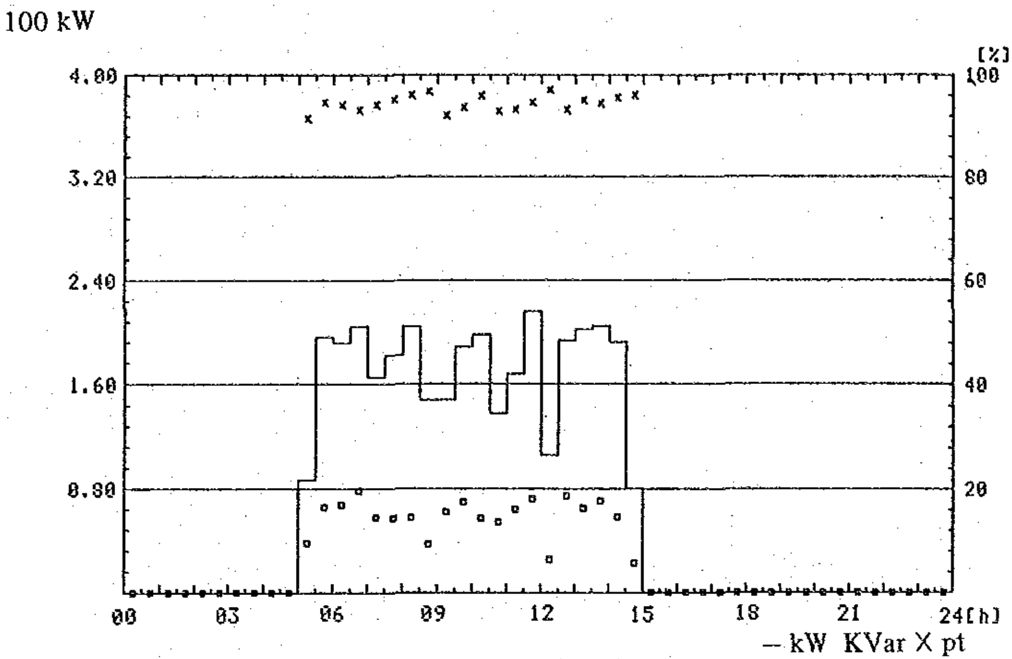


Figure 5–8–15 Load of Aro Furnace

3. Load condition for induction furnaces

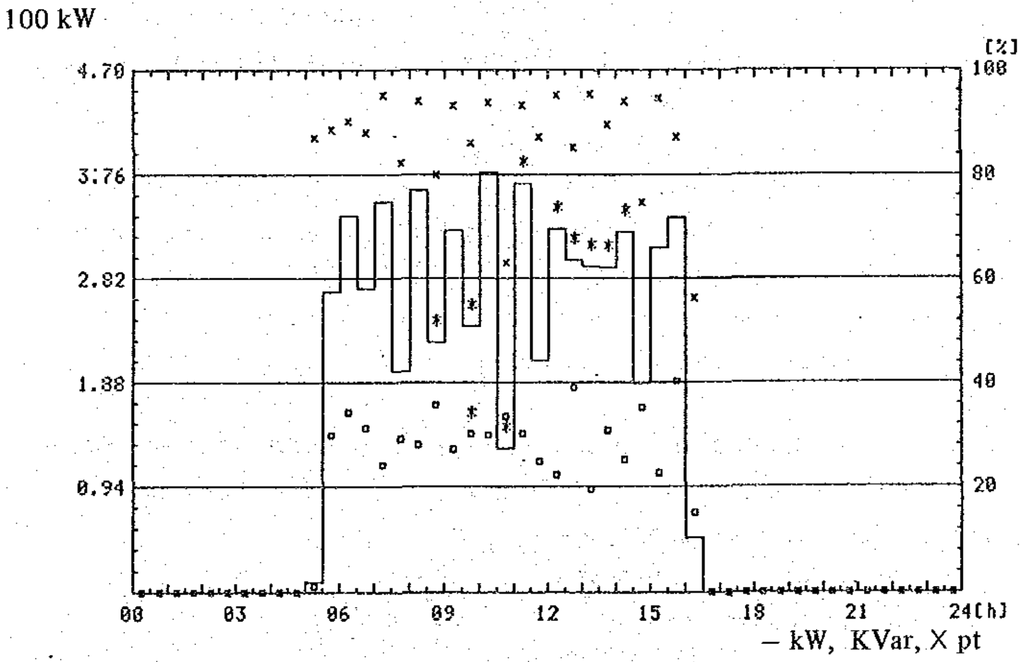


Figure 5–8–16 Load of Induction Furnace

4. Load condition for air compressors

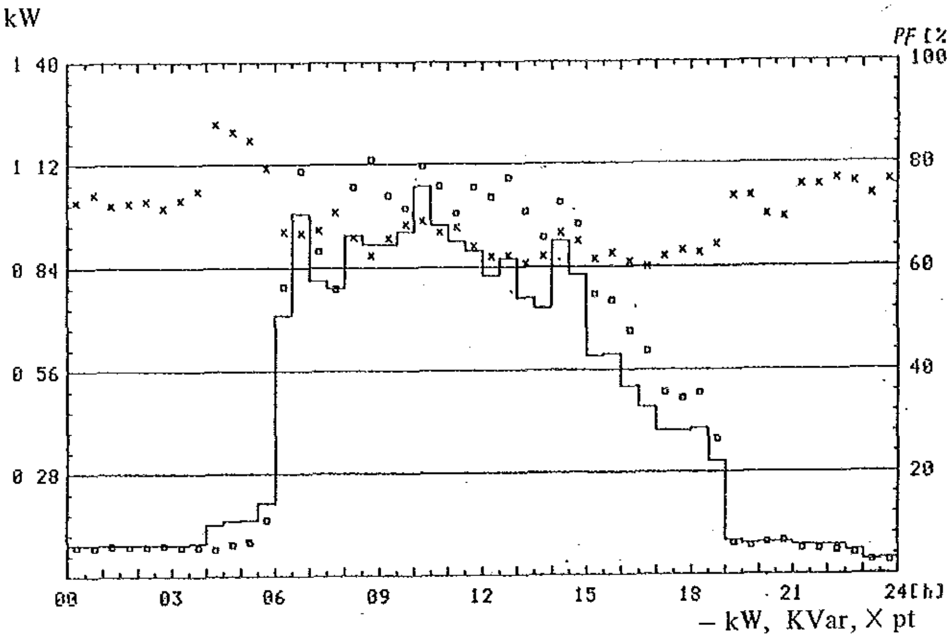


Figure 5–8–17 Load of Air Compresser

(3) Incomplete drawings and data

The one line diagrams such as Figure 5-8-5 need to be completed so as to facilitate the grasp of the whole aspect of electric system. In addition, it is better to prepare the lists of furnaces, motors, etc. to clarify each specifications and prepare for interchangeability and procurement of spare parts.

(4) Separating no-load transformer of arc furnace

In spite of the shut-down of Arc furnace No. 3 the primary side of the transformer was kept connected with the condensers. It is necessary to separate the transformer wiring from the condenser wiring and turn the primary side of no-load transformer OFF.

A transformer, when charged at no-load, causes no-load loss (iron loss). The transformer for Arc furnace No. 3 having a capacity of 300 kVA is producing about 1kW of iron loss.

Power conservation is also made by turning the transformer for Arc furnace No. 2 (250 kVA) and the transformer for high frequency induction furnace(630 kVA)off at the primary side except during operation.

The effect is calculated as follows.

From the no-load loss of about 1kW for Arc furnace No. 3 transformer.

1 kW x 24 h x 365 days = 8,760 kWh/y

From the no-load loss of about 1 kW, 0.7 kW for Arc Furnace No.2 and induction furnace transformers, and no-load hours of 14 a day (1 + 0.7) kW X (14 h x 250 d + 24 h X 115 d) = 10,642 kWh/y.

A total of 19,402 kWh/y can be saved.

(5) Leakage of compressed air

Of 4 sets of reciprocating air compressors (202 CV in total), one set with 60 CV is operated in the daytime while one set with 30 CV is operated during light-load period such as at night. Compressed air pressure is 5 to 5.6 kg/cm^2 with repeated LOAD-UNLOAD operation.

The leak portions of compressed air include 1) the safety valve and drain valve for compressed air tank on the roof, 2)drain valve for burr removal job-site,3) hose for sand tamping, 4) fixing joint of air piping at the rear wall of the sand remover and others.

The leakage is caused by breakage and carelessness such as failute to close the valve. The leakage factor was investigated by the method as shown in Figure 5-8-18 from the pressure rising time and pressure lowering time during rest hours in the factory and operation of 60-CV machine only. The result was about 50%.

In view of the above, it is necessary to repair the leakage portions of the safety valve for air tank, drain valves, piping, etc. and to thoroughly execute the air leak prevention related to equipment handling during work shutdown. Further, it is preferable to close the main valve, if possible, during rest. Assuming that the air leakage factor is decreased from 50% to 20%, the power conservation is calculated as follows from the observed power consumption of 41 kWh/h during 60 CV running:

41 kW x (0.5 – 0.2) x 10 h/y X 250 d/y = 30,750 kWh/y

The use of the machine with a small capacity such as 30 CV machine for the work after 4:00 p.m., etc. can decrease the power consumption at no-load from 8 kW (for 60 CV) to 6 kW (for 30 CV) and can save electric power consumption.

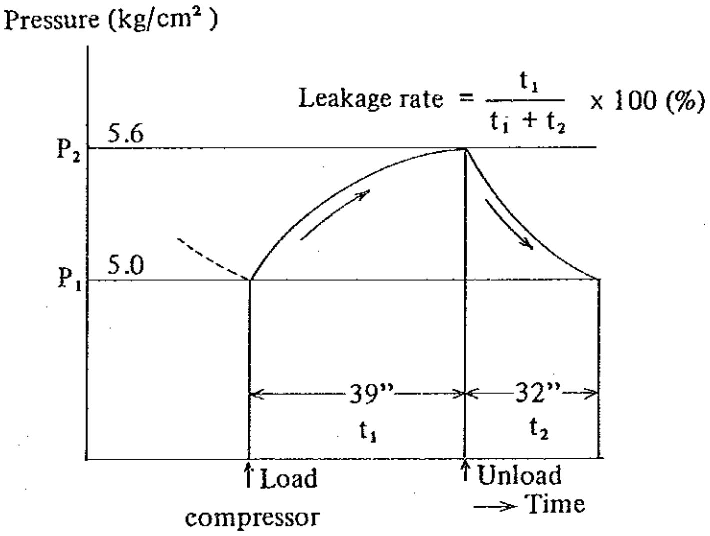


Figure 5–8–18 Measuring Method of Leakage Rate

5.8.3.6 Summary

The following are the effects of the aforementioned improvement that can be estimated quantitatively.

Item		Possible annual amount of saving	%
Reduction of the heat capacity of heat treatment furnace body and truck	Gas	14,400 m^3	13.1
Improvement of heat treatment furnace air ratio		27,500	25.0
Use of exhaust gas heat of heat treatment furnace		4,300	3.9
Total		46,200	42.0
Improvement of arc furnace operation	Electric power	100,000 kWh	8.1
Improvement of high frequency furnace operation		66,600	5.4
Separation of non-load transformer		19,400	1.6
Prevention of leakage of compressed air		30,800	2.5
Total		¥216,800	17.6

5.9 Results of Survey of Machining Factory

5. Survey of the Use of Energy in Model Factory

5.9 Results of Survey of Machining Factory

5.9.1 Outline of the Factory

(1) Name of the factory: TIFEC S.A.I.C. y F.

(2) Type of work: Machining

(3) Location of the factory: Cno. San Carlos km 2.5 – (5000) Cordoba C.C. 369 Prov. Cordoba

(4) Summary

This factory produced the gears for automobile and tractor. The factory was originally built 35 years ago. The factory is divided into two factories, forging and machining, and the object of the survey is only the machining factory.

Products are partially delivered to automobile manufacturing factories and tractor manufacturing factories, but most of the products are directly put on the market as replacement parts. The factory holds a share of 70% of the replacement parts market, and is a large one of the 5 to 6 machining factories in Argentina. After the peak in 1974 the production has been on the decrease, and the present operation rate of the factory is about 50%.

The factory uses many imported machine tools and also has NC lathes.

Recently, more condensers were installed to improve the power-factor.

(5) Number of employees: 96, of which five are engineers.

(6) Survey period: November 14 to 18, 1988

(7) Survey members:

Name	Assignment
Mitsuo Iguchi	Chief
Yukio Nozaki	Heat treatment process
Shoji Nakai	Heat management
Isamu Taki	Heat management
Teruo Nakagawa	Heat management
Toshio Sugimoto	Electrical management

INTI members

Mr. Ernesto M. Leikis	Chief
Mr. Jorge A. Fiora	Unit operation, process
Mr. Alberto Berset	Heat using equipment
Mr. Anibal A. Monzon	Heat using equipment, mobile unit driving
Mr. Miguel A. Bermejo	Electric receiving and distributing equipment
Mr. Arturo D. Verghelet	Electric receiving and distributing equipment
Mr. Roberto Domecq	Heat using equipment
Mr. Juan C. Balmayor	Heat using equipment

(8) Interviewed

Ing. Raul Barroso	Director
Ing. Jose Romagnoli	Energy manager
Ing. Eduardo T. Machado	Q.C. manager

Ing. J. Alberto Tondo Electric engineer

(9) Production

Table 5–9–1 Production

Year	1983	1984	1985	1986	1987
M. Benz Truck (Set)	2,400	2,400	2,400	2,400	2,800
Fiat Tractor (Set)	2,400	2,400	2,400	2,400	2,000
Zanello Tractor (Set)	6,000	5,100	2,500	1,200	1,000
M. Benz Direct (Piece)	4,800	6,000	6,000	7,200	8,000
Total Weight (t)	211.2	196.2	144.2	121.2	121.6

(10) Energy consumption

Table 5–9–2 Energy Consumption

Year	1983	1984	1985	1986	1987
Natural gas $1000\ m^3$	490	490	430	460	494
Elect. power Mwh	726	734	800	801	816
Energy/product					
Natural gas $1000\ m^3/t$	2.3	2.5	3.0	3.8	4.1
Power kWh/t	3.4	3.7	5.6	6.6	6.7

Electric Power unit price 0.06 U$S/kWh

Natural Gas unit price 0.05 U$S/$Nm^3$

Unit: one thousand

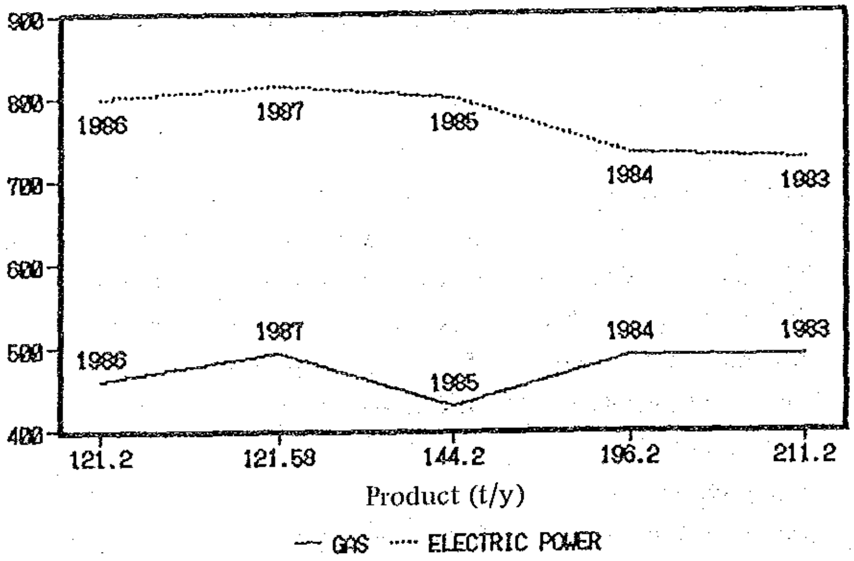


Figure 5–9–1 Production and Energy Consumption

Unit: one thousand

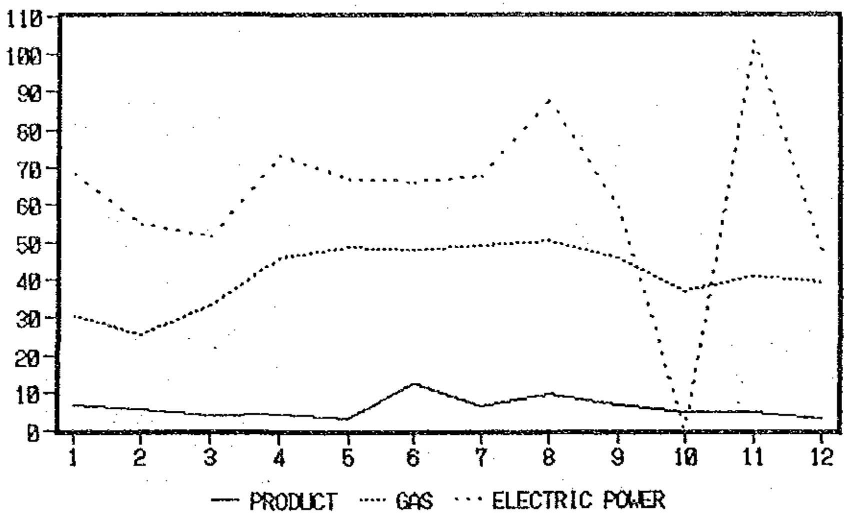


Figure 5–9–2 Monthly Production and Energy Consumption in 1987

(11) Factory layout

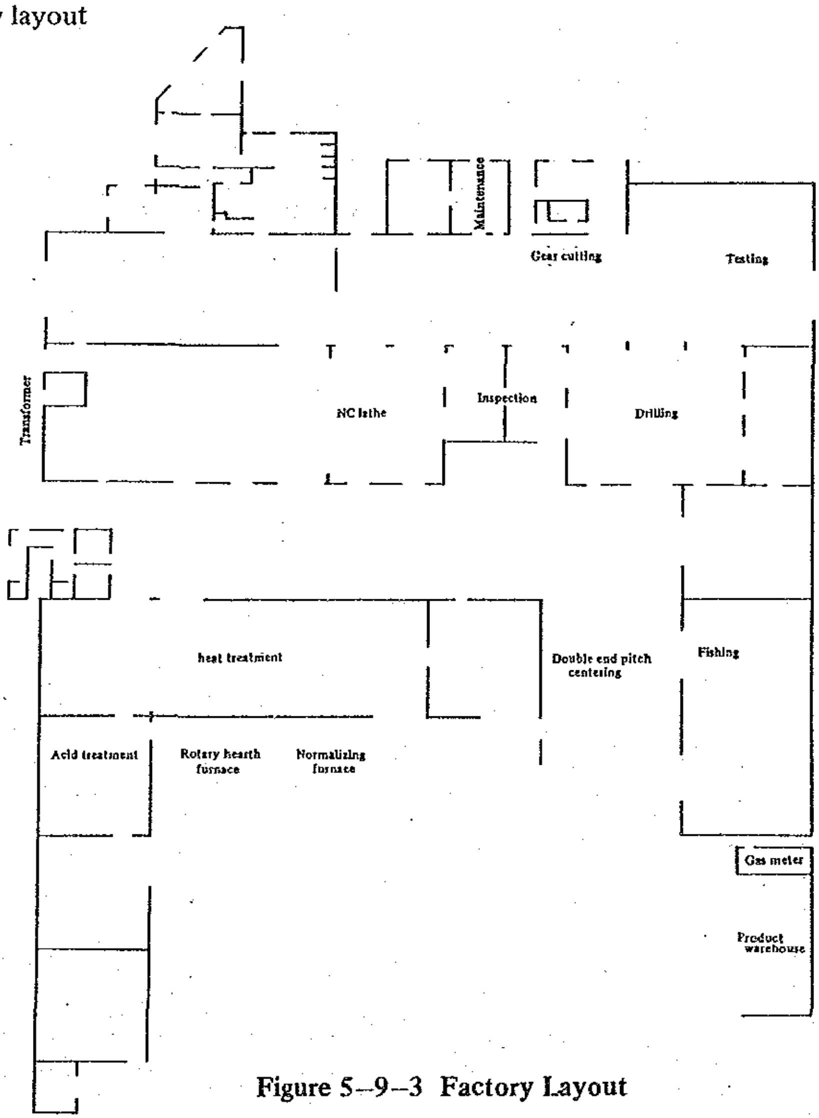


Figure 5–9–3 Factory Layout

(12) Production process

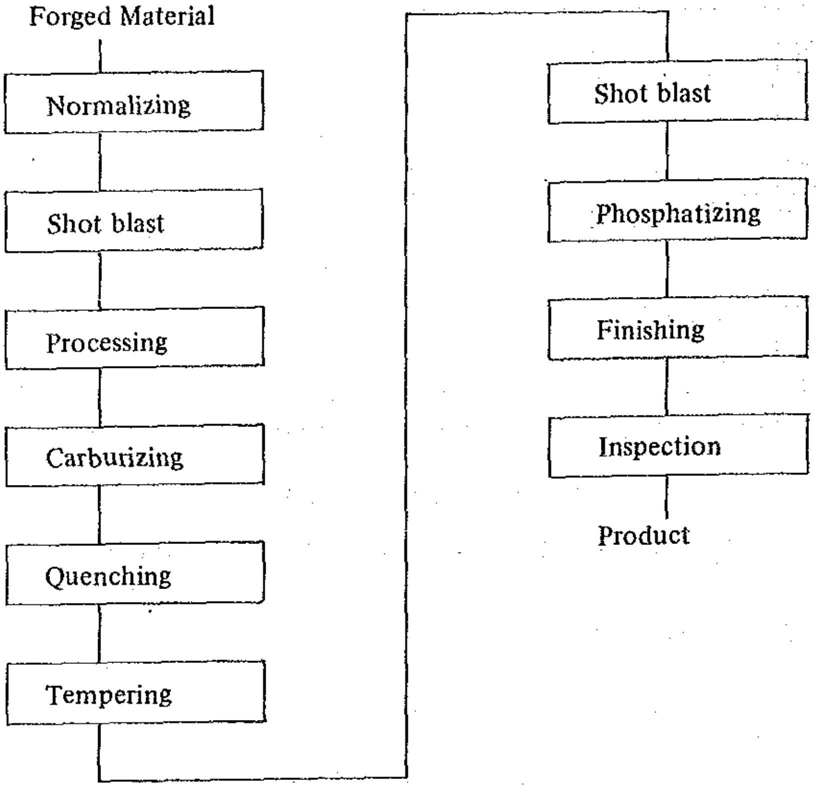


Figure 5–9–4 Production Process

(13) One line diagram

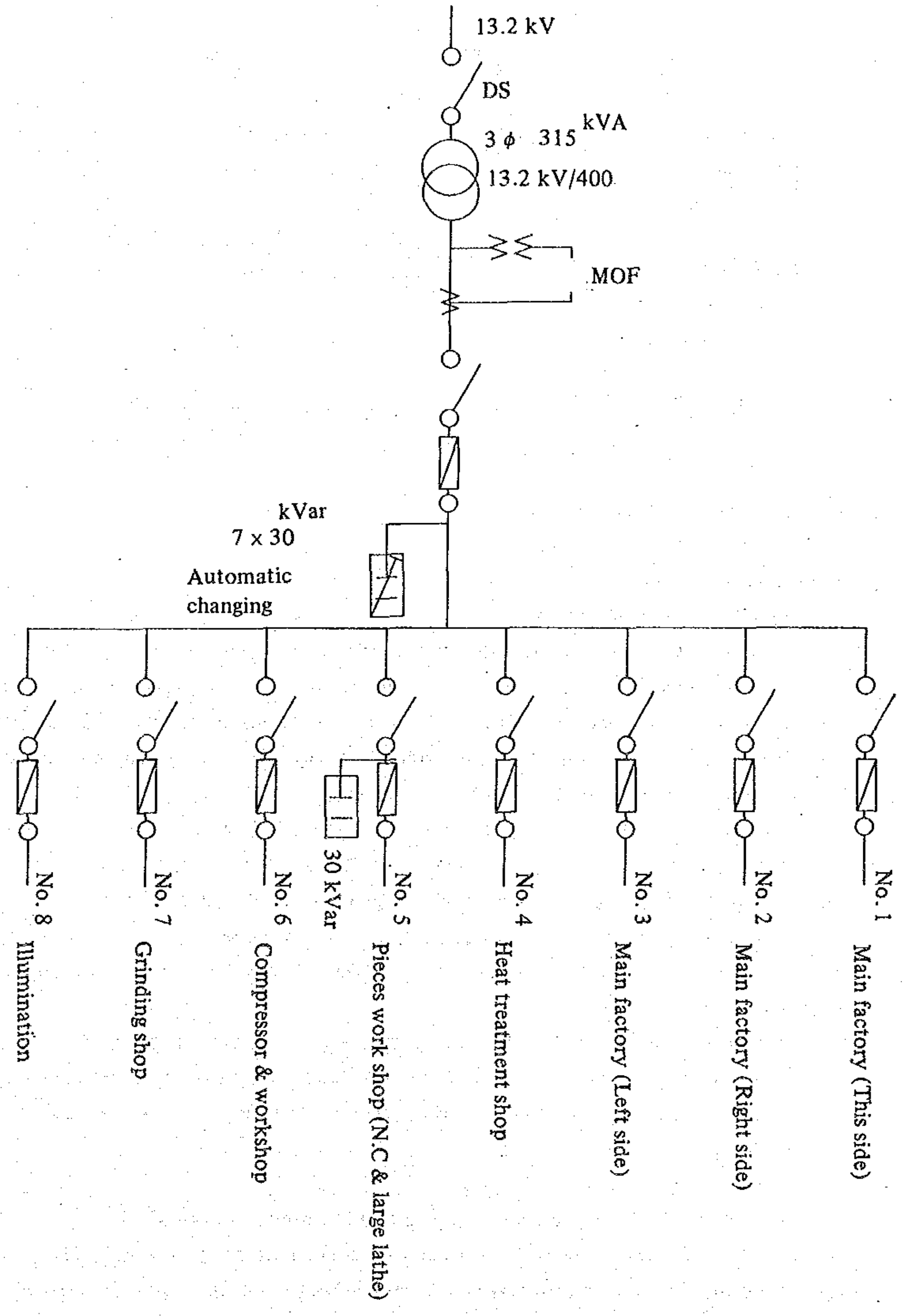


Figure 5–9–5 One Line Diagram

(14) Major energy consuming equipment

Table 5–9–3 Major Energy Consuming Equipment

Name	Number	Specification
Normalizing Furnace	3	Continuous, semimuffle (1) Batch, radiant tube (2)
Carburizing Furnace	4	Batch, integral type (1) Batch, radiant tube (2) Rotary hearth, radiant tube (1)
Annealing Furnace	1	Batch, radiant tube
Atomospheric Gas Generator	2	19 m^3/h, 28 m^3/h
Compressor	2	Rotary type 40 CV, 30 CV

(15) Factory operating time

9.2 h/d X 272 d/y = 2,502 h/y

5.9.2 Energy management

(1) Energy conservation target

The factory executives are interested in the energy conservation. However, they do not have a target for reducing energy consumption because a variety of machines and equipment are used. Therefore, no concrete measures for improvement are taken at present.

Many fuels are consumed for heat treatment along with the machining power using many motors in the machining industry. The energy expenditure of this factory is said to account for about 5% of the sales. However, Table 5-9-2 shows that the consumption of gas and electric power do not be decreased and the energy consumption ratio is now twice what it was probably due to the change of products pattern inspite of the lowering of production level on the weight basis year by year. In this sense, the energy conservation not only suites the national policy of the country but also serves as an effective measure to reduce the production cost.

The first step necessary for promoting an energy conservation program is to clearly show the direction in which all the employees must proceed by determining a target of energy conservation or a target of energy consumption ratio for each production process and product.

(2) Determining energy consumption

To reduce the energy consumption ratio and improve the productivity and product quality, it is essential to record the operating conditions every day and thus accurately determine the facts about the factory for comparison and examination. If variations from data values are found, or if deviatives occur from the planned values or design values, clues to improvement may be found by investigating the cause and taking proper measures.

The factory keeps a weekly record of gas consumption and electric power consumption, monthly calculates gas consumption rate and electric consumption rate, and thus monitors the trends of energy consumption. However, it is desirable to keep such a record daily if possible, to investigate the cause of variations in the data and take proper measures. If the actual energy consumption is calculated and informed to the operators, it can automatically induce the operators to initiate an energy saving action.

(3) Employee education and training

The engineers of this factory also take a great interest in matters related to energy conservation. As the machining factories are few in Cordoba State, there is no opportunity available for exchange of technical information. However, the engineers of this factory attend the training courses given by the state export federation, for which the top executive of this factory takes office as chairman, for the improvement of technical capacity of enterprises in the state. At present, no special employee education is given. Even though the employees want to make improvements, they won't be able to do so unless they know how. It seems that the necessity of employee education is well recognized and a plan is being made at this factory.

(4) Equipment management

Equipment management in this factory appeared generally satisfactory. The equipment including the furnace door seals, measuring instruments and controller were kept clean and properly cared for, and the drawings and technical data were properly filed.

5.9.3 Problems with Use of Energy and Remedial Measures

5.9.3.1 Continuous Normalizing Furnace

(1) Heat balance

(a) Basis of heat balance calculation

It is based on the data collected for one hour and half from 14:30 to 16:00 on November 15.

1)	Type of fuel	Natural gas		
2)	Fuel consumption	(Ff)	33.62	Nm^3
3)	Heating value (Lower value)	(Hl)	9,003	$kcal/Nm^3$
4)	Specific heat of fuel	(Cp)	0.39	$kcal/(Nm^3 \cdot °C)$
5)	Fuel temperature	(Tf)	50.97	°C
6)	Ambient temperature (Reference temperature)	(To)	41.65	°C
7)	Temperature of combustion air	(Ta)	41.65	°C
8)	Specific heat of combustion air	(Cpa)	0.3	$kcal/(Nm^3 \cdot °C)$
9)	O_2 content (%) of dry exhaust gas	(O_2)	5.46	%
10)	CO_2 content (%) of dry exhaust gas	(CO_2)	6.33	%
11)	CO content of dry exhaust gas	(CO)	8.5	ppm
12)	Temperature of exhaust gas	(Tg)	731.67	°C
13)	Specific heat of exhaust gas	(Cpg)	0.33	$kcal/(Nm^3 \cdot °C)$
14)	Quantity of theoretical air	(Ao)	10.897	Nm^3/Nm^3
15)	Quantity of theoretical wet exhaust	(Go)	11.951	Nm^3/Nm^3

	gas			
16)	Air ratio	(m)	1.87	
17)	Temperature of gas in furnace	(Tr)	959	°C
18)	Weight of charged steel	(Sw)	214	kg
19)	Temperature of steel before charge	(Tsa)	44	°C
20)	Heat content of steel before charge	(Hsa)	0	kcal/kg
21)	Temperature of steel heated	(Tab)	930	°C
22)	Heat content of steel heated	(Hsb)	137.3	kcal/kg
23)	Weight of tray	(Kw)	65.3	kg
24)	Temperature of tray before charge	(TKa)	44	°C
25)	Heat content of tray before charge	(HKa)	0	kcal/kg
26)	Temperature of tray heated	(TKb)	930	°C
27)	Heat content of tray heated	(HKb)	137.3	kcal/kg
28)	Surface temperature of each part of furnace			
	Combustion chamber		251.7	°C
	Side wall of heating chamber		178.0	°C
	Roof		178.0	°C
	Door		201.3	°C

(b) Heat input

1) Combustion heat of fuel (Hf)

$Hf = HI \times Ff = 9{,}003 \times 33.62 = 302{,}681$ kcal

2) Sensible heat of fuel (Qf)

$Qf = Cp \times (Tf - To) \times Ff$

$= 0.39 \times (50.97 - 41.85) \times 33.62 = 122$ kcal

3) Total heat input (Qi)

$Qi = Hf + Qf = 302{,}681 + 122 = 302{,}803$ kcal

(c) Heat output

1) Heat content of steel (Qs)

$Qs = (Hsb - Hsa) \times Sw = (137.3 - 0) \times 214$

$= 29{,}382$ kcal

2) Heat required for heating tray (Qk)

$Qk = (HKb - HKa) \times Kw = (137.3 - 0) \times 65.3$

$= 8{,}966$ kcal

3) Heat taken away by exhaust gas (Qg)

$Qg = \Sigma\ [G \times Cpg \times (Tg - To) \times Ff]$

$= 126{,}580$ kcal

4) Heat radiated from furnace (Qr)

$Qr = 46{,}770 \times 1.5 = 70{,}155$ kcal

Table 5–9–4 Heat Loss from Normalizing Furnace Surface

Part		Temperature (°C)	Surface area (m^2)	Heat loss kcal/(m^2 · h)	Heat loss (kcal/h)
Combustion room	Side, front & back wall	251.72	5.58	4,337.52	24,203
	Bottom	251.72	1.45	3,777.43	5,477
Heating room	Side, front & back wall	178.0	1.12	2,258.67	2,530
	Ceiling	178.0	4.84	2,538.43	12,286
	Door	201.27	0.80	2,841.90	2,274
	Total				46,770

5) Other heat loss (Qm)

Qm = Qi – (Qs + QK + Qg + Qr)
= 302,803 – (29,382 + 8,966 + 126,580 + 70,155)
= 67,720 kcal

6) Total heat output (Qo)

Qo = Qs + Qk + Qg + Qr + Qm
= 29,382 + 8,966 + 126, 580 + 70,155 + 67,720
= 302,803 kcal

d) Heat balance table

The above may be summarized as shown in Table 5-9-5.

Table 5–9–5 Normalizing Furnace Heat Balance

Heat input			Heat output		
Item	kcal	%	Item	kcal	%
Combustion heat of fuel	302,681	99.96	Heat content of steel	29,382	9.70
Sensible heat of fuel	122	0.04	Heat content of tray	8,966	2.96
			Heat taken away by exhaust gas	126,580	41.80
			Heat loss from furnace surface	70,155	23.17
			Other heat loss	67,720	22.37
Total	302,803	100.00	Total	302,803	100.00

Fuel consumption ratio for steel of 1 ton 1414 X 10^3 kcal/t

The results of heat balance shows that the other heat loss of the heat output accounts for as much as about 22 percent. It must be because the temperature of exhaust gas is measured too low contrasting with the furnace temperature. Of the total heat, about 65 percent is divided into the heat taken away by exhaust gas accounting for 41.80 percent and the heat radiated from the surface of furnace accounting for 23.17%. Therefore, the reduction of these heat loss is an effective means to save fuel.

(2) Improvement of air ratio for combustion

To reduce the heat taken away by exhaust gas, it is necessary to properly regulate the amount of air for combustion of fuel and to decrease the air entering the furnace.

On-off combustion system is adopted for the continuous normalizing furnace. The oxygen concentration of exhaust gas is less than 1 percent when fuel is burnt as shown in Figure 5-9-6. However, the figure shows that the oxygen concentration is abnormally so high as 18% at the maximum when the combustion is suspended because of the cool air absorbed by the furnace. In addition, the on-off frequency is very large to such an extent that the on-off operation is repeated at an interval of 1 to 2 minutes.

Accordingly, it is necessary to minimize the on-off frequency at first. The on-off frequency can be minimized by lengthening the combustion time by adjusting the fuel cock to decrease the quantity of fuel gas. However, as the burner used at present is a blast type burner that sucks the air by injecting pressurized gas, the quantity of drawn air will be reduced by lowering gas pressure if the cock is throttled. Therefore, the relation between the aperture of the throat for sucking the air and the quantity of fuel gas should be determined by the method of trial and error.

Another method is to decrease the number of burners used. The furnace burners are now installed on both sides of loading and extraction. However, as the on-off time is divided into halves, the burner capacity is considered sufficient if only one burner is used. It can be safely suggested to locate a burner on the loading side alone and suspend the combustion of the burner on the extraction side. In this case, the duct brick between the combustion chamber and heatting chamber on the loading side is sealed by about 1/3 – 1/2 of the furnace length, and the exhaust gas is discharged only from the stack on the loading side so that the loading side of the furnace can be used as a preheating zone by contacting the flame and the loaded treated material counter-currently. The on-off frequency can be minimized by doing so.

If the present air ratio of 1.87 is improved to 1.3, the amount of exhaust gas decreases by about 29 percent and the fuel consumption is reduced by 5.4 percent as shown in Table 5-9-6.

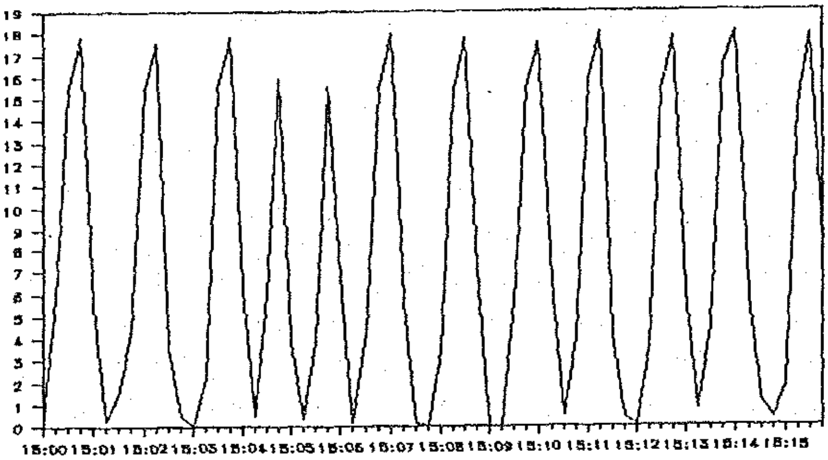


Figure 5–9–6 O_2 of the Exhaust Gas

Table 5–9–6 Reduction of the Exhaust Gas Heat Loss by improving the Air Ratio

Item	Unit	Present	Improved
Amount of oxygen in exhaust gas	%	5.46	4.85
Air ratio		1.87	1.3
Amount of theoretical combustion air	Nm^3/Nm^3	10.90	10.90
Amount of theoretical exhaust gas	Nm^3/Nm^3	11.95	11.95
Actual amount of air	Nm^3/Nm^3	20.38	14.17
Actual amount of exhaust gas	Nm^3/Nm^3	21.43	15.22
Exhaust gas temperature	°C	731.67	731.67
Heat taken away by exhaust gas	$kcal/Nm^3$	3,765	3,466

The fuel reduction rate (S) obtained by the air ratio decrease is calculated by the following equation.

$$S = 1 - \frac{Hi - Qga}{Hi - Qgi} = 1 - \frac{302,803 - 126,580}{302,803 - 126,580 \times (3,466/3,765)}$$

$$= 0.054 = 5.4\%$$

where

Hi: Amount of heat input (kcal)

Qga: Heat taken away by exhaust gas at present (kcal)

Qgi: Heat taken away by exhaust gas after improvement (kcal)

As the fuel consumption was found to be 157 Nm^3/t by the present investigation, fuel was saved by 8.5 Nm^3 per steel of 1 ton. If steel of 121.6 tons is treated annually, the amount of fuel saved is as shown below.

$$0.05\ \mathrm{U\$S/Nm^3} \times 8.5\ \mathrm{Nm^3/t} \times 121.6\mathrm{t/y} = 51.68\ \mathrm{U\$S/y}$$

(3) Strengthening of furnace heat insulation

In case that a furnace is continuously operated for a certain period of time with almost no temperature variation, a heat insulating material is generally added to the outer side of the furnace wall to reduce the heat radiated from the furnace wall. However, as it is difficult to perform the addition because the external wall is made of steel sheet, it is considered better to veneer the inner wall of the heating chamber with ceramic fiber.

(a) Improvement plan

A 50 mm thick ceramic fiber is veneered to the inner wall of the heating chamber ranging from the side wall to the ceiling above the gas distribution brick between the combustion chamber and the heating chamber. Veneering is performed by bonding a ceramic block to the existing chamotte brick with adhesion mortar. For the ceiling it is desirable to stand a stud on the existing chamotte brick to fix and support the fiber. Moreover, it is necessary to coat the ceramic fiber surface by a coating material for protection. The fixing and supporting method is shown in Fig. 5-9-7.

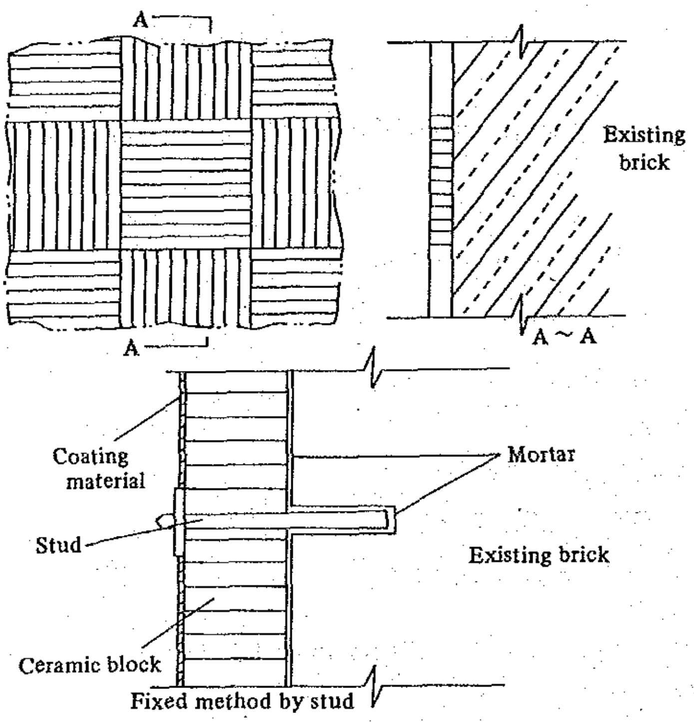


Figure 5–9–7 Veneering method

(b) Improvement effect

The radiated heat after heat insulation is estimated by the method of trial and error. The heat flux through the furnace wall (Q_1) should be equal to the radiated heat from the furnace wall surface (Q_2). Repeating calculation of Q_1, Q_2 using a probable assumed surface temperature, until Q_1 is equal to Q_2.

$$Q_1 = \frac{(t_1 - t_3)}{(l_1/\lambda_1) + (l_2/\lambda_2)} = \frac{(t_1 - t_2)}{(l_1/\lambda_1)}$$

$$Q_2 = 4.88 \times \epsilon \times [\{(273 + t_3)/100\}^4 - \{(273 + t_0)/100\}^4] + 2.8 \times (t_3 - t_0)^{1.25}$$

where

t_1 : Inner furnace wall temperature
t_2 : Temperature at the border of existing brick and ceramic fiber
t_3 : Outer furnace wall temperature
t_0 : Outside air temperature
λ_1 : Heat conductivity of ceramic fiber
λ_2 : Heat conductivity of existing brick
l_1 : Thickness of ceramic fiber
l_2 : Thickness of existing brick
ϵ : emissivity

Results of the trial calculation of the heat radiated from the furnace before and after heat insulation are shown in Table 5-9-7.

Table 5–9–7 Reduction of Heat Loss by Heat Insulation

	Surface temperature (°C)	Heat loss from furnace surface (kcal/h)
Before heat insulation	178	12,286
After heat insulation	134.1	7,223

The radiated heat is reduced by 5,063 kcal/h. When it is computed in terms of fuel on the basis of the annual operation time of 2,502 hours, the fuel decrease is 2,283 Nm³/y.

The effective heat ratio for conversion saved heat after the improvement of air ratio to fuel is used as the base. The effective heat ratio is calculated as shown below.

(1) Heating value of fuel	9,003 kcal/Nm³
(2) Sensible heat of exhaust gas	3,466 kcal/Nm³

$$\text{Effective heat ratio} = \frac{(1) - (2)}{(1)} = 0.615$$

(c) Forecasted economic effect

Price of fiber 1400 50 x 300 x 300 mm 9.5 U$S

Price of natural gas	0.05 U$S/Nm^3
Surface area of furnace ceiling	3.1 m^2
Fiber cost 9.5 x 3.1 ÷ 0.09	= 327.2 U$S
Profit 0.05 x 2,288	= 114.4 U$S/y
Cost recovery 327.98 ÷ 114.4	= 2.9 years

(4) Decrease of carrier heat capacity

In case of typical crown the carrier of 25 kg in total including one tray of 16 kg and nine separators of 1 kg is used for the treated material of 114 kg, and in case of pinion the carrier of 40.3 kg including the upper and lower trays are used for the treated material of 100 kg. The carrier weight equals to 22 – 40% of the treated material.

It is desirable to decrease the heat capacity of lightening the carrier used (for example, by changing the structure of separator to △ form structure that uses heat resisting alloy round bars).

If the carrier weight is reduced by half, the heat required for heating the carrier is 2,989 kcal/h, and the fuel can be reduced by 1,350.5 Nm^3/y when it is converted into fuel.

The fuel conversion is calculated on the basis of the effective heat ratio of 0.615.

(5) Use of heat of exhaust gas

As seen from the results of heat balance, the heat loss of exhaust gas is as large as 41.80%, and the temperature of exhaust gas is also so high as 732°C. The first method to utilize the sensible heat of exhaust gas is to use it for preheating the combustion air. However, as the burners now in use are blast type, it is necessary to introduce the preheated air by providing a wind box surrounding the burners though it is actually a little difficult to do so.

The second method is to preheat the loaded treated matter after providing a preheating room that is lined with ceramic fiber beside the existing furnace. There is an example that 2.3% of the fuel consumption was saved by preheating by the exhaust gas of about 700°C for about 25 minutes.

The third method is to use the exhaust gas for heating the washing water for surface treatment. Of the aforementioned three methods, this is the method that can be applied most easily. In this method, the heat exchanger now not in use and washing tank are connected with pipe to circulate and heat warm water.

In this case, valves should not be fitted to the outlet pipe of heat exchanger to avoid the generation of internal pressure.

5.9.3.2 Chamber Furnace

(1) Heat balance

(a) Basis of heat balance calculation

It is based on the data on 6 hours and 30 minutes from the loading at 10:47 to the finishing at 17:17 on November 16.

1)	Type of fuel		Natural gas	
2)	Fuel consumption	(Ff)	60.97	Nm^3
3)	Combustion heat of fuel (Low value)	(Hl)	9,003	kcal/Nm^3

4)	Specific heat of fuel	(Cp)	0.39	kcal/(Nm^3 . °C)
5)	Temperature of fuel	(Tf)	40.94	°C
6)	Air temperature (Basic temperature)	(To)	38.42	°C
7)	Temperature of combustion air	(Ta)	45.98	°C
8)	Specific heat of combustion air	(Cpa)	0.31	kcal/(Nm^3 . °C)
9)	O_2 (%) in dry exhaust gas	(O_2)	8.625	%
10)	CO_2 (%) in dry exhaust gas	(CO_2)	5.62	%
11)	CO (%) in dry exhaust gas	(CO)	0	%
12)	Temperature of exhaust gas	(Tg)	690.71	°C
13)	Specific heat of exhaust gas	(Cpg)	0.33	kcal/(Nm^3 . °C)
14)	Amount of dry theoretical combustion air	(Ao)	10.897	Nm^3/Nm^3
15)	Amount of theoretical wet exhaust gas	(Go)	11.951	Nm^3/Nm^3
16)	Air ratio	(m)	1.68	
17)	Amount of actual wet exhaust gas	(G)	19.35	Nm^3/Nm^3
18)	Amount of charged steel	(Sw)	364.8	kg
19)	Temperature of steel before charge	(Tsa)	41.0	°C
20)	Heat content of steel before charge	(Hsa)	0	kcal/kg
21)	Temperature of steel after heating	(Tsb)	947.42	°C
22)	Heat content of steel after heating	(Hsb)	140.7	kcal/kg
23)	Weight of tray	(Kw)	98.0	kg
24)	Temperature of tray before charge	(Tka)	41.0	°C
25)	Heat content of tray after heating	(HKa)	0	kcal/kg
26)	Temperature of tray after heating	(Tkb)	947.42	°C
27)	Heat content of tray after heating	(Hkb)	140.7	kcal/kg
28)	Surface temperature of each part of furnace			
	Side wall temperature		113.32	°C
	Back wall temperature		113.03	°C
	Ceiling temperature		163.38	°C
	Bottom temperature		187.47	°C
	Door temperature		141.57	°C
29)	Flow rate of atmosphere gas			
	Flow rate of atmosphere gas	(Fa)	32.20	Nm^3
	Flow rate of rich gas	(Ef)	3.40	Nm^3
30)	Temperature of atmosphere gas	(Tfg)	49.0	°C
31)	Specific heat of atmosphere gas	(Cpf)	0.31	kcal/(Nm^3 . °C)
32)	Furnace inside temperature after heating	(Tr)	947.42	°C

(b) Heat input

1. Fuel combustion heat (Hf)

$Hf = Hl \times Ff = 9.003 \times 60.97 = 548{,}913$ kcal

2. Sensible heat of fuel (Qf)

   $Qf = Cp \times (Tf - To) \times Ff = 0.39 \times (40.94 - 38.42) \times 60.97$

   $= 60$ kcal

3. Sensible heat of combustion air (Qa)

   $Qa = Cpa \times m \times Ao \times (Ta - To) \times Ff = 0.31 \times 1.68 \times 10.897 \times (45.98 - 38.42) \times 60.97 = 2{,}616$ kcal

4. Sensible heat of atmosphere gas (Qe)

   $Qe = Cpf \times (Tfg - To) \times Fa + Cp \times (Tf - To) \times Ef$

   $= 0.31 \times (49.0 - 38.35) \times 32.2 + 0.39 \times (40.94 - 38.35) \times 3.40$

   $= 110$ kcal

5. Total heat input (Qi)

   $Qi = Hf + Qf + Qa + Qe = 548{,}913 + 60 + 2{,}616 + 110$

   $= 551{,}699$ kcal

(c) Heat output

1. Heat content of steel (Qs)

   $Qs = (Hsb - Hsa) \times Sw = (140.70 - 0) \times 364.8$

   $= 51{,}327$ kcal

2. Heat for heating tray (Qk)

   $Qk = (Hkb - Hka) \times Kw = (140.70 - 0) \times 98.0$

   $= 13{,}789$ kcal

3. Heat taken away by exhaust gas (Qg)

   $Qg = \Sigma [G \times Cpg \times (Tg - To) \times Ff]$

   $= 289{,}596$ kcal

4. Heat taken away by atmosphere gas (Gh)

   $Qh = Cpf \times (Tr - Tfg) \times Fa + Cp \times (Tr - Tf) \times Ef$

   $= 0.31 \times (947.42 - 49.0) \times 32.20 + 0.39 \times (947.42 - 40.9) \times 3.40 = 10{,}170$ kcal

5. Heat radiated from furnace (Qr)

   $Qr = 22{,}122 \times 6.5 = 143{,}793$ kcal

Table 5–9–8 **Heat Loss from Chamber Furnace Surface**

Part	Temperature (°C)	Surface area (m^2)	Heat loss kcal/(m^2.h)	Heat loss (kcal/h)
Side & front wall	113.32	7.04	988	6,956
Back wall	113.03	2.43	983	2,389
Ceiling	163.38	2.52	2,219	5,592
Bottom	187.47	2.72	2,170	5,902
Door	141.57	0.85	1,510	1,284
Total				22,122

6. Other heat loss (Qm)

Qm = Qi – (Qs + Qk + Qg + Qh + Qr)

= 551,699 – (51,327 + 13,789 + 289,596 + 10,170 + 143,793)

= 43,024 kcal

7. Total heat output (Qo)

Qo = Qs + Qk + Qh + Qg + Qr + Qm

= 51,327 + 13,789 + 289,596 + 10,170 + 143,793 + 43,024

= 551,699 kcal

(d) The above can be summarized as shown in Table 5-9-9.

Table 5–9–9 Chamber Furnace Heat Balance

Heat input			Heat output		
Item	kcal	%	Item	kcal	%
Combustion heat of fuel	548,913	99.50	Heat content of steel	51,327	9.30
Sensible heat of fuel	60	0.01	Heat content of tray	13,789	2.50
Sensible heat of combustion air	2,616	0.47	Heat taken away by exhaust gas	289,596	52.49
Sensible heat of atmosphere gas	110	0.02	Heat taken away by atmosphere gas	10,170	1.85
			Heat loss from furnace surface	143,793	26.06
			Other heat loss	43,024	7.80
Total	551,699	100.00	Total	551,699	100.00

Fuel consumption rate for steel of 1 ton: 1,505 x 10^3 kcal/t

Results of heat balance show that the heat taken away by exhaust gas accounts for 52.49% of heat output. The decrease of the heat taken away by exhaust gas is expected a noticeable effect on fuel conservation. It can be achieved by decreasing the amount of exhaust gas or by lowering the temperature of exhaust gas. The former method requires to regulate the amount of combustion air properly, and the latter method needs to recover the heat carried by exhaust gas.

(2) Improvement of combustion air ratio

The combustion system of this furnace employs the two position combustion method for high and low. The characteristics for each combustion are shown in Figure 5-9-8. As seen from the figure, the ratio of combustion time is the repetition of 7 – 8 minutes for the low combustion and 1 minute for the high combustion. Thus, almost all the combustion time is applied to the low combustion. The oxygen concentration is 6.6% for the high combustion, whereas it is 10.8% for the low combustion. The oxygen concentration is especially high for the low combustion. Since the concentration of oxygen in exhaust gas generally considered proper for the low combustion is 5 – 6%, it is desirable to adjust the oxygen concentration to such percent. In addition, as air enters through the clearance between the lower part of the radiant tube and the burner by draft effect for both the high combustion and the low combustion, it causes the lowering of the temperature of the radiant tube and the increase of the amount of exhaust gas. Therefore, it is recommended to block up the clearance with asbestos or the like.

The average concentration of oxygen in exhaust gas is 8.63% and the air ratio is 1.68 at present. If the oxygen concentration is reduced to 5%, the air ratio will become 1.31 and the amount of exhaust gas will decrease by about 21%, contributing to the saving fuel of 25.2%.

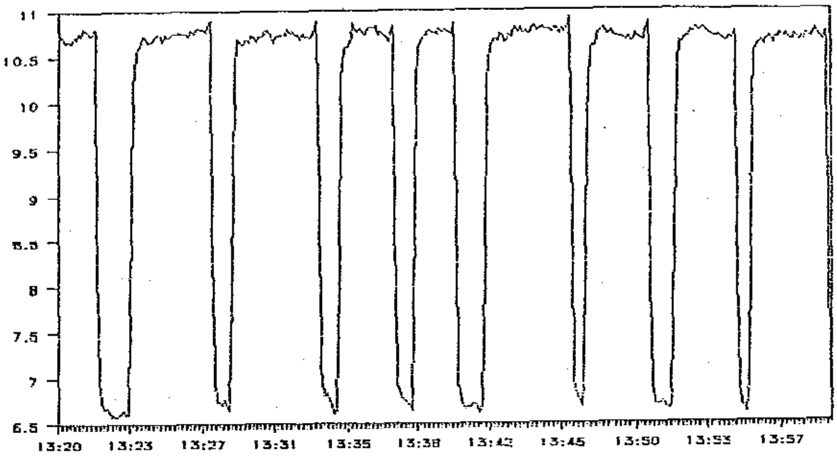


Figure 5–9–8 O_2% in the Exhaus Gas

Table 5–9–10 **Reducing the Amount of Heat Taken Away by Exhaust Gas by improving the Air Ratio**

Item	Unit	Present	Improved
Amount of oxygen in exhaust gas	%	8.63	5.0
Air ratio		1.68	1.31
Amount of theoretical combustion air	Nm^3/Nm^3	10.897	10.897
Amount of theoretical exhaust gas	Nm^3/Nm^3	11.951	11.951
Actual amount of air	Nm^3/Nm^3	18.31	14.28
Actual amount of exhaust gas	Nm^3/Nm^3	19.36	15.33
Exhaust gas temperature	°C	690.71	690.71
Heat taken away by exhaust gas	$kcal/Nm^3$	4,750	3,300

The fuel saving rate (S) obtained by the decrease of air ratio is calculated by the following equation.

$$S = 1 - \frac{Hi - Qga}{Hi - Qgi} = 1 - \frac{551{,}699 - 289{,}596}{551{,}699 - 289{,}596 \times (3{,}300/4{,}750)}$$
$$= 0.252 = 25.2\%$$

where

Hi:	Amount of heat input	(kcal)
Qga:	Heat taken away by exhaust gas at present	(kcal)
Qgi:	Heat taken away by exhaust gas after improvement	(kcal)

Because the amount of fuel used is 167 Nm^3/t, 42 Nm^3 can be saved for steel of 1 ton.

If 121.6 tons are treated annually, the amount of the saved fuel will be as shown below.

0.05 U\$S/Nm^3 x 42 Nm^3/t x 121.6 t/y = 255.36 U\$S/y

(3) Use of heat of exhaust gas

As a method to use the sensible heat taken away by exhaust gas, the heat of exhaust gas can be used for heating the washing water by providing a water tank of about 200W x 1,500L x 200H about 150 mm apart from the upper part of the radiant tubes on both sides of the furnace and connecting the tank to the washing tank for surface treatment. As the furnace operation time is limited, it is better to do so that the aforementioned continuous normalizing furnace can be used in combination.

It is also recommended to consider the employment of the radiant tubes with recuperator. For your reference, the example of the radiant tubes with recuperator is shown in Figure 5-9-9.

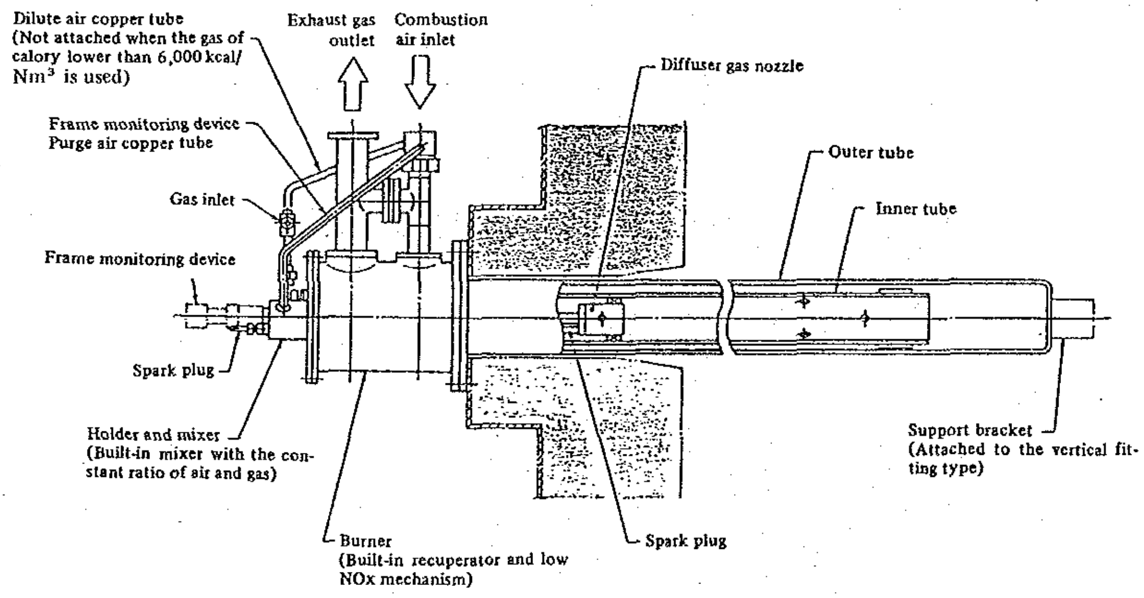


Figure 5–9–9 Radiant Tube with Recuperator

5.9.3.3 Rotary Hearth Furnace

We attended the test running of Rotary Hearth Furnace and investigated the amount of fuel used in no-load condition, the heat insulation of furnace and the combustion condition.

(1) Heat insulation effect

Results of the measurement of the furnace surface temperature are shown in Table 5-9-11. The insulation is in good order.

Table 5–9–11 Surface Temperature (°C)

Side wall					Ceiling		Bottom	
1	2	3	4	5	1	2	1	2
72.4	53.0	64.6	66.6	77.3	58.2	57.6	69.0	62.2

The door is located between 4 and 5.

(2) Combustion condition

The fuel consumption in no-load condition for the trial operation was 50.8 Nm^3/h.

For this furnace, the treated steel is heated by the heat radiated from 4 U-shaped radiant tubes, of which 2 tubes are used for the upper part and 2 tubes for the lower part. The combustion exhaust gas is forced to be discharged by the air ejector attached to each radiant tube. The measurement was made in no-load condition at the outlet of radiant tubes for the exhaust gas temperature, oxygen concentration and carbon dioxide gas concentration. The results are shown in Table 5-9-12.

As the oxygen concentration is extremely different for each radiant tube, it is necessary to adjust the amount of combustion air to keep the oxygen concentration for each radiant tube less than 4% in actual operation.

Table 5–9–12 Characters of Exhaust Gas

Part	Temperature (°C)	Oxygen concentration (%)	Carbon dioxide concentration (%)
The upper part of charging side	740	13.8	3.0
The lower part of charging side	830	2.8	9.0
The upper part of opposite side	900	5.8	7.0
The lower part of opposite side	840	8.3	6.0

5.9.3.4 Power Receiving and Distributing and Electrical Facilities

(1) Outline of power receiving facilities and load facilities

Power from the 13.2-kV enters the 315-kVA transfromer (1 unit) installed in the premises through the underground cable of about 20m and is received on the 400V side. A supply integrating wattmeter and integrating reactive wattmeter are installed at the point where power is received. At the same time, seven 30-kVA condensers are installed to improve the power factor and automatically conduct the on-off operation.

The loads are motors for lathes, grinders and air compressors, and power is distributed to 5 factories using 8 circuits.

The average power used for day time on the day of measurement (November 17) was 155-kW (peak demand of 191-kW), and the power factor was about 95%. The approximate loads for day time are 38-kW for the main factory, 30-kW and 34-kW for heat treatment and compressor respectively, and about 18-kW for polishing. However, the power factor on the load side is as low as less than 60%.

(2) Measurements

The following measurements were made using watt-power-factor meter (PFM-1000, PFMA-5210, PFM-1000P), AC clip-on power meter, 12-point recorder, and supply integrating wattmeter.

1) Load of the whole factory

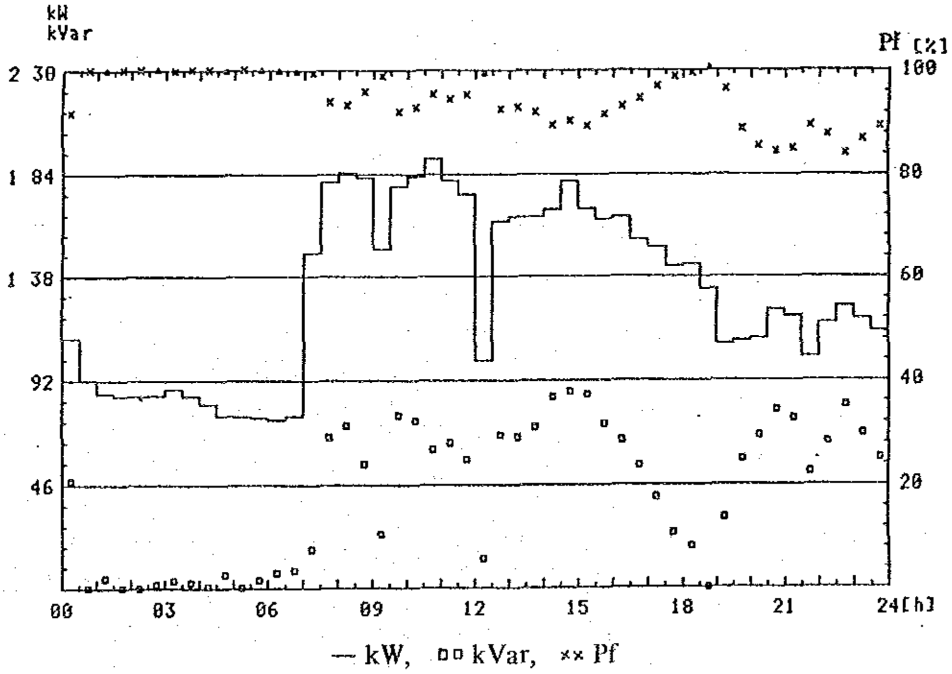
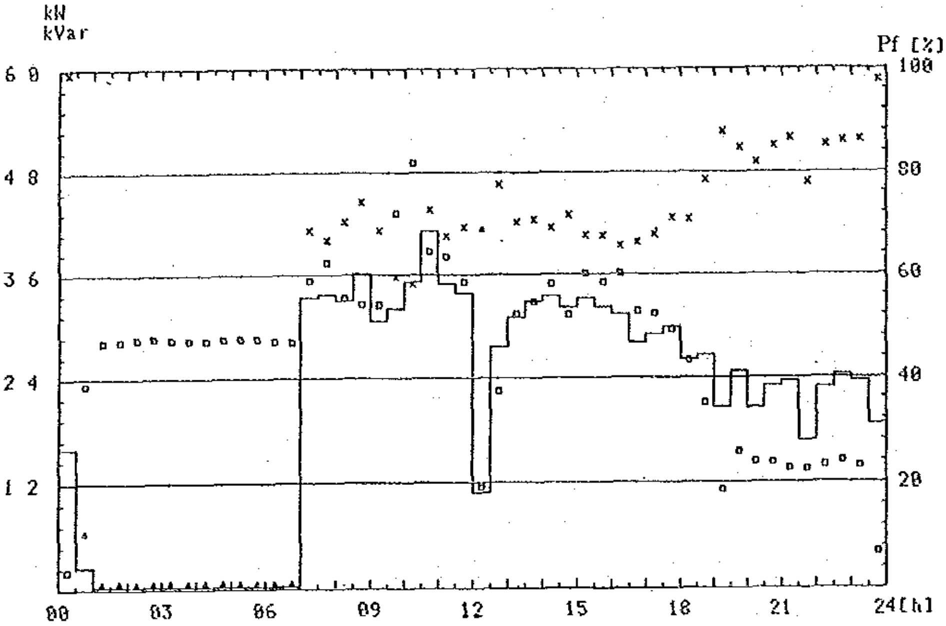


Figure 5-9-10 Total Power of Factory

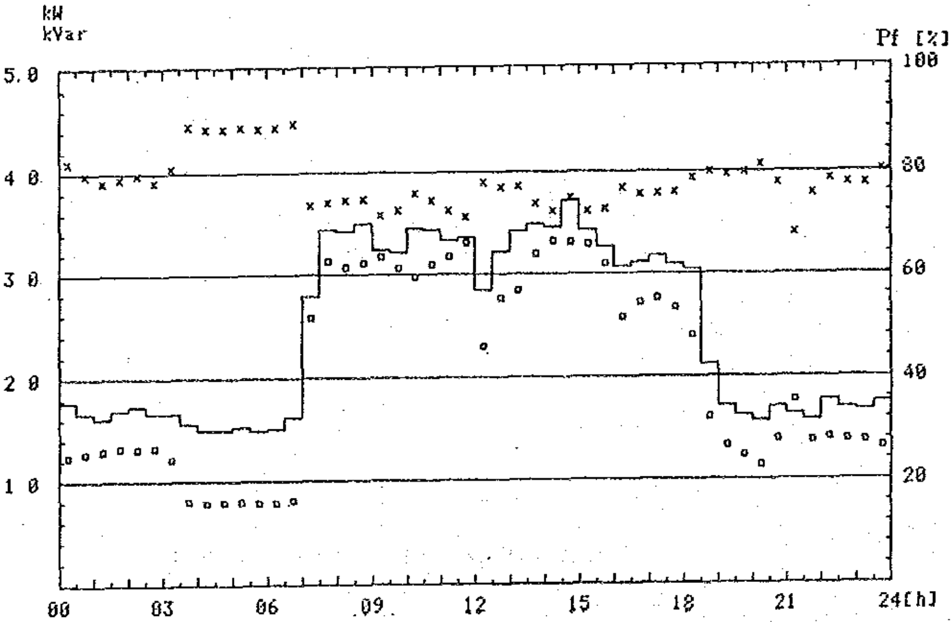
2) Load of automatic lathe circuit



1988 11 17 —— kW ▫▫kVar ×× Pf

Figure 5–9–11 Consuming Power of NC-Lathe Circuit

3) Load of compressor and small lathe circuit



— kW, ▫▫ kVar, ×× Pf

Figure 5–9–12 Consuming Power of Compressor and Small Lathe Circuit

4) Consuming power of major motors

Table 5–9–13 Consuming Power of Major Motors

Factory	For use	Rating		Actual		Load
		CV	kW(A)	kW(B)	Cos φ	(B/A×100)
Main shop	Automatic lathe				%	%
	(DF-315)	21	15.4	6.0	61	39.0
Main shop	(BANCO)	12.5	9.2	2.5	42	27.2
	universal	18.5	13.6	2.5	35	18.4
Parts shop (Line No. 5)	CFLV-250	22 kW	16.2	11	46	67.9
	OF-16	26	19.1	4.4	48	23.0
Compressor & small lathe (Line No. 6)	Rotaivo	40	29.4	29	87	98.6
	(unload)			(18)	(80)	61.2
		30	22	17.5	90	79.5
	(unload)			6	78	27.2
Grinder shop (Line No. 7)	SI4	37	27.2	2.5	35	9.2
	Sase 20002	17.1	12.6	5.8	49	46.0

(3) Power consumption

One example of the power consumption is shown in Figure 5-9-10. The power consumption for a day is about 3100- kWh, and the power factor is 95.4% on the average because a condenser is installed. As the power consumed for night is larger than half of day time, the load factor of 68.2% is relatively good. However, as the load of each factory is as shown in Table 5-9-14 and the power factor is low, the voltage drop and line loss in the factories are large.

Table 5–9–14 Load of Each Factory (1988-11-17)

Name of factory	Consuming power		Share (B/A×100)	Power factor	Remark circuit No.
	Power kW	kWh(B)			
Main	38	910	29.2	40	1, 2, 3
Heat treatment	29 (41)	700	22.4	60	4
Parts shop (Automatic lathe)	20 (41)	480	15.4	40	5
Compressor & small lathe	24 (37)	570	18.3	70	6
Grinding	12 (22)	290	9.3	40	7
Illumination	7	170	5.4		8
Total	130 (191)	(A) 3,120	100.0	95.4	

( ): Peak demand

(4) Improvement of NC machine circuit

The automatic operating condenser installed for improving the power factor of NC machine circuit is operated manually because it is likely to disturb the operation of NC machine. If it can be automatically operated, it will help to further decrease the value of reactive power (kVar). The following two causes are considered for the influence of the automatic switching of condenser given on the operation of NC machine.

a) Abnormal voltage is produced when the condenser is operated to cause the improper operation of NC machine.

b) The operating circuit of NC machine is subject to the influence of noise or voltage variation.

To cope with such situation, the following measures can be taken.

To cope with a), the reactor corresponding to 6% of the kVar of the condenser is connected in series. By so doing, it becomes possible to prevent the influece of circuit higher harmonics and suppress the rush current for operating the condenser and the abnormal voltage for cutting it off. The connection generally used is as shown in Figure 5-9-13.

The load condition of the factory shows that the load is light and the power factor is low, compared with the motor capacity. In this case, if the condenser is fitted to the operating switch of the motor located at the end of the load, the line loss will become smaller even when the voltage drops.

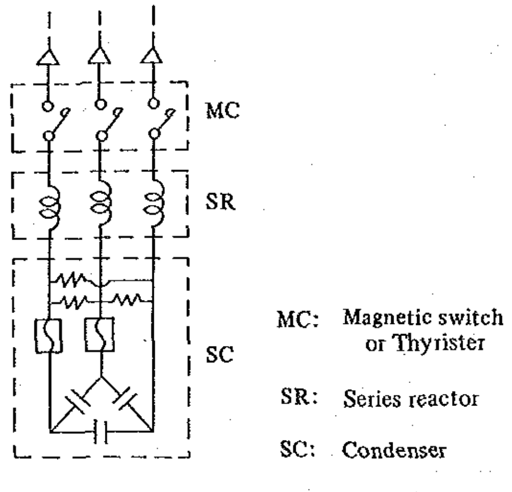


Figure 5–9–13 Connection of Condenser

The cause b) was examined, and the following results were obtained.

Even when the automatic lathe No. 21 wired with NC machine was started repeatedly (the power supply voltage decreased to about 12V), NC machine did not stop. However, when the condenser of 30 kVar wired with NC machine was set to Off, NC machine stopped (the power supply voltage increased by about 30V). The voltage variations at this time were as shown in Figure 5-9-14. The NC machine did not stop even when the same degree voltage variations were caused several times. It is therefore considered that NC machine stops due to the disorder of wave form and noise caused by the switching of the condenser, not due to the voltage variations. The following measures can be taken to solve the problem.

(1) Fitting a circuit to prevent the noises from the other line like power supply to the operating circuit of NC machine is effective.

(2) Perfect grounding of the operating circuit independently from others for preventing the variations of its electric potential.

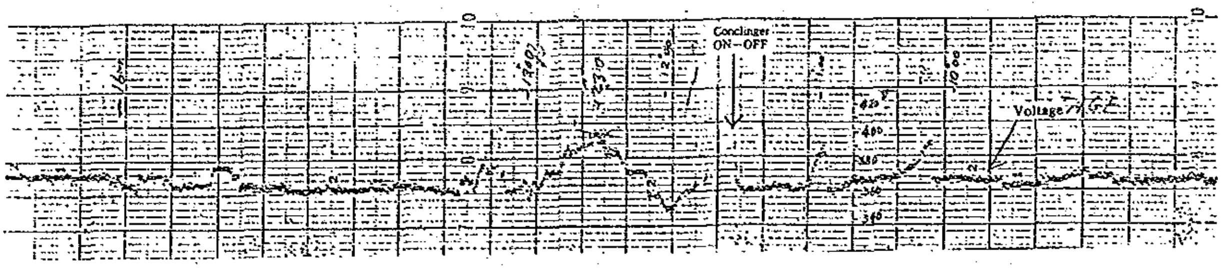


Figure 5–9–14 Variation of Source Voltage

(5) Improvement of the operating method of air compressor

The air compressor of 40 CV was operated in day time and 30 CV at night, and its pressure was 6 kg/cm². However, as the air inlet was provided close to the oil cooler, the temperature of the suction air was so high as 49°C and a part of the air leaked. Therefore, the following measure should be taken.

(a) The air inlet located in the heat blast from the oil cooler is shifted so that the air of room temperature can be sucked.

As the power required for the air compressor is proportioned to the volume of air being sucked, much more power is required when the air temperature becomes higher even if the air amount is same in standard condition.

If the suction air temperature is lowered from 50°C to 30°C, the electric power of 6.2% can be saved by the following equation.

$$\frac{273+30}{273+50} = 0.938$$

If the electric power used for the present air compressor is 28.2 kWh/h in day time and 11 kWh/h at night, the electric power can be saved annually as shown below.

$$(28.2 \times 11.5 + 11 \times 12.5) \times 0.062 \times 272 \text{ d/y} = 7{,}788 \text{ kWh/y}$$

(b) Prevention of the leakage of compressed air

The compressed air was found to leak at 3 – 4 sections. The leakage was large at the point where the pipes were connected. Some leakage was considered to be caused by the breakage of valves and the mistake in handling. Therefore, it seems necessary to avoid such a leakage in its early stage by periodical check and to train the employees for proper operation.

(6) Improvement of illumination

Incandescent lamps were used for illuminating the factory. The life of incandescent lamp is shorter than those of mercury lamp and high pressure sodium lamp, and its efficiency is less than 1/4. Therefore, it is better to change the incandescent lamps to fluorescent mercury lamps for the workshop and to high pressure sodium lamps for the warehouse. As about 40% of the lamps used in the factory was incandescent lamp, the electric power consumption for illumination can be saved as shown below if these incandescent lamps are replaced by fluorescent mercury lamps.

$$(7\ \mathrm{kW} \times 0.4) \times \frac{1}{4} \times 24\ \mathrm{h} \times 272\ \mathrm{d} = 4{,}570\ \mathrm{kWh/y}$$

5.9.3.5 Summary

The following are the effects of the aforementioned improvement that can be estimated quantitatively.

Item		Possible annual amount of saving	%
Improvement of heat treatment furnace air ratio	Gas	6,100 Nm^3	1.2
Strengthening of heat insulation of heat treatment furnace		2,300	0.5
Reduction of the weight of heat treatment furnace carrying equipment		1,400	0.3
Total		9,800	2.0
Lowering of the inlet temperature of air compressor	Electric power	7,800 kWh	1.0
Improvement of lighting		4,600	0.6
Total		12,400	1.6