## 1.3 Results of the Study at the LACZNIKOW Steel Making Factory

(1) Study period: October 16, 19 to 23, and 26, 1998

(2) Member of the study team

a. JICA Team

Mr. Yozo Takemura : Leader
Mr. Norio Fukushima : Leader of energy audit & Heat management
Mr. Seiichiro Maruyama: Process management
Mr. Jiro Konishi : Heat management
Mr. Kazuo Usui : Electricity management
Mr. Masashi Miyake : Heat management
Mr. Kiyotaka Nagai : Measuring engineering
Mr. Akihiro Koyamada : Measuring engineering

b. Local consultants: Warsaw University of Technology

Dr. Tadeusz KRUCZEK : Heat management
Dr. Krzusztof WILK : Heat management
Dr. Joachim BARGIEL : Electricity management

(3) Interviewees

Mr. inz. Roman REJMER : Deputy Director for Technical Matters
Mr. eng. Stefan SZCZYKUTOWICZ: Engineer
Mr. eng. Kazimierz NAWROT : Head of Electrical Department
Mr. eng. Piotr GRODZICKI : Leader of Electrical Group
Mr. Andrej. PROKOP : Head of Heat Department
Mr. eng. Marian ZUREK : Head of Quality Test Department

### 1.3.1 Profile of the Plant

(1) Factory name: FABRYKA LACZNIKOW

(2) Address: ul. Stalowa 3, 26-600 RADOM

(3) Number of employees: 1,088

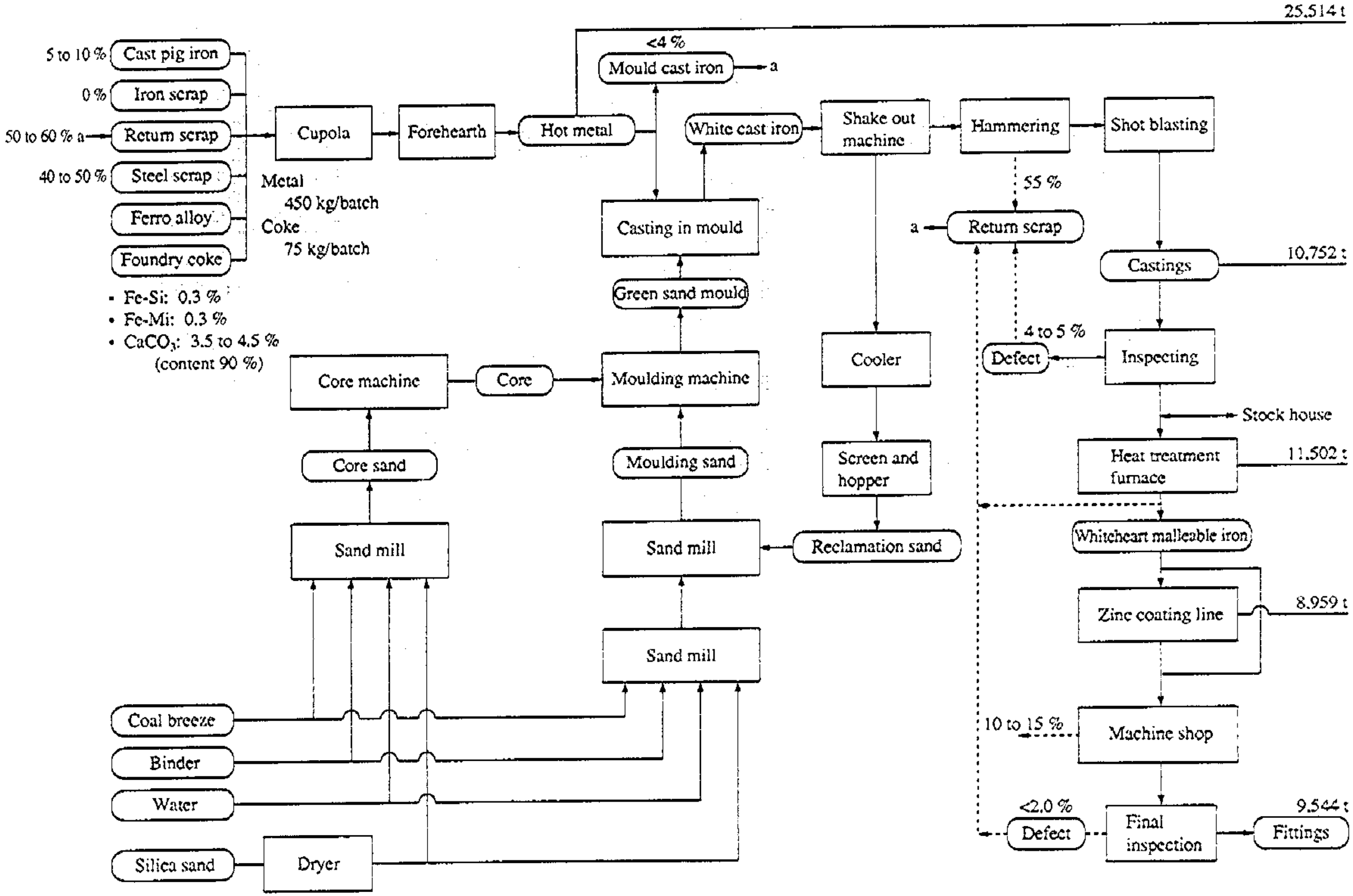
(4) Major products: Piping fittings (white-heart malleable cast iron)

(5) Production capacity: Casting capacity: 12,000 t/y (fittings products: 10,200 t/y)

(6) Process overview

FABRYKA LCZNIKOW manufactures white iron in the cupola furnace, casts it into the mold, makes white iron castings, and then decarbonizes them in the heat treatment furnace to obtain whiteheart malleable cast iron. Then, in the zinc hot dipping furnace and machining plant, necessary surface treatment and threading are performed to produce pipe fittings.
Figure 1.3.1 shows the process flow.
More than 200 types of joints including 1/2 to $4^B$ elbows, tees, sockets, nipples, etc. are being produced. This factory supplies 80 % of the total volume used in Poland.

**Figure 1.3.1 Process Flow**



## (7) Factory history and future issues

In 1963, it was determined that a pipe joint producing factory would be constructed at this location and thus a state-run enterprise was founded. Production was started in 1965. Full production (i.e. production volume equivalent to that in 1997) was reached at the end of 1970s.

When a free economy system was started in 1990, production dropped drastically. However, production was recovered in 1993 and the present production volume has been reached. Quality is improved every year. In March, 1999, certification with ISO 9002 will be obtained.

This is the only one state-run enterprise making a profit in the RADOM province. In spring of 1999, this company will be shifted to a private company. Since the demand for pipe fittings does not increase any more, production of castings for automobiles is being studied for diversified business.

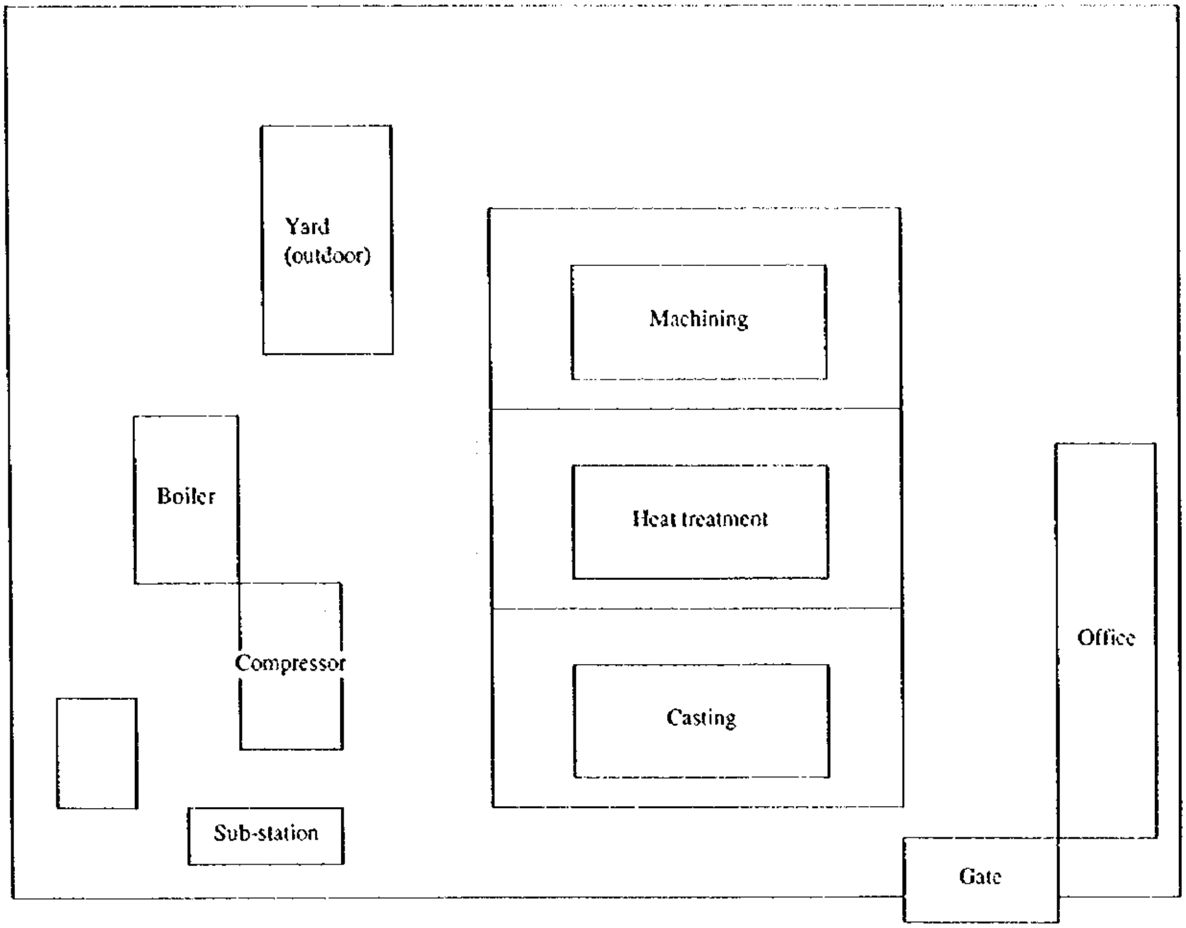
Presently, two of four cupolas are shut down. According to their plan, within five years, these two cupolas will be abolished and low-frequency induction furnaces will be installed. With present pricing, the manufacturing cost of the cupola is lower but the environment tax (emission fee), etc. may be imposed. Additionally, in their view, if various products such as casting parts for automobiles are being produced, the low-frequency induction furnace has higher availability.

As mentioned above, this factory is making a profit, supported by the employees' high morale and technology. To survive as a factory in EU after joining EU in the foreseeable future, it will be necessary to aggressively proceed with equipment modernization/ diversification (diversified products), enhancement of the anti-pollution equipment, and improvement of competitive power in costs (man-power saving, energy conservation, productivity improvement, yield improvement, etc.).
Thus, the business administration strategy should be determined, the total factory modernization plan including the profit-making plan and fund procurement plan should be prepared, and a system allowing necessary investment at a proper timing should be arranged at an earlier stage. For this factory, the issue to be solved first will be to acquire the competitiveness in costs.

(8) Plant layout

Figure 1.3.2 shows the plant layout.

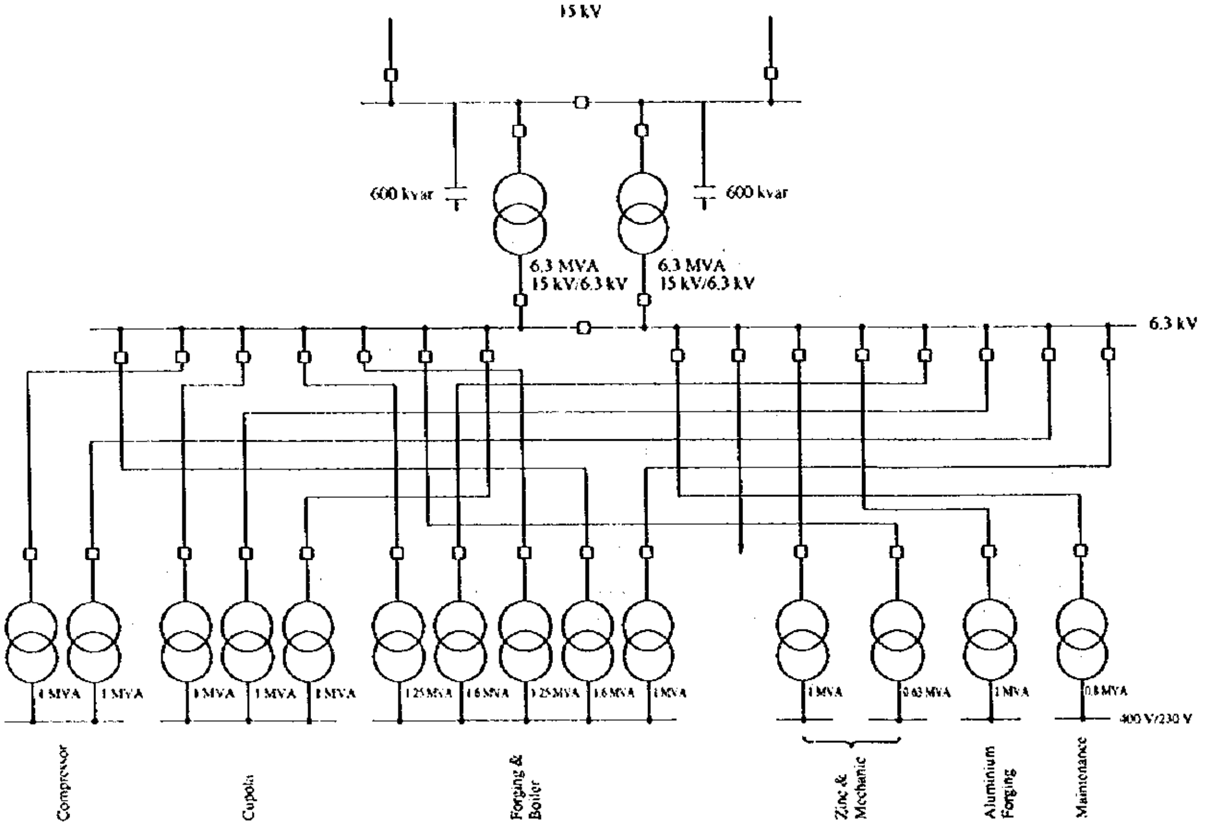
Figure 1.3.2 Plant Layout



(9) One line diagram

Figure 1.3.3 shows the electricity one-line diagram.

**Figure 1.3.3 Electricity One Line Diagram**



(10) Overview of major equipment

Table 1.3.1 Major Equipment

| Process | Equipment | Unit | Specificaition |
|---|---|---|---|
| Melting and casting | Cupola | 4 | Inner diameter 1,000ϕ, 7.5 t/h unit<br>Hot blast, water cooled |
| | Forehearth | 4 | 2 t/unit |
| | Pouring ladle | 5* | 180 kg/unit * in operation |
| Moulding | Moulding machine | 2 | 200 sets/h unit, DISAMATIC |
| | | 1 | 1,000 sets/7.5 h, Manual squeeze |
| | Core machine | 6 | Hot box method, COREBELTER |
| | Sand mixer | 2 | 90 t/h unit |
| Finishing of casting | Shake out machine | 3 | |
| | Shot blast machine | 1 | |
| Heat treatment | Furnace | 10 | Resistance heating, 360 kW/unit<br>0.333 t/h unit |
| Zinc coating | Zinc plating bath | 4 | Resistance heating, 110 kW/unit |
| Machining | Thread cutter | 200 | |
| Utilities | Main transformer | 2 | 15 kV/6 kV, 6.3 MVA/unit |
| | Air compressor | 7 | 200 kW, 33 $m^3$/min × 0.68 MPa, Reciprocating |
| | Boiler | 4 | 5 Gcal/h each, hot water, coal combustion stoker type |
| | Boiler | 2 | 163 kW/each, oil combustion |

(11) Energy price and heat value

Table 1.3.2 lists the energy price and heat value.

**Table 1.3.2 Energy Price and Heat Value**

| Energy | Price | Heat value |
|---|---|---|
| Coke | 370 PLN/t | 33,494 MJ/t |
| Electricity | 161 PLN/MWh | 10,258 MJ/MWh |
| Heavy oil | 690 PLN/kL | 33,900 MJ/kL |
| Coal | 161.24 PLN/t | 23,848 MJ/t |

### 1.3.2 Energy Consumption Status

#### (1) Trend of production

Production in each year of past five years is approximately the same. Table 1.3.3 lists the trend of production.

**Table 1.3.3 Trend of Production**

| Products | Unit | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|
| Hot metal | (t) | 26,990 | 25,313 | 26,541 | 26,732 | 25,514 |
| Castings | (t) | 10,588 | 9,835 | 10,680 | 10,300 | 10,752 |
| Fittings | (t) | Lack | 9,092 | 9,216 | 8,985 | 9,544 |

#### (2) Trend of energy consumption

Table 1.3.4 shows energy consumption in 1993 through 1997.

**Table 1.3.4 Trend of Energy Consumption**

| Energy | Unit | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|
| Coke | (t) | 4,566 | 4,644 | 5,597 | 5,546 | 5,333 |
| Electricity | (MWh) | 27,096 | 25,864 | 17,250 | 26,509 | 27,963 |
| Heavy oil | (kL) | 0 | 131.6 | 144.1 | 99.3 | 172.8 |
| Coal | (t) | 4,190 | 2,940 | 2,475 | 5,462 | 3,250 |

#### (3) Trend of energy intensity

Energy intensity in each year, excluding 1996, is approximately the same. Table 1.3.5 lists energy intensities in 1993 through 1997.

**Table 1.3.5 Trend of Energy Intensity**

| Energy | Unit | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|
| Coke | (GJ) | 152,934 | 155,934 | 187,466 | 185,758 | 178,624 |
| Electricity | (GJ) | 277,951 | 265,313 | 279,531 | 271,929 | 286,844 |
| Heavy oil | (GJ) | 0 | 4,461 | 4,885 | 3,366 | 5,858 |
| Coal | (GJ) | 99,923 | 70,113 | 59,024 | 130,258 | 77,506 |
| Total energy | (GJ) | 530,807 | 495,433 | 530,905 | 591,311 | 548,832 |
| Energy intensity | (MJ/t) | – | 54,491 | 57,607 | 65,811 | 57,505 |
|  | (Mcal/t) | (–) | (13,015) | (13,759) | (15,719) | (13,735) |

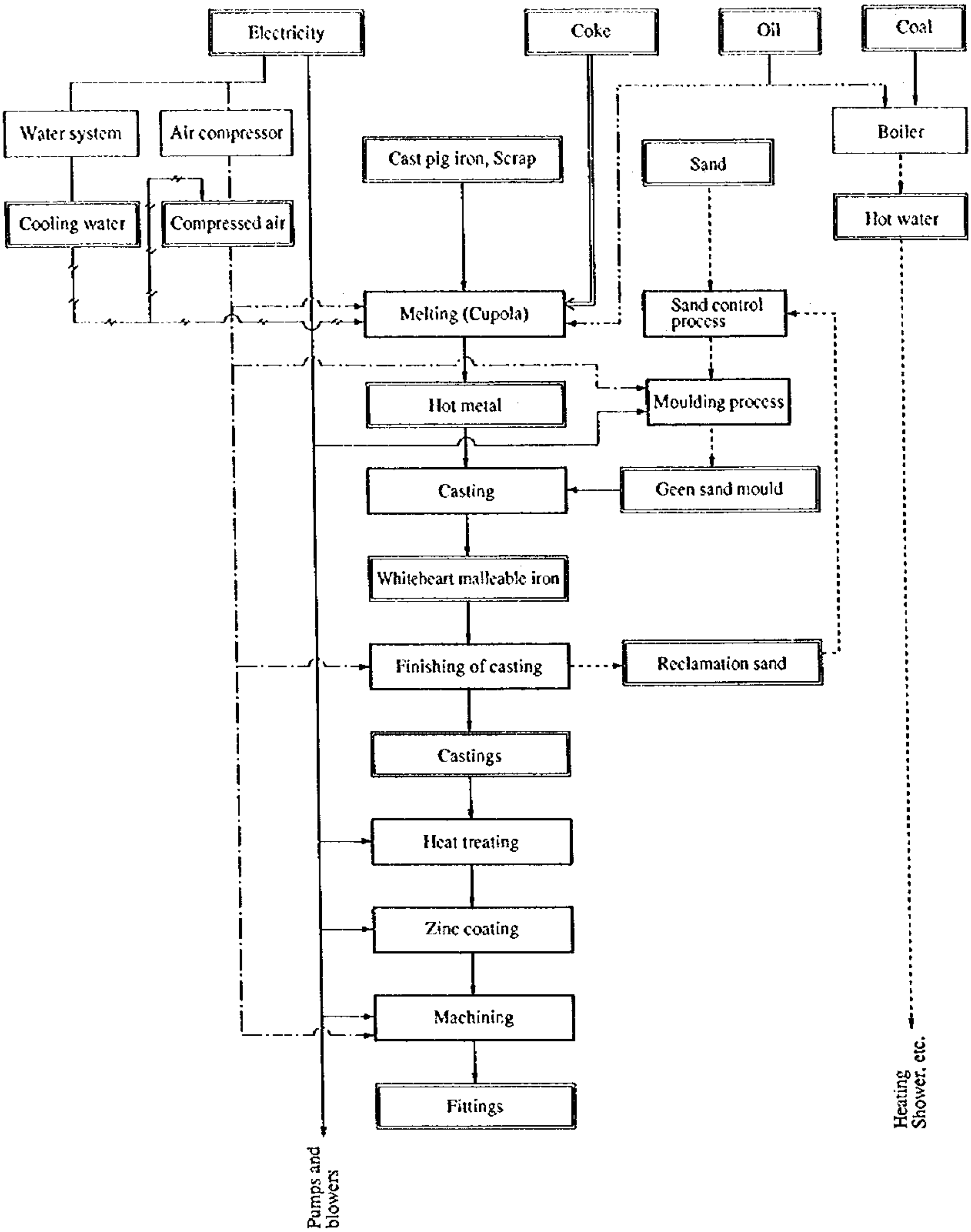
(4) Percentage of energy cost in manufacturing cost

Approximately 10 %

(5) Energy flow

Electricity (52 %), coke for casting (33 %), and coal (14 %) account for a major proportion of the purchased energy. Additionally, fuel oil (1 %) is purchased. In the foundry plant, cupolas are used in the melting process which consumes a largest amount of energy and the major energy source is foundry coke. A large amount of electricity is used for machining, air compressors, motors driving fans and pumps, and other purposes. Among equipment using a large amount of electricity other than the rotating machines, there are the heat treatment furnace adopting the heating method with electric resistance and the zinc hot dipping bath. Figure 1.3.4 shows the energy flow.

Figure 1.3.4 Energy Flow



### 1.3.3 Current Situation of Energy Management

(1) Setting the target for energy conservation

a. Setting the target value

As the goal in 1999, a 5 % reduction of electricity used by the heat treatment furnace and air compressors has been determined. This goal will be made known to every employee.

This company collects improvement plans from employees at the beginning of each year. Top managers including the president and the personnel in charge select about 90 best plans, determine the improvement plans and improvement goals, and implement them accurately. Approximately 10 % of them may not be brought into effect in the year but they are implemented in the next year. A board indicating the implementation status of improvement proposals is installed in the president's room.

b. Issues in promoting energy conservation

Top managers understand that the first problem is that they cannot grasp the actual status because there are few meters for measuring energy consumption. Installation of watt meters has been preferentially implemented since about 3 years ago and their installation has been completed at 70 % of locations requiring the meters.

Top managers of this company are very positive for energy conservation but it seems that personnel who will become the company's brain are insufficient. Therefore, for a company like this that is enthusiastic for energy conservation, the following technical support will bring about a great effect:

1) Preparation of a master plan for energy conservation (All feasible energy conservation subjects are selected to obtain the energy conservation amount and required investment amount, and to determine the priority order for implementation.)

2) Operation improvement (cooperation for establishing the energy conservation oriented operating method)

3) Preparation of the executive plan for the energy shift plan (The cost performance and operation risk for each process are analyzed and the energy shift executive plan for the factory is prepared.)

(2) Systematic activities

a. Establishment of a section dedicated to energy conservation

Although a dedicated section is not available, the director charged with engineering leads the related sections in the top managers meeting to promote the energy conservation activities.

b. Establishment of the energy conservation committee

The officials meeting and top managers meeting function as the energy conservation committee. Its promoter is the director in charge of engineering.

c. Stance of top managers

Cost reduction is considered to be the top priority issue in business administration and energy conservation takes precedence in cost reduction. To promote energy conservation, participation by all people in the company is considered important. Therefore, the improvement proposal system is introduced.

d. Personnel evaluation system

There is no system that reflects energy conservation activities on personnel evaluation. However, energy conservation proposals (improvement proposals) are implemented. If a proposal is adopted and implemented, a bonus is given to that person. Managers are highly evaluating this system.

(3) Data-based management

a. Grasping the energy consumption

They have grasp of energy consumption.

b. Grasping the energy consumption by each major equipment

They keep track of consumption of electricity, coke, and coal for each major equipment. Although they know the amount of energy (e.g. electricity) used to manufacture compressed air, cooling water, and hot water (for living purposes such as heating, shower, etc.), there is no meter used to distribute such energy to each destination. Therefore, energy is distributed in percents predetermined based on the design value.

c. Grasping energy intensity of major products

For major products, they have grasp of each energy intensity by process.

d. Installation of meters

Coke, coal, and fuel oil : Meters installed for each equipment using such energy.
Electricity : Meters installed for each major equipment. There are many meters installed.
Compressed air and cooling water: Meters not installed.
Hot water : Production volume meter only installed.

e. Production management and cost management

Production management and cost management are performed.

f. Comment by top managers

Watt meters meters have been installed for each component since a few years ago and analysis of electricity consumption is allowed. Upon this field investigation, we found that we would be able to calculate the energy conservation potential. Therefore, we would like to utilize the performance data when examining energy conservation measures.

(4) Training of employees

a. Commendation system

If an improvement proposal is adopted and implemented, a bonus is supplied.

(5) Plant engineering

a. Scheduled maintenance system

Equipment maintenance is performed systematically. No large accident has occurred during normal operation.

b. Equipment maintenance status

There are many old types of equipment but they are maintained well. The inside of the factory is cleaned well. Since "the basics of maintenance is cleaning", the cleaning campaign is promoted aggressively.

### 1.3.4 Problems and Countermeasures Related to Energy Use

#### (1) Comparison of energy intensity with the excellent foundry

The energy intensity in a foundry largely varies depending on the type, size (weight per piece of product) and product specification (material, etc.) of the product manufactured. Another factor greatly affecting the energy intensity is the weight ratio between the molten metal and product, that is, product yield. If large castings are produced, the product yield reaches approximately 90 %. If small castings such as pipe joints are produced, the product yield drops to approximately 40 %.

For pipe joints produced at LCZNIKOW, the material is white-heart malleable cast iron. Since the amount of reduction in casting is large and fluidity of the molten metal is low, approximately 40 % is required as the head volume. As a result, the product yield becomes extremely low. Additionally, the product unit weight is 100 g minus to hundreds of grams, furthermore threading is performed in finishing them and therefore approximately 10 % of the product is cut and removed, thus further decreasing the yield. Consequently, the energy intensity per product ton becomes very bad.

Although there is no factory producing the products with the same product specification in Japan, several factories are manufacturing products with similar size/quality. Table 1.3.6 lists comparison with energy intensities of these factories. Comparison of the total energy intensity in the melting and heat treatment processes that account for 55 % of energy consumption shows a 32 % difference.

For LACZNIKOW, it is presumed that the energy conservation potential corresponding to this value is 32 %.
18,211 ÷ 57,505 × 100 = 32 %

Table 1.3.6 Comparison of Energy Intensity

| | Gross (MJ/t-final products) | | | | Melting only | Heat treatment only |
|---|---|---|---|---|---|---|
| | Total | Melting | Heat treatment | Others | (MJ/t-hot metal) | (MJ/t-castings) |
| Lacznikow | 57,505 | 19,560 | 11,979 | 25,967 | 7,317 | 9,940 |
| Excellent factory | 39,294 | 13,863 | 6,278 | 19,153 | 5,345 | 5,087 |
| Difference | 18,211 | 5,697 | 5,701 | 6,813 | 1,972 | 4,853 |

#### (2) Estimating the energy conservation potential

Energy conservation steps are categorized into:
First step : Management enhancement
Second step: Equipment improvement
Third step : Process improvement

### A. Processes

Table 1.3.7 lists the processes in this factory in decreasing order of net energy consumption.

**Table 1.3.7 Energy Consumption by Process**

| Process | Production | | Energy consumption | | | | |
|---|---|---|---|---|---|---|---|
| | Products | (t, GJ) | Coke, Coal (t) | Electricity (MWh) | Fuel oil (kL) | Total (GJ) | Share (%) |
| Melting (Cupola) | Hot metal | 25,514 | Coke 5,333 | 466.8 | 96.3 | 186,677 | 34.0 |
| Heat treatment | Cast products | 11,502 | – | 11,145 | – | 114,325 | 20.8 |
| Boiler | Hot water | 61,120 GJ | Coal 3,250 | 186 | 76.5 | 82,007 | 14.9 |
| Machining | Fittings | 9,544 | – | 3,852 | – | 39,514 | 7.2 |
| Zinc coating | Cast products | 8,959 | – | 3,235 | – | 33,185 | 6.0 |
| Casting | Castings | 10,752 | – | 3,116.4 | – | 31,906 | 5.8 |
| Air compressor | Compressed air | – | – | 2,650 | – | 27,184 | 5.0 |
| Others | – | – | – | 3,311.8 | – | 33,972 | 6.2 |
| Total | | | Coke 5,333<br>Coal 3,250 | 27,963 | 172.8 | 548,832 | 100.0 |

a. Cupola

Since LACZNIKOW performs independent melting in cupolas but the excellent factory uses a system of combining the cupola and low-frequency induction furnace, comparison and examination will cover also the low-frequency induction furnace.

a1. Difference due to external factors

Both LACZNIKOW and excellent factory produce white iron which is said to be hard to cast in terms of fluidity and reducibility. In both factories, the casting temperature is at least 1,430 °C and therefore there is no significant difference in melting and casting.

For the operation time, the cupolas in LACZNIKOW are run with two shifts (16 hours) but the cupola in the excellent factory is run for 16 to 20 hours. Therefore, there is a slight difference.

Particularly for LACZNIKOW, operation is performed every day by switching to a new furnace, and thus energy loss is larger.

a2. Difference due to technical factors

1) Comparison of the energy intensity for melting in the cupola (coke ratio)

Table 1.3.8 lists comparison of the cupola coke ratio in 1997 with that in the excellent factory (including electricity for the low-frequency induction furnace). If energy intensity in the excellent factory (4,454 MJ/t) is converted into a coke ratio, it is 133 kg/t. Therefore, the difference between both is 76 kg/t as a coke ratio.

**Table 1.3.8 Comparison of Cupola Coke Ratio**

| | Unit | Laczníkow | Excellent factory |
|---|---|---|---|
| Coke ratio | kg/t-hot metal | 209 | 110 |
| Electricity | kWh/t-hot metal | – | 75 |
| Total | MJ/t-hot metal | 7,000 | 4,454 |

2) Factor causing the coke ratio difference

We observed the operation in LACZNIKOW and investigated the operation index. (See Table 1.3.9.) As a result, we found that there was a large difference in the coke ratio. As a result of survey, the following factors are considered:

① High-temperature tapping

Normally, 50 °C to 80 °C temperature drop occurs until the molten metal is poured into the mold after tapping. If the casting speed does not match the tapping speed, the difference can be absorbed by the forehearth to a certain degree but temperature drop occurs in this case.

The excellent factory has a large low-frequency induction heat holding furnace and the necessary temperature can always be held. Therefore, the cupola can perform tapping at approximately a constant speed and a constant temperature (approximately 1,500 °C). In contrast, LACZNIKOW has a small forehearth but does not have the heat holding function, and thus tapping from the cupola is performed at higher temperatures (1,500 to 1,550 °C) compared with the excellent factory.

② Keeping the bed coke height at a higher position

To maintain the maximum tapping volume and the tapping temperature at 1,500 to 1,550 °C, the bed coke height is 2 m, which is higher than the standard, and the charged coke ratio is 167 kg/t in operation.

In-furnace exhaust gas analysis for the cupola (CO and $CO_2$) exhaust gas temperature distribution measurement, and in-coke moisture analysis are not performed.

If the bed coke is made too high, the preheating zone height reduces. Therefore, the exhaust gas temperature rises, the CO content increases, and cupola's heat efficiency drops. Although the CO content prevents oxidization of Si and Fe in the cupola, there is almost no iron oxide that results in reducing reaction. Therefore, it is not necessary to increase the CO content in the exhaust gas than required. The CO content is generated by the following reaction, which consumes coke and moreover is an endothermic reaction. In other words, if CO is too much, coke charged into the cupola is not effectively utilized. Therefore, exhaust gas analysis, silicon loss calculation, in-coke moisture measurement, etc. should be carried out on a regular basis to precisely grasp the cupola's running status. Also, the operation should be managed so that the inside of the cupola will always be maintained in good status (e.g. optimum bed coke height).

$$C + O_2 \rightarrow CO_2 + 409 \text{ MJ/kmol}$$
$$CO_2 + C \rightarrow 2CO - 157 \text{ MJ/kmol}$$
$$H_2O + C \rightarrow CO + H_2 - 123 \text{ MJ/kmol}$$

③ Adjustment of the tapping volume

Since the forehearth is small, the blast volume is dropped and the tapping volume is reduced during the period between the first and second shifts and the break time in late afternoon.

In this case, the molten metal is reddish. The tapping temperature is obviously lower.

④ Switching from a cupola to another cupola every day

Switching from a cupola to another is performed every day. On the other hand, the furnace is repaired only once a week in the excellent factory. Some foundries perform switching from a furnace to another once a month.

⑤ Large silicon (Si) loss

Silicon loss is large considering that the Si level is low in spite of charging of FeSi (3 kg/t), higher bed coke and tapping temperature. Silicon loss is not so large during normal operation. However, silicon loss sometimes becomes larger due to heat loss caused by furnace switching in units of 16 hours and the worsened cupola furnace status. Therefore, it is presumed that silicon loss is large on an average.

## Table 1.3.9 Comparison of Cupola Operation Index

| | Unit | Laczników | Excellent factory |
|---|---|---|---|
| Capacity | t/h | 7.5 | 12 |
| Actual tapping | t/h | 7 ~ 8 | 8 |
| Charge cast iron | % | ≒10 % | ≒10 % |
| Tapping temperature | °C | 1,500 ~ 1,550 | 1,500 |
| Casting temperature | °C | > 1,430 | > 1,430 |
| Annual coke ratio | kg/t | 209 | 110 |
| Charge coke ratio | kg/t | 167 | 100 |
| Fine coke injection | kg/t | not installed | (12*) |
| Hot metal | | | |
| Chemical composition | [C] % | 2.7 ~ 3.15 | 2.1 ~ 3.3 |
| | [Si] % | 0.4 ~ 0.85 | 1.5 ~ 2.0 |
| | [Mn] % | 0.4 ~ 0.7 | 0.3 ~ 0.5 |
| | [S] | 0.25 maximum | ≒0.14 |
| | [P] | 0.15 maximum | |
| Blast temperature | °C | 300 ~ 350 (recuperator) | 350 (light oil combustion) |
| $CO/CO_2$ measurement | | No | once every 30 minutes** |
| $CO/CO_2$ meter | | not installed | not installed |
| Si loss | % | 15 | 20 ± 5 |
| Slag | kg/t | 20 | 20 |
| Cupola rotation | | every day | every week |
| Operation hour | | 2 shifts (16 th) | 2 shifts (20 h) |
| Cupola inner diameter | mm | 1,000 | 1,400 |
| No. of cupola tuyeres | | 5 | 6 |
| Forehearth and hoding furnace | t | 2 | 15<br>(low freqency induction furnace) |
| Pouring ladle capaciy | kg | 180 | 900 |

Note * : (* 12 kg/t)fine coke injection is included in charge coke ratio.

**: In case of abnormal condition, once every 15 minutes.

### 3) Estimating energy efficiency of the cupola system during normal operation

#### ① Heat balance of the cupola

Heat radiation loss, exhaust gas heat loss (exhaust gas sensible heat and latent heat), and heat loss caused by cooling water were investigated. An attempt was made to measure exhaust gas (temperature, $CO_2$ content, etc.) by using the carbon balance method and $N_2$ balance method to examine how to reduce the coke ratio in the cupola. However, there was no location where measurement could be performed in a safe status; therefore scheduled data could not be obtained sufficiently.

However, the following facts were found:

- The cupola blower was run with the specified capacity and the blast flow meter was normal.
- The blast temperature was approximately in a level of 340 °C, which is rather high. The recuperator maintains the performance within the design value range.
- The exhaust gas temperature of the cupola is 700 °C, which is slightly high. The reason is that the bed coke height is 2 m and the preheating zone in the cupola is relatively about 1 m shorter.

#### ② Estimating heat efficiency of the cupola system with the simplified method

- Heat retained in the hot metal

  The contents of the hot metal are assumed as listed below based on the document on past performance. The heat retained in the hot metal (1 ton) is 1,367 MJ/t at 1,500 °C, and 1,405 MJ/t at 1,550 °C.
  The heat value of each element used in this calculation is shown in the column at right.

| Chemical composition | | Heat content (MJ/t) | | Heat capacity (MJ/t) | | |
|---|---|---|---|---|---|---|
| | | 1,500 °C | 1,550 °C | 1,400 °C | 1,500 °C | Δ |
| [Fe] | 95.5 | | | 1,249 | 1,321 | 72 |
| [C] | 3.0 | | | 2,232 | 2,430 | 198 |
| [Si] | 0.7 | | | 3,039 | 3,147 | 108 |
| [Mn] | 0.6 | | | 1,310 | 1,390 | 80 |
| [S] | 0.2 | | | 932 | 1,004 | 72 |
| Total | 100 | 1,367 | 1,405 | – | – | – |

(UNIDO: Seiminar Text)

- Volume of carbon transferred to the hot metal

  The carbon balance was calculated by using data of the charged material and hot metal contents. As a result, it was found that the amount of in-coke carbon transferred to the hot metal was approximately 11 kg/t.

- Oxidizing heat of Si, Mn, Fe, etc.

  Normally, oxidizing heat of Si, Mn, Fe, etc. is 3 to 5 % of the coke heat value in the cupola. This value is assumed to be 3 %.

- Heat input during normal operation of the cupola: $Q_I$

  $Q_I = 1.03 \times (\text{Coke ratio} - 11) \times (\text{LHV of coke}) = 1.03 \times (172 - 11) \times 29$
  $\fallingdotseq 4{,}809$ MJ/t
  where
  172: Coke intensity (kg/t) per ton of hot metal during normal operation
  LHV: Lower heat value

- Heat efficiency of the cupola system

  $$n = \frac{1{,}405}{Q_I} = \frac{1{,}405}{4{,}809} \fallingdotseq 29\ \%$$

4) Analysis of the cupola coke ratio difference

The annual coke ratio obtained by dividing the annually purchased coke volume in LACZNIKOW by the volume of hot metal produced is 209 kg/t-hot metal.

On the other hand, the ratio of coke charged into the cupola during normal operation is as follows. Coke breeze is not blown into the cupola but sold to the outside at a low price or used for the boiler.

One-day average charged coke ratio: 180 kg/t (186 kg/t-hot metal)
Charged coke ratio during operation: 167 kg/t (172 kg/t-hot metal)
Note: The value in ( ) was calculated on the assumption that the cupola's metal loss was 3 %.

In contrast, the lump coke ratio in the excellent factory is 100 kg/t-hot metal (110 kg/t-hot metal if both lump coke and coke breeze are included). The reason of this difference was examined based on the experience of engineers in LACZNIKOW and performance data reported in the Japan's casting industry.

① Loss caused by switching from a cupola to another every day: loss of coke ratio (17 kg/t-hot metal)

The difference (14 kg/t) between the coke ratio during operation (172 kg/t-hot metal) and one-day average coke ratio (186 kg/t-hot metal) is considered to be an apparent loss caused by switching from a cupola to another every day. However, heat accumulation loss occurs until the cupola refractory temperature reaches the constant level after cupola switching. Therefore, part of charged coke during operation is consumed to compensate for this heat accumulation loss. The loss caused by switching from a cupola to another every day is 14 + $\alpha$kg/t.

The coke loss caused by shutdown and repair of the cupola once a week in the excellent factory is approximately 2 to 3 kg/t-hot metal. Therefore, if this loss is applied to LACZNIKOW where furnace switching is performed every day, the loss is presumed to be 10 to 15 kg/t-hot metal. However, LACZNIKOW keeps the bed coke height at 2 m, and therefore the volume of coke discharged during shutdown increases and the loss is presumed to be 15 to 20 kg/t-hot metal. Thus, the loss was estimated at 17.0 kg/t-hot metal as an intermediate value.

The results are summarized below.

a) Coke loss caused by switching from a cupola to another every day: 17.0 kg/t-hot metal
b) Volume of coke used after switching and before initial tapping (including the bed coke): 14.0 kg/t-hot metal
c) Heat corresponding to the remaining 3 kg/t is supplied from coke during operation (172 kg/t-hot metal): 3.0 kg/t-hot metal

[Reference]

Heat loss caused by switching from a cupola to another every day is presumed as follows:

- Bed coke waste loss: Bed coke volume: 900 kg
  One-day tapping volume: 100 t
  900 kg/d ÷ 100 t/d = 9.0 kg-coke/t-hot metal

- Heat loss for reheating the bed coke
  : Carbon (C) heat capacity: 2,430 MJ/t
  LHV of C: 29 MJ/kg
  Heating efficiency: 70 %
  0.009 t/t × 2,430 MJ/t ÷ 0.7 ÷ 29 MJ/kg = 1.1 kg-coke/t-hot metal

- Heat loss for heating the replaced refractory

  : Replaced amont: 3 t
  Specific heat: 1.17 MJ/t°C
  Thermal efficiency: 70 %

  3 t/100 t × 1.17 × (1,300 – 20) ÷ 0.7 ÷ 29 = 2.2 kg-coke/t-hot metal

As a result, the subtotal is 12.3 kg-coke/t-hot metal

- Heat accumulation loss of the refractory

  Amount of refractory not replaced in the cupola: 20 t
  Average temperature rise of refractory: 200 °C → 750 °C
  Specific heat: 1.17 MJ/t·°C

  20 t/100 t × 1.17 (750 – 200) ÷ 29 = 4.4 kg-coke/t-hot metal

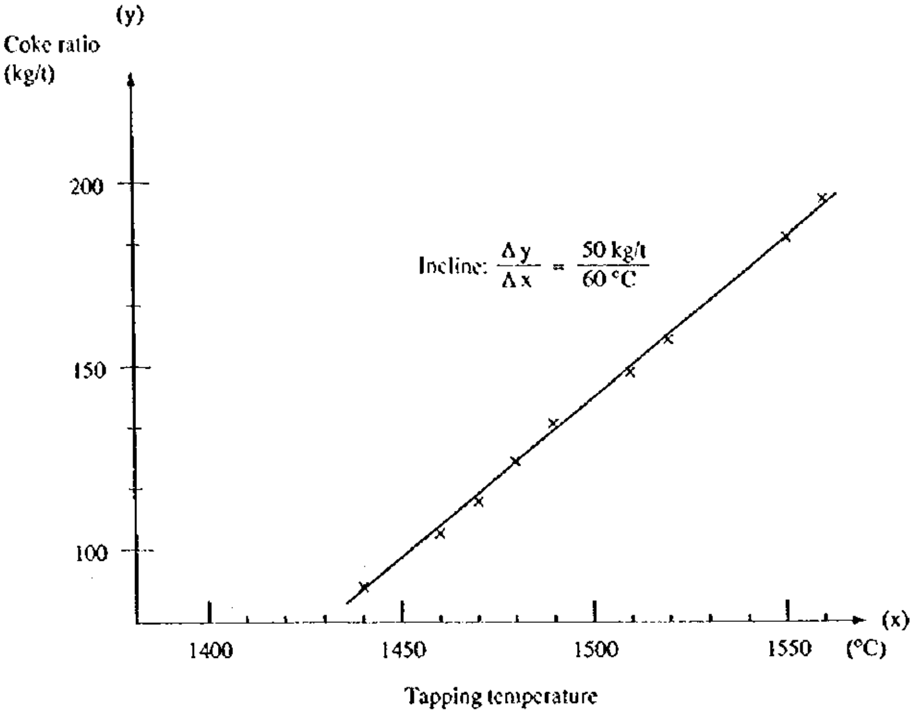
According to these calculations, the coke loss caused by switching from a cupola to another every day is at least 16.7 kg/t.

② Effect of high-temperature tapping

Figure 1.3.5 shows the relationship between the targeted tapping temperature and coke ratio on the assumption that the cupola inside diameter (inner capacity) is constant (Castings Handbook (1986) Maruzen, Japan). In other words, the coke ratio should be increased by 50 kg/t to make the tapping temperature rise by 60 °C.

On the other hand, it is said that the coke ratio drops by 20 kg/t if the tapping temperature drops by 30 °C according to the experience of LACZNIKOW. This matches the result in Figure 1.3.5. The hot metal temperature in LACZNIKOW is 1,530 °C on an average, which is 30 °C higher than 1,500 °C in the excellent factory, and therefore the effect of the increase in the coke ratio is presumed to be 25 kg/t-hot metal.

Figure 1.3.5 Coke Ratio vs Tapping Temperature



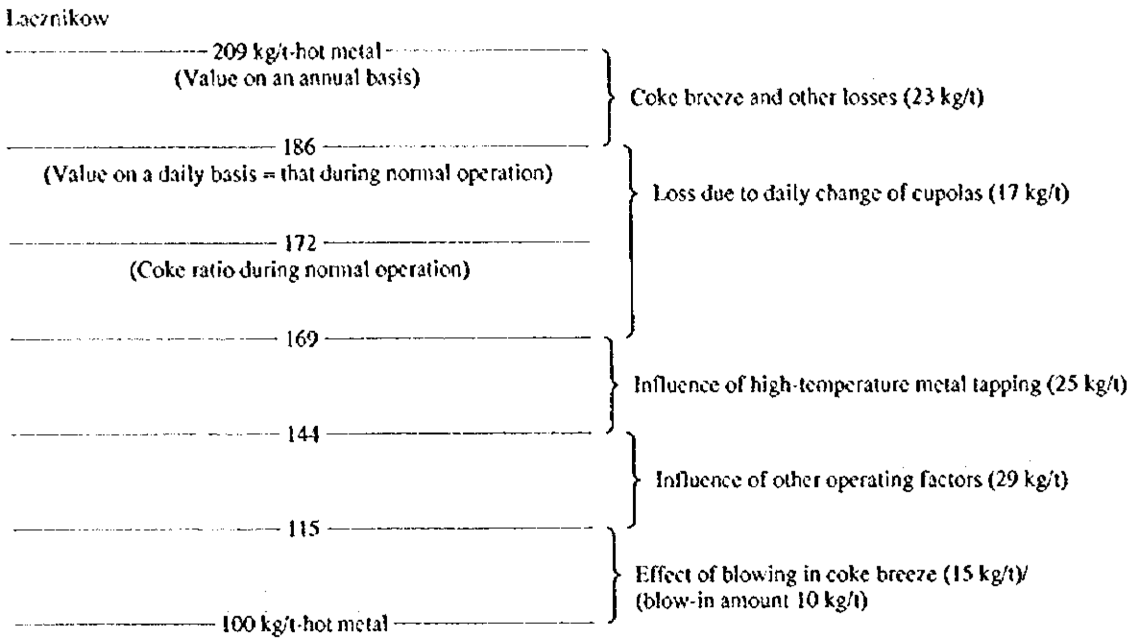
Source: Castings handbook (1986), Maruzen, Japan.

③ Effect of injecting coke breeze: 15 kg/t

According to the performance in the excellent factory, the lump coke can be reduced by 15 kg/t if coke breeze (10 kg/t) is injected.

The result of examination described above is shown in Figure 1.3.6. In Figure 1.3.6, the effects (29 kg/t) of other operation factors are the effect caused by keeping the bed coke high, the effect of in-coke moisture, etc., as mentioned in item ② of section 2), and they may be reduced by improving the operation.

**Figure 1.3.6 Difference of Coke Ratio between Laczniknow and Excellent Factory**



Excellent factory (lump coke intensity)

(Note) Metal yield of cupola is supposed to be 97 %, and coke ratio 167 kg/t calculated based on charged coke is converted to 172 kg/t-hot metal.

5) Relationship between the operation time and energy conservation measures

When various types of equipment are being examined to select a production process, the "operation time" is an important factor. Similarly, when energy conservation measures are being compared and examined, the "operation time" is an important factor. In LACZNIKOW, two-shift operation is basically maintained for the cupolas. The coke ratio reduction measure for the cupola greatly depends on whether the two-shift operation is continued or the melting, casting, and molding sections are put into three-shift operation (i.e. 3-shift operation in weekdays but no operation on Saturdays and Sundays).

① Case of two-shift operation

The cupolas are (consuming about 1/3 of energy in LACZNIKOW) suitable for continuous operation. As the continuous operation is maintained longer, the energy conservation effect increases and economy is improved. However, if the current two-shift operation is to be continued, energy conservation measures following this policy should be considered. As a result of surveying this factory, the following four plans are regarded as the improvement measures: (One of these plans should be implemented.)

a) Energy conservation measures should be promoted while the current process is basically maintained.
Example: Extending the furnace life by improving the refractory, injecting coke breeze, etc.

b) A low-frequency induction furnace should be newly installed as a holding furnace, to modify process for the double melting system with the cupola plus low-frequency induction holding furnace.

c) The cupolas should be abolished. The process is changed into the double melting system with the rotating oxy-fuel furnace plus (low-frequency induction holding furnace).

d) The cupolas are abolished. The process is changed into the double melting system with the high-frequency induction furnace plus low-frequency induction holding furnace.

Table 1.3.10 shows a simple comparison among the energy costs of these processes. For reference, the energy intensity when the cupolas are run in 3-shift operation is also shown.

## Table 1.3.10 Comparison of Melting Process Energy Cost

| | | Energy cost | Yield improvement | Energy consumption per ton-hot metal | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | (PNL/t-hot metal) | (PNL/t-final product) | Energy intensity (MJ/t) | Electricity (kWh/t) | Coke (kg/t) | Natural gas ($m^3{}_N$/t) | |
| Existing | Cupola | 81 (100 %) | ○<br>(base) | 7,205 (100 %) | 20 | 209 | - | |
| a | Cupola | 75 (93) | | 6,687 (93) | 25.0 | 192* | - | Coke breeze injection<br>$O_2$ enrichment to hot blast |
| b | Cupola + Holding Furnace | 65 (80) | | 5,592 (78) | 75.0 | 144** | - | 50 kWh/t: For holding |
| c | Rotating Oxygen-fuel Furnace + Holding Furnace | 91 (112) | | 6,308 (88) | 100.0 | - | 147 | 75 kWh/t: For heating up and holding |
| d | Induction Furnace + Holding Furnace | 97 (120) | | 6,155 (85) | 600 | - | - | 50 kWh/t: For holding<br>550 kWh/t: For melting |
| e | 3-shift operation<br>Cupola + Holding Furnace | 54 (67) | | 4,719 (66) | 29 | 132*** | - | |

Note 1: Operating condition: a ~ d: 16 h/d, continuous tapping 7 t/h
e: 24 h/d, continuous tapping 5 t/h

Note 2: Energy price and equivalent heat value

| Energy | Electricity | Coke | Natural gas |
|---|---|---|---|
| Price | 0.161 PLN/kWh | 0.37 PLN/kg | 0.51 PLN/$m^3{}_N$ |
| Equivalent heat value | 10.258 MJ/kWh | 33.494 MJ/kg | 35.93 MJ/$m^3{}_N$ |

Note 3: Rotating Oxygen-fuel furnace natural gas consumption of 147 $m^3{}_N$/t includes energy consumption of oxygen production. The oxy-fuel furnace consumes 77 $m^3{}_N$ of natural gas and 174 $m^3{}_N$ of oxygen per tonne.

Note 4: In future cupola electricity intensity will increase by about 30 kWh/t for pollution control measures.

Note 5: Induction furnace (for reference)
High frequency, 2 × 5 t, tap-to-tap time: 65 minutes (Melting: 53 minutes, Loss time: 12 minutes), 14 ch/d × 2 (maximum)
Low frequency, 1 × 7 t, 400 kW

Note *: Coke ratio $= (186 - 15) \times \frac{209}{186} = 192$

Note **: Coke ratio $= (186 - 15 - 25 - 15 - 3) \times \frac{209}{186} = 144$

Note ***: $(186 - 15 - 25 - 15 - 3 - 11) \times \frac{209}{186} = 132$

According to this comparison table, it can be seen that a) or b) is an attractive plan. However, depending on progress of diversified management or changes of economic situation, c) or d) may become feasible. Therefore, sufficient examination should be performed to adopt a plan that will not result in double investment.

[Supplementary note -- 1]

For plan d) two high-frequency furnaces are also considered. In this case, since the tapping speed of the high-frequency furnace must be equivalent to the speed of casting into the mold, the furnace capacity increases if 7.5 t/h should be secured. LACZNIKOW plans production of castings other than pipe joints. Various types of hot metal should be produced in the high-frequency furnace at high speed. Hot metal for pipe joints should be received by the low-frequency holding furnace and tapping should be performed at 1,500°C according to the casting speed.

[Supplementary note -- 2]

Plan c):
More than 150 rotating oxy-fuel furnaces are running in Western Europe. The construction cost is lower than 1/2 of that of the high-frequency furnace with the equivalent capacity (including the power supply equipment). Only a few operators are enough to run this furnace and the labor load is small. It is easy to stop/shut down the furnace, and therefore this furnace is suitable for two-shift operation. However, metal loss is large (approximately 7 %).

② Case of three-shift operation

In this factory, the heat treatment furnace and zinc hot dipping bath run in three-shift operation. The molding and casting lines run in two-shift operation. The cupolas are run in two-shift production operation (16 hours). However, the operators work in three-shift operation for preparation of furnace switching and new furnace startup.

Considering that the excellent factory with the equivalent production is operated by about 150 workers, it can be said that there may be plenty of room for man-power saving for LACZNIKOW. Therefore, man-power saving for the melting/casting section including the molding and casting lines should be rapidly implemented and the melting, molding, and casting lines should be changed into the three-shift operation system by using the excess personnel. As a result, the coke ratio of the cupola can be greatly improved (by approximately 77 kg/t).

When changing into this system, it is recommended that the following equipment investment be performed as well. The coke ratio reduction effect (77 kg/t) described above includes these improvement effects:

- High-class refractory should be used in the cupola to extend the furnace life.
- The forehearth should be replaced with a 7 t/h low-frequency induction furnace or channel type induction heating furnace and the ladle should be made larger. With this improvement, production variation is absorbed and drop of the molten metal temperature is prevented.
- Installation of the coke breeze injecting unit
- Oxygen enrichment for blasting

6) Measure for reducing the cupola's coke ratio

In Poland, coke is inexpensive and the energy cost per ton of hot metal is 83 PLN/t (approximately 3,400 yen/t) which is low. The annual cost is approximately 2,115 × $10^3$ PLN/y (approximately 87 million yen/y). If it is assumed that this energy cost can be reduced by 25 % through equipment investment and the payback period is 5 years, the permissible investment amount is calculated to be 2,600 × $10^3$ PLN (about 108 million yen). This value will be a reference for investment.

① Installation of a holding furnace

Hot metal produced in LACZNIKOW is so-called "white iron", whose viscosity is high. Therefore, this hot metal should be cast into the mold at a temperature of 1,430 °C or higher. Various temperature dropping factors exist during cupola operation as described below. Various actions such as increasing the bed coke level and making the tapping temperature higher, are taken so that any situation can be accommodated.

- Because of the relationship with the casting speed, the production volume and tapping speed are reduced (i.e. blast volume reduction). Blast volume reduction relatively increases the heat emission heat value and decreases the tapping temperature.

- After blast volume reduction or upon startup in early morning, the molten metal temperature is lower and the ladle temperature is not sufficiently high. Therefore, a temperature drop of hot metal in the ladle further increases.

If a heat holding furnace with a proper size corresponding to the operation is available, it is possible to absorb variation of the casting speed, cupola operation is stabilized, and the bed coke level can be made lower. If the molten metal temperature drops during casting, the molten metal can be returned to the holding furnace and reheated. Therefore, the hot metal yield (casting amount ÷ hot metal production volume) is improved and the product quality is stabilized.

[Effect]

Since the molten metal temperature can be adjusted in the heat holding furnace if the heat holding furnace is provided, it is not necessary to force the molten metal temperature to rise in the cupola.

Therefore, it is possible to make the temperature of molten metal produced in the cupola drop to 1,500 °C as the level in the excellent factory. Furthermore, variation of the casting speed, etc. can be absorbed with the heat holding furnace, the cupola can maintain production of the constant volume and the operation is stabilized.

According to the performance in LACZNIKOW, chemical contents of the hot metal are within the standard range and there is no quality problem even though the tapping temperature is down to 1,500 °C.

- Reduction of the coke ratio : Drop of the tapping temperature to 1,500 °C: 25 kg/t
  : Reduction of coke loss upon cupola switching: 3 kg/t
  (Bed coke height reduction: –0.8 m)
  Operation improvement in ② (expected effect): 15 kg/t
- Reduction of molten metal loss: 2.5 % (currently approximately 4 %)
- Defective product reduction : 2.5 % (currently approximately 5 %)

This effect represented by the energy intensity per ton of product is ▲5,388 MJ/t.

[Specifications of the heat holding furnace]

Effective capacity

- Capacity : 7 t × 1 set (1 set for 2 cupolas)
- Type : Crucible type low-frequency furnace (or channel type furnace)
- Electric capacity : 400 kW/set (or 300 kW/unit)
- Electricity intensity required for holding: 40 kWh/t (channel type furnace)
  50 kWh/t (low-frequency furnace)

For the capacity of the heat holding furnace, usually a furnace with a capacity equivalent to the cupola capacity to approximately twice larger is installed. To achieve the measured mentioned in ⑤, a capacity that is twice larger than the cupola capacity is desirable. However, 7 t is recommended from the viewpoint of cost performance.

② Improvement of cupola operation: 15 kg/t

If the heat holding furnace is installed, the cupola can perform tapping approximately at a constant speed. Reheating can be performed with the heat holding furnace even though the tapping temperature temporarily drops. In other words, conditions allowing the cupola's features to be exhibited to the maximum are provided. Therefore, the coke ratio can be improved to the level of the excellent factory through operation improvement. According to Figure 1.3.6, the improvement potential through operation improvement is 29 kg/t, and thus improvement by 15 kg/t will be possible.

In addition to the tapping temperature and molten metal components, the following items are provided as cupola control items:

- Si loss
- Analysis of CO and $CO_2$ in exhaust gas
- Measurement of exhaust gas temperature distribution
- Blast volume and blast temperature
- Moisture in blast
- Moisture in coke
- Blast pressure
- Speed of hot blast through the tuyere

To proceed with operation improvement actually, it is first necessary to obtain and analyze the performance data. The following cases are provided as improvement examples:

- By repairing air leak through the flange of the tuyere, the melting speed was improved by 8 %.

- To prevent unevenness of the height of the charged material, a movable material distribution plate was installed, in-furnace gas distribution was made uniform, and the melting speed was increased to reduce the coke ratio.

- The height of the charged material was increased (i.e. the height of the preheating zone was increased) to reduce the coke ratio.

- The tuyere sleeve was attached at the end of the tuyere so that the speed of blast into the furnace could be kept constant even though the blast volume changes and that the coke ratio could always be kept in a low level.

- Based on two types of data, i.e., vertical temperature distribution of gas in the preheating zone and silicon loss, a method of estimating the bed coke height was elaborated. The bed coke height was adjusted at an earlier stage, fluctuation of the molten metal temperature was reduced, and foundry defects were reduced.

- Based on data such as $CO/CO_2$ and exhaust gas temperature distribution, software for judging the furnace status was developed. With stabilized operation of the cupola, the coke ratio was reduced.

③ Measures for reducing moisture in coke

Moisture in coke reacts with coke in the cupola and results in heat absorbing reaction.

$$H_2O + C \rightarrow CO + H_2 - 123 \text{ MJ/kmol}$$

Therefore, moisture in coke is reduced by 1 % (10 kg-moisture/coke), the amont of reacting coke is reduced by 6.7 kg and the amount of coke compensating for an endothermic reaction is reduced by 4.2 g. The coke ratio is totally reduced by 10.9 kg/coke/t-hot metal. Therefore, in coming one year, moisture in purchased coke should be measured upon purchasing. Moisture in coke stored in the outdoor stockyard and moisture in coke immediately before charging should be measured about once a week. It is recommended that the following measures be taken according to the measurement result:

a) If moisture in purchased coke is always low:
The indoor stockyard should be selected to prevent increase of moisture.

b) If moisture in coke before charging is at least 1 % lower than coke in the outdoor stockyard:
The period of storing indoors should be increased.

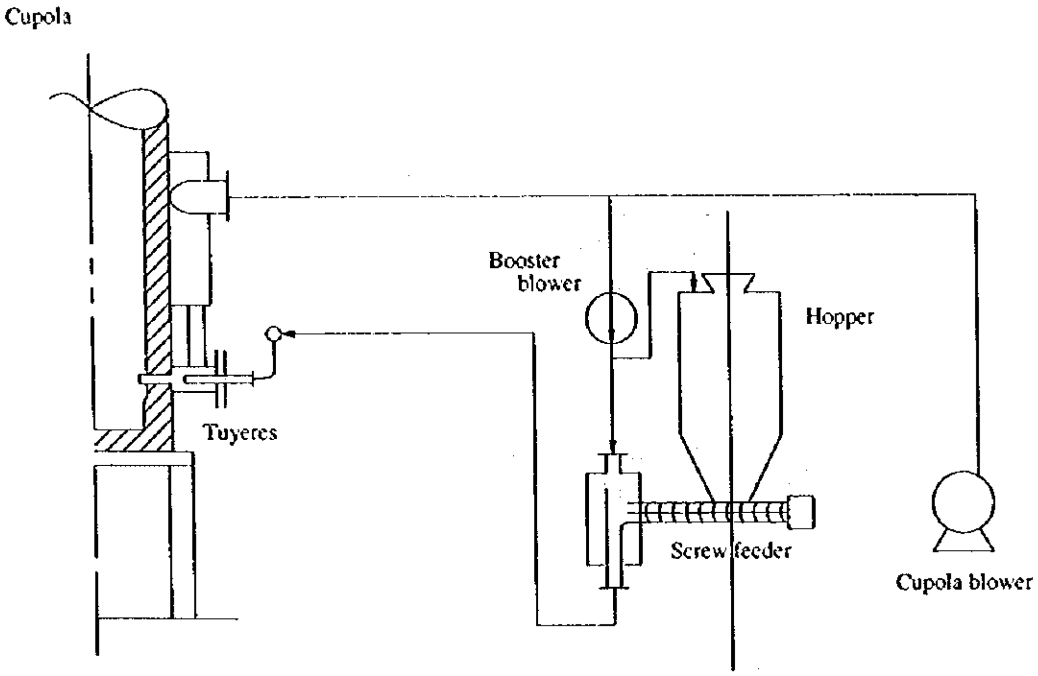
c) If moisture in coke before charging is 3 % or over:
An action should be taken to increase the amount of charged coke according to the moisture volume for correction.

④ Coke breeze injecting equipment

The effects of coke breeze injection are the rise of the molten metal temperature, increase in the tapping capacity, and coke ratio reduction. (Blowing 10 kg/t improves the coke ratio by 15 kg/t.)

Since the cupolas in LACZNIKOW are running with upper limits of their capacity, this equipment should be installed.
Figure 1.3.7 shows the flow sheet of the coke breeze injecting equipment.

**Figure 1.3.7 Flow Diagram of Coke Breeze Injection System**



⑤ Shifting to cupola switching once a week

LACZNIKOW is planning to replace the furnace side wall refractory with high-quality refractory having a life of 3 to 4 weeks to reduce the labor load. In this case, if the bottom refractory is also replaced with refractory having a life of 1 week, cupola switch once a week is enabled.

a) For three-shift operation:
Shifting to furnace switching once a week is easy. As a result, the coke volume used can be reduced by 11 kg/t per 1 ton of hot metal.

b) For two-shift operation:

As the operation method for 8 hours in the nighttime, the banking method or the method of repeating blast and blast stop can be considered. If the capacity of the heat holding furnace is 7 t, it is hard to adopt the method of repeating blast and blast stop. (Generally, the blast stop time should be within 4 hours to prevent consolidation of the melting material in the furnace. If blast is stopped for 4 hours and operation is performed for the remaining 4 hours by reducing the production volume to 50 %, the capacity of the heat holding furnace should be at least 15 t.) Procedure of banking method is to melt all metal charged into the furnace, to discharge all through the drain hole, to block the tapping hole, to stop blast, and to bake coke to maintain the cupola. The excellent factory has experienced this method but LACZNIKOW has not used this method. Therefore, LACZNIKOW should originally develop the techniques.

⑥ Enrichment of oxygen for blasting

LACZNIKOW has already implemented hot blasting. If oxygen enrichment is implemented in addition to hot blasting, the coke ratio will be reduced by 10 kg/t for 1.5 % of oxygen enrichment according to the performance in excellent factory. However, such improvement brings about few investment merits.

However, oxygen enrichment provides secondary effects such as 16 % increase of the melting capacity and 15 °C rise of the tapping temperature in addition to reduction of the coke ratio. The excellent factory implements oxygen enrichment only at the initial stage of operation as a means of allowing the tapping temperature to rise to the specified temperature shortly upon operation startup. Therefore, although LACZNIKOW uses methods such as increasing the bed coke height as a means of allowing the tapping temperature to rise shortly upon cupola operation startup or upon increasing blast volume after blast volume reduction operation, implementation of oxygen enrichment is recommended instead.

⑦ Automation of the molding line (man-power saving)

People in LACZNIKOW say that the molding line is the bottleneck of this factory's production capacity. In the molding plant, three of four lines have already been automated. Therefore, if the remaining one line can be automated, man-power saving and enhancement of the production capacity can be achieved at the same time. With automation of this line, molten metal tapped from the cupola can be treated in a short period, production drop during lunch break and the period between shifts is reduced, and conditions allowing the cupola to maintain a stable production volume are made available. Therefore, the result of automating existing lines should be evaluated at an earlier stage. It is recommended that automation be implemented at an earlier stage if merits are provided, for stabilized operation of cupolas.

⑧ Three-shift operation of melting, molding, and casting: 11.2 kg/t

As mentioned in Item ② of 5) the cupolas can exhibit their features to the maximum if three-shift operation is possible. Therefore, energy saving operation is allowed.

[Effect]
If it is assumed that the measures in b) of Item ① are implemented, the incremental effect is reduction of coke loss upon furnace switching. In other words:

$$(17-3)-\frac{17-3}{5}=11.2\text{ kg/t}$$

b. Heat treatment furnace

Since the energy intensity in the heat treatment furnace plant largely depends on the product manufactured (material standard and weight), it is hard to presume the energy conservation potential by simply comparing the intensities.

Therefore, the theoretically required energy intensity is calculated and compared with the intensity in actual operation and then the energy conservation potential is presumed by analyzing the difference. Further, if energy is converted, the cost and energy intensity can be improved. Therefore, this should be added.

1) Theoretical energy intensity (theoretical electricity intensity)

To estimate energy that is theoretically required by the heat treatment process, the energy is obtained through theoretical calculation or the required energy intensity is presumed by analyzing data in actual operation. By using these two methods, the energy intensity was obtained to estimate a theoretical energy intensity of 240 kWh/t.

① Method using calculation

- Heat value contained in pipe joints:
  1,000 kg × 0.67 kJ/kg°C (1,020 – 25) ÷ 3,600 kJ/kWh = 185.2 kWh/t

- Heat value contained in baskets:
  185.2 × 0.15 = 27.8 kWh/t

- Heating the ambient gas
  Air : 27 $m^3{}_N$/t × 1.41 kJ/$m^3{}_N$°C (1,020 – 25) ÷ 3,600 kJ/kWh = 10.5 kWh/t
  Steam: 15 kg/t × 2.13 kJ/kg°C (1,020 – 80) ÷ 3,600 kJ/kWh = 8.3 kWh/t
- Reaction heat of ambient gas

$H_2O + C \rightarrow CO + H_2 - 123$ MJ/kmol
+ 0.833 kmol × 123 MJ/kmol ÷ 3.6 MJ/kWh = 28.5 kWh/t

$CO + \frac{1}{2}O_2 \rightarrow CO_2 + 283$ MJ/kmol
– 0.208 kmol × 283 MJ/kmol ÷ 3.6 MJ/kWh = –16.4 kWh/t

Total: 243.9 kWh/t

[Supplementary note]

Components of ambient gas are as follows:
$[CO]/[CO_2] = 2.7 \sim 4.1$, $23\% < [CO] < 31\%$, $7\% < [CO_2] < 10.5\%$
$[H_2O]$: 25 % ~ 35 %
$[CH_4]$: ≒ 1.2
$[N_2]$ : Remaining (≒ 27)

② Method of estimation using field investigation data

Table 1.3.11 summarizes data of the study conducted in Poland on October 21.

**Table 1.3.11 Measuring Data of Heat Treatment Furnace**

| Furnace No. | Power consumption (kWh/h) | Radiation heat loss (kWh/h) | Amount of treatment (t/h) |
|---|---|---|---|
| No. 6 | 200 | 138.8 | 0.250 |
| No. 7 | 225 | 148.6 | 0.286 |

Date of measurement: October 21, 11:30 to 12:30.

The theoretical electricity intensity was obtained by using the following formula and the result is shown in Table 1.3.12:

Theoretical electricity intensity = Electricity intensity – Heat radiation loss (kWh/t) – Other losses (kWh/t)

As shown in Table 1.3.12, heat radiation loss accounts for a major portion of heat loss of the heat treatment furnace. Other losses include heat emission from the opening generated when the material to be heat-treated is carried into and taken out from the furnace, emission of ambient gas, etc. As a result of watching the worksite, it was found that this volume was very small. Therefore, it is assumed that other losses are 2.5 % of the electricity amount loaded.

**Table 1.3.12 Estimation of Theoretical Energy Intensity on Measuring Data**

| Furnace No. | Theoretical energy intensity (kWh/t) | Radiation heat loss (kWh/t) | Other losses (kWh/t) | Electricity intensity (kWh/t) |
|---|---|---|---|---|
| No. 6 | 225 | 555 | 20 | 800 |
| No. 7 | 247 | 520 | 20 | 787 |

2) Electricity intensity in actual operation

Heat emission loss accounts for a major portion of heat loss of the heat treatment furnace. Heat emission loss is approximately constant regardless of the production volume. Therefore, electricity intensity in normal operation is in reverse proportion to the volume of product treated in the heat treatment surface (t/h) unless the performance of the heat insulation material is changed. In other words, electricity intensity is improved as the volume of product treated in a heat treatment furnace increases.

① Average volume of product treated in the heat treatment furnace

People of LACZNIKOW say that the heat treatment volume per product is as follows:

| productivity | production ratio |
|---|---|
| 0.333 t/h | 80 % |
| 0.250 t/h | 10 % |
| 0.167 t/h | 10 % |
| 0.294 t/h | Average (balanced average) |

Therefore, the balanced average volume of product treated is 0.294 t/h. On the other hand, people of LACZNIKOW say that the actual volume of product treated is 0.27 t/h.

② Targeted heat radiation loss and average heat radiation loss

For No. 6 furnace surveyed this time, the side wall temperature (excluding the charging and discharging sides) and the roof temperature are 63 °C and 80 °C, respectively. The heat insulation state is good. (Continuous operation has been performed since August 1997.) For the No. 7 furnace measured at the same time, heat emission loss is 149 kWh/h, which is slightly higher than that of No. 6 furnace. Therefore, heat radiation of the No. 6 furnace is the targeted heat emission loss, which is 139 kWh/h. If the average of heat radiation losses of No. 6 furnace and No. 7 furnace is assumed to be the average heat radiation loss, the average heat radiation loss will be 144 kWh/h.

③ Targeted electricity intensity and average electricity intensity

If the theoretical electricity intensity is 240 kWh/t, the targeted heat radiation loss is 139 kWh/h, and other losses are 20 kWh/t, the targeted electricity intensity is the one shown in Table 1.3.13.

Similarly, if it is assumed that the average heat radiation loss is 144 kWh/h, the average electricity intensity is the one shown in Table 1.3.14.

**Table 1.3.13 Electricity Intensity vs Productivity (in case of Radiation Loss of 139 kWh/h)**

| Productivity (t/h) | Theoretical energy intensity (kWh/t) | Radiation heat loss (kWh/t) | Other losses (kWh/t) | Electricity intensity (kWh/t) | Power consumption (kWh/h) |
|---|---|---|---|---|---|
| 0.333 | 240 | 417 | 20 | 677 | 226 |
| 0.250 | 240 | 556 | 20 | 816 | 204 |
| 0.167 | 240 | 834 | 20 | 1,094 | 182 |
| 0.294 | 240 | 473 | 20 | 733 | 216 |
| 0.283 | 240 | 491 | 20 | 751 | 213 |
| 0.270 | 240 | 515 | 20 | 775 | 209 |

Note: Heat loss due to radiation is assumed to be constant, i.e. 139 kWh/h.

Table 1.3.14 Electricity Intensity vs Productivity (in case of Radiation Loss of 144 kWh/h)

| Productivity (t/h) | Theoretical energy intensity (kWh/t) | Radiation heat loss (kWh/t) | Other losses (kWh/t) | Electricity intensity (kWh/t) | Power consumption (kWh/h) |
|---|---|---|---|---|---|
| 0.333 | 240 | 432 | 20 | 692 | 231 |
| 0.250 | 240 | 576 | 20 | 836 | 209 |
| 0.167 | 240 | 864 | 20 | 1,124 | 187 |
| 0.294 | 240 | 490 | 20 | 750 | 221 |
| 0.270 | 240 | 533 | 20 | 793 | 214 |

Note: Heat loss due to radiation is assumed to be constant, i.e. 144 kWh/h.

3) Discussion on the annual average electricity intensity

Table 1.3.15 shows the annual average electricity intensity of the heat treatment furnace in LACZNIKOW.

① During three months from January through March, 1997, six heat treatment furnaces run. Since May, operation with five furnaces has been adopted. As a result, the electricity intensity is improved from 1,003 kWh/t to 890 kWh/t.

② However, as annual averages, the volume of product treated by a heat treatment furnace is 0.265 t/h and electricity intensity is 934 kWh/t.

③ According to heat treated material mix, treatment of product of 0.294 t/h is possible based on calculation. However, 0.283 t/h can be achieved practically with operation of five heat treatment furnaces according to performance in past. The value actually achieved is 0.270 t/h.

④ In 1997, heat treatment furnaces were switched from one to another four times. Furnace switching causes heat accumulation loss, etc. If switching is performed one time during operation of five furnaces, electricity intensity in that month is worsened by approximately 30 kWh/t.

⑤ Troubles of the heat treatment furnaces occur once/3-furnaces-year, and thus the frequency is low.

### Table 1.3.15 Electricity Intensity of Heat Treatment Furnace in 1997

| | | January | February | March | April | May | June | |
|---|---|---|---|---|---|---|---|---|
| Productivity | (t/h) | 0.253 | 0.263 | 0.237 | 0.276 | 0.256 | 0.273 | |
| No. of furnaces | | 6 | 6 | $6_{-2+1}$ | $5_{-1}$ | $4_{+1}$ | 5 | |
| Electricity intensity | (kWh/t) | 1,044 | 1,025 | 985 | 1,077 | 893 | 904 | |
| | | July | August | September | October | November | December | Total |
| Productivity | (t/h) | 0.311 | 0.273 | 0.283 | 0.238 | 0.254 | 0.274 | 0.266 |
| No. of furnaces | | $5_{-1}$ | $4_{+1}$ | 5 | $5_{+1}$ | $6_{-1}$ | 5 | |
| Electricity intesnity | (kWh/t) | 856 | 870 | 876 | 965 | 854 | 901 | 934 |

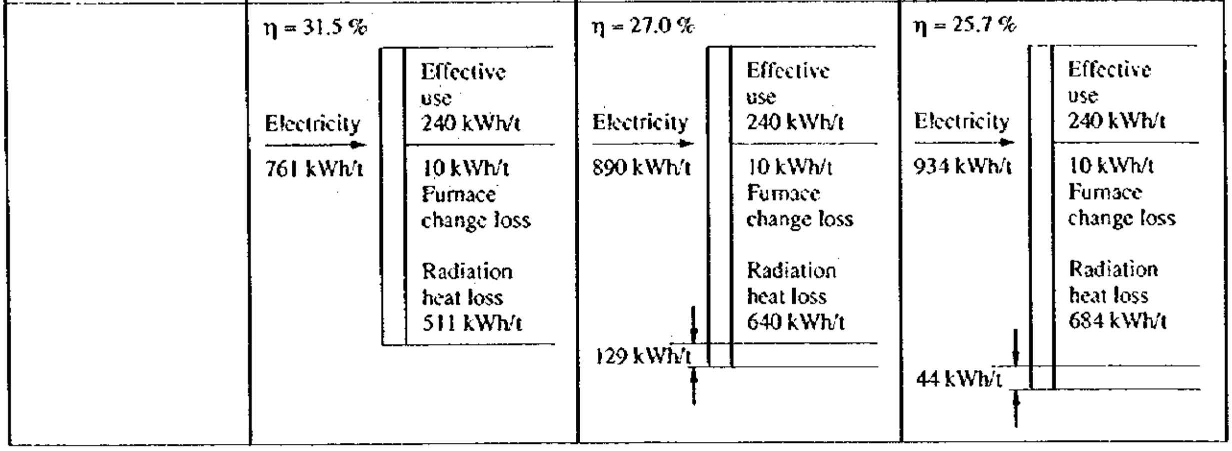
* Productivity is estimated based on furnace electricity consumption record.

4) Energy conservation potential

Figure 1.3.8 shows the energy conservation potential calculated by comparing the field investigation result with the electricity intensity of the heat treatment furnaces in 1997.

Figure 1.3.8 Energy Conservation Potential in Heat Treatment Furnace

| | Target of operation | Result of operation after May 1997 | Result of operation in 1997 |
|---|---|---|---|
| Number of furnaces | N = 5 | N = 5 | N = 6 |
| Productivity | 0.283 t/h | 0.270 t/h | 0.265 t/h |
| Radiation heat loss | 20 kWh/t + 139 kWh/h | | |
| Furnace exchange loss | 30 kWh/t × 4 times/y | same as left | same as left |



As shown in this figure, the energy conservation potential in 1997 is 173 kWh/t (18.5 %). The energy conservation potential for the achieved values in May through December, 1997 is 129 kWh/t (14.5 %).

On the other hand, if electricity is replaced with natural gas for heating, the improvement effect expected is 4,604 MJ/t (51 %). Therefore, the energy conservation potential provided by changing the source of energy is 51 %.

5) Measures for improving electricity intensity of heat treatment furnaces

① Enhancing management of heat radiation loss from the heat insulation material of the heat treatment furnace

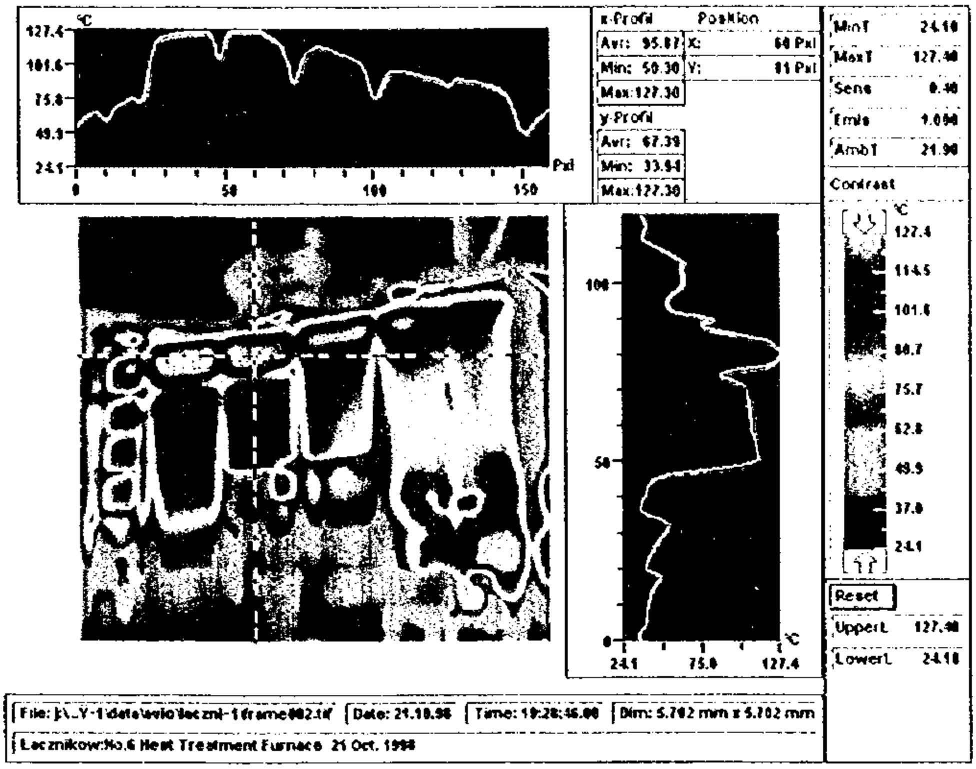
For the heat insulating material of the heat treatment furnace, a proper material and a construction method are selected for the ambient gas containing hydrogen (30 %). This fact can be understood from the electricity intensity and temperature measurement result obtained through field investigation (i.e. the outer side wall temperature is maintained at 60 °C and the heat emission loss of No. 6 furnace that has been running for more than 15 months is low (139 kWh/t).

On the other hand, if the heat radiation losses are calculated based on the electricity intensity in May through December, 1997 and on the electricity intensity provided when the volume of product treated (0.283 t/h) was recorded as a result of continuous operation of five heat treatment furnaces, they are 167 kWh/h and 174 kWh/h, respectively. It can be seen that some surfaces have a larger heat radiation loss.

Therefore, it is necessary to find degrading of heat insulation performance of the heat treatment furnace at an earlier stage, determine the repair time, and manage the performance changes of each furnace (i.e. measurement of the surface temperature, relationship between the volume of product treated and electricity intensity, etc.) to check to see if there is any problem in the refractory, construction method, etc.

The energy conservation effect expected through enhancement of managing the heat insulation material (i.e. construction method, measurement of heat insulation performance) is approximately 101 kWh/t.
Figure 3.1.9 shows the result of measuring surface temperature distribution of the No. 6 heat treatment furnace.

Figure 1.3.9 Infrared Thermal Range of No. 6 Heat Treatment Furnace



x-Profil
Avr: 95.87
Min: 50.30
Max: 127.30

Position
X: 60 Pxl
Y: 81 Pxl

y-Profil
Avr: 67.39
Min: 33.94
Max: 127.30

MinT 24.10
MaxT 127.40
Sens 0.40
Emis 1.000
AmbT 21.90

UpperL 127.40
LowerL 24.10

File: j:\...Y-1\data\avio\leczni-1frame002.tif
Date: 21.10.98
Time: 19:28:46.00
Dim: 5.702 mm x 5.702 mm

Lacznikow:No.6 Heat Treatment Furnace 21 Oct. 1998

② Enhancing management of the volume of product treated in the heat treatment furnace

If the volume of product treated in the heat treatment furnace can be increased from 0.270 t/h (current value) to 0.283 t/h, energy intensity can be improved by 28 kWh/t. To increase the volume of product treated, it is necessary to prepare the target production plan for each treatment furnace and manage the result every day. If the target cannot be achieved, the cause should be investigated and improvement should be performed.

Additionally, based on the annual production plan, if the furnace switching time is properly selected and operation with 6 furnaces is temporarily combined with operation with 4 furnaces, the volume of product treated can be increased to 0.283 t/h or more.

6) Improving the energy intensity by changing the energy source for the heat treatment furnace

In this factory, a large volume of electricity is consumed by the heat treatment furnace, zinc hot dipping bath, etc. Along with economic growth of Poland, it is expected that the electricity demand will steadily increase, while the electricity cost will gradually increase.

The new type of regenerative radiant tube burner has been developed for the heat treatment furnace. Also there have emerged products that can withstand use, with low $NO_X$ volume generated and controllability improved.
It is recommended that feasibility study be implemented and this improvement be performed for cost reduction and improvement of the energy intensity of the heat treatment furnace to a half, assuming that natural gas is led to the location near the factory in future.

[Effect]
- Improvement in electricity intensity: Δ800kWh/t (8,719 MJ/t)
  800 × 11,502 = 9,202 MWh/y
- Increase in natural gas consumption: +4,115 MJ/t
  4,115 MJ/t × 11,502 = 47,331 GJ/t

  Difference : Δ4,604 MJ/t (51 % reduced from the current value (8,924 MJ/t))

[Regenerative radiant burner]
- Specification (reference) : 35 kW × 14 burners/furnace
- Heat exchanger : Ceramic honeycomb
- $NO_X$ : 200 ppm or lower ($O_2$: 11 % conversion)

[Cost]
525,000 PLN/furnace

c. Machining shop

The threading machine in the machining shop is manually operated (i.e. the operator loads the material one by one into the loading hole in the specified direction). However, the subsequent machining process is automated. If there is no more material to be machined, the machine stops automatically. This system is designed so that the motor idling time will be minimized.

Therefore, based on the judgement that there would be almost no energy conservation potential, measurement by the field investigation group (heat/electricity) was not performed.

d. Zinc hot dipping shop

The zinc hot dipping shop involves the processes of pickling, drying, and zinc hot dipping. Electricity is used for drying, zinc heating and melting. People of LACZNIKOW say that the production capacity of the zinc hot dipping shop is twice larger than the current production. Presently, production has been declining, and only three of four lines are running. Two lines are mainly running, while one line is running at a reduced production speed. The basic processes for zinc hot dipping are similar among any foundries. However, there is no foundry in Japan that produces similar products as those in LACZNIKOW and performs zinc hot dipping in similar processes. Therefore, the energy conservation potential is presumed according to the following calculation. Presently, the exhaust gas processing equipment is not installed for the pickling process, and thus anti-pollution measures will be required in the future. In this case adoption of the shot blast method used in the excellent factory will be studied to improve eelctricity intensity.

1) Theoretical electricity intensity

- Heat value contained in pipe joints:
  1,000 kg × 0.544 kJ/kg°C (470 – 25) ÷ 3,600 kJ/kWh = 67.2 kWh/t

- Heat value contained in zinc:
  72 kg/t × 0.53 kJ/kg°C (550 – 25) ÷ 3,600 kJ/kWh = 5.6 kWh
  Subtotal: 72.8 kWh/t

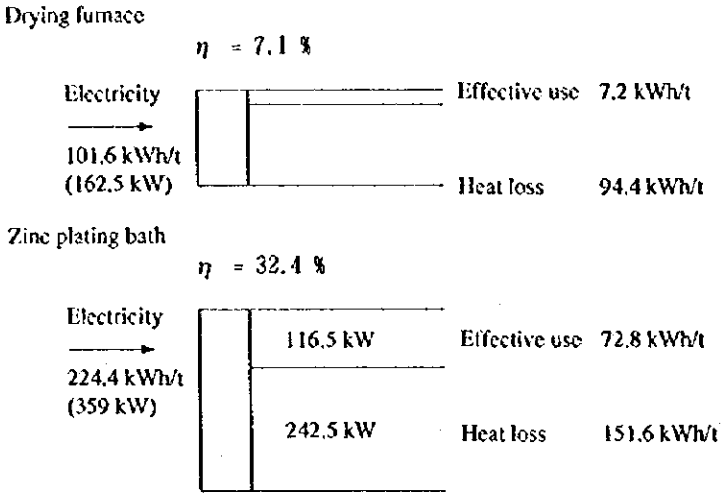
- Water evaporation heat:
  10 kg/t × 2,575 kJ/kg°C ÷ 3,600 kJ/kWh = 7.2 kWh/t

The zinc deposit volume of 72 kg/t uses the operation value in LACZNIKOW, while the moisture deposit volume of 10 kg/t before drying is assumed.

2) Electricity intensity during actual operation

Most heat loss of the drying furnace is sensible heat of the exhaust gas and heat emission from side walls. Similarly, most heat loss of the zinc hot dipping furnace is heat emission from the furnace. The heat balance is obtained from the field study data. The result is shown in Figure 1.3.10.

**Figure 1.3.10 Heat Balance of Zinc Coating Process**



3) Annual actual electricity intensity

① The actual electricity intensity of the zinc hot dipping line is 361 kWh/t.

② For zinc hot dipping lines, three of four lines are running.

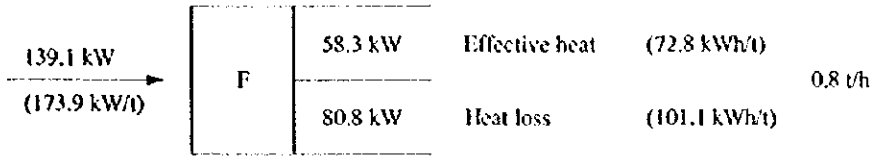
4) Energy conservation potential

① Running two zinc hot dipping furnaces: 50 kWh/t

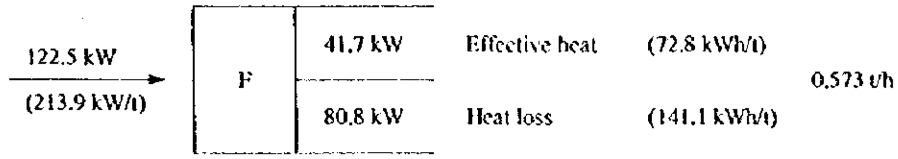
As a result of calculating and studying the heat balance, the total capacity of two furnaces is presumed to be approximately 7,000 t/y. It is found that the current production volume cannot be maintained with operation of two furnaces.

For operation of two furnaces, the heating capacity with electrical resistance for the zinc hot dipping furnace should be enhanced by 20 kW or the heat insulation cover of the zinc hot dipping baths should be improved to enhance heat insulation of the bath body and reduce heat emission.
In this case, the heat balance per bath is as follows, The effect of the operation of two furnaces is therefore calculated to be 224.4 – 173.9 = 50.5 kWh/t.
224.4 kWh/t is the electricity intensity for the operation of three furnaces, which is shown in Figure 1.3.10.

[Operation of 2 furnaces]



[Operation of 3 furnaces]



Note: The rating of the heating equipment for the zinc hot dipping bath is 110 kW but the actual load according to field study data is 122.5 kW.

② Measures for removing moisture before drying: 23 kWh/t

If processes such as air blowing in front of the drying furnace and shaking the case containing joints back and forth are added, drying electricity can be reduced by approximately 23 kWh/t.

As a result of field survey, it is found that a large volume of water remains in joints after they come out of the drying furnace. It is necessary to remove water before charging into the drying furnace.

5) Measures for improving the intensity

① Installation of a mechanical water removing equipment in front of the drying furnace (or manual removal by the operator): 23 kWh/t
Annual electricity saving: 23 kWh/t × 8,959 t = 206 MWh/t

② Shifting to a two-furnace operation system by modifying the zinc hot dipping baths: 50 kWh/t
Annual electricity saving: 50 kWh/t × 8,959 t = 448 MWh/y

6) Improvement of the cleaning process

Muriatic acid is used for pre-processing of zinc coating. Examination of the measures for preventing diffusion of the muriatic acid gas will be required in future from the viewpoint of sanitation. In this case, it is recommended that improvement be determined by comparing with and examining other techniques such as cleaning with shot blast. If the present system is improved to the shot blast system, electricity intensity will be somewhat improved compared with that in the current system. Furthermore, no investment and running cost of the equipment for handling the muriatic gas will be required.

e. Improvement of the product yield

Reducing the percentage of the defective products in the joint manufacturing processes brings about a great effect for energy conservation activities. Therefore, improvement of the product yield is also considered and calculated as the energy conservation potential.

1) Current yield

- Hot metal rejection rate: <4 % (Cast iron ÷ Hot metal)
- Casting rejection rate : 4 to 5 % (Casting defect)
- Rejection products : 1 to 2 % (Defect at final inspection)

2) Energy conservation potential

Table 1.3.16 shows the energy conservation amount expected if the yield is improved.

**Table 1.3.16 Energy Conservation Potential Relating to Yield**

| | Result (A) | Target (B) | (A) – (B) | Energy intensity | Ratio | Energy conservation potential |
|---|---|---|---|---|---|---|
| Disqualified hot metal | 3 ~ 4 | 1.0 | 2.5 | 7,317 MJ/t-hot metal | 2.6733 | 489 MJ/t-fittings |
| Casting defect | 4 ~ 5 | 2.0 | 2.5 | 20,330 MJ/t-castings | 1.1266 | 573 MJ/t-fittings |
| Products defect | 1 ~ 2 | 0.5 | 1.0 | 57,505 MJ/t-fittings | 1.0000 | 575 MJ/t-fittings |
| Total | | | | | | 1,637 MJ/t-fittings |

Note: Ratio means product ratio to final products of fittings.

3) Measures for improving the yield

We asked LACZNIKOW about the rejection product occurrence status and the cause analysis result but could not obtain their answers. Although efforts may be made to prevent the occurrence of rejection product, follow-up seems to be insufficient. We hope that the target in Table 1.3.16 will be achieved earlier.

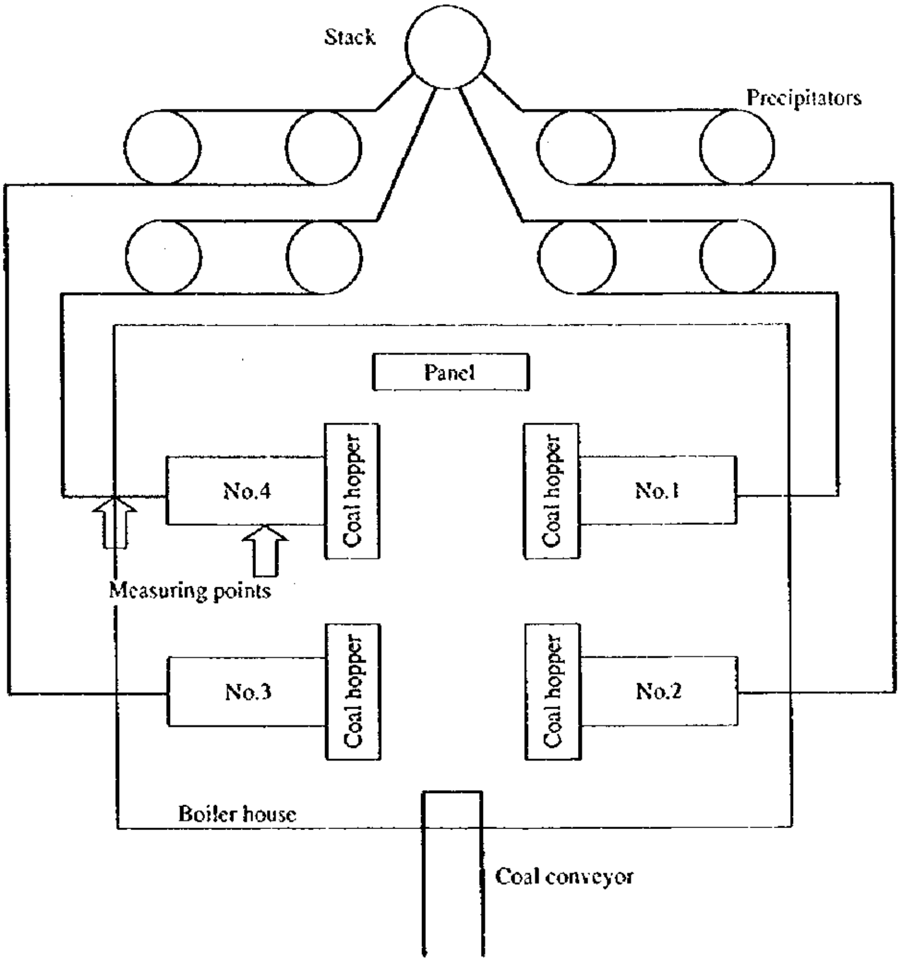
It is presumed that such occurrence of rejection products may be attributable to a severe condition that the molten metal temperature drops if any problem arises during casting operation because white iron is made by single melting in the cupola. Therefore, in order to improve the yield to the level in the excellent factory, it will be essential to implement, at an earlier stage, improvement measures such as installation of a holding furnace having an induction heating equipment.

B. Utility (heat utilization equipment)

a. Boiler

In this factory, coal-fired hot water boilers are installed to supply hot water for heating and living. Also, the small oil-fired hot water boiler is available to supply a small volume of hot water in summer. Table 1.3.1 lists the boiler specifications. Figure 1.3.11 shows the layout in the boiler house.

**Figure 1.3.11 Boiler House Layout**



l) Improvement of boiler air ratio

To know the boiler air ratio, oxygen concentration of the exhaust gas in the flue of the No. 3 boiler and exhaust gas concentration were measured. After measurement of the exhaust gas in the flue, oxygen concentration in the in-furnace gas was measured on a spot basis through the inspection hole in the boiler combustion chamber. This measurement was performed at a higher speed of the stoker on the assumption that the coal charging state is changed. Because of the heat resistance problem of the sample tube, this measured values were not connected to the recorder. Figure 1.3.12 shows the graph of measured values. Table 1.3.17 shows the average, maximum, and minimum of the measured values.

**Figure 1.3.12 Water Boiler Exhaust Gas**
Laczników, 19-October/1998

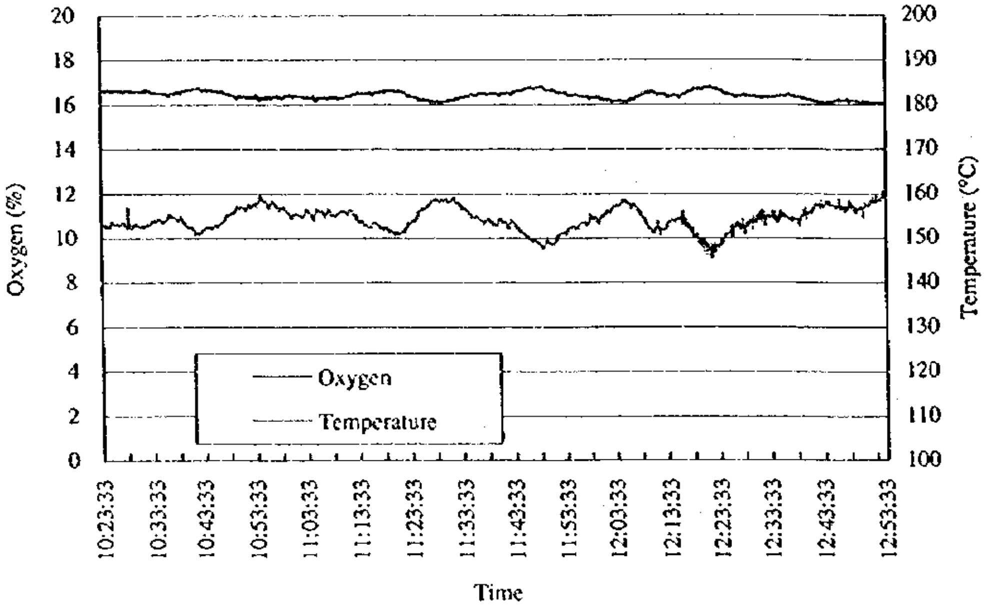


**Table 1.3.17 Measured Values**

| | Oxygen (%) | Temperature (%) |
|---|---|---|
| Average | 16.4 | 154.1 |
| Maximum | 16.8 | 160.5 |
| Minimum | 16.0 | 145.5 |

If the combustion air ratio is adjusted and oxygen in the exhaust gas is reduced to 11 %, the resulting energy conservation is the one in Table 1.3.18. This oxygen concentration (11 %) is a typical value for this type of boilers.

## Table 1.3.18 Combustion Calculation

| Premises | |
|---|---|
| Fuel | |
| Heat value Net (kJ/kg) | 23,647 |
| Heat value Net (kcal/kg) | 5,648 |
| Ash content | 15.1 % |
| Water | 6.0 % |
| Combustion air temperature | 20 |
| Exhaust temperature | 154 |

Rem: Measured after furnace (no AH).

| Results | Theoretical | AR actual | AR improved |
|---|---|---|---|
| Exhaust gas oxygen | 0.0 % | 16.4 % | 11.0 % |
| Air ratio | 1.00 | 4.48 | 2.08 |
| Air volume ($m^3$/kg) | 6.5 | 29.3 | 13.6 |
| Exhaust gas ($m^3$/kg) | 6.9 | 29.7 | 13.9 |
| Exhaust gas heat loss (to fuel) | | 22.6 % | 10.9 % |
| Fuel saving | | | 13.1 % |

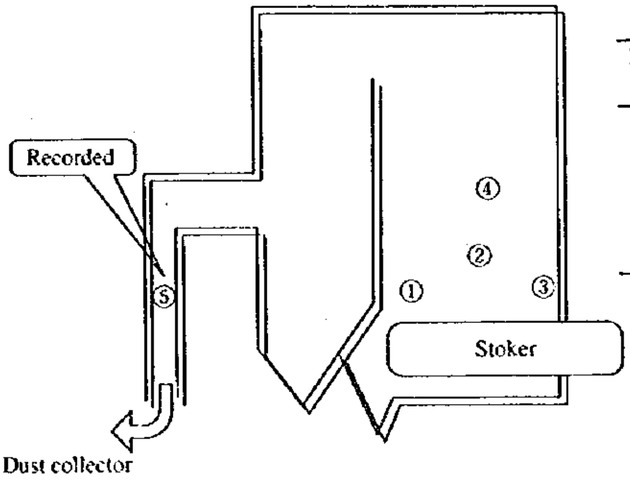
Rem: AR improved is the minimum of existing measured sample.

As shown above, the air ratio is improved from 4.48 to 2.08. As a result, the fuel consumption is reduced by approximately 13 %. Since the exhaust gas volume is reduced from 29.7 $m^3$/kg to 13.9 $m^3$/kg, exhaust gas heat loss is reduced from 22.6 % to 10.9 %, and thus boiler efficiency is improved by approximately 10 %.

As a result of observing the combustion chamber during boiler operation, it was found that combustion was completed on the first half of the hearth and air is uselessly supplied to the second half. This air increases the exhaust gas volume and heat loss caused by the exhaust gas. Therefore, it is necessary to keep the air ratio to the minimum by controlling and improving the combustion conditions such as the air supply damper and stoker speeds.

After measurement of gas in the flue, we asked the operator to conduct a test for increasing the stoker speed so as to make combustion continue to the second half of the hearth, and thus measured oxygen content in the combustion chamber, etc. on a spot basis. The result is shown in Figure 1.3.13.

**Figure 1.3.13 Oxygen Spot Measuring Under Stoker Feed Speed Adjusting**



| Oxygen in exhaust gas | | |
|---|---|---|
| Measured point | Stoker feed speed Normal | Increased |
| 1 | 20.2 % | 8.4 % |
| 2 | 5 to 7 % | – |
| 3 | 20 % | – |
| 4 | – | 7.3 % |
| 5 | – | 12.4 % |

As shown in Figure 1.3.13, oxygen concentration in the exhaust gas is reduced. In this case, an incomplete combustion state such as emission of a black smoke from the stack was not observed.

As can be seen from the field study result, the coal boiler is run at the air ratio of m = 4.48 (oxygen concentration in exhaust gas: 16.4 %). Since energy loss is large, immediate improvement is required.
There are several improvement methods. At least, one of effective methods is changing the grate speed, implemented by the study team. Actually, the air ratio (m) was reduced to 1.6 and fuel intensity was improved by 15.8 %.

It is recommended that based on this test LACZNIKOW examine and implement appropriate measures so that the air ratio will be improved to 1.6 ($O_2$ concentration: 8 %).

Based on data in Table 1.3.7, boiler heat efficiency is calculated to be 76.3 %. As thermal efficiency of an oil-fired hot water boiler, 95 % can be achieved. For the coal-fired boiler, 85 % can be achieved as the annual average. Efforts should be made to achieve these levels by enhancing combustion control.

If it is assumed that boiler thermal efficiency is improved to 85 %, the fuel consumption saved is calculated as follows:

$$80{,}099\ \mathrm{GJ/y}\left(1-\frac{0.765}{0.85}\right)=8{,}198\ \mathrm{GJ/y}$$

b. Reduction of the hot water load

The hot water demand is 6,404 MJ/t (1,530 Mcal/t) per ton of product-ton, which is very large.
On the other hand, the annual heat load per heated area is calculated to be 1,440 MJ/m².
$61{,}120 \times 0.8 \div 33{,}949 = 1{,}440\ \mathrm{MJ/m^2y}\ (344\ \mathrm{Mcal/m^2y})$

If it is considered that space heating load for a steel making factory in Poland is 2,224 MJ/m²y (531 Mcal/m²y) and the average atmospheric temperature in November through March is -0.24 °C, the average heat load for heating in LACZNIKOW is regarded as lower than standard (excellent).

The heat load for hot water is also related to the number of personnel required. If it is assumed that the number of employees in LACZNIKOW is equivalent to that in the excellent factory and the heat load for hot water is as shown below, the energy conservation potential can be calculated as shown below.

[Assumed conditions]

| | Load (heat value ratio) | Load characteristics |
|---|---|---|
| Shower/hot water supply | 20 % of the total load | Proportional to the number of employees |
| Heating for machines | 50 % of the total load | Not related to the number of employees |
| Heating for employees | 30 % of the total load | 15 % in proportion to the number of employees |

[Energy conservation potential]

Reduction in the number of required employees : 938 (86 %) redution
Shower/hot water load : $61{,}120 \times 0.2 \times 0.86 = 10{,}513$ GJ/y
Load for space heating : $61{,}120 \times 0.15 \times 0.86 = 7{,}884$ GJ/y
Total: 18,397 GJ/y

c. Heat insulation for valves of hot water piping

In this factory, the valves of hot water piping are not insulated. Since the temperature of hot water piping is lower than that of steam piping, the radiation heat loss is smaller. However, simple heat insulation is effective for energy conservation. Table 1.3.19 shows the result of heat emission calculated assuming the number of valves, valve surface temperature, and ambient temperature based on factory investigation. Table 1.3.19 also shows calculation of reduction in heat emission by insulating these valves.

### Table 1.3.19 Heat Emission from Bare Valve Surface

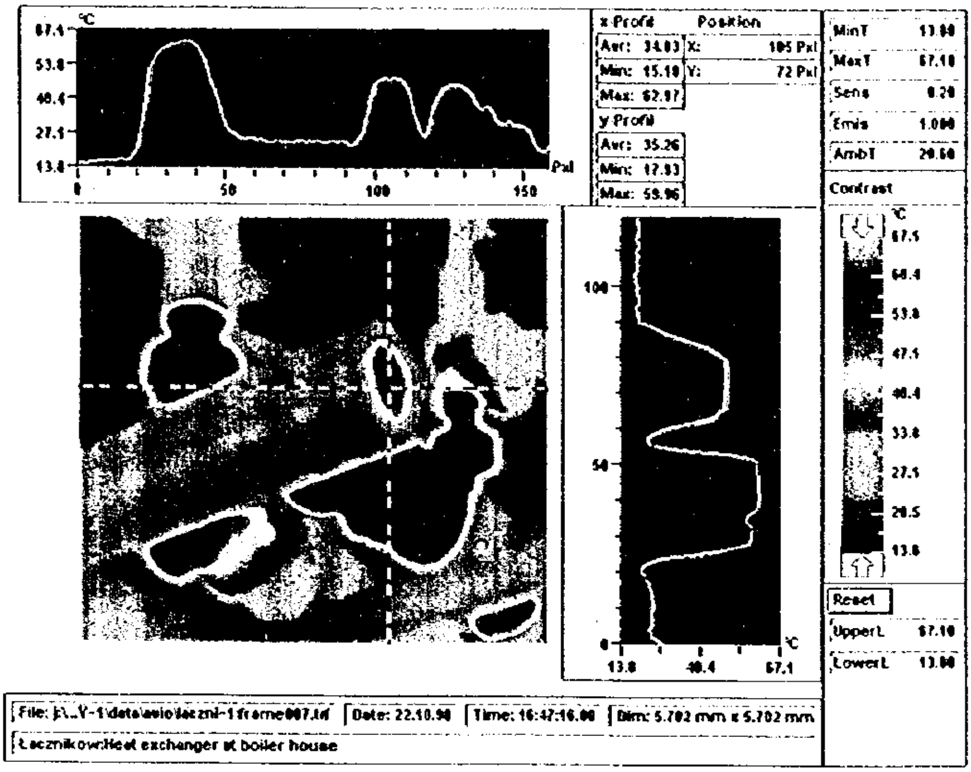
| Nominal size (mm) | Equivalent length (m) | No. of valves | Length (m) | Surface temperature (°C) | Ambient temperature (°C) | Emissivity | Unit heat (kcal/m/h) | Total heat (kcal/h) | Total heat (kJ/h) |
|---|---|---|---|---|---|---|---|---|---|
| 400 | 2.15 | 20 | 43.0 | 70 | 20 | 0.8 | 289 | 25,365 | 106,205 |
| 300 | 1.91 | 20 | 38.1 | 70 | 20 | 0.8 | 462 | 17,605 | 73,713 |
| 250 | 1.76 | 40 | 70.5 | 70 | 20 | 0.8 | 388 | 27,342 | 114,480 |
| 200 | 1.68 | 100 | 168.0 | 60 | 10 | 0.8 | 299 | 50,301 | 210,612 |
| 150 | 1.50 | 100 | 150.0 | 60 | 10 | 0.8 | 229 | 34,302 | 143,621 |
| 100 | 1.27 | 200 | 254.0 | 60 | 10 | 0.8 | 158 | 40,188 | 168,266 |
| 50 | 1.11 | 300 | 333.0 | 60 | 10 | 0.8 | 84 | 27,888 | 116,766 |
| Sum | | | | | | | | 222,991 | 933,663 |
| Reduction of heat emission by insulation | | | | 80 % | | | | 178,393 | 746,931 |

No. of valves are assumed value.

The steam volume saved by heat insulation is as follows:
746,931 kJ/h × 24 h ×180 d/y/1,000,000 = 3,227 GJ/y

In the small hot water boiler room, hot water piping is insulated, while the attached valves are not insulated. According to the thermal video image, it can be seen that the surface temperature of the uninsulated portion is higher as shown in Figure 3.1.14. In this image, the temperature of the uninsulated portion is approximately 60 °C, while the temperature of the insulated portion is approximately 20 °C.

Figure 1.3.14 Thermal Image of the Packaged Hot Water Boiler Safety Valve



x Profil

Avr: 34.03

Min: 15.10

Max: 62.97

Position

X: 105 Pxl

Y: 72 Pxl

y Profil

Avr: 35.26

Min: 17.93

Max: 59.96

MinT 13.00

MaxT 67.10

Sens 0.20

Emis 1.000

AmbT 20.00

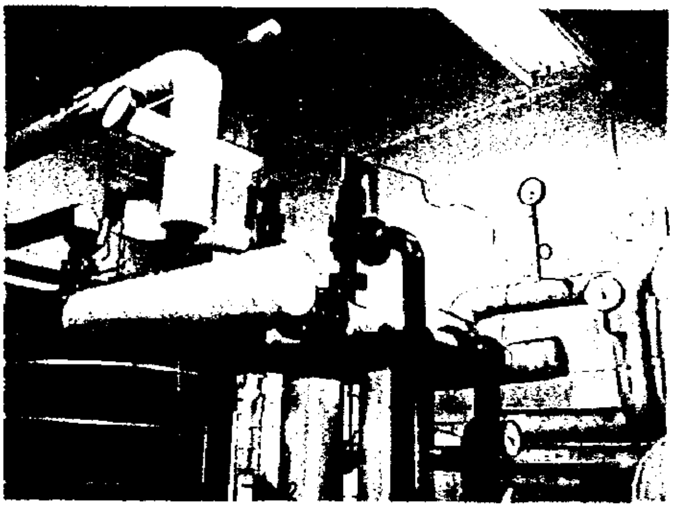
Contrast

UpperL 67.10

LowerL 13.00

File: j:\...\~1\data\avio\laczni~1\frame007.tif Date: 22.10.98 Time: 16:47:16.00 Dim: 5.702 mm x 5.702 mm

Lacznikow:Heat exchanger at boiler house



C. Utility

a. Power receiving equipment

Figure 1.3.15 shows transition of electricity received by the factory for a week in the last half of September, 1998. In working days, the maximum electricity of approximately 5,000 kW is consumed in the first shift, 4,000 to 4,500 kW is consumed in the second shift, and approximately 2,500 kW is consumed in the nighttime. Thus, the operation patterns are approximately the same. On holidays, about 2,000 kW is consumed every day.

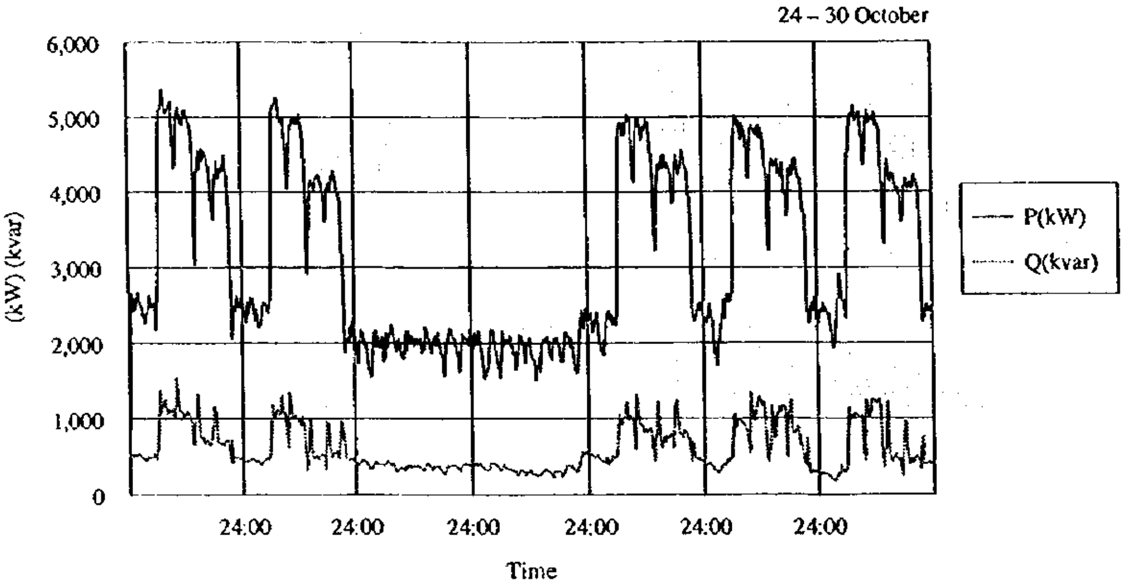
The power factor achieved is approximately 96 %. Although operation on Saturdays was examined in terms of electricity charge, it could not be implemented because of labor limitation. The contract demand is 6,100 kW, which has an approximately 1,000 kW allowance for the current operation. Therefore, the contract demand should be reduced.

If the contract demand is reduced to 5,500 kW, reduction of electricity charge is as follows:

(6,100 – 5,500) × 3.09 × 1.8 × 12 m = 40,000 PLN/y

Even if the demand monitor equipment (2 million yen) is installed for monitoring, the investment can be recovered in 2 years.

**Figure 1.3.15 Lacznikow Receiving Power (1 Week)**



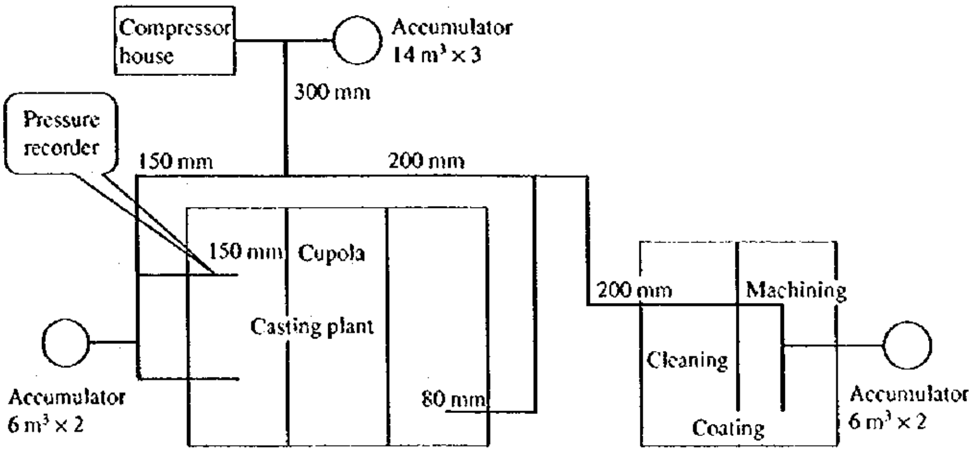
b. Air compressor

1) Prevention of compressed air leak

In this factory, compressed air is used in many processes such as the zinc hot dipping process and threading process. Piping from the air compressor room enters the building of each process and the piping is branched to many destinations in the building. If air supply is stopped during the time zone in which the factory does not use the air to grasp pressure reduction in the piping line on a time-series basis, the air leak volume can be calculated from the result and the capacity of air piping.

In this factory, a pressure recorder is installed on the air piping at the entrance of the foundry. The air leak volume was obtained by analyzing the pressure record chart when all air compressors were shut down on a weekend. Figure 1.3.16 shows the air piping line and Figure 1.3.17 shows the pressure measurement chart.

**Figure 1.3.16 Compressed Air Main Line**



**Pipeline volume:**

| Nominal diameter | Inside diameter | Length | Volume |
|---|---|---|---|
| mm | mm | m | m³ |
| 300 | 305 | 50 | 3.65 |
| 200 | 205 | 150 | 4.94 |
| 150 | 155 | 50 | 0.95 |
| Miscellaneous, assumed 200 % of main line | | | 19.08 |
| Accumulator, compressor house | | | 42 |
| Accumulator, casting plant | | | 12 |
| Accumulator, machining house | | | 12 |
| Sum | | | 95 |

Figure 1.3.17 Air Pressure Chart at Casting Shop

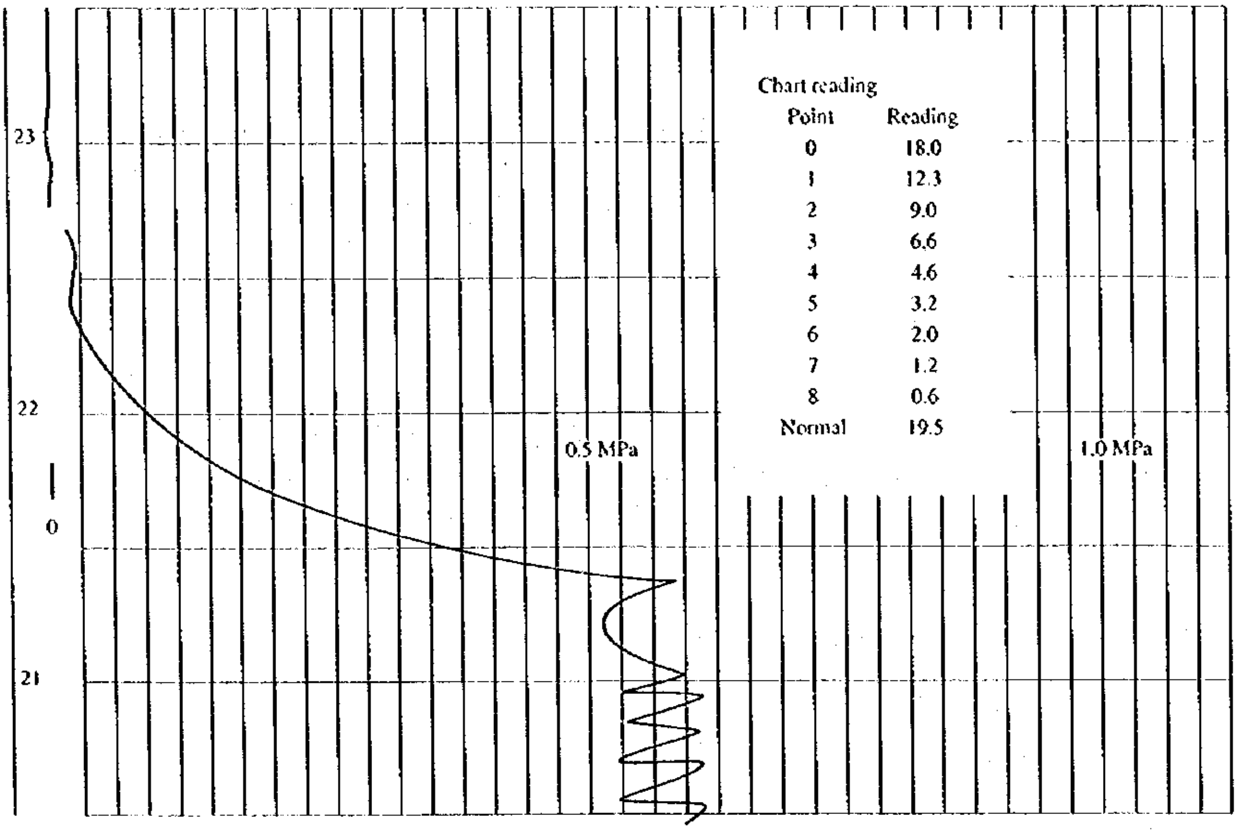


Chart reading

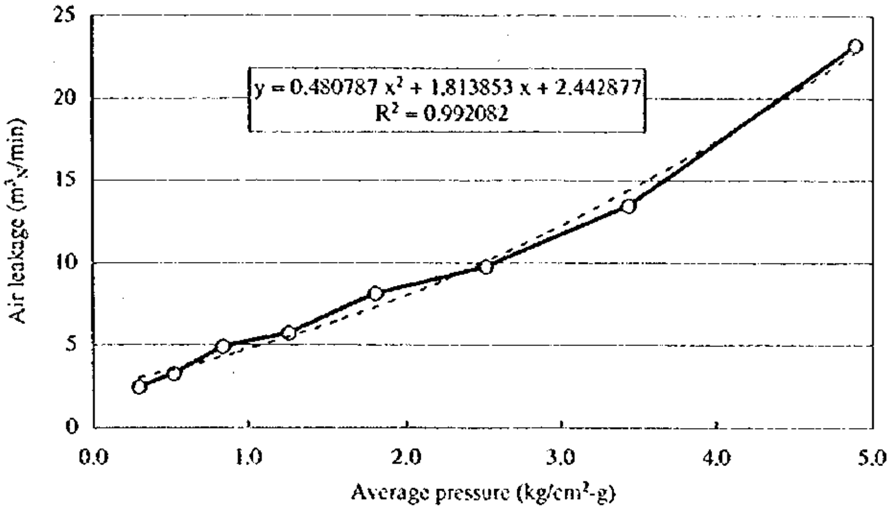
| Point | Reading |
|---|---|
| 0 | 18.0 |
| 1 | 12.3 |
| 2 | 9.0 |
| 3 | 6.6 |
| 4 | 4.6 |
| 5 | 3.2 |
| 6 | 2.0 |
| 7 | 1.2 |
| 8 | 0.6 |
| Normal | 19.5 |

The progress of pressure drop was read from the chart. The air leak volume was obtained from the result and the piping capacity. Since the leak volume depends on the pressure, linear approximation was applied for the calculated leak volume by using the pressure as a variable. Approximation through extrapolation was performed for the leak volume at the pressure in normal operation. Table 1.3.20 and Figure 1.3.18 show the calculation sheet and the pressure and calculated leak volume, respectively. This figure also shows the primary approximation formula using the pressure.

**Table 1.3.20 Air Leakage Assumption**

| Time | MPa | kg/cm²g | Pressure difference | Pressure average | Leakage ($m^3_N$/h) |
|---|---|---|---|---|---|
| 0.0 | 0.563 | 5.811 | | | |
| 7.5 | 0.384 | 3.971 | 1.84 | 4.89 | 1,392.3 |
| 15.0 | 0.281 | 2.905 | 1.07 | 3.44 | 806.1 |
| 22.5 | 0.206 | 2.131 | 0.77 | 2.52 | 586.2 |
| 30.0 | 0.144 | 1.485 | 0.65 | 1.81 | 488.5 |
| 37.5 | 0.100 | 1.033 | 0.45 | 1.26 | 342.0 |
| 45.0 | 0.063 | 0.646 | 0.39 | 0.84 | 293.1 |
| 52.5 | 0.038 | 0.387 | 0.26 | 0.52 | 195.4 |
| 60.0 | 0.019 | 0.194 | 0.19 | 0.29 | 146.6 |
| Normal operating | | 6.295 | | | 1,975 |

**Figure 1.3.18 Air Leakage by Pressure**



The air leakage at an air pressure of 0.5 MPa in normal operation is 24 $m^3_N$/min as shown in Figure 1.3.18. The air leak volume per hour is 1,440 $m^3_N$ (= 24 × 60). This volume corresponds to 70 % of the capacity of the air compressor (2,000 $m^3_N$/h).

In other words, if air leak is completely eliminated, electricity for 0.7 of an air compressor can be saved during the operation time. The compressed air leak location can be detected with its leak sound while factory operation stops. Since leak check this time does not need any particular measuring instrument, such check should be performed from time to time to grasp the leak volume.

According to the result of analysis performed by the study team, LACZNIKOW immediately investigated leak locations, found closing failures of pressure adjusting bypass valves in the factory, and closed those valves. This means that LACZNIKOW wasted compressed air for a year after the bypass valves were installed.

Annual working days are 215 days and the compressed air intensity for the air compressor is 10 $m^3_N$/kWh (= 2,000 $m^3_N$/h/200 kW), and therefore electricity loss due to air leak is as follows:

1,440/10 × 24 × 215 = 743,040 kWh/y = 743 MWh/y

For this detection of air leakage, LACZNIKOW expressed their appreciation to the study team.

2) Pressure control by starting/stopping the compressors

Figure 3.1.19 and Figure 3.1.20 show results of measuring compressor's electricity consumption and air pressure. Three or four compressors are run in the first and second shifts and one compressor is run in the third shift. On the day of our survey, the No. 3, No. 4, and No. 6 compressors were measured. Each compressor ran with an approximately 200 kW constant output.

Figure 1.3.19 Power Consumption of Compressors

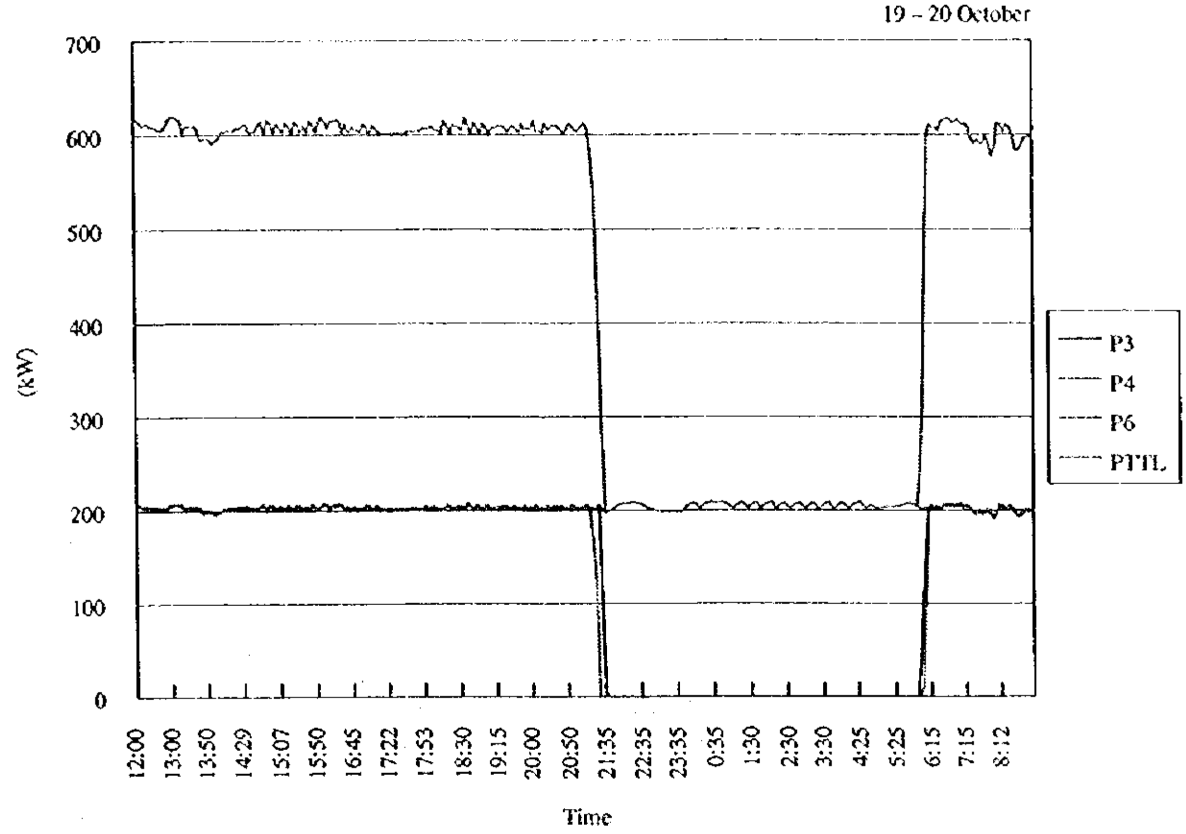
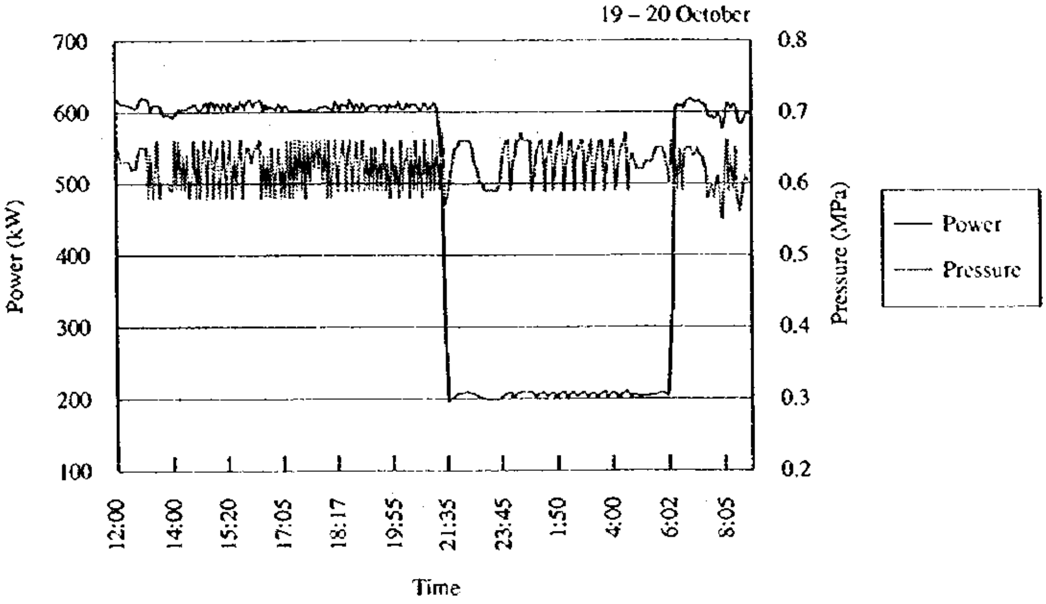


Figure 1.3.20 Power Consumption and Air Pressure



As shown in Figure 1.3.21, pressure control for the air compressor is performed by opening/closing the spring type relief valve. For muffling, the air is discharged into the suction piping. Previously, pressure control was performed with the unloading mechanism of the compressor. However, because of the increase of the maintenance cost for wear of the valve seat and valve plate, the method was changed to the current pressure control system using the relief valve.

When the pressure of the air compressor exceeds the upper limit (0.66 MPa), air is discharged through the relief valve. When the pressure becomes lower than the lower limit (0.58 MPa), the relief valve is closed. Thus, the pressure is controlled within the specified range. However, air was discharged 84 times during 21 hours upon measurement survey. Air is discharged about 100 times a day, resulting in a significant volume of energy loss.

For the air compressor running time, the air compressor is continuously run from 6:15 in the morning to 21:00 in the evening in the daytime. In the nighttime, a compressor runs continuously and the output is constant (200 kW).

Capacity of the air compressor : 2,000 $m^3_N$/h (33 $m^3_N$/min), 200 kW
Storage tank and piping capacity : 95 $m^3$ (See Figure 1.3.14.)
Electricity volume used per day : 600 kW × 15.25 h + 200 kW × 8.75 = 10,900 kWh/d
Air compressor running time per day: 10,900 kWh/200 kW = 54.5 h/d

The air volume discharged from the relief valve when the relief valve is activated is as follows.

From Figure 1.3.22, the air balance upon air pressure increase/discharge is calculated to be 49 $m^3_N$/min. The air balance is calculated as described below.

① Pressure increase: Time 13:14 to 13:21 (7 min), Pressure 0.58 MPa to 0.66 MPa (0.08 MPa)

Air increase in piping caused by pressure increase
: 0.08/0.1 × 95 = 76 $m^3_N$
Discharged volume from the air compressor during the pressure increase time: 33 $m^3_N$/min × 3 sets × 7 min = 693 $m^3_N$
Air volume used in the factory during the pressure increase time
: 693 − 76 = 617 $m^3_N$
Air volume used in the factory per unit time: 617/7 = 88 $m^3_N$/min

② Air discharge: Time 13:21 to 13:23 (2 min), Pressure 0.66 MPa to 0.58 MPa (0.08 MPa)

Air volume reduction in piping during the discharge time
: $0.08/0.1 \times 95 = 76\ m^3_N$
Volume delivered from the air compressor for two minutes of discharge time: $33\ m^3_N/min \times 3\ sets \times 2\ min = 198\ m^3_N$
Air volume used in the factory during the discharge time
: $88\ m^3_N/min \times 2\ min = 176\ m^3_N$
Air volume discharged: $76 + (198 - 176) = 98\ m^3_N$
Air volume discharged from the relief valve per unit time
: $98/2 = 49\ m^3_N/min$

Figure 1.3.22 shows that the discharging time is two minutes, the average discharge interval in the daytime is 10 minutes (4 minutes when short), and the continuous discharging time at the upper limit pressure is approximately 10 minutes.

$Gc = 49\ m^3_N/min \times 2\ min/time \times 6\ time/h \times 15.25\ h + 10\ min \times 49\ m^3_N/min$
$= 9{,}457\ m^3_N$

Volume discharged in the nighttime Gn: Air is discharged 14 times in the nighttime. The continuous discharging time at the upper limit pressure is 60 minutes.

$Gn = 49\ m^3_N/min \times 2\ min \times 14\ time + 49\ m^3_N/min \times 60\ min = 4{,}312\ m^3_N$

Volume discharged per day Gd : $Gd = Gc + Gn = 13{,}769\ m^3_N/d$
Percentage of discharge per day: $13{,}769/(54.5\ h \times 33\ m^3_N/min \times 60\ min) \times 100 = 12.8\ \%$

For this air compressor, the output is 200 kW and the delivered volume is $2{,}000\ m^3_N/h$. Therefore, the compressed air intensity is $10\ m^3_N/kWh$. If the annual working days are 215 days, the annual electricity loss is:
$(215\ d/y \times 13{,}769\ m^3_N/d)/10\ m^3_N/kWh = 296{,}000\ kWh/y = 296\ MWh/y$

As shown in Figure 1.3.20 and Figure 1.3.22, during 10 minutes around 14:00 for changing from the first shift to the second shift, machines consuming compressed air stop and the air volume used is nearly 0. However, three air compressors are runing with a full load. Since the pressure in piping is at the lower limit (0.58 MPa), the safety valves may have been opened for 10 minutes. In this case, all delivery volume of three air compressors ($33\ m^3_N/min \times 3\ sets \times 10\ min = 990\ m^3_N$) was discharged into the atmosphere.

For the measure of preventing electricity loss, adoption of controlling the number of operating compressors should be considered although the start/ stop times are limited because the motor is 200 kW and relatively large (i.e. one compressor stopped at the pressure upper limit, one compressor started at the pressure lower limit).

Figure 1.3.21 Compressed Air Line in Air Compressor Room

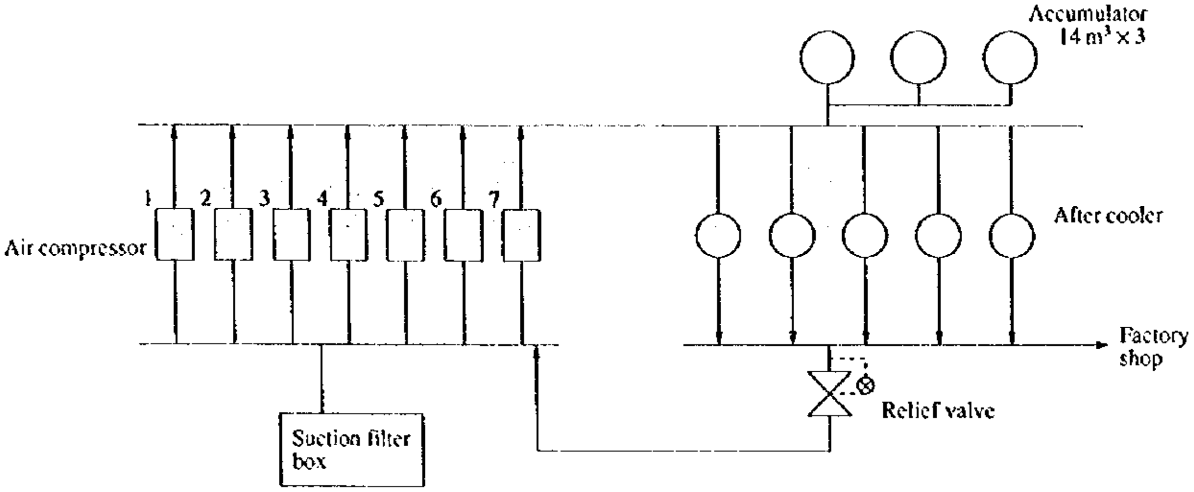
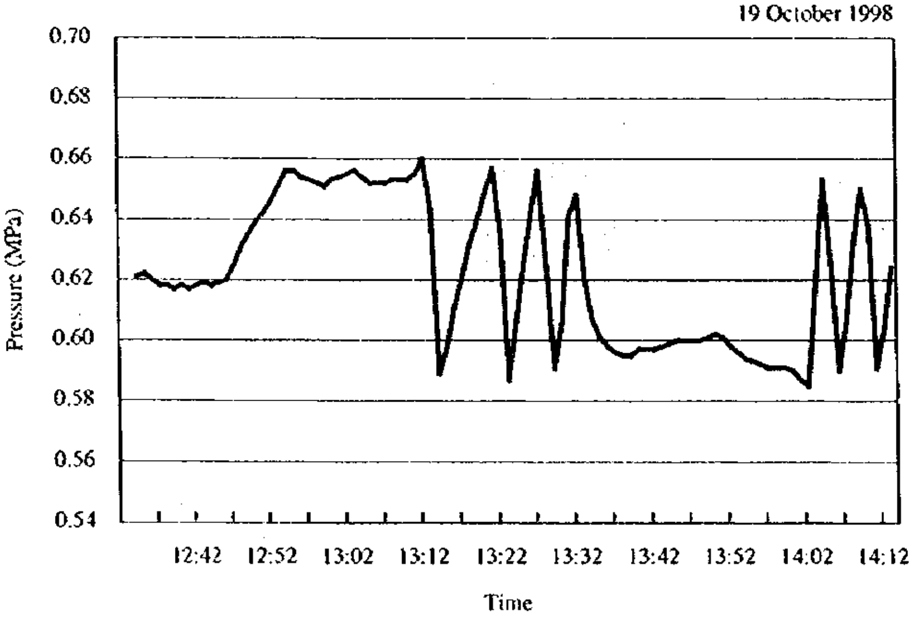


Figure 1.3.22 Lacznikow Compressed Air Pressure



3) Installation of the flow meter for compressed air used

A flow meter should be installed on the outlet of compressed air to manage electricity intensity of the compressor for efficient operation (reduction of air discharged to the atmosphere, decision of inter-cooler cleaning cycle, etc.). Also, effects of energy conservation through reduction of the compressed air volume used at the destination should be made known quantitatively to enhance the motivaton for of energy conservation. With this meter installed, the compressed air volume discharged to the atmosphere can be calculated.

4) Installation of the new compressor

Since compressors in this factory are old, they have a plan to renew them. It is necessary to determine the compressor specifications such as the type, capacity, number of compressors, etc. after the flow meter is installed on the outlet of compressed air and to clarify the changing status of the compressed air volume used in the factory. In this case, it is necessary to determine the air compressor minimizing the electricity consumption per day and its control system (e.g. inverter system) on the assumption that compressors will be run according to the actual status in the factory, instead of comparing only the performaces of single compressors.

5) Installation of a small compressor for light load

In the nighttime, a 200 kW compressor runs to supply 2,000 $m^3_N/h$ compressed air to the factory. If air leak in the factory (1,440 $m^3_N/h$) shown in b. 1) is subtracted, the required compressed air volume is 560 $m^3_N/h$. Therefore, it should be examined that a 75 kW class small air compressor will be installed for nighttime operation, after the leak locations are repaired.

Electricity saving by the installation of a 75 kW compressor:

$(200\ kW - 75\ kW) \times 8\ h \times 365\ d/1{,}000 = 365\ MWh/y$

c. Blower pump

1) Cooling water pump for compressor

Figure 1.3.23 shows the result of measuring the electricity consumption. Two of four 37 kW pumps were running. For three compressors running until 21:00, operation at approximately 56 kW was performed. For a compressor running in the nighttime, operation was at approximately 41 kW. As can be seen from this result, the electricity volume used for one-compressor operation is larger and electricity for the pumps may be reduced.

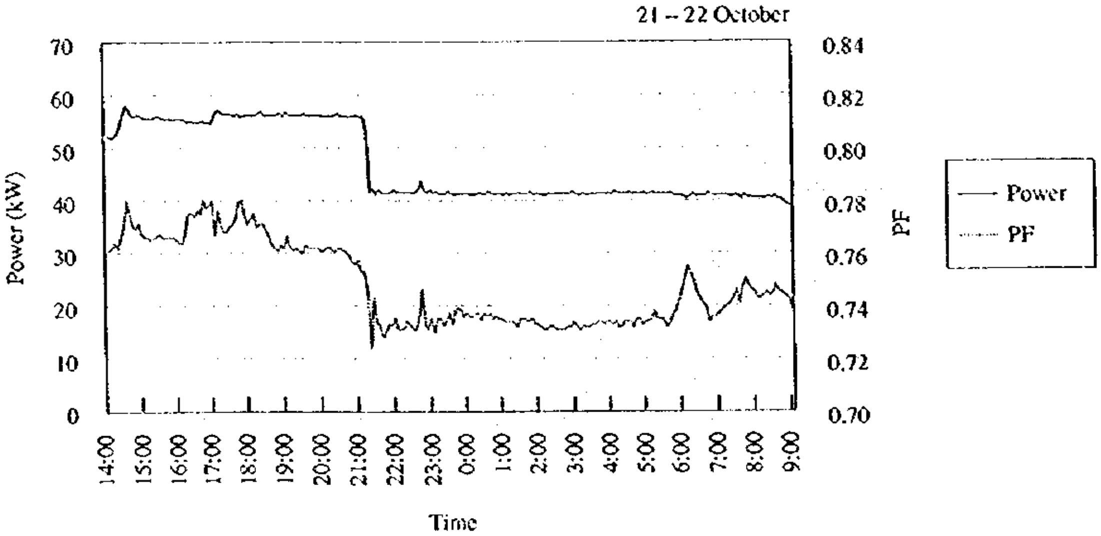
First, a water volume recorder should be installed to grasp the required water volume and its changes and then adoption of variable speed control of pump, etc. should be examined.

Since the power factor is as low as 0.73 to 0.77 and light-load operation is performed, replacement of the motor should be planned as appropriate.

In any case, it is necessary to review the pump equipment upon renewal of the compressors.

Variable speed cotrol with an inverter unit improves electricity consumption by 40 %.
Electricity saving by installation of an inverter unit:
{56 kW × 16 × 250 + 41 kW (8 × 250 + 24 × 115)} × 0.4 = 135 MWh/y

Figure 1.3.23 Power Consumption of Compressor Cooling Pumps

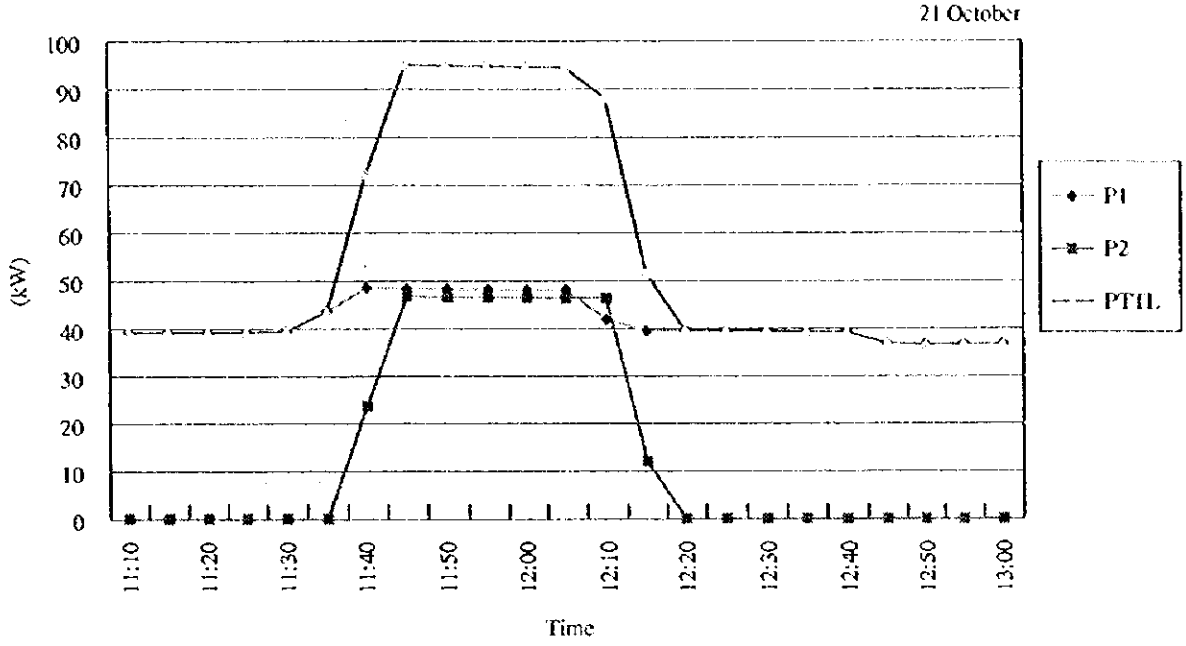


2) Cupola equipment: blower

Figure 1.3.24 shows the result of measuring the electricity consumption. Two 75 kW blowers are installed. Usually, one blower is running. If necessary, another is run additionally. The air volume may be changed according to the cupola's operation level. Therefore, variable speed control should be examined in future. The output of these motors is 40 kW to 50 kW and light-load operation is performed. They should be replaced with those having a proper capacity as appropriate.

Variable speed control with inverter unit improves electricity consumption by 40 %.
Electricity saving by installation of an inverter unit:
50 kW × 16 h × 250 × 0.4 = 80 MWh/y

**Figure 1.3.24 Power Consumption of Cupola Blower**



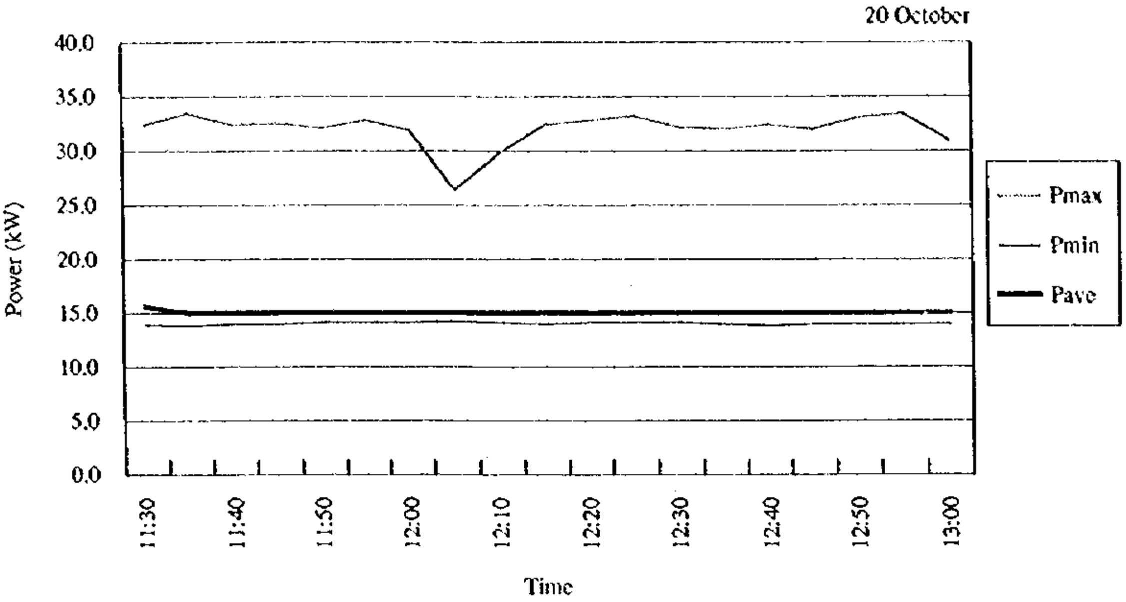
3) Cupola equipment: cooling pump

Figure 1.3.25 shows the result of measuring the electricity consumption used. This pump is one of two 37 kW pumps and used to feed the cupola cooling water. The average output for 5 minutes (P-ave) is 15 kW and approximately constant. The maximum electricity (P-max) is up to 33 kW and 14 kW is shown as the minimum electricity (P-min).

It is presumed that the period in which the maximum electricity occurs is short. According to the average electricity, there is a significantly large allowance. Therefore, the pump should be replaced with the one having a proper capacity or driven through variable speed control with an inverter unit as appropriate.

Variable speed control with an inverter unit improves electricity consumption by 40 %.
Electricity saving by installation of an inverter unit:
15 kW × 16 h × 250 d × 0.4 = 24 MWh/y

Figure 1.3.25 Power Consumption of Cupola Cooling Pump



The total electricity saving for pump and blower motors: 239 MWh/y

d. Factory lighting

Typical measured values are as follows:

Cast products sorting workshop: 250 to 300 Lx. (standard: 300 Lx.)
Cupola : 50 to 150 Lx. (standard: 100 Lx.)
Heat treatment furnace : 100 Lx. (sky lighting on the ceiling is available) (standard: 100 lx.)
Mold breaking workshop : 30 to 50 Lx. (standard: 100 Lx.) Although there are many mercury lamps (about 80 lamps), they ca provide almost no lighting effect because of high ceiling. Electricity can be saved by changing to sodium lamps. However, illuminance is already insufficient presently and the work environment should be improved. Therefore, the energy conservation effect is offset and no substantial effect can be obtained.
Machining plant window side : 1,000 Lx. (standard: 200 Lx.) Under natural light from the window, about a hundred 40 W fluorescent lamps are lit.

[Measures]

For the machining plant, fluorescent lamps on the window side should be turned off in the daytime. Since natural light is taken from the ceiling of the machining plant, cleaning this skylight further allows other lamps to be turned off in the daytime. The amount of electricity saved by energy conservation is as follows:

40 W × 100 lamps × 8 h × 215 d/1,000 = 7,000 kWh/y

For the other plants, energy conservation can be achieved by replacing mercury lamps with sodium lamps if the current illuminance is acceptable. Actually, however, there are many points at which illuminance does not meet the standard. Therefore, illuminance should be improved. Otherwise the energy conservation effect by electricity saving described above would be offset.

### (3) Summary of Energy Conservation Potential

#### a. Improvement of Environment through Energy Conservation

If fuel consumption is reduced through energy conservation, the quantity of pollutants emitted to the atmosphere also decreases. Additionally, if the amount of purchased power is reduced through energy conservation, so is the amount of power generated, that is, the quantity of pollutants emitted to the atmosphere by power plants. This reduction in emission quantity due to energy conservation depends not only on the amount of energy conservation, but also the type of fuel, and equipment, such as boilers, etc. Therefore the correct way to estimate the quantity of pollutants is to use the actual amount emitted by each factory. Here, however, for the sake of the consistency with the comprehensive study on Poland as a whole, calculations are based on information on the unit emission quantity (pollutant tonnage/fuel-heating value TJ), per industrial sector and per fuel type, provided by a document from the Institute of Environmental Protection. The reduction in the emission of air pollutants from this factory achieved as a result of energy conservation is compiled at each stage of energy conservation, and shown in Table 1.3.21.

**Table 1.3.21 Emission Improvement by Energy Conservation Measures**

| Measure | Reduction [ton/year] | | | |
|---|---|---|---|---|
| | $CO_2$ | $SO_2$ | $NO_x$ | Dust |
| Step 0 | | | | |
| Step 1 | 2,102 | 15.6 | 3.6 | 3.3 |
| Step 2 | 5,883 | 43.0 | 9.8 | 9.3 |
| Step 3 | –967 | 14.0 | –39.2 | 2.7 |
| Step 1-3 | 7,018 | 72.5 | –25.9 | 15.3 |

Reduction includes emission from fuel and electricity.

Also, in Poland, there is a system available that charges an emission fee (fee) to the polluter, and thus, the emission fee can be reduced through energy conservation. The unit price of the fee is specified per pollutant type. Additionally, for emissions that exceed a certain amount, a penalty fee (charge) is charged. The unit price of the charge is 100 times that of the fee. The prices listed below are the regular emission fees.

The result of calculating the amounts of reduction in pollutant emission, for the energy conservation items that were proposed based on our factory survey, and the corresponding reductions in emission fees, is shown in Table 1.3.22. Furthermore, the length of time required to recover investments in energy conservation including the effect of reduced emission fees, and the payback period based only on fuel reductions, are listed together in this table.

**Table 1.3.22 Payback Period Improvement by Emission Fee Reduction**

| Measures | Energy cost advantage | Emission fee advantage | Total advantage | Investment | Eco-Environ PBP | Economical PBP |
|---|---|---|---|---|---|---|
| Step 0 | | | | | | |
| Step 1 | 530 | 7 | 537 | 115 | 0.21 | 0.22 |
| Step 2 | 938 | 19 | 956 | 2,075 | 2.17 | 2.21 |
| Step 3 | 1,048 | –7 | 1,040 | 3,721 | 3.58 | 3.55 |
| Step 1-3 | 2,516 | 18 | 2,534 | 5,911 | 2.33 | 2.35 |

Units: Thousand PLN or thousand PLN/y for expense, Year for PBP

As evident from this Table 1.3.22, the reduction in emission fee is only a few percents at most compared to reduction in energy cost, and thus, the effect of reduced emission fees on the payback period is also negligible.

In this factory, the emission fee for $CO_2$ somewhat increases along with the change of the heating source for heat-treatment furnace from the current electricity to gas. This is due to the fact that $CO_2$ emission per unit of electricity is larger than that per unit of fuel.

b. Summary of Energy Conservation Potential

The energy conservation potential of this factory is shown in Table 1.3.23.

The energy conservation potential using the Excellent factory as the benchmark for energy consumption intensity, and energy conservation measures in Steps 1, 2, and 3 are shown in Figure 1.3.26. The relationship between energy conservation potential, the payback period and the investment cost is shown in Figure 1.3.27.

# Table 1.3.23 Summary of Energy Conservation Potential

Natural gas: 0.514 PLN/$m^3_N$ (36.5 MJ/$m^3_N$)   Electricity: 0.172 PLN/kWh 1 PLN = 30 yen   Coal: 170 PLN/t (23.8 GJ/t)   Coke: 400 PLN/t (33.5 GJ/t)

| Item | Energy Conservation Potential | | | | | | | Investment | Payback period |
|---|---|---|---|---|---|---|---|---|---|
| | Fuel | | | Electricity | | | Total | | |
| | GJ/y | $10^3$ PLN/y | % | MWh/y | $10^3$ PLN/y | % | $10^3$ PLN/y | $10^3$ PLN | year |
| Step 0 (Already implemented) | | | | | | | | | |
| 1. 5-furnace operation in the heat treatment factory | | | | 506 | 87 | 1.8 | 87 | 0 | 0.0 |
| Subtotal | 0 | 0 | 0.0 | 506 | 87 | 1.8 | 87 | 0 | 0.0 |
| Step 1 | | | | | | | | | |
| 2. 3-shift operation in the casting shop and 1-cycle switching of cupolas | 11,622 | 139 | 4.4 | | 0 | | 139 | 0 | 0.0 |
| 3. Improving the productivity of the furnaces in the heat treatment shop | | | 0.0 | 322 | 55 | 1.2 | 55 | 0 | 0.0 |
| 4. Removing the moisture before the drying process in the zinc galvanizing shop | | 0 | 0.0 | 206 | 35 | 0.7 | 35 | 25 | 0.7 |
| 5. Improving the boiler air ratio | 8,198 | 59 | 3.1 | | 0 | | 59 | 20 | 0.3 |
| 6. Insulating the valves of the hot water piping | 3,227 | 23 | 1.2 | | 0 | | 23 | 40 | 1.7 |
| 7. Reducing the peak power demand | | 0 | 0.0 | 600 kW | 40 | | 40 | 0 | 0.0 |
| 8. Improving the compressed air system | | 0 | | 296 | 51 | 1.1 | 51 | 30 | 0.6 |
| 9. Preventing the leakage of compressed air | | 0 | | 743 | 128 | 2.7 | 128 | 0 | 0.0 |
| 10. Turning off unnecessary lamps during daytime in the machining shop | | 0 | 0.0 | 7 | 1 | 0.0 | 1 | 0 | 0.0 |
| Subtotal | 23,047 | 220 | 8.8 | 1,574 | 309 | 5.6 | 529 | 115 | 0.2 |
| Step 2 | | | | | | | | | |
| 11. Upgrading the forehearth in the casting factory and improving the operation | 50,384 | 602 | 19.2 | Δ1,174 | Δ202 | -4.2 | 400 | 1,250 | 3.1 |
| 12. Injecting coke in the cupola in the casting factory, and oxygen enrichment | 14,402 | 172 | 5.5 | | 0 | | 172 | 313 | 1.8 |
| 13. Reinforcing the control of heat insulation and performance of furnaces in the heat treatment factory | | | 0.0 | 1,162 | 200 | 4.2 | 200 | 200 | 1.0 |
| 14. Increasing the capacity of the hot zinc dipping furnace in the galvanizing shop | | 0 | | 448 | 77 | 1.6 | 77 | 113 | 1.5 |
| 15. Installing an inverter for pumps and blower motors | | 0 | 0.0 | 239 | 41 | 0.9 | 41 | 129 | 3.1 |
| 16. Installing small-size air compressors | | 0 | | 365 | 63 | 1.3 | 63 | 70 | 1.1 |
| Subtotal | 64,786 | 774 | 24.7 | 1,040 | 179 | 3.7 | 953 | 2,075 | 2.2 |
| Step 3 | | | | | | | | | |
| 17. Switching from electricity to natural gas for heating source in the heat treatment furnace | Δ47,331 | Δ667 | -18.1 | 9,202 | 1,583 | 32.9 | 916 | 3,150 | 3.4 |
| 18. Automation of the casting mold process in the casting factory | 18,397 | 131 | 7.0 | | 0 | | 131 | 571 | 4.3 |
| Subtotal | Δ28,934 | Δ535 | -11.0 | 9,202 | 1,583 | 32.9 | 1,048 | 3,721 | 3.6 |
| Total (Step 1, 2, and 3) | 58,899 | 459 | 22.5 | 11,816 | 2,071 | 42.3 | 2,530 | 5,911 | 2.3 |

As of 1997: Fuel consumption (Coke, coal and fuel oil): 261,988 GJ/y
Electricity consumption: 27,963 MWh/y

Figure 1.3.26 Lacznikow Energy Conservation Potential

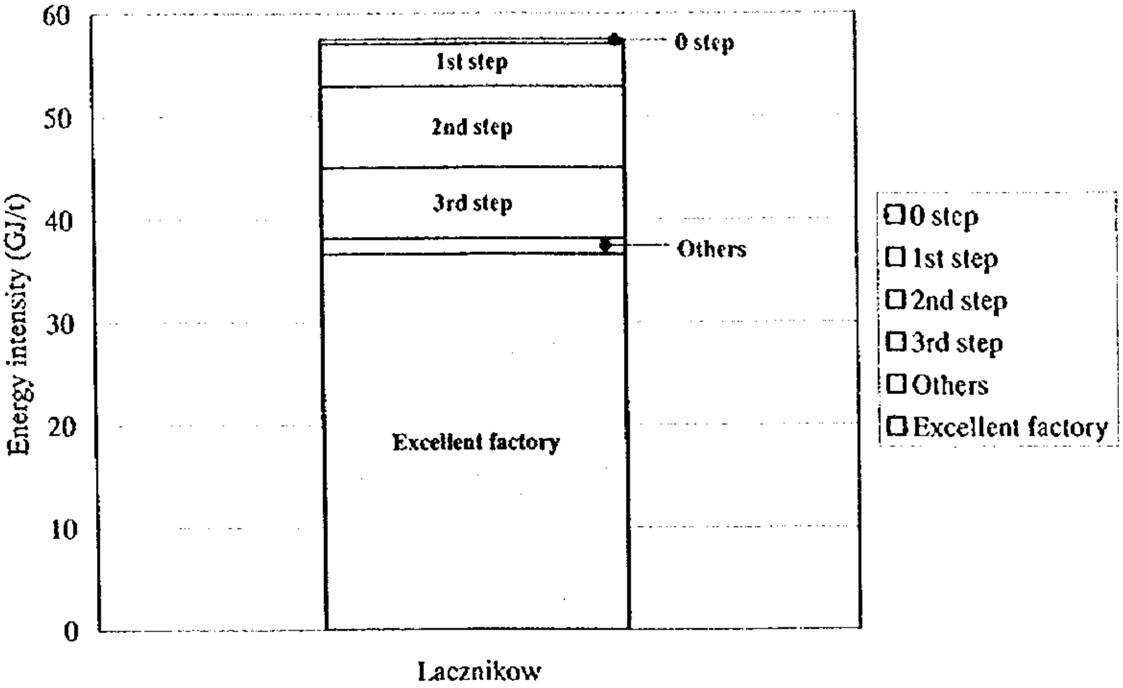
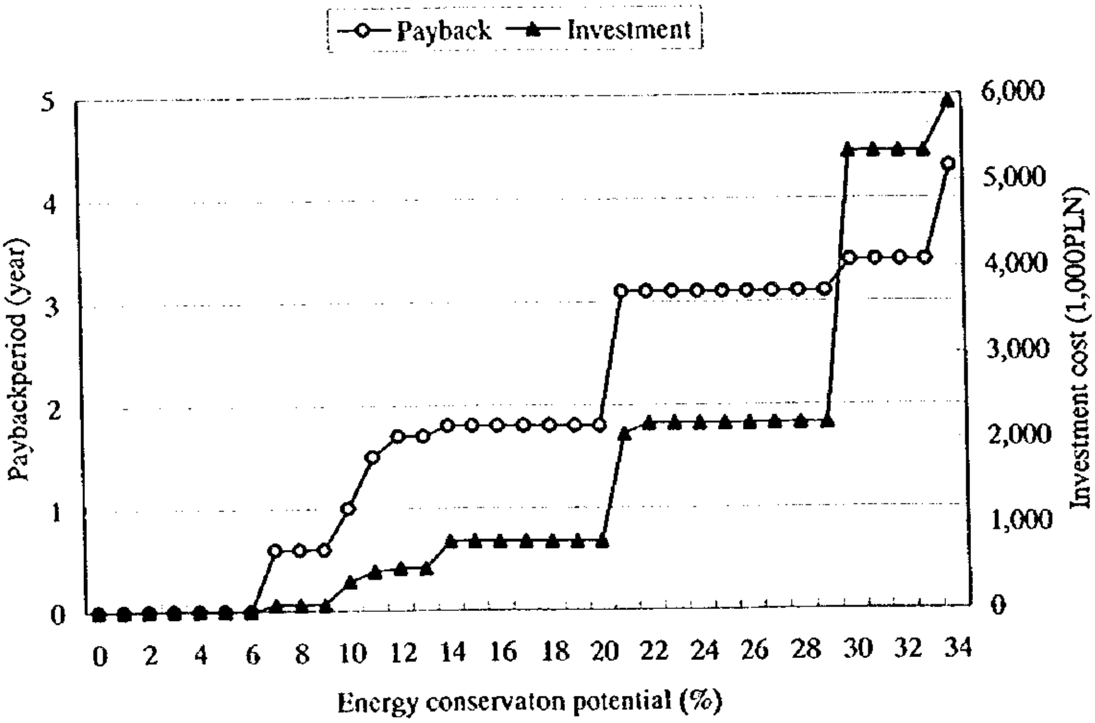


Figure 1.3.27 Lacznikow Energy Conservation Potential



# 2. RESULTS OF THE STUDY ON THE CHEMICAL INDUSTRY

## 2. RESULTS OF THE STUDY ON THE CHEMICAL INDUSTRY

### 2.1 Results of the Study at Blachownia Chemical Plant

(1) Study period: August 27 to 29, 1997

(2) Members of the study team

a. JICA Team

Mr. Norio Fukushima : Leader of energy audit & Heat management
Mr. Masashi Miyake : Process management
Mr. Jiro Konishi : Heat management
Mr. Masami Kato : Heat management
Mr. Toshio Sugimoto : Electricity management
Mr. Akihiro Koyamada: Measuring engineerring

b. Local consultants

POLESCO Investment SA
Mr. Piotr Bortnowski: Vice President
Dr. Tadeusz Kruczek: Heat management
Dr. Wieslaw Goc : Electricity management
Dr. Marcin Szega : Heat management

(3) Interviewees

Mr. Antoni Zelazny : Managing Board Member, Director for Techniques
Eng. Stanislaw Galdys : Chief Engineer for Technics
M. Sc. Eng. Jerzy Marszycki : Head of the Petrochemistry Department
M. Sc. Eng. Andrzej Mierzwinski : Head of the Ethylbenzene Section in Petrochemistry Department
Mr. Wladyslaw Kociel : Main Operator, Ethylbenzene Installation
M. Sc. Eng. Krystian Hennek : Head of the Benzol Section in Petrochemistry Department
M. Sc. Eng. Malgorzata Siedlecka: Process Engineer, Benzol Section
M. Sc. Eng. Janusz Helik : Head of Tar Distillation Section in the Coke Chemistry Department
M. Sc. Eng. Marek Sarzynski : Process Engineer of Tar Distillation Section in the Coke Chemistry Department
M. Sc. Eng. Roman Koczur : Chief of Energy Department
M. Sc. Eng. Maiusz Rozmiarek : Deputy Chief of the Energy Department
M. Sc. Eng. Ryszard Kraus : Specialist responsible for electricity in Energy Department
Eng. Woldemar Bullo : Electricity
Eng. Jan Witkowski : Deputy Head of the Benzol Section in Petrochemistry Department

M. Sc. Eng. Andrzej Kuchar : Head of the Coke Chemistry Department
M. Sc. Eng. Hieronim Konopka : Head of the Plastics Department
Mr. Marian Pieczyrak : Main operator of rotary furnace

### 2.1.1 Profile of the Plant

(1) Plant name: Zaklady Chemiczne, "BLACHOWNIA"

(2) Plant address: 47-225 Kedzierzyn-Kozle ul Szkolna 15

(3) No. of employees: 1,574

(4) Major products: Ethylbenzene, bisphenol-A, polyethylene, etc.

(5) Production capacity: 451,609 t/y (27 processes)

(6) Overview of the process

The production fields of Zaklady Chemiczne, "BLACHOWNIA" include coke chemistry, petrochemistry, synthesis and plastics, comprising 27 treatment and production processes in total and producing 75 items. The unit operations include distillation, organic synthesis and polymerization. They purchase the main materials, i. e., coal tar, crude benzene, ethylene and acetone, and moreover all energy sources such as steam, coke oven gas and electricity. The main processes are described below. (Figure 2.1.1)

a. Coal tar distillation

The purchased coal tar is distilled by means of Otto type distillation equipment (OTTO process) to obtain fractions ranging from carbolic oil to pitch through fractional distillation. The phenol in the carbolic oil among the fractions is used as raw material for bisphenol-A, while the other components are utilized as raw materials for various kinds of derivatives. The heat is used for the pipe still and the distillation tower.

b. Crude benzene distillation

The purchased crude benzene is distilled by using the hydrogenation desulfurizing equipment (pipe still), and the benzene thus refined is used as synthesis material for ethylbenzene. The heat is utilized at the distillation tower.

c. Synthesis of ethylbenzene

Benzene obtained from the crude benzene distillation process and the purchased ethylene are synthesized into ethylbenzene through an aluminum chloride catalyst. The product is marketed as raw material for a styrene monomer. The heat is utilized at the distillation tower for benzene, ethylbenzene (EB) and polyethylbenzene (PEB).

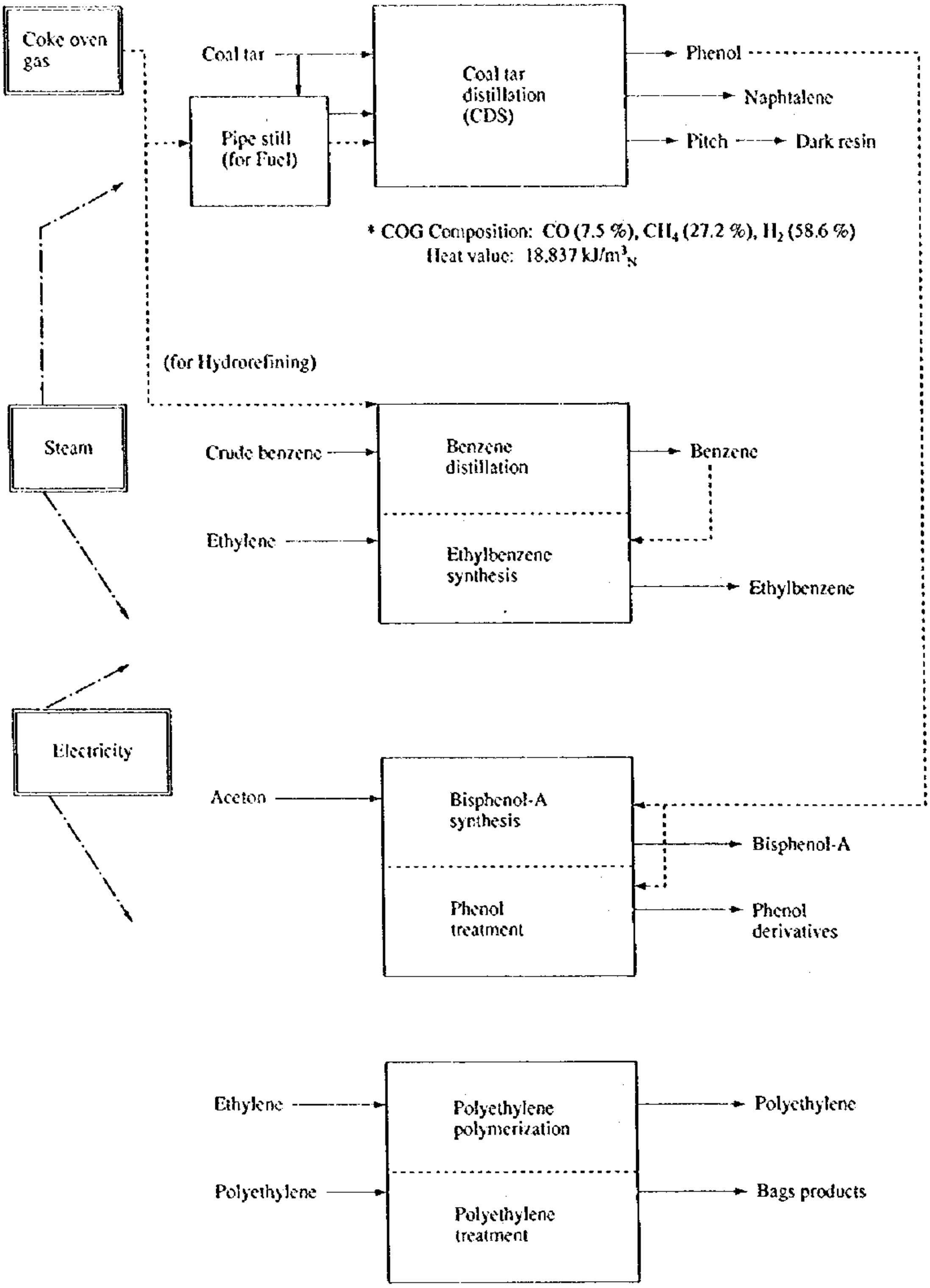
d. Synthesis of bisphenol-A

Bisphenol-A (BPA) is obtained by synthesizing phenol from the coal tar distillation process and acetone by means of hydrochloric acid. The product thus obtained is marketed as raw material for synthetic resin, while the heat is utilized for the distillation tower.

e. Polymerization of polyethylene

The purchased ethylene is polymerized into polyethylene in the high-pressure, low-density process (ICI Process/ICI: Name of company). The product, which is of high quality, is put on market instead of being used as the material for the company polyethylene bags. The heat is utilized for the distillation tower, and a great amount of electricity is consumed by the compressor.

Figure 2.1.1 Main Process Flow



* COG Composition: CO (7.5 %), $CH_4$ (27.2 %), $H_2$ (58.6 %)
Heat value: 18,837 $kJ/m^3_N$

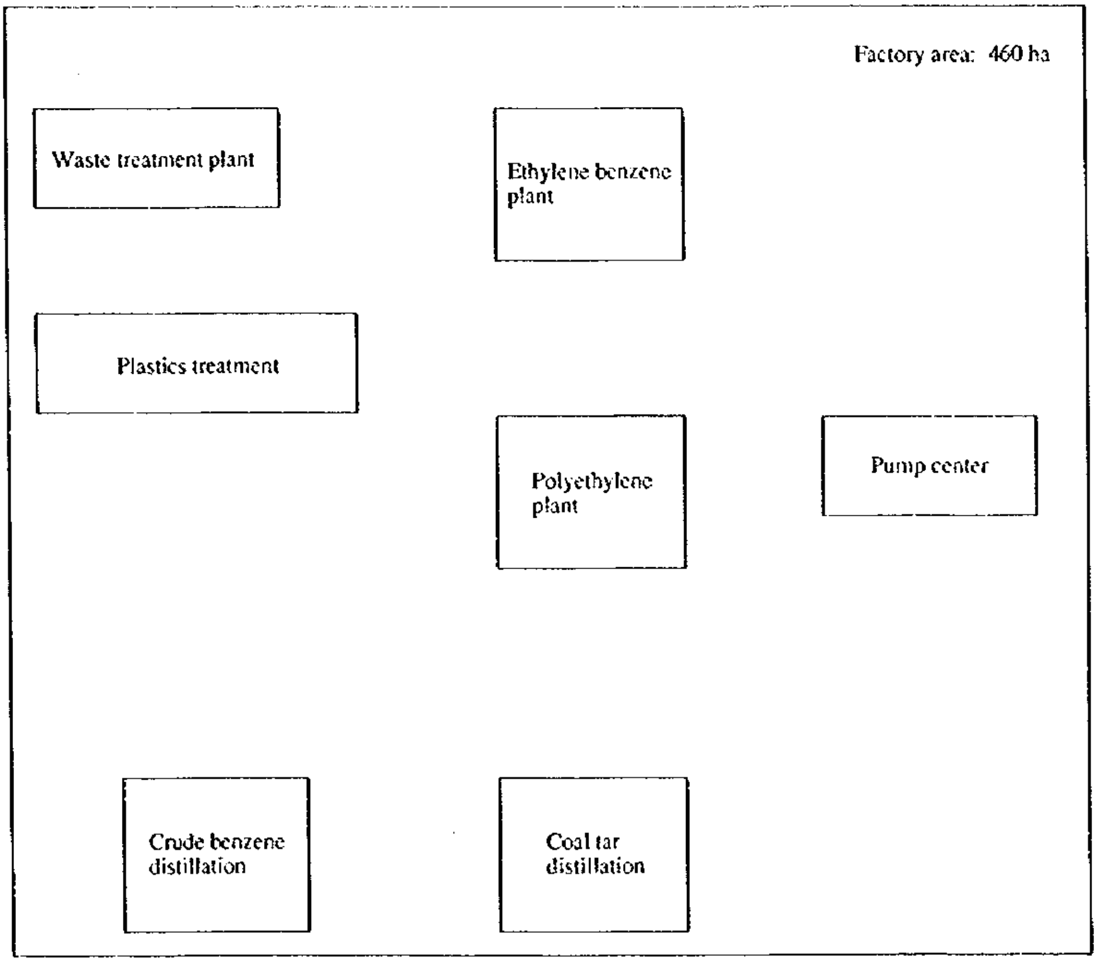
(7) History of the plant

"Blachownia Chemistry" was established in 1941, followed by setting up of the plants for processes for crude benzene in 1952, ethylbenzene in 1963, bisphenol-A in 1964, and polyethylene in 1966. This plant, which is among the leading chemical plants in Poland, has not so far realized an originally-planned integrated chemical plant: The main raw material— ethylene— is still purchased and the ethylbenzene processed through synthesis is marketed as raw material for styrene monomer. Under these circumstances, the layout for each process is not always rational. For the export ratio, polyethylene accounts for 30%, while the others are used for domestic consumption.

They have a specific plan for restructuring the plant by effective use of the vast premises as well as affordable utility services such as steam, electricity, etc.

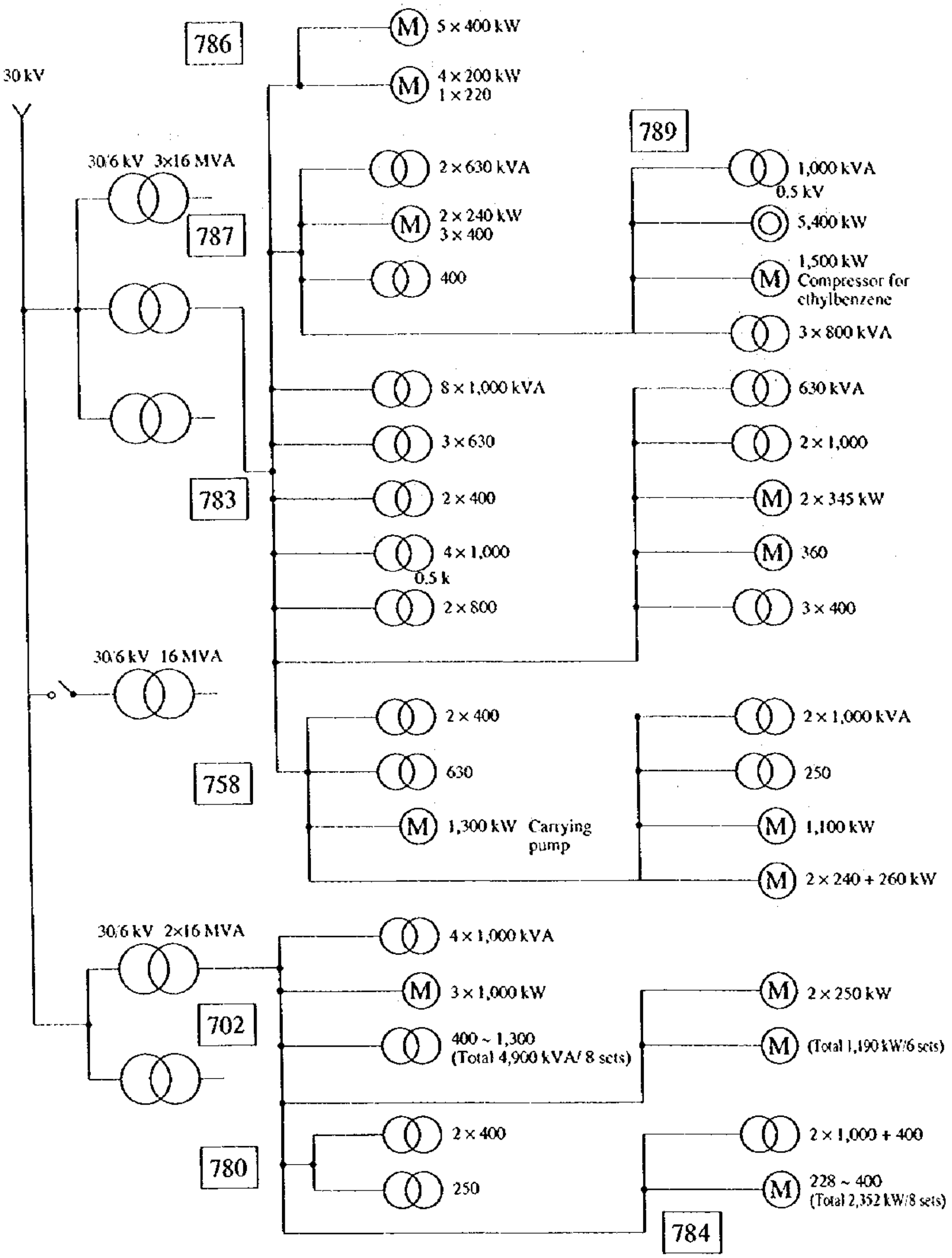
(8) Plant layout

Figure 2.1.2 Plant Layout



(9) One line diagram

Figure 2.1.3 One Line diagram



(10) Outline of major equipment

**Table 2.1.1 Major Equipment**

| Factory Specification<br>Equipment | Design | |
|---|---|---|
| Tar distllation (OTTO PROCESS) | CDS I | 87,500 t/y |
| Pipe still | | Capacity: 100,000 t/y |
| Distillation columns | CDS II | 87,500 t/y |
| | CDS III | 195,000 t/y (Stop) |
| Crude benzene distillation (HYDROREFINING) | 100,000 t/y | |
| Distillation columns | Start up: 1952; thereafter many times modernized. | |
| | Recent modernization 1996-1997 | |
| Ethylbenzene synthesis ($AlCl_3$ process) | 103,000 t/y | |
| Benzene distillation column | Start up: 1975 | |
| EB distillation column | | |
| PEB distillation column | | |
| Bisphenol-A synthesis (HCl process) | 8,000 t/y | |
| BPA distillation column | After modernized: 96,000 t/y | |
| | Start up: 1977 | |
| Polyethylene polymerization (ICI process) | 60 t/d | |
| Compressor (125 MP) | Start up: 1966 | |
| Utilities Pump | 4 | |
| Compressor | NA | |

(11) Energy price

**Table 2.1.2 Energy Price and Heat Value**

| | Energy Price | Heat Value |
|---|---|---|
| Steam | 13.6 PLN/GJ | |
| Coke oven gas | 0.17 PLN/$m^3_N$ | (18,837 kJ/$m^3_N$) |
| Electricity | 0.09 PLN/kWh | |
| Water from river | 0.08 PLN/$m^3$ | |
| Nitrogen | 0.14 PLN/$m^3$ | |

(1st half of 1997)

## 2.1.2 Energy Consumption Status

### (1) Trend of production

**Table 2.1.3 Trend of Production and Preparations**

| | Unit | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|
| Preparation | | | | | |
| Tar distillation | t | 141,131 | 123,335 | 117,416 | 90,993 |
| Benzene distilation | t | 65,354 | 71,000 | 70,252 | 65,838 |
| Production | | | | | |
| Ethylbenzene | t | 52,955 | 58,875 | 56,020 | 56,490 |
| Bisphenol-A | t | 2,903 | 5,616 | 8,321 | 8,433 |
| Polyethylene | t | 17,288 | 18,870 | 19,160 | 16,959 |

### (2) Trend of energy consumption

**Table 2.1.4 Trend of Energy Consumption**

| | Unit | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|
| Electricity | MWh | 70,777 | 69,883 | 70,623 | NA |
| Steam | TJ | 1,641 | 1,565 | 1,767 | NA |
| Coke oven gas | GJ | 38,823 | 35,564 | 80,773 | NA |
| Compressed air | $10^3m^3$ | 51,533 | 49,635 | 49,814 | NA |
| | MWh | 7,266 | 6,999 | 7,024 | NA |

Coke oven gas: 18,837 $kJ/m^3$

Compressed air: 0.141 $kWh/m^3$

## (3) Trend of energy intensity

### Table 2.1.5 Trend of Energy Intensity

| | Unit | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|
| a. Tar distillation | | | | | |
| Electricity | kWh/t | 2.89 | 7.46 | 6.26 | 4.83 |
| Steam | MJ/t | 1,618.3 | 1,438.5 | 1,552.8 | 1,408.1 |
| Coke oven gas | MJ/t | 89.6 | 51.8 | 410.5 | 1338.5 |
| Compressed air | $m^3$/t | 10.52 | 36.74 | 36.53 | 38.07 |
| | kWh/t | 1.5 | 5.2 | 5.2 | 5.4 |
| b. Benzene distillation | | | | | |
| Electricity | kWh/t | 11.16 | 11.70 | 10.85 | 14.38 |
| Steam | MJ/t | 5,401.0 | 4,564.7 | 5,418.0 | 4,864.2 |
| Coke oven gas | $m^3$/t | 0 | 8.6 | 13.6 | 12.9 |
| | MJ/t | 0 | 162.6 | 256.1 | 242.2 |
| Compressed air | $m^3$/t | 76.31 | 126.69 | 114.88 | 160.52 |
| | kWh/t | 10.8 | 17.9 | 16.2 | 22.6 |
| c. Ethybenzene synthesis | | | | | |
| Electricity | kWh/t | 25.80 | 24.03 | 28.74 | 35.09 |
| Steam | MJ/t | 3,601.4 | 4,007.8 | 3,704.2 | 3,927.0 |
| Compressed air | $m^3$/t | 32.86 | 29.89 | 31.03 | 30.52 |
| | kWh/t | 4.6 | 4.2 | 4.4 | 4.3 |
| d. Bisphenol-A synthesis | | | | | |
| Electricity | kWh/t | 752.33 | 630.70 | 545.13 | 514.99 |
| Steam | MJ/t | 46,573.8 | 27,572.7 | 25,445.6 | 26,314.8 |
| Compressed air | $m^3$/t | 1,049.26 | 676.10 | 634.42 | 666.07 |
| | kWh/t | 147.9 | 95.3 | 89.5 | 93.9 |
| e. Polyethlene polymerization | | | | | |
| Electricity | kWh/t | 1,034.48 | 999.18 | 1,018.27 | 1,059.26 |
| Steam | MJ/t | 1,272.2 | 1,415.1 | 1,677.9 | 2,067.0 |
| Compressed air | $m^3$/t | 301.13 | 259.36 | 222.70 | 186.56 |
| | kWh/t | 42.5 | 36.6 | 31.4 | 26.3 |

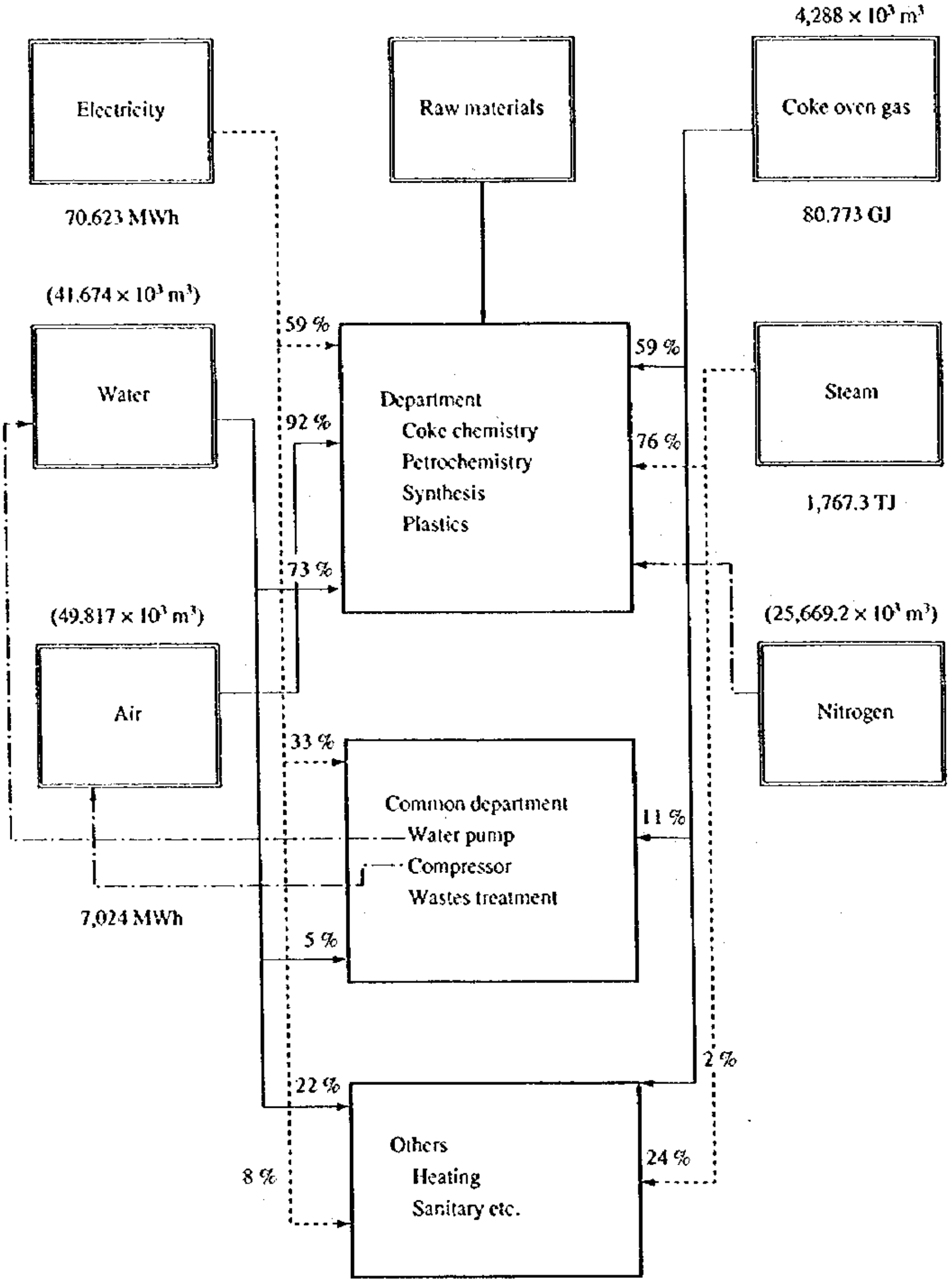
## (4) Percentages of the energy costs in the total production cost

Although no data on the production cost could be obtained, the following information was provided:
The percentages of the energy costs in the gross sales (274,271 × $10^3$ PLN) are electricity 2.5 %, steam 8 % and coke oven gas 0.3 %, amounting to 10.8 % in total in 1995.

(5) Energy flow

59 % of electricity, 76 % of steam, 87 % of coke oven gas, 92 % of compressed air and 73 % of service water are used for processes, while 33 % of electricity, 11 % of coke oven gas, 1 % of compressed air and 5 % of water are consumed in the common departments including sewage treatment, compressor, and so on. The rest are available for heating and sanitary uses. Figure 2.1.4 shows energy flow in 1995.

**Figure 2.1.4 Energy Flow**



### 2.1.3 Energy Management Status

(1) Setting the target for energy conservation

a. Setting the target value

The target values are determined in considerably great detail, and documented. However, this has been just started in the filing form in the administration department, and these data have not been effectively utilized for management purposes.

b. Problems in the promotion of energy conservation efforts

On the understanding that energy conservation at the current stage is attained, more impotance now seems to be laid on quality control.

(2) Systematic activities

a. Setting up a department dedicated to energy conservation

The energy management department is available.

b. Setting up an energy conservation committee

A liaison meeting is held particularly when abnormal energy consumption occurs in the production department. Hence, it has not yet been established as a daily practice.

c. Top management's stance

They are positively motivated to set up a management system for energy conservation activities.

d. Personnel evaluation system

There is no proposal system related to energy conservation.

(3) Data-based management

a. Grasping the energy consumption

People in the energy management department keep track of the energy consumption, but they have only a scanty knowledge of the process and show little interest in it including energy conservation.

b. Grasping the energy consumption for each main equipment

The information on energy consumption situation in each department is fed back from the energy management department every week. The cost of compressed air is allocated in cost accounting on the proportional distribution basis.

c. Grasping the energy intensity for major products

None of such works as coordination, tabulation and graph plotting are carried out.

d. Installing measuring instruments

The production process is continuous and is controlled automaticaly. Necessary measuring equipment for the operation are wholly installed.

e. Production management and cost management

They have just obtained ISO 9000 certification, and thus the management system is still at the preparation stage.

(4) Plant engineering

The plant consists of old equipment and new equipment, thus constituting a complicated system. As to the equipment conditions, it is not classified into a well maintained conditon.

### 2.1.4 Problems and Countermeasures related to Energy Use

Tar and crude benzene distillation process, ethylene synthesis and high-pressure polyethylene polymerization process among the above-mentioned treatment and production processes are discussed here excluding bisphenol-A on which data is unavailable.

Energy conservation is divided into the following three steps to sort out its potential.

Step 1: Enhancing the management
Step 2: Improving the equipment
Step 3: Improving the processes

### 2.1.4.1 Tar distillation

(1) Comparison of energy intensity with the excellent factory

This factory consumes by far larger amounts of energy except electricity than the Excellent company. The reason why electricity consumption in the excellent company is greater is that vacuum pumps are used for reducing pressure in the vacuum distillation.

## Table 2.1.6 Comparison of Energy Intensity in Tar Distillation Process (1)

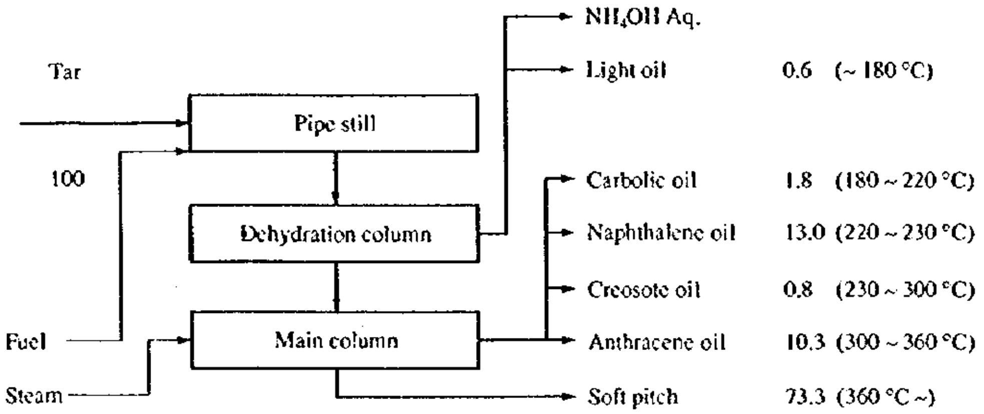
| | Unit | Blachownia | Excellent factory | Difference |
|---|---|---:|---:|---:|
| Electricity | kWh/t-tar | 4.8 | 6.9 | -2.1 |
| Steam | MJ/t-tar | 1,408.1 | 534 | 874.1 |
| Fuel | MJ/t-tar | 1,338.5 | 333 | 1,005.5 |
| Compressed air | $m^3$/t-tar | 38.1 | 4.1 | 34 |
| | kWh | 5.4 | 0.6 | 4.8 |
| Water | $m^3$/t-tar | 6.1 | 0 | 6.1 |
| Production capacity | t/y | 100,000 | 500,000 | |

(2) Estimating the energy conservation potential

a. Process

1) Material balance and fractional distillation temperature examples

## Figure 2.1.5 An Example of Material Balance and Fractional Distillation in the Tar Distillation Process



2) Difference in energy intensity

## Table 2.1.7 Comparison of Energy Intensity in Tar Distillation Process (2)

| | Unit | Blachownia | Excellent factory | Difference |
|---|---|---:|---:|---:|
| Heat | MJ/t | 2,747 | 867 | 1,880 |
| Electricity | MJ/t | 106 | 77 | 29 |
| Total | MJ/t | 2,853 | 944 | 1,909 |

① Difference due to external factors

Compared with Blachwria with Japanese excellent company, raw materials tar and COG (coke oven gas) are purchased from the coke factory, thus producing no significant difference in the type and quality of the process. There is no difference in production processes and systems either.

Since the production capacity of the excellent factory is 5 times larger than that of Blachownia, an approximately 10 % energy intensity is due to scale merit. The annual average temperature is 8 °C in Katowice, and 20 °C at the excellent factory, with a temperature difference of approx. 12 °C. Assuming the operating temperature for the tar distillation process to be 350 °C, the difference due to the temperature difference will be theoretically around 3.5 % (12/350 = 3.5 %) since there is no significant difference in raw material and product composition. Under the present situation where heat radiation from facilities, furnace body and piping is approximately 30 % of the supplied heat value, the following formula is obtained.

$2{,}747 \times 0.3 \times 0.035 = 29$ MJ/t

Therefore, the difference in energy intensity due to external factors will be as follows:

Energy intensity difference: $29 + 2{,}853 \times 0.1 = 314$ MJ/t

② Difference due to technical factors

1) Production control system

Judging from the large monthly fluctuation range of energy intensity and a lack of definite correlation with the production amount, it is advisable to set up a system which will feed back the information on energy intensity to the production department at the earliest possible opportunity in order to investigate the cause and take a countermeasure for it.

2) Improving the air fuel ratio for the tar heating furnace

While various types of fuel can be used, the heating efficiency is low. Besides, combustion control is inadequate. Hence, the adjustment of air ratio will make a 0.6 % energy conservation possible. The measured values and the analysis are given in b. 1).

Energy conservation amount: $1{,}338.5 \times 0.016 = 21$ MJ/t (1,911 GJ/y)

3) Enhancing the heat insulation of the surface of the tar heating furnace

Since the surface temperature of the tar heating furnace is as high as 70 to 350 °C, heat insulation needs to be enhanced. The analysis result of measured values is shown in b. 2).

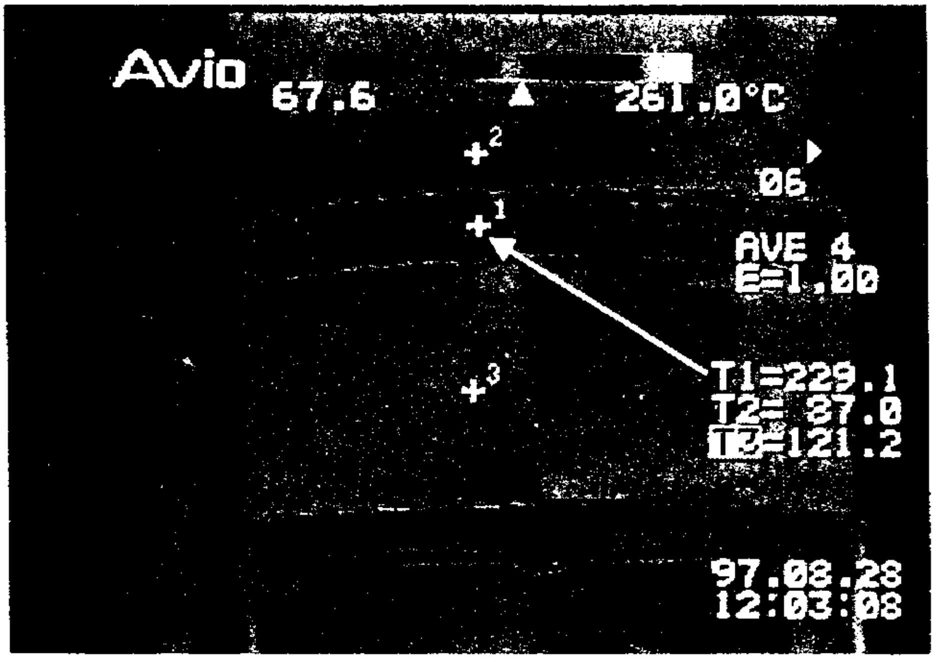
Energy conservation amount: 3,102 GJ/y (34 MJ/t)

4) Reinforcing the heat insulation of the distillator

No heat insulation is provided to the flange section, thus causing a great heat loss. Reinforcing the heat insulation allows a 10 % energy conservation. Figure 2.1.6 shows the image of flange surface temperature distribution taken using the infrared thermal imaging system.

2,747 × 0.1 = 275 MJ/t (25,023 GJ/y)

Figure 2.1.6 Thermal Image of the Flange Section



5) Leakage of compressed air

Consumption of compressed air is 7 times larger than that of the excellent factory, though it is not so clearly categorized regarding whether it is used for processing or for controlling. This suggests that the piping system needs to be checked for any air leaks. In our initial schedule, this was to be implemented in the fourth study in Poland; however it could not be carried out because the subject factory for the study was changed. The result of our survey on this factory led us to believe that compressed air used for controlling could be reduced to a half or less the current volume. Thus in this section, energy conservation potential for this factory was calculated on the assumption that the consumption of compressed air could be reduced to about 3 times that of the excellent factory. As a result of calculation based on this presumption, energy conservation potential of 26 MJ/t (2,366 GJ/y, 231 MWh/y) could be obtained.

6) Enhancing heat exchangers

Installing heat exchangers newly will bring about a 30 % energy conservation.

Energy conservation amount: 2,747 × 0.3 = 824 MJ/t (74,978 GJ/y)

7) Ejector of the distillator

The steam intensity of the steam ejector for generating vacuum in the distillator is 160 MJ/t, which is too large. The reasons for this include steam pressure higher than necessary, enlarged nozzle diameters due to poor maintenance of nozzles, etc.. In our view, improving these points will allow steam consumption to be reduced by 30 %.

Energy conservation amount: 160 × 0.3 = 48 MJ/t (4,368 GJ/y)

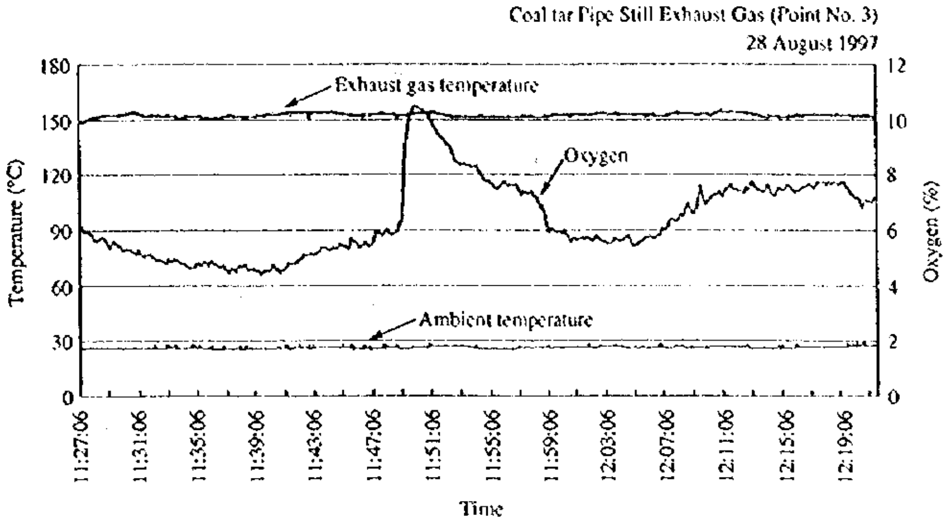
b. Utilities (Facilities using heat)

1) Measurement and analysis of the exhaust gas from the tar pipe still

For measurement of exhaust gas, $O_2$ concentration and gas temperature were measured and recorded for about 30 minutes each at 3 points in the lower part of the contact heating section closest to the inlet of the flue from the contact heating section of the tar pipe still. Measurement was not simultaneously performed at 3 points but by shifting the measuring point one after another.

Figure 2.1.7 shows an example of measurement results, and Table 2.1.8 shows the mean value for each measuring point.

## Figure 2.1.7 Measurement of Exhaust Gas from Tar Pipe Still



## Table 2.1.8 Measurement of Exhaust Gas from Tar Pipe Still

| | Oxygen | | | Temperature (°C) | | |
|---|---|---|---|---|---|---|
| | Average | Maximum | Minimum | Average | Maximum | Minimum |
| Point-1 | 7.31 % | 9.15 % | 6.25 % | 127 | 129 | 123 |
| Point-2 | 5.87 % | 6.90 % | 4.81 % | 150 | 152 | 145 |
| Point-3 | 6.14 % | 10.48 % | 4.43 % | 152 | 154 | 149 |
| Grand: | 6.44 % | 10.48 % | 4.43 % | 143 | 154 | 123 |

Table 2.1.9 shows the results of calculating the amount of fuel saved by means of air ratio adjustment. In this calculation, the fuel saving rate is obtained on the assumption that the oxygen concentration is decreased from the average to the minimum in the measured values by means of adjusting the air flow.

## Table 2.1.9 Fuel Saving Effect by Air Ratio Control

| Preconditions | |
|---|---|
| Fuel gas | |
| Net heat value (kJ/m$^3$) | 18,613 |
| Net heat value (kcal/m$^3$) | 4,446 |
| Combustion air temperature | 26 |
| Exhaust gas temperature | 143 |
| Furnace infiltrating air ratio | 0 % |

Calculation Result

| | Theoretical Combustion | Current Air Ratio | Air Ratio after Improvement |
|---|---|---|---|
| Oxygen in exhaust gas | 0.0 % | 6.4 % | 4.6 % |
| Air ratio | 1.00 | 1.39 | 1.25 |
| Air amount (m$^3$/m$^3$) | 4.6 | 6.4 | 5.8 |
| Exhaust gas amount (m$^3$/m$^3$) | 5.3 | 7.1 | 6.4 |
| Exhaust gas loss rate (to fuel heat) | | 6.2 % | 5.7 % |
| Fuel saving rate | | | 1.6 % |

Notes: The improved air ratio is the reference value based on judgment criteria in Japan.

As shown in the table, decreasing the exhaust gas oxygen to 4.6 % will make it possible to save fuel by 1.6 %. The fuel composition used for this calculation is as given in Table 2.1.10.

Table 2.1.10 Fuel Gas Composition of Tar Pipe Still

| Gas Content | $CO_2$ | $H_2$ | $CH_4$ | $C_2H_4$ | $C_2H_6$ | $C_3H_8$ | $C_4H_{10}$ | $N_2$ | $O_2$ | $H_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Wet volume | 2.2 % | 58.6 % | 27.2 % | 2.7 % | – | – | – | 1.5 % | 0.3 % | – |

2) Measurement and heat radiation value of tar pipe still surface temperature

The results of measuring each part of the furnace surface temperature by the use of a contact thermometer show that the side wall temperature at the ground level is 50 °C or lower but the temperature at the work platform level is higher. With regard to this part, the heat radiation amount was calculated based on the measured temperature and the estimated surface area, the result of which is shown in Table 2.1.11, together with the test calculation for the surface temperature of 50 °C. This table shows that if the surface temperature can be decreased to 50 °C by means of reinforcing heat insulation, the present radiation heat loss can be reduced by as much as 82%. Additionally, it is recommended that the portions of high surface temperature be checked with regard to any broken brick, drop off, or joint damage, and thereafter to be repaired.

## Table 2.1.11 Tar Pipe Still and Heat Radiation

(Measured value)

| Portion | Area | Temperature | Heat conductivity Conductivity | Heat conductivity Radiation | Unit heat amount | Radiation amount | Radiation amount |
|---|---|---|---|---|---|---|---|
| | ($m^3$) | (°C) | ($kcal/m^2/h/°C$) | | ($kcal/h/m^2$) | (kJ/h) | (kcal/h) |
| Upper deck | | | | | | | |
| Front/rear wall | 35.00 | 70.0 | 4.60 | 5.78 | 483 | 70,757 | 16,903 |
| Side wall (burner side) | 24.50 | 79.0 | 4.86 | 6.04 | 605 | 62,058 | 14,825 |
| Side wall (Counter-burner side) | 24.50 | 200.0 | 6.75 | 10.54 | 3,052 | 313,009 | 74,775 |
| 8 Manholes | 0.63 | 350.0 | 7.82 | 19.24 | 8,835 | 23,197 | 5,542 |
| End wall plate | 0.54 | 250.0 | 7.18 | 13.02 | 4,576 | 10,343 | 2,471 |
| Total | | | | | | 479,364 | 114,516 |

(Test calculation of the effect by increasing the heat insulation)

| Portion | Area | Temperature | Heat conductivity Conductivity | Heat conductivity Radiation | Unit heat amount | Radiation amount | Radiation amount |
|---|---|---|---|---|---|---|---|
| | ($m^3$) | (°C) | ($kcal/m^2/h/°C$) | | ($kcal/h/m^2$) | (kJ/h) | (kcal/h) |
| Upper deck | | | | | | | |
| Front/rear wall | 35.00 | 50.0 | 3.86 | 5.24 | 241 | 35,313 | 8,436 |
| Side wall (burner side) | 24.50 | 50.0 | 3.86 | 5.24 | 241 | 24,719 | 5,905 |
| Side wall (Counter-burner side) | 24.50 | 50.0 | 3.86 | 5.24 | 241 | 24,719 | 5,905 |
| 8 Manholes | 0.63 | 50.0 | 3.86 | 5.24 | 241 | 633 | 151 |
| End wall plate | 0.54 | 50.0 | 3.86 | 5.24 | 241 | 545 | 130 |
| Total | | | | | | 85,929 | 20,528 |
| | | | | | | 82 % | 82 % |

Energy conservation amount: (479,364 − 85,929) × 8,760 × 0.9 = 3,102 GJ/y

where

8,760: h/y

0.9 : operation rate

c. Energy conservation potential

1) Improving the air fuel ratio of the tar heating furnace:
Energy intensity improvement: 21 MJ/t
2) Enhancing heat insulation for the wall of the tar heating furnace:
Energy intensity improvement: 34 MJ/t
3) Enhancing the insulation of the distillator:
Energy intensity improvement: 275 MJ/t
4) Leakage of compressed air: Energy intensity improvement: 26 MJ/t
5) Enhancing heat exchangers: Energy intensity improvement: 824 MJ/t
6) Distillator ejector : Energy intensity improvement: 48 MJ/t

### 2.1.4.2 Benzene distillation

(1) Comparison of energy intensity with that of excellent factory

Table 2.1.12 Comparison of Energy Intensity in Benzene Distillation (1)

| | Unit | Blachownia | Excellent Factory | Difference |
|---|---|---|---|---|
| Electricity | kWh/t-c.B | 14.4 | 46.8 | -32.4 |
| Steam | MJ/t-c.B | 4,864.2 | 1,779.1 | 3,085.1 |
| Hydrogen | $m^3$/t-c.B | | 17.9 | -17.9 |
| Hydrogen source (COG: $H_2$ 60 %) | $m^3$/t-c.B | 12.9 | | 12.9 |
| | MJ/t-c.B | 242.2 | 302.6 | -60.4 |
| Compressed air | $m^3$/t-c.B | 160.5 | 8.5 | 152 |
| | kWh/t-c.B | 22.6 | 1.2 | |
| Water | $m^3$/t-c.B | 67 | 157.3 | -90.3 |
| Nitrogen | $m^3$/t-c.B | | 8.5 | -8.5 |
| Production capacity | t/y | 100,000 | 140,000 | |
| BTX/c.B (%) | | 80 | 85 | |

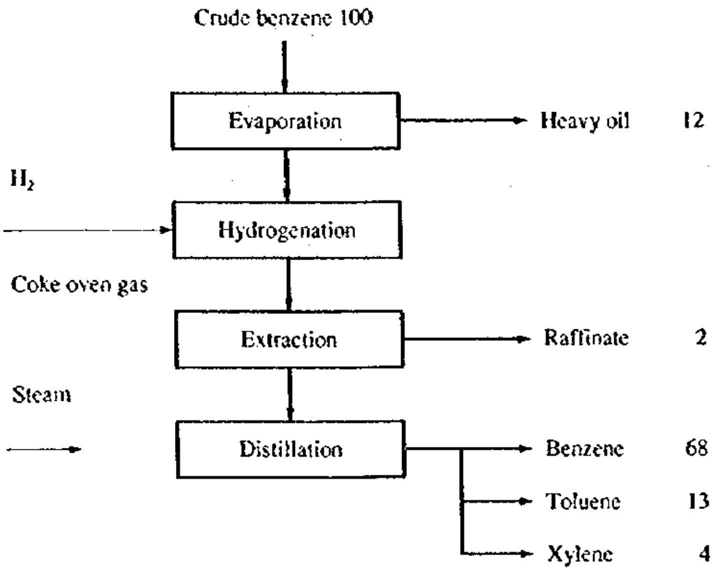
C.B : Crude Benzene
BTX: Benzene, Toluene, Xylene

(2) Estimating the energy conservation

a. Process

1) Material balance

Figure 2.1.8 Material Balance in Benzene Distillation



2) Difference in energy intensity

Table 2.1.13 Comparison of Energy Intensity in Benzene Distillation (2)

| | Unit | Blachownia | Excellent factory | Difference |
|---|---|---|---|---|
| Heat | MJ/t | 4,864 | 2,082 | 2,782 |
| Electricity | MJ/t | 381 | 496 | -115 |
| Total | MJ/t | 5,245 | 2,578 | 2,667 |

Coke oven gas is used as the hydrogen source, with no significant difference in its cosumption observed between Blashownia and excellent factory.

① Difference due to external factors

Raw materials -crude benzene and coke oven gas- are purchased products from the coke factory, producing no large difference in the product type and quality. There is basically no significant difference in the process and system either despite the difference in the hydrogen source for hydrogenation, i. e., coke oven gas (for Blachownia) or hydrogen (for Excellent factory). According to our initial plan, this point was to be further investigated in detailed energy audit but could not be implemented because the subject of the study was changed.

Since the production capacity of the excellent factory is around 1.4 times larger than that of Blachownia. The difference in energy consumption due to the difference in production capacity need not be taken into account. The annual average temperature is 8 °C in Katowice, and 20 °C at the excellent factory, with a temperature difference of approx. 12 °C. Assuming the operating temperature for crude benzene process to be 100 °C, the difference due to the temperature difference will be theoretically around 12 % (12/100 = 12 %) since there is no significant difference in raw material and product composition. Under the present situation where heat radiation from facilities, furnace body and piping is approximately 30 % of the supplied heat energy, the following formula is obtained.

4,864 × 03 × 0.12 = 175 MJ/t

From 1994 onward, the crude benzene distillation process has been undergoing modification, which was performed on an extensive scale particularly in 1997. Thus, the energy intensity submitted by the factory are presumed to include heat loss resulting from the decline in the operation rate. Assuming that the heat loss due to the above-mentioned external factor is 15 % of the supplied heat value, the following equation will be obtained:

4864 × 0.15 = 730 MJ/t

Therefore, the difference in energy intensity due to external factors will be as follows:

Energy intensity difference: 175 + 730 = 905 MJ/t

② Difference due to technical factors

1) Production management system

The monthly fluctuation range of energy intensity is large, showing a lack of definite correlation with the production amount. This may be inevitable since each process is currently under modification. However, this may be partially attributable to the inadequacy of a system, and thus it is recommendable to set up a system which will feed back the information on energy intensity to the production department at the earliest possible opportunity in order to investigate the cause and take a countermeasure for it.

2) Reinforcing the heat insulation of the distillator

Heat radiation loss is large because of inadequate heat insulation in the flange part. The result of our factory survey shows that enhancing the heat insulation is estimated to produce a 10 % energy conservation.

4,864 × 0.1 = 486 MJ/t (31,997 GJ/y)

3) Leakage of compressed air

Consumption of compressed air is 20 times larger than that of the excellent factory, though it is not so clearly categorized regarding whether it is used for processing or for controlling. This suggests that the piping system needs to be checked for any air leaks. In our view, consumption of compressed air for controlling can be reduced to around 3 times that of the excellent factory, and thus a saving of 195 MJ/t (12,832 GJ/y, 1,251 MWh/y) can be achieved.

4) Enhancing heat exchangers

Installing heat exchangers newly will bring about a 20 % energy conservation.

Reduction in heat value: 4,864 × 0.2 = 973 MJ/t (64,060 GJ/y)

5) Energy conservation potential

① Enhancing the insulation of the distillator
: Reduction in energy intensity: 486 MJ/t
② Leakage of compressed air: Reduction in energy intensity: 54 MJ/t
③ Enhancing heat exchangers: Reduction in energy intensity: 973 MJ/t