No. 80

REPORT OF THE STUDY ON ENERGY CONSERVATION PROJECT IN THE KINGDOM OF THAILAND

DECEMBER, 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Kingdom of Thailand, the Government of Japan decided to conduct a survey on Energy Conservation Project in Thailand and entrusted the survey to the Japan International Cooperation Agency (JICA). The JICA sent to Thailand a survey team headed by Mr. Masakazu Ue four times starting in August 1982.

The team exchanged views on the Project with the officials concerned of the Government of Thailand and conducted a field survey in and around the metropolitan area of Bangkok. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Kingdom of Thailand for their close cooperation extended to the team.

Tokyo, December 1984.

Keisuke Arita

Keisuke Arita
President
Japan International Cooperation Agency

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I. Outline of the Study, Energy Situation

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2. Background of the Study - Energy Situation in Thailand

1.1 Primary energy demand

Thai economy has attained remarkable development over the past 20 years. Although Thailand suffered temporary economic stagnation following the oil crisis, its gross domestic product in real terms registered about a fourfold increase during the period, and both expantion of infrastructural investment, diversification of agricultural production and industrialization mainly in the field of import substitutive industries progressed rapidly.

In consequence of such economic development and changes in the industrial structure, the demand for energy also registered a sharp rise. The demand for primary energy made a 10-fold increase from 1961 through 1982, resulting in total demand of 18,120 million litres of crude oil equivalent in 1982.

The annual average growth rate of domestic energy demand was 11.6 percent during the 1961-1982 period, but phenomenal changes were noted in the trend of energy demand after the oil crisis broke out in 1973. More specifically, the annual average rate of increase in the demand for energy, which had stood at 15.4 percent before the oil crisis (1961-1973), dwindled to 7.1 percent after the oil crisis (1973-1982).

Hence, the energy consumption elasticity for GDP (real terms), which had averaged nearly 2 before the oil crisis, dropped to 1.04 after the oil crisis.

Likewise, energy consumption per unit GDP, which had doubled during the decade preceding the oil crisis, has remained almost at the same level since 1973.

1.2 Energy supply structure

There has also been a major change over the past decade in the energy supply structure.

Table – 1 Primary Energy Supply

(Unit : 10^6 ℓoe, %)

Year / Energy	1973		1982		Growth Rate '73 ~ '82
	10^6 ℓ	Share %	10^6 ℓ	Share %	
Petroleum	8,422.4	85.8	10,872.1	60.0	2.9
Hydroelectric	659.9	6.7	1,300.3	7.2	7.8
Coal & Lignite	149.3	1.5	766.3	4.2	19.9
Traditional Energy	586.6	6.0	3,881.3	21.4	23.4
Natural Gas	–	–	1,300.6	7.2	–
Total	9,818.2	100	18,120.5	100	7.1
Share of Net Import %	86.2		61.0		–

Note : Traditional Energy includes Fuel Wood, Charcoal, Paddy husk and Baggasse.

As shown in Table I, petroleum is the biggest source of primary energy. Thailand imports almost all of the petroleum it consumes from abroad.

As in the case of other countries, since 1973 Thailand's dependence on petroleum has decreased sharply from 86 percent to 60 percent because of the development and exploitation of natural gas, lignite and traditional energy in an effort to cope with a sharp upswing in oil prices and also because of rather slight increase in domestic petroleum consumption.

Although this attests to the fact that the energy supply stability in Thailand has remarkably improved over the past 10 years, both the country's energy dependence on oil and dependence on imported energy still remains at high level of 60 percent. Therefore, the energy supply structure in Thailand is still apt to be affected by changes in the energy situation abroad. In fact, a sharp increase in oil price, caused by the oil crisis which struck twice in the 1970s, has imposed a heavy burden on the economy of Thailand.

The ratio of Thailand's energy import value to total import value, which had stood at 10.4 percent in 1973, nearly trebled to 29.8 percent in 1982. The country spends 37 percent of the valuable foreign currency earned from exports on purchasing oil from abroad, and this is seemed to be main cause for Thailand's chronic trade deficits.

1.3 Final energy demand

The final domestic demand for energy is 14,810 million litres (1982) in terms of crude oil. Table 2 shows the by-sector demand for energy.

The transport sector is the largest consumer of energy, but the share of this sector in final energy consumption has been decreasing in recent years. Instead, the shares of industrial sector, household commercial and other sector have been increasing, and the demand for energy in these major sectors is fast growing to be equal.

In the manufacturing industry, food, textile, non-metal (cement and others) and chemical industries are major energy consumers. In fact, these four industries account for 70 to 80 percent of the energy consumed by the whole manufacturing industry.

The supply structure of secondary energy is shown in Table 3. Here, petroleum products occupy an overwhelmingly large share in energy supplies, but its share is going down steadily, and, instead, the shares of electric power, lignite and traditional energy are on a gradual increase.

1.4 Energy strategies

The primary objective of the Fifth National Economic and Social Development Plan (1982-1986) in Thailand lies in lowering the external trade deficit and restoring the financial positions of the country. To attain this objective curbs on increase in energy consumption and reduction of energy dependence on imported energy (imported oil) are taken up as basic strategies in the energy field.

Under these strategies, the following energy targets are set forth in the Fifth Plan:

(1) To reduce the average annual growth rate of total energy consumption to 4.8 percent by promoting efficient use of energy and energy conservation particularly in the transport and industrial sectors;

Table – 2 Final Energy Demand by Sector

(Unit : Share %)

Year	1979	1980	1981	1982
Industrial	28.6	28.5	28.8	29.5
Transportation	38.4	35.8	34.6	33.6
Agriculture	10.0	8.5	7.2	9.1
Construction	1.0	0.8	0.9	0.9
Residential, commercial and others	22.1	26.4	28.5	26.9
Total	100	100	100	100

Table – 3 Final Energy Demand by Energy Source

(Unit : Share %)

Year	1979	1980	1981	1982
Electricity	7.0	9.1	8.9	9.5
Coal & Lignite	1.0	0.7	0.6	2.1
Traditional Energy	18.6	24.0	25.7	26.2
Petroleum Products	73.4	66.2	64.8	62.2
Total	100	100	100	100

(2) To reduce the amount of oil import by 3 percent per year during the Fifth Plan period.

(3) To decrease the ratio of oil imports to total energy consumption from 75 percent in 1980 to 46 percent in 1986.

In order to attain these targets, the 1986 production goals of domestic substitutes of oil have been laid down as follows:

A) Natural gas
At least 525 million cubic feet (15.75 million cubic meters) per day

B) Hydroelectric power generation capacity
2,013 MW, 1.6 times more than in 1980

C) Electric power generation capacity using lignite
885 MW, 4.2 times more than in 1980

D) Non-conventional energy
220 to 290 million litres of crude oil equivalent

(4) To increase, by 1986, the oil refining capacity to 280,000 bbl. a day;

(5) To increase the rate of electrification of rural communities from 36 percent in 1980 to 92 percent in 1986;

(6) To increase the amount of oil reserve to 60 days, by 1986.

1.5 Future energy demand and supply

NEA has worked out, as Table 4 shows, a long-term energy demand/supply forecast for up to 1991 with the aforementioned energy targets in mind.

The forecast may be summarized as follows:

(1) The annual average growth rate of total energy consumption (1982-1991) will drop to 5 percent (4.6 percent during the Fifth Plan period). Consequently, the energy consumption elasticity for GDP will go down to 0.7 compared with the economic growth rate (6.6 percent in real terms) during the Fifth Plan period.

(2) As for demand by source of primary energy

A) The demand for petroleum will remain at almost the same level as in 1982. As a result, the energy dependence on oil will decrease sharply from 60 percent in 1982 to 48.7 percent in 1986 and to 38.0 percent in 1991.

B) The demand for both lignite and natural gas will rise at the rate of about 20 percent a year. They will cover more than 80 percent of the energy demand expected to rise during the next decade. Especially, natural gas, the production of which was started in the Gulf of Thailand in 1981, is anticipated to make a substantial increase of 30 percent per annum during the first half of the forecast period. In consequence, the total share of lignite and natural gas will go up to 36 percent in 1991 to reach almost the same level of the share of oil.

Table – 4 Forecast of Energy Demand

Year / Energy	1982		1986		1991		Growth Rate %		
	10^6 ℓ	Share %	10^6 ℓ	Share %	10^6 ℓ	Share %	'82~ '86	'86~ '91	'82~ '91
Petroleum	10,872.1	60.0	10,698.8	48.7	10,703.2	38.0	0.04	0	0.02
Hydro-electric	1,300.3	7.2	1,433.6	6.5	2,116.8	7.5	2.5	8.1	5.6
Coal & Lignite	766.3	4.2	1,742.0	7.9	3,412.5	12.1	22.7	14.4	18.0
Traditional Energy	3,881.3	21.4	4,082.3	18.6	4,444.8	15.8	1.3	1.7	1.5
Natural Gas	1,300.6	7.2	3,668.6	16.7	6,857.5	24.3	29.6	13.3	20.3
Non-conventional Energy	–	–	350.2	1.6	640.8	2.3	–	12.8	–
Total	18,120.5	100	21,975.5	100	28,175.6	100	5.0	5.1	5.0

Note : Non-conventional Energy includes Garbage, Mini-hydro, Alcohol, Fast grow plant, Solar etc.

C) The demand for hydroelectric power will make a steady increase of 5.6 percent a year, while the demand for traditional energy, which had registered a sharp upswing in the past, will mark only a slight increase of 1.5 percent per annum in the future.

D) Besides, the development and exploitation of non-conventional energy sources including mini-hydraulic power, alcohol and oil shale, will be expedited, and in 1991 their supplies are estimated to reach the equivalent of 641 million litres of crude oil, though their shares in total will stand at only 2.3 percent.

Should such a forecast materialize, Thailand's dependence on imported energy will go down below 50 percent in 1986 and to 40 percent or so in 1991, contributing a great deal to reduction of the country's trade deficits and stabilization of its national economy.

1.6 Energy conservation measures

(1) Measures laid down in the Fifth Plan

In order to improve the energy utilization efficiency in transport sector and industrial sector, the following measures are laid down in the Fifth Plan, and some of those have already been put into practice:

A) Improve the efficiency of the traffic and mass transit systems in the metropolitan area of Bangkok;

B) *Adopt the progressive taxation system for large passenger cars and limit the* extension of car licenses for old and run down cars;

C) Encourage the use of telephones and telegraphs;

D) Improve the National Railways' freight transportation services;

E) Improve the river and coastal transportation systems;

F) Put the manufacturing factories consuming much energy under an obligation to keep records on energy use and to report them periodically to relevant governmental agencies;

G) Establish mobile energy conservation service units to advice factories;

H) Provide soft loans for energy-saving investment;

I) Reduce taxes for energy-saving equipment and materials;

J) Consider energy conservation as a factor in granting BOI's investment promotion privileges;

K) Determine standards for use of energy by type of manufacturing industry;

L) Hold energy conservation conferences or seminars between the government agencies and the private sector;

M) Campaign to enlighten the general public on the importance of energy conservation;

N) Adjust energy prices to promote energy conservation.

(2) Measures implemented hitherto

As in the case of other countries, Thailand, in an effort to cope with an unstable supply of oil and a rise in oil prices in the 1970s, organized a committee devoted to energy conservation and implemented various energy-saving measures including, in the transport sector, road speed limits, creation of bus lanes, limiting service hours at gasoline stations and limiting the engine capacity of government cars, and in the electric power sector, reducing service hours of entertainment places, putting a ban on TV broadcasting service time, and 50 percent cut down of illumination on all main streets.

However, many of these were in the nature of emergency step to restrain energy consumption by direct government control rather than for encouraging more efficient use of energy.

Besides, technical assistance and soft loans were extended to energy-saving investment in the industrial sector though extent was limited. In 1981 the Energy Conservation Center was established within NEA. This center is engaged in the following activities at present:

A) Providing technical service to industrial factories regarding energy audits;
B) Distributing information concerning energy conservation technologies;
C) Training in energy conservation (seminars and conferences);
D) Energy conservation demonstration programs (demonstration of energy conservation technologies by extending low-interest financial aid to selected industrial factories).

Furthermore, aside from the said Energy Conservation Center, a plan to establish a new private organization to promote energy conservation under the financial aid of the government is being pushed at present, and the general outline of the plan have already been formulated.

As stated in the foregoing, improvement in the efficiency of energy utilization or energy conservation is ranked as one of the most important problems in the energy policy system of the Kingdom of Thailand. In fact, the economic structure of Thailand is expected to shift to a more energy intensive pattern parallel to the future progress of industrialization and improvement of people's living standards in the country. Hence, it is believed that more efficient use of energy will increase further in importance in the country.

2. Content of the Study

2.1 Objective of the Study

The objective of the Study is to contribute to the promotion and strengthening of energy conservation program in the field of manufacturing industry in the Kingdom of Thailand.

2.2 Process of the Study

In order to attain the above objective, the Study was carried out as mentioned below in accordance with the Scope of Work:

(1) In order to precisely grasp energy utilization situation in the field of manufacturing industry in Thailand, the study teams were sent to Bangkok three times, each for a period of 35 days, August 1982, January 1983 and June 1983. These study teams visited 55 factories of the following 6 types of industry located in and around the metropolitan area of Bangkok, surveyed energy utilization situation as well as possibility of energy conservation, and made suggestions on what to do for more efficient utilization of energy:

Type of industry	Number of factory
Ceramics and glass	10
Paper	9
Textile	9
Metal	9
Chemical and plastic	9
Food	9

The names of factories covered in the Study are as given in the Attached data-6.

The results of surveys conducted on these factories were compiled each time by type of industry and by individual factory and reported to NEA.

(2) During the factory surveys, the study teams extended to Thai counterparts technical staffers, who accompanied the teams, technical guidance in how to handle measuring instruments, and how to make energy audit, and thus transferred technologies to them.

(3) Parallel to the factory surveys, data and information regarding the energy situation in industrial sector in Thailand were collected.

(4) Following the factory surveys, JICA dispatched a review team to Thailand in January 1984 to discuss how to proceed with future surveys. In March of the same year a fourth study team visited Thailand to investigate energy conservation measures and systems enforced in the industrial sector of the country.

(5) Based on the results of the aforementioned surveys, the draft of guideline for rationalization of energy use, classified by type of manufacturing industry, and the recommendation of measures (e.g. taxation system, financing, diffusion of technologies) to promote energy conservation in the field of manufacturing industry were

formulated.

(6) The Study was conducted with the following points in mind.

A) Rationalization of fuel combustion
B) Prevention of heat loss by radiation and conduction
C) Recovery and reutilization of waste heat
D) Prevention of electricity loss by resistance, etc.
E) Rationalization of conversion of electricity into power, heat, etc.

2.3 Study methods

(1) Factory Energy Audit

A) Preliminary survey through questionnaire

Questionnaires (Attached data-9) were distributed in advance to factories, asking that the following items be filled in:

a. Outline of factory (capital, annual sales, number of employees, number of technical staffers, principal products, production capacity, etc.);
b. Volume of energy consumption (fuel, electric power and water);
c. Main facilities using energy (name, type, year of installation, capacity, fuel used and operating hours);
d. Production process chart;
e. Energy flow chart;
f. One-line diagram;
g. Factory layout;
h. Points at issue in furthering energy conservation.

B) *Interviews with entreprenuers and managers*

Interviews were conducted on the following items, using recovered questionnaires *and energy management check lists (Attached data-10) for reference:*

a. Present status of production and sales;
b. Energy conservation measures implemented to date;
c. Energy management situation;
d. Points at issue in the production phase.

C) Inspection of factory as a whole

Inspection was made of the factory as a whole in accordance with the production process to grasp the following items:

a. General factory management situation;
b. Factory layout;
c. Spots requiring survey and measuring on a priority basis;

D) Survey and measuring

In accordance with items in the check lists, surveys and measuring were conducted on priority facilities regarding the following items:

a. Measuring of facility dimensions;
b. Collection of data, using records kept by factories and meters;
c. Measuring by means of measuring instruments

—State of fuel combustion

—State of heating, cooling and conduction

—State of heat release prevention

—State of waste-heat recovery

—State of conversion of heat into motive power

—State of electricity loss by resistance, etc.

—State of conversion of electricity into motive power and heat

E) Discussions

The results of surveys and measuring were outlined to entreprenuers and managers, and discussions were conducted on what appeared to pose problems.

(2) Transfer of technologies to counterparts

A) Handling of measuring instruments

To begin with, factory energy audit was preceded by explanations on the performance of the instruments, purposes for their use and how to handle them, in accordance with manuals. Later on, actual guidance in how to handle measuring instruments was offered simultaneously with the factory survey.

B) Guidance on energy audit methods

Explanations were given in advance on the check list items and their meanings, and in the subsequent factory survey, concrete guidance was offered on how to fill in the check lists. Also, explanations were offered—on a day devoted to classifying data collected following the factory survey—regarding aspects of problems involving the production process of factories surveyed and energy audit. At the same time, guidance on energy audit methods was provided through comments on information available from data collected.

(3) Collecting of related information

Information was collected through relevant government agencies, including NEA, and private organizations, regarding the country's energy policy, energy situation, production situation of the manufacturing industry, etc.

2.4 Others

(1) In implementing the Study, NEA, as the Thai counterpart agency responsible for accepting the Japanese study teams, offered cooperation to them in arranging their visits to the factories, relevant authorities and private institute concerned and also in providing them with office and vehicles, etc.

(2) Measuring instruments used for the factory surveys (Attached data-11) were carried from Japan. These instruments were donated to NEA by JICA following the completion of the factory survey.

(3) Parallel to the Study, JICA accepted nine NEA technical staffers on three occasions for training in energy conservation technologies in Japan.

II. Outline of the Results of the Factory Energy Audit

I. Factories Surveyed

(1) Items manufactured and capital groups

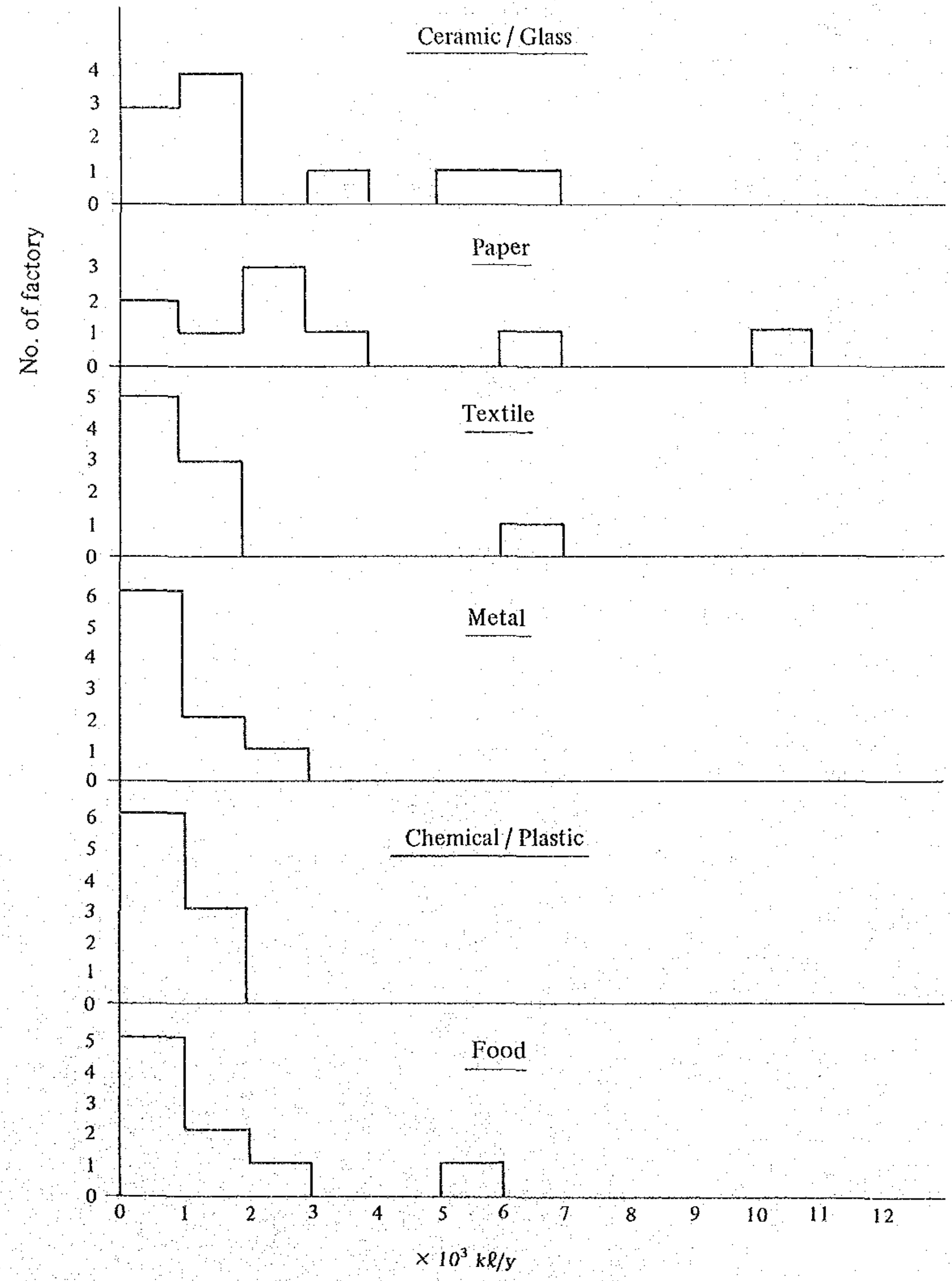
- Almost a half of the factories surveyed belong to the groups of joint ventures with foreign companies or of influential domestic enterprises.
- The names of the factories are as shown in Attached data-6.

No. of factory / Items manufactured	Joint venture with foreign co (s)	Belonging to Group	Others	Total
Ceramic/Glass				
Glass bottle, glass	1	0	3	4
Tile	0	0	2	2
Sanitary ware / Insulator	1	0	1	2
Others	0	0	2	2
Subtotal	2	0	8	10
Paper				
Paper	0	3	5	8
Corrugated cardboard	0	0	1	1
Subtotal	0	3	6	9
Textile				
Spinning / Cloth weaving	2	1	3	6
Nylon polymerization/Spinning	1	1	0	2
Socks	1	0	0	1
Subtotal	4	2	3	9
Metal				
Steel bar for concrete	1	2	0	3
PC Wire	1	0	0	1
Wire	1	0	0	1
Foundry	0	0	2	2
Tractor parts	0	1	0	1
Nail, screw, bolt/nut	0	1	0	1
Subtotal	3	4	2	9
Chemical/Plastic				
Organic chemicals	1	0	3	4
Inorganic chemicals	0	1	2	3
Gas separation	1	0	0	1
Plastic moulding	0	1	0	1
Subtotal	2	2	5	9
Food				
Marine product canning	0	1	2	3
Oil and fat	1	0	1	2
Feed	0	3	0	3
Alcoholic drinks	0	0	1	1
Subtotal	1	4	4	9
Total	12	15	28	55

(2) Fuel oil consumption per factory

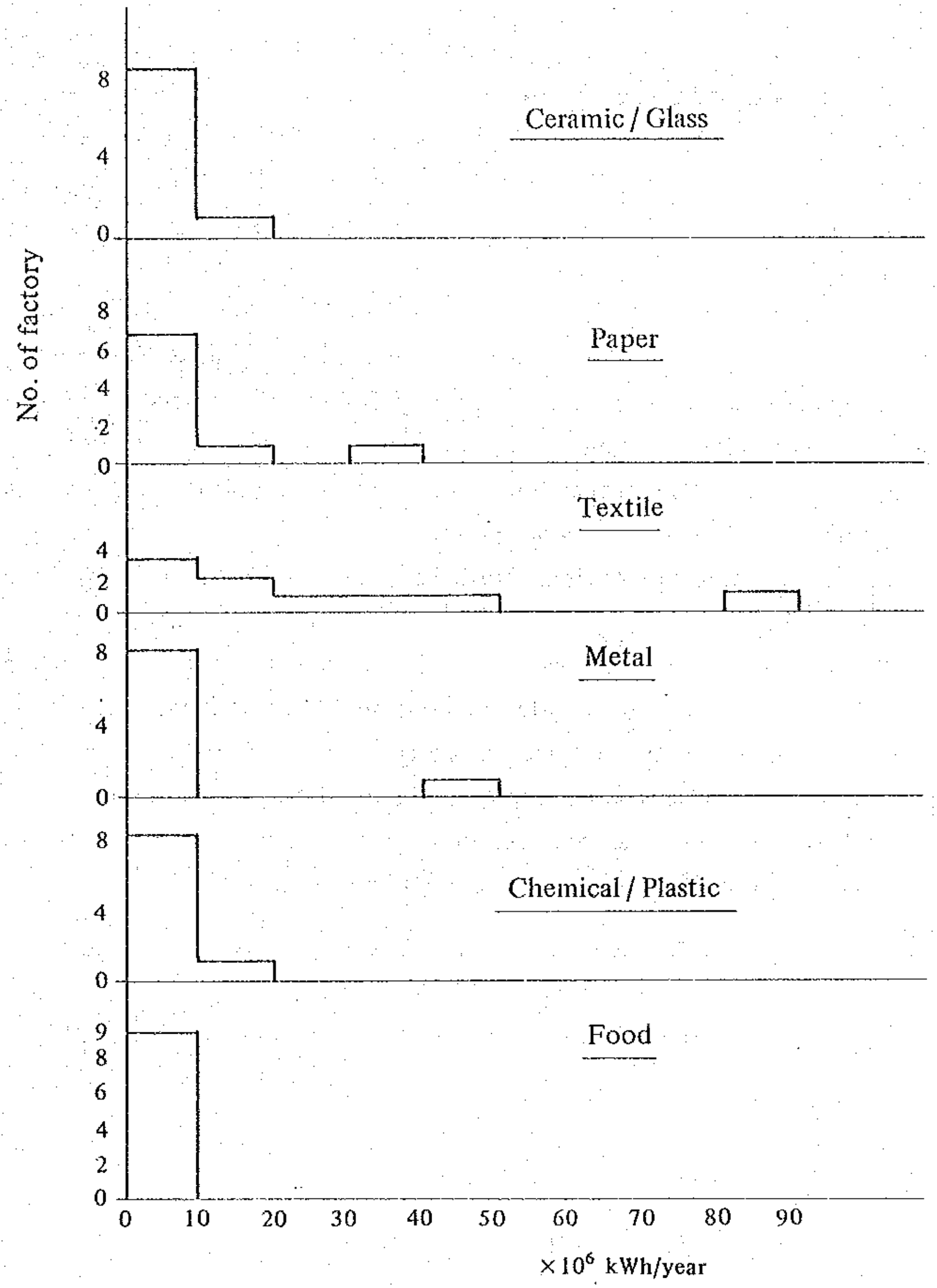
(Lignite converted in heavy oil equivalent. Excludes LPG and fuel for power generation)

1,000 kl/year or less	49%
1,000 ~ 3,000 kl/year	36%
3,000 kl/year or more	15%



(3) Electric power consumption per fatory

10 × 10^6 kWh/year or less	80%
10 ~ 20 × 10^6 kWh/year	9%
20 × 10^6 kWh/year or more	11%



2 State of Energy Management

(1) Generally, the management is highly concerned about energy conservation. However, only a few factories establish and notify definite policies of the enterprise and concrete target values.

(2) The factories which have some energy conservation measures enforced have reached 2/3 of the total number.

(3) The factories which provide an opportunity for discussion of energy problems have reached approx. 40% of the total number. The majority of these factories make use of general staff meetings for the discussion. Only three factories have a specialized ad hoc committee for energy conservation. One factory once had a committee devoted toward energy conservation, but abolished it because of its lack of know-how for the operation of the committee.

(4) At 9 factories, the QC circles are already off the ground centering around the staff. These circles are also being prepared at one other factory. Nevertheless, they have not reached a stage that their QC circle's activities are successful with favorable results for energy conservation.

(5) The suggestion system is established at factories equivalent to approx. 1/4 of the total number, but it is basically not operated.

(6) Energy consumption is being recorded by factories equivalent to approx. 60% of the total number.

However, any appropriate measures taken whenever necessary through calculation of the energy consumption rate, preparation of a control chart, and analysis of causes of demand variation, that is, management through data, are not fully implemented. The same is true about quality and yield.

(7) Staff are often sent to external seminars. However, internal "transfer education" by the staff who have participated in the external seminars is basically not carried through.

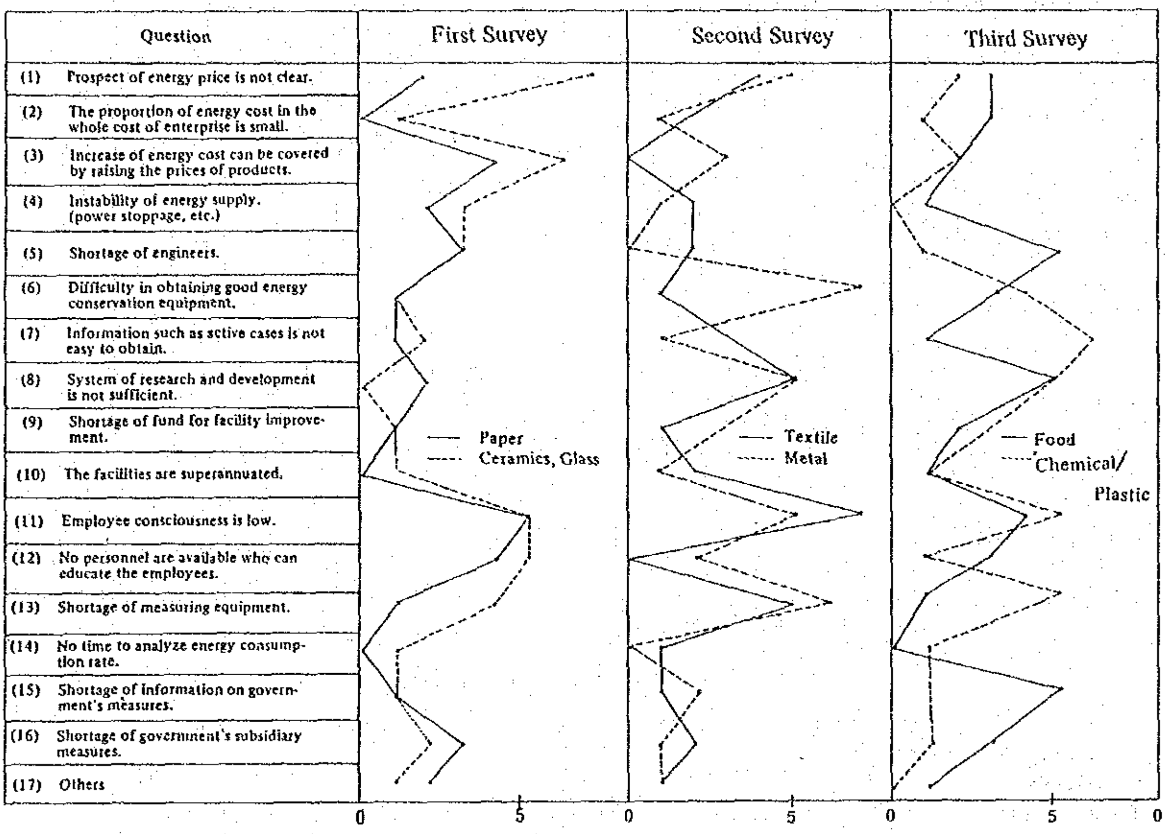
Item	Ceramic/ Glass	Paper	Textile	Metal	Chemical/ Plastic	Food	Total
Company policy							
• Establishment and notification of target values	–	–	2	2	2	4	10
• Measures hitherto taken	5	6	9	5	7	5	37
Participation of all personnel							
• Setting up of committees	3	2	7	4	4	2	22
• Project team	–	2	–	–	–	1	3
• QC circle	1	–	2	4	1	1	9
• Suggestion System	2	2	2	1	1	6	14
• Appeal to employees	5	2	4	4	4	6	25
Management through data							
• Grasping of daily consumption	8	4	6	3	4	8	33
• Grasping of consumption by process	6	2	6	2	5	6	27
• Calculation of energy consumption rate	5	5	3	4	4	3	24
• Preparation of control chart	1	1	1	1	1	2	7
• Analysis of causes of demand variation	1	1	2	–	2	3	9
Technological leveling-up of employees							
• Participation of staff in external training courses	6	5	6	7	6	9	39
• Education of operators	1	–	3	1	1	–	6
• Information exchange within the same industry	–	–	1	–	–	1	2
Total no. of factories	10	9	9	9	9	9	55

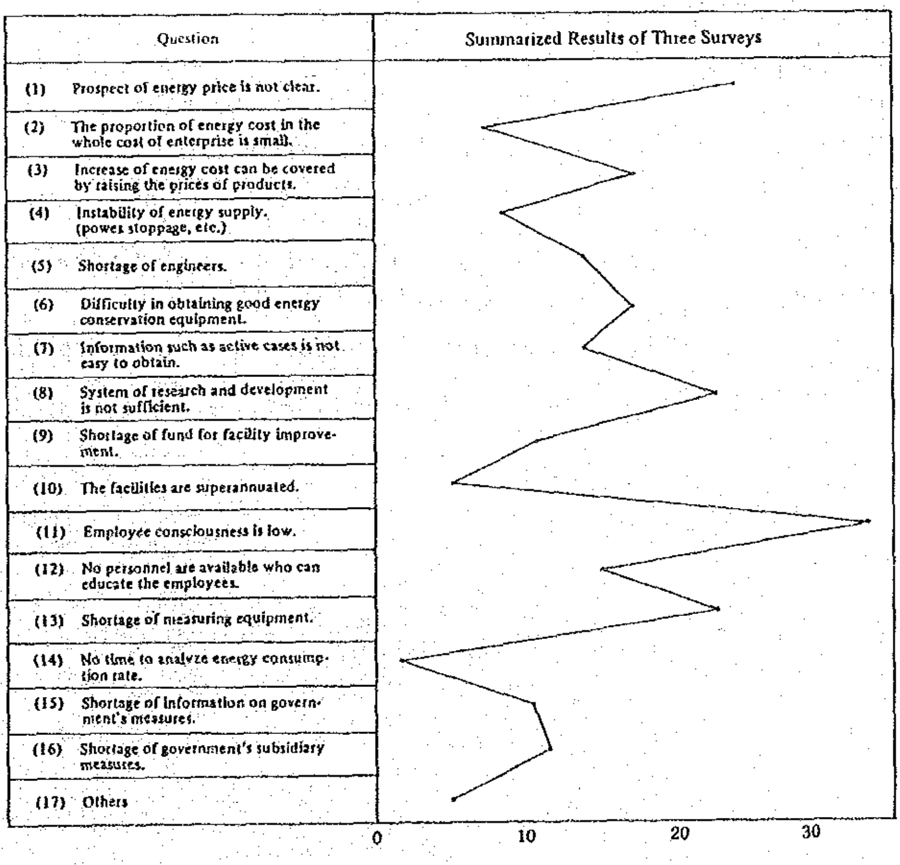
(Note)

1. Under "Setting up of the Committees", the committees include also those other than the committee solely for energy conservation.
2. Under "Calculation of Energy Consumption Rate", the calculation includes those based on monthly data.

3. Answers to Questionnaire "Problems Encountered in the Promotion of Energy Conservation."

Replies to Questionnaire "Problems Encountered in the Promotion of Energy Conservation"





4. Problems of Heat Control
   - (1) Rationalization of Fuel Combustion
     - A) Incorrect air ratio
       - Inadequate adjustment of the air damper
       - Unsuitable burner capacity and insufficient cleaning
       - Deterioration of nozzle function
       - Inappropriate fuel oil temperature
       - Unsatisfactory adjustment of furnace pressure
       - Air suction through the opening due to faulty sealing
     - B) Incorrect flame direction because of the wrong installation of the burners
     - C) Oil leakage from the burners
     - D) Shortage of control instruments
     - E) No concern about the quality of fuel oil
   - (2) Rationalization of Heating, Cooling and Heat Transfer
     - A) Insufficient cleaning of the heat transfer surface
     - B) Large heat capacity of objects other than those for heating
     - C) Exceedingly high steam pressure
     - D) Inappropriate furnace design and capacity
     - E) Defective charging of objects to be heated
     - F) Insufficient utilization of heat obtained through the preceding process
     - G) Faulty air purge during steam heating
     - H) Room for higher-efficiency equipment for the evaporator, furnace and other equipment
     - I) Necessity of reducing dehydrating heat energy through mechanical separation of higher efficiency
     - J) High rejection rate of products
     - K) Defective boiler feed water treatment
       Insufficient water blow-down for the boiler
   - (3) Prevention of Heat Loss by Radiation and Conduction etc.
     - A) Considerable heat radiation from the furnace wall
     - B) Uninsulated steam-using facilities and piping and deteriorated insulation
       - The following are especially noteworthy of defects
       - Steam valves, headers, flanges, condensate recovery pipe, feed water pipe, feed water tankage, dyeing device, cookers, hot water tanks
     - C) No installation of cover on the hot water of tank
     - D) Inadequate provision of enclosures, hoods and lids for drying equipment and melting furnace
     - E) Neccesity of reinforcement of insulation of the upper surface of a tunnel kiln truck
     - F) Unsuitable color of the heat radiation surface
     - G) Steam leakage from valves

H) Inadequate maintenance of steam traps

I) Inappropriate blow-down quantity of boiler water

(4) Recovery and Utilization of Waste Heat

A) Room for the recovery of waste heat

Waste heat of exhaust gas of furnace, electric furnace, tunnel kiln, paper machine

Potential heat of process fluid for the distillation tower and deodorizing tower

B) Room for the recovery of waste pressure

Steam and high-pressure water

C) Room for the recovery of condensate

D) Insufficient utilization of flash steam

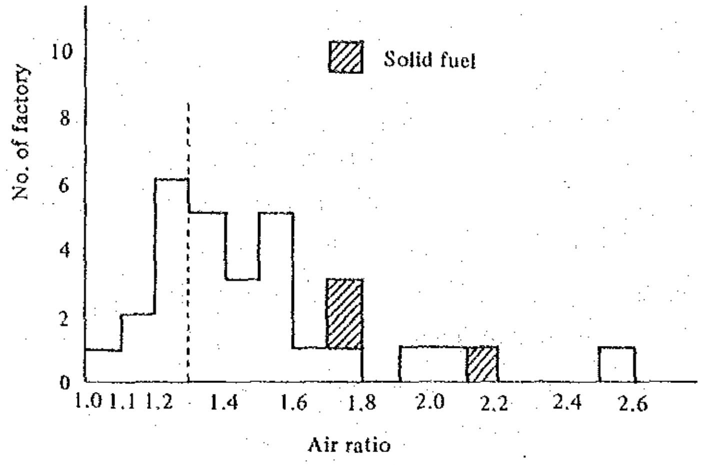
E) Inadequate handling of recovered waste heat

Overflow of recovered condensate

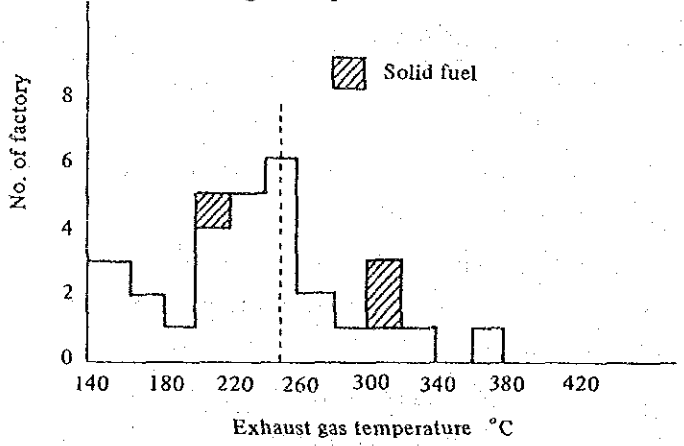
Defective insulation of recovered waste heat transport pipe

5. Problems of Electric Power Control
  - (1) Rationalizaiton of Conversion of Heat to Power
    - Insufficient use of heat of diesel generator for emergency
  - (2) Prevention of Electric Power Loss by Resistance etc.
    - A) Room for the improvement of power factor
      - The condensers are not yet installed or are not arranged satisfactorily
      - Excess motor capacity, Inadequate speed control method
    - B) Insfufficient efforts to suppress peak demand
    - C) Room for the reduction of loss in the transformer
      - Integration of load, Cut off of transformer during shutdown
    - D) Inbalance of 3-phase current
    - E) Insufficient maintenance and shortage of control instruments
  - (3) Rationalizaiton of Conversion of Electricity to Power and Heat etc.
    - A) Room for the reduction of power for fluid transport
      - Leakage of compressed air,
      - Release of surplus, Exceedingly high pressure,
      - Incorrect position of intake port, Faulty valves,
      - Room for the integration of low-load equipment, Increase of the number of pumps due to defective layout,
      - Clogging of filters for air-conditioning,
      - Increased load on the air-conditioning system attributed to the inflow of atmospheric air,
      - Throttling loss of the damper on account of excess blower capacity
    - B) Excess capacity of some of electric motors
    - C) Inadequate maintenance of power transmission belts
      - Number of pieces, Tension, Material
    - D) Room for the rationalization of lighting
      - Insufficient cleaning of apparatus
      - Improper position for installation
      - Room for the changing of lamps from the existing energy consuming type to the high-efficiency energy conservation type
    - E) Reinforcement of insulation of electroheating equipment
    - F) Recovery of fluid pressure

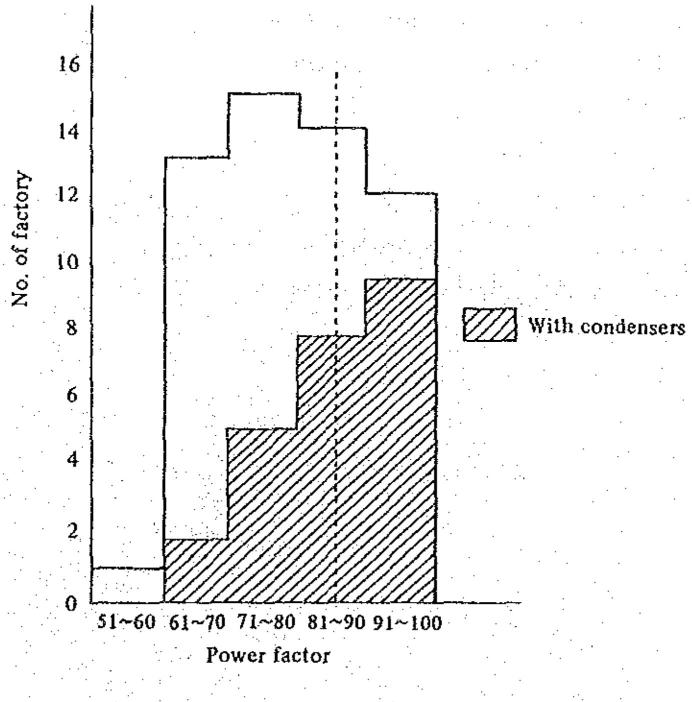
Distribution of air ratios of boilers



Boiler exhaust gas temperature



Power factor distribution



6. Targets for Improvement and Projected Effects

( ) means ratio in % to consumption.

Classification	Item	Targets for Improvement	Projected Effects of Improvement Heavy oil equiv. kℓ/y						
			Ceramic /Glass	Paper	Textile	Metal	Chemical /Plastic	Food	Total
Rationalization of fuel combustion	Improvement of air ratio. Lowering temperature of exhaust gas.	Air ratio 1.3 max. (Solid fuel: 1.5) Exhaust gas temperature 250°C max.	1,088 (4.5)	1,668 (5.7)	209 (1.6)	165 (2.0)	44 (0.6)	1,026 (7.6)	4,200 (4.4)
Rationalization of heating, cooling, heat transfer	Improvement of production process and heating method.	–	–	2,724 (9.3)	3 (–)	1,495 (18.0)	–	213 (1.6)	4,435 (4.6)
Prevention of heat loss by radiation, convection, and conduction.	Reinforcement of insulation of furnace and carriage.	Surface temperature	1,221		440	180			1,841
	Reinforcement of insulation of facilities using steam.	Newly built glass-melting furnace <200°C		419		10	344	364	1,137
	Installation of cover and hood.			371		20	68	6	465
	Lowering surface emissivity.	Upper surface of firing zone of newly built tunnel kiln. <100°C						10	10
	Optimization of blow water quantity.				31			9	40
	Prevention of steam leakage.	Facilities using steam < 60°C		11				8	19
	Smaller radiation area.						3		3
	Subtotal		1,221 (5.0)	801 (2.7)	471 (3.5)	210 (2.5)	415 (5.8)	397 (3.0)	3,515 (3.7)
Recovery and utilization of waste heat	Recovery and utilization of waste heat of exhaust gas.		648	261	22		131	11	1,073
	Recovery and utilization of waste heat of waste water.				130		166		296
	Heat exchange of process fluid.							280	280
	Recovery of condensate and utilization of flash steam.			761	537		46	81	1,425
	Subtotal		648 (2.7)	1,022 (3.5)	689 (5.1)	–	343 (4.8)	372 (2.8)	3,074 (3.2)
Total			2,957 (12.2)	6,215 (21.1)	1,372 (10.2)	1,870 (22.5)	802 (11.1)	2,008 (15.0)	15,224 (15.8)
Fuel consumption	Heavy oil equiv. kℓ/year		24,319	29,397	13,460	8,310	7,201	13,420	96,107

Classification	Item	Targets for Improvement	Projected Effects of Improvement 10^3 kWh/y						
			Ceramic /Glass	Paper	Textile	Metal	Chemical /Plastic	Food	Total
Rationalization of conversion of heat to power, etc.									
Prevention of electricity loss by resistance, etc.	Improvement of power factor.	Receiving power factor 85% minimum	87	11	52	169	73	32	424
	Reduction of transformer loss.		37	209	181	514	44	76	1,061
	Improvement of frequency converter efficiency.					39			39
	Subtotal		124 (0.4)	220 (0.3)	233 (0.1)	722 (1.0)	117 (0.4)	108 (0.4)	1,524 (0.3)
Rationalization of conversion of electricity to power, heat, etc.	Reduction of power for fluid transportation.								
	compressor / refrigerater		227			17	93	287	624
	pump			9					9
	air-conditioning load		7		4,908				4,915
	Improvement of conduction belt/ Change of gear ratio.				470	149			619
	Change of motor capacity / Optimization of motor voltage.		46		147	2	74	473	742
	Reduction of heat loss of electric heating equipment.		57		250	338	119		764
	Rationalization of lighting.		9	15	664	49	22	26	785
	Recovery of waste energy.						964		964
	Application of high efficiency equipment.				525				525
	Subtotal		346 (1.1)	24 (–)	6,964 (3.2)	555 (0.8)	1,272 (4.0)	786 (2.7)	9,947 (2.1)
Total			470 (1.5)	244 (0.3)	7,197 (3.3)	1,277 (1.7)	1,389 (4.4)	894 (3.1)	11,471 (2.5)
Electric power consumption 10^3 kWh/year			30,578	79,919	219,610	73,292	31,874	28,877	464,150

Effects as extended to Thailand's respective entire industries

	Fuel		Electric Power	
	kℓ/year		Mwh/year	
Ceramic / Glass	6,500	(46%)	1,080	(35%)
Paper	18,600	(33%)	510	(33%)
Textile	10,600	(13%)	55,400	(13%)
Metal	7,500	(25%)	5,100	(25%)
Chemical / Plastic	21,100	(4%)	36,500	(4%)
Food	32,400	(6%)	52,500	(2%)
Total	96,700		151,090	

(   ) Coverage rate (%)

Calory of the above (A)	kcal/year 0.94×10^{12}	kcal/year 0.13×10^{12}
Total consumption by Thailand's manufacturing industry (B)	$30{,}557 \times 10^{12}$	$7{,}709 \times 10^{12}$
A / B	3.1%	1.7%

Note : (B) Thailand Energy Situation 1981~82

III. Guideline for Rationalization of Energy Use

I. Ceramic and Glass

Contents

1. Character of Guide Line

This Guide Line is a summary of technical matters considered important for the promotion of energy saving at the factories of the ceramic and glass industries. The Guide Line is to be used for the following purposes.

1) (1) As technical reference for factory's engineers when they plan to rationalize use of energy in the factory.
   (2) As a diagnostic guidance manual.
   (3) As referential data for determining the progress of rationalization.
   (4) As a text for seminars.

2) Descriptive level which should be understandable by engineers having only 4 to 5 years' experience of actual service after college graduation, but not actually working in the subject industries.

3) In consideration of the present industrial status of the Kingdom of Thailand, the descriptive coverage is limited to the process-related matters of the factories which we diagnosed. Also, the basic items and numerical values regarding this process —energy-saving techniques and referential instances or actual records — are described.

It is hoped that the Guide Line prepared here will be further supplemented and *substantiated by the addition of information obtained in future through NEA's own* factory diagnosis and other means.

For information, the Guide Line contains standard values published by the Japanese Government (Ministry of International Trade and Industry) as a basis for judgement in promoting energy saving for factory managers through its notification.

(1) The standard values are the most frequent values (refer to Fig. III-1-1) of statistical distributions of numerous examples. As such they represent a realistic level for factory managers to attain without difficulty from the technical and economic points of view.

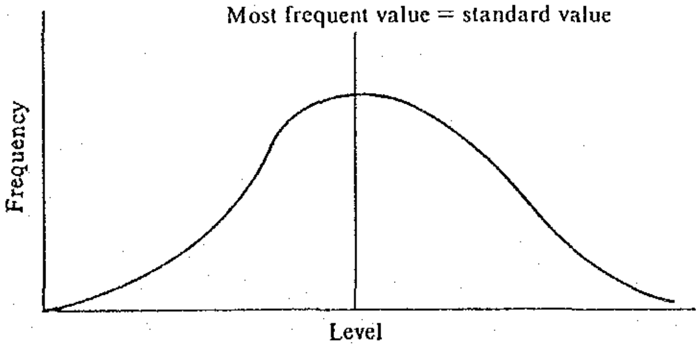


Fig. III−1−1

(2) The standard values do not necessarily represent the values which factory managers should be satisfied with after reaching them and also the minimum values which it must reach by all means. These values are rather those designed to improve the inferior value toward an average level, thus shifting the whole distribution of values into a better direction. Therefore, the most frequent value will be resought and a new standard value established after the elapse of a certain period.

The standard value establishment plan described in the report was prepared based on these standard values considering the present industrial status of the Kingdom of Thailand.

These standard values will be a starting point for the establishment of standard values for the rationalization of energy use in industry of the Kingdom of Thailand. It is recommended that the Kingdom of Thailand itself accumulates data during factory diagnosis to be put into practice, and evaluates it periodically and revises or newly establishes standard values.

2. Characteristics of Energy Use

2.1 Manufacturing Process and Principal Facilities

2.1.1. Ceramic Industries

The manufacturing process charts of tile, insulator and sanitary ware manufacturing industries are shown in Fig. III-1-2 as those eligible for diagnosis.

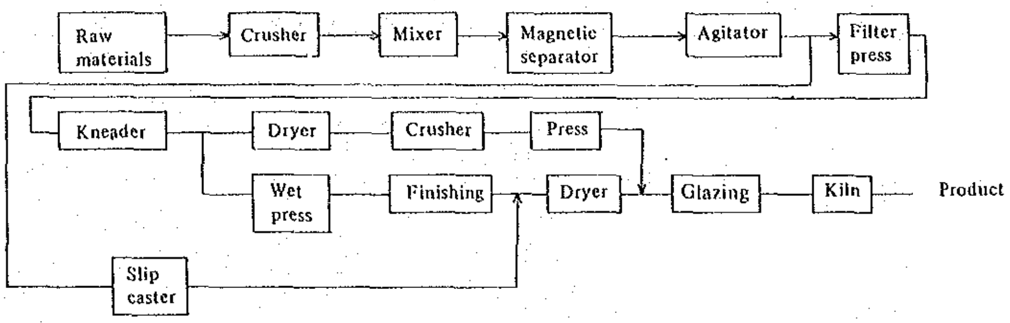


Fig. III–1–2 Manufacturing process for ceramic products e.g. tile

(1) Manufacturing Process

Quartz as aggregate and feldspar and clay as flux are crushed to an appropriate size respectively and mixed at a proper ratio.

In wet mixing process, the slurry is dehydrated with a filter press after sufficient stirring and mixing. Then the dehydrated slurry is mold as it is or after drying, with the help of an extruder or a press.

In the case of wet-molding, moisture content of the slurry is reduced to less than 3% by means of hot air drying or natural drying. For burning, in some cases, biscuit firing and glost firing are provided and in the other cases, only one-firing is provided. For biscuit firing, oxidizing flame at approx. 1,200° C is used for hard ceramics and at approx. 800° C for others. In the process of glost firing for white ceramics, oxidizing flame is used to heat up to approx. 1,000° C, then reduction flame up to approx. 1,250° C and finally neutralizing flame to finish the firing process.

The burning temperature of other ceramics ranges from approx. 900° C to approx. 1,700° C according to the grade of finished product. All of them are burned by oxidizing flame. When painting, they are burnt once again at approx. 800° C.

(2) Main equipments

As to crushing equipments, the jaw crusher, impact breaker, etc. are available for coarse crushing, and the ball mill and edge runner for pulverizing.

As regards the dryers, the belt dryer and spray dryer are used for the drying of materials for dry molding. For the drying of molded products, the box-type and tunnel-type driers are used. The heat for drying is sufficiently fed by waste heat from the kiln.

Concerning burning facilities, the tunnel kilns (direct heating type, indirect heating type as shown in Fig. III-1-3 (muffle type) for mass production with less variety are used. As a batch kiln, the shuttle kiln using a car (refer to Fig. III-1-4) is used.

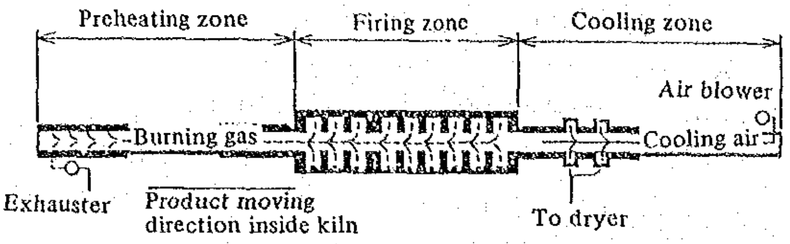


Fig. III–1–3 Tunnel kiln

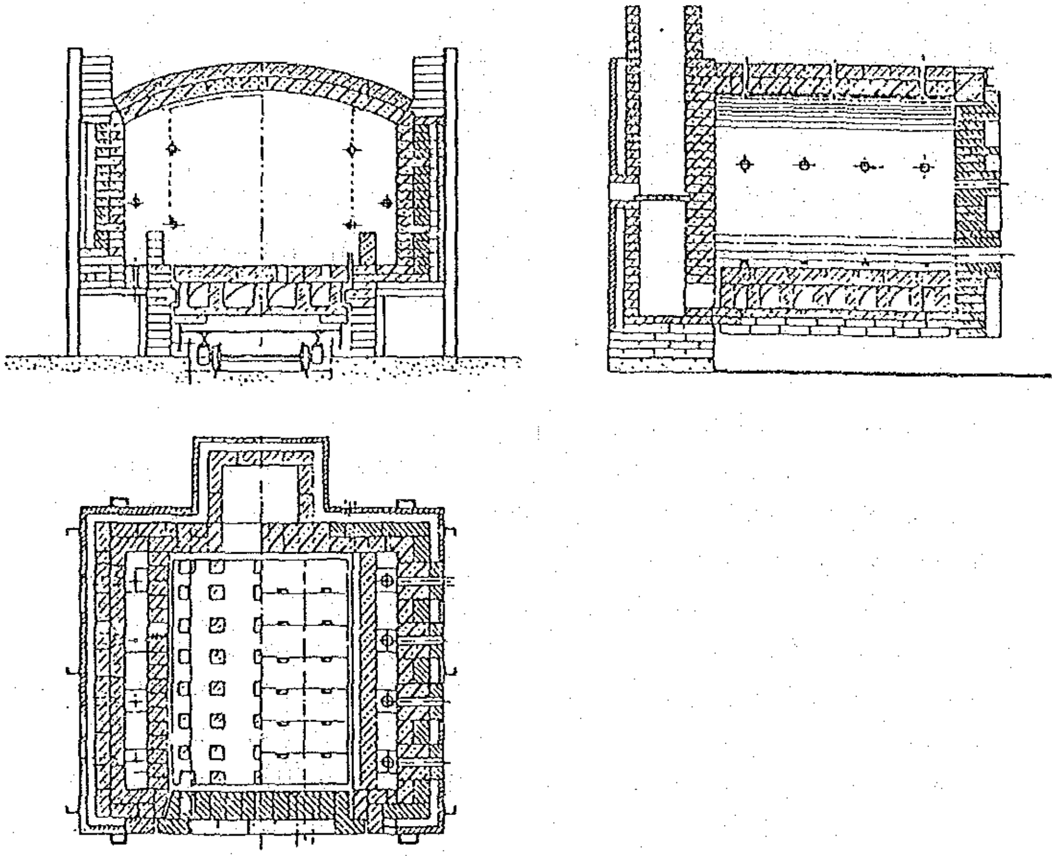


Fig. III–1–4 Shuttle kiln

2.1.2 Glass industries

The manufacturing process of the bottle and glass tableware manufacturing industry subjected to our diagnosis is comparatively simple as shown in Fig. III-1-5.

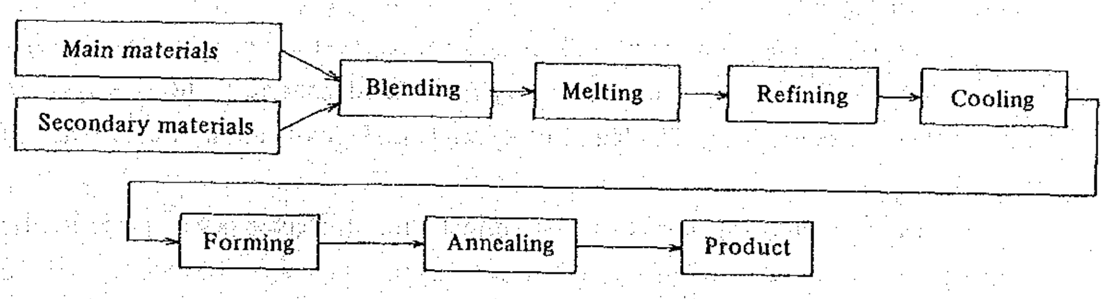


Fig. III–1–5 Manufacturing process for glass products

Although the glass composition varies according to use, glass for bottle and tableware is of the soda-lime type as shown in Table III-1-1.

Table III–1–1 Composition of glass for vessel

Components	Contents
SiO_2	70 ~ 74 %
$A\ell_2O_3$ Fe_2O_3	1.5 ~ 2.0
CaO MgO	8 ~ 12
Na_2O K_2O	13 ~ 16

(1) Manufacturing process

Silica sand, soda ash, lime stone, dolomite etc. are mixed in accordance with the glass composition of production grade. Then this mixture is blended with a small quantity of secondary raw materials such as clarifier, coloring agent and decoloring agent and an appropriate quantity of cullet as a compound of feedstock.

The compound feedstock is charged into the melting furnace maintained at approx. 1,500° C (refer to Fig. III-1-6), and then melts under the radiant heat of flame in the upper space. Further, the compound feedstock is clarified and subjected to foam separation. At that time, the temperature is distributed in such a way that the center of the furnace may be at high temperature to prevent the unmolten or low-temperature raw material inside the furnace from flowing into the refiner.

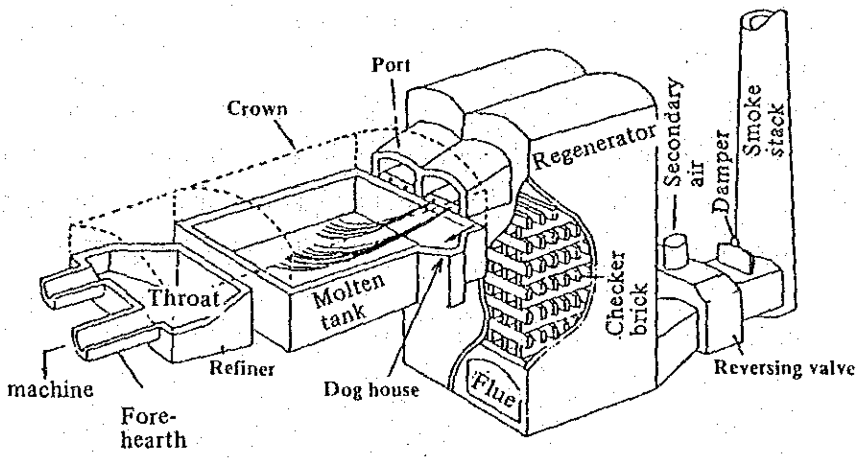


Fig. III–1–6 Outline sketch for middle-size tank furnace (End Port type)

Clarified molten glass enters the refiner through the throat and then is supplied to the molding machine from the forehearth. In the refiner and forehearth, the temperature of glass is adjusted to an appropriate one for molding in accordance with the weight and shape of a molded product. In this section, glass is heated by a plurality of small-type burners which use LPG or kerosene as fuel.

Molding is sometimes manually handled. However, in the case of mass production, generally the I.S. machine is used.

The molded product is cooled slowly to remove thermal strain. The annealing temperature and time varies according to glass composition, thickness of finished product, etc. But normally, the product is cooled slowly at 500 ~ 550° C to approx. 400° C at a processing rate of 1 to 5° C/min. As an annealing furnace, in addition to the batch kiln, the continuous tunnel furnace called "Lehr" provided with a mesh belt is used extensively. Annealed products are packed after examination.

(2) Main facilities

The melting furnace is classified as a tank suitable for continuous mass production and a pot for multigrade small-lot production. At all the factories diagnosed by us, the tank was used exclusively, so the tank is described here. Fig. III-1-6 shows a typical middle-type tank furnace.

For glass melting, a high temperature of approx. 1,500° C is required. Therefore, it is necessary to preheat air for burning heavy oil through a heat exchange with combustion exhaust gas. As shown in the Fig. the regenerator or the recuperator is used. Another heating method is to directly electrify molten glass by inserting an electode into it instead of using fuel or as an auxiliary heat source.

As refractories for the melting tank, the corrosion-resisting electrocast brick of ZrO_2-Al_2O_3-SiO_2 is used in the lower part touching molten glass and the silica brick in the upper part.

The burners are aligned in the axial direction of the tank (end-port type) except for the large-size-tank. In the tank with a regenerator an even number of burners are provided, each half of which being switched alternately for use at the interval of a fixed time (normally every 15 to 20 min.)

The regenerator is partitioned into 2 chambers. The burner side under combustion is used for preheating air for burning. On the other hand the opposite side regenerates heat into the checker brick by passing combustion exhaust gas. Generally, the regenerator has a higher heat recovery rate than the recuperator.

2.2 Status of Energy Utilization

2.2.1 Ceramic industries

In the ceramic factory, energy is used for the following purposes:

Purpose	Equipment	Energy source
Pulverization	ball mill, etc.	electric power
Mixing	agitator	electric power
Molding	press	electric power
Firing	kiln, electric kiln	heavy oil, kerosene, electric power
Drying	*drier*	*utilization of waste heat, steam*
Illumination, others		Electric power

The energy consumption proportion averages approx. 92% for fuel and 8% for electric power. The thermal source for the drier is mostly provided by waste heat. In this sense, energy conservation is important in the firing kiln.

The firing of ceramics has characteristic of the following.

a) Water is used in the crushing and molding process and is left in the material before firing. As water has significant specific heat or evaporation latent heat, the temperature rising speed of material varies depending on the existence of moisture. In addition, as the volume of water changes significantly when it evaporates, sudden drying and firing would cause damage on the finished product.

b) Tools such as shelf board or saggers for protecting finished product are required. These have a higher weight ratio than the finished product. Both finished product and tools has less heat conductivity. The required amount of energy for heating them at more than 1,000° C is very large (refer to Table III-1-2)

Table III–1–2

Heat conductivity	(Chamotte brick, ceramic) 1 to 1.5 kcal/m h °C	
Specific heat:	**Prepared clay**	0.34 kcal/kg °C
	Chamotte brick	0.27

c) It is required to adjust the atmospheric gas to such grades as oxidizing, deoxidizing or neutral during the firing stage, according to finished product. In addition, unless the finished product after firing is avoided to contact combustion gas, a qualitative problem may occur.

d) When glazed, attention must be given to firing because the glazed part constitutes a compound of material and glaze, which have different melting points and coefficients of expansion.

e) If exposed to sudden heating, the molded product generates a thermal stress and easily breaks down due to a temperature difference in the interior of material. Accordingly, heating and cooling must generally be carried out at considerably slow tempo.

The unit fuel consumption rate varies widely due to the influence by factors such as shape and kind of finished product, firing temperature, application of glaze, type of kiln, etc. Table III-1-3 shows the examples of the Kingdom of Thailand and some parts of Japan for reference. In these examples, there are no recognizable differences attributable to scale and fuel. Instead it seems that the effects of various factors such as described above are significant.

Table III–1–3 Example of fuel consumption rate for tile

Kiln	Fuel	Production t/day	Fuel consumption rate MM kcal/t	Remark
Tunnel	Heavy oil	1	3.8	Japan
〃	Gas	5	2.5	Japan
〃	Heavy oil	7	4.6	Thailand
〃	〃	8	5.1	Japan
〃	〃	11	2.3	Japan
〃	〃	12	1.4	Japan
〃	〃	12	3.7	Japan
〃	〃	12	2.5	Japan
〃	〃	13	3.3	Japan
〃	〃	26	2.2	Japan
〃	〃	41	4.1	Thailand
Average (excluding Thailand)		8	2.4	

Table III-1-4 shows an example of the actual status survey for 18 Japanese factories. Thermal efficiency of this table is shown in the following formula.

$$\text{Thermal efficiency (finished product)} = \frac{\text{Weight of finished product} \times \text{Specific heat}(0.3) \times \text{Heating temp}}{\text{Supplied calorific value}}$$

From this table, the following tendency is noticed:

a) The continuous kiln has a more favorable unit fuel consumption rate than the batch kiln.

b) Gas is more advantageous than heavy oil in terms of unit fuel consumption rate.

c) The smaller the ratio, auxiliary tool/finished product, the more favorable the unit fuel consumption rate becomes.

Table III-1-5 shows the summary of the Japan Industrial Standard (JIS R 0301) "Heat Balancing of Pottery and Refractory Firing Tunnel Kiln". Table III-1-6 and Table III-1-7 show a typical calculation example under the formula for reference. Various specific heat values are as shown in Table III-1-8 to Table III-1-11. In this calculation example, the thermal efficiency for sanitary ware is low because of the heavy weight of sagger and tools and the high heat regeneration amount of a car. Further, in some calculations, the heat brought out by cooling air is included in a heat loss caused by radiation transfer, etc.

Table III-1-12 shows the summary of the Japan Industrial Standard (JIS R 0302) "Heat Balancing of Pottery and Refractory Firing Periodic Kiln".

As facilities using electric power in the ceramic industry, the crusher, agitator, kneader, molding machine, pump, compressor, blower, electric kiln and illumination are available.

The energy consumption of these facilities depends on the manufacturing method, equipment and type of finished product.

Table III–1–4 Survey table for the actual status of kilns

Factories surveyed	Classification of finished product	Kind of kiln					Firing time (length of car) m	Unit fuel consumption unit						Tool/ finished product kg/kg	Temp. of exhaust gas °C	Surfacial temp. °C	Thermal efficiency.		Gas in the kiln			Air ratio
		Fuel	Type	Size	Atmosphere	Firing temp. °C		Fuel consumption t/day (time)	Weight of finished product t/day (time)	Weight of tool t/day (time)	Fuel consumption/ finished product kg/t	Fuel consumption/ finished product +tool kg/t	Fuel consumption/ kiln volume kg/m³				Finished product	Finished product and saggar	CO_2	O_2	CO	
1	Table-ware	Heavy oil	Tunnel	58 m	R	1300	30 min/car (1.5)	4.7	5.7	23.45	820	116	56	4.1	420	—	4.8	24.5	12.4	0.1	2.2	0.96
2	〃	Light oil	〃	63 m	R	1300	30 min/car (1.5)	3.8	8.78	38.11	440	81	59	4.3	620	85	8.9	48.1	—	—	—	—
3	〃	Heavy oil	Periodic	21 m³	R	1300	20 hrs.	3.33	2.35	11.8	1440	240	159	5.0	600	40	2.8	16.3	12.3	0.5	3.1	0.74
4	〃	〃	〃	21 m³	R	1300	20 hrs.	3.69	2.72	8.88	1360	320	176	3.3	600	30	2.9	12.1	12.9	0	2.6	0.75
5	〃	〃	Shuttle	6 m³	R	1300	17 hrs.	1.3	0.93	2.93	1390	340	217	3.1	—	—	2.8	11.4	12.3	0.5	3.1	0.95
6	〃	〃	〃	6 m³	R	1300	17 hrs.	1.4	1.01	2.72	1380	380	233	2.7	630	35	2.8	10.2	—	—	—	—
7	〃	Gas	Tunnel	24.4 m	O	1200	26 min/car (1.1)	0.48	3.10	4.41	155	64	31	1.4	600	85	19.4	46.9	14.0	0.5	0	1.02
8	〃	〃	〃	27 m	O	1160	50 min/car (1.1)	0.6	1.10	3.20	548	140	96	2.9	620	160	5.3	20.8	10.6	8.8	0	1.7
9	〃	〃	〃	21 m	R	1310	58 min/car (1.0)	0.4	0.74	3.12	537	104	66	4.2	550	122	6.1	31.6	9.0	0	8.7	0.83
10	〃	〃	Shuttle	3 m³	R	1230	13 hrs.	0.3	1.82	0.95	366	170	80	1.2	990	190	8.4	18.1	11.6	0	3.4	0.93
11	〃	〃	〃	2 m³	R	1230	24 hrs.	0.25	0.25	0.64	1008	280	124	2.6	747	81	3.1	10.9	12.2	0	1.4	0.97
12	〃	〃	〃	2.5m³	O	1160	17 hrs.	0.2	0.49	0.55	408	192	100	1.1	703	90	7.11	14.55	8.4	7.8	0	1.54
13	Tile	Heavy oil	Tunnel	64 m	O	1230	65 min/car (1.8)	3.86	7.6	35.42	510	90	74	4.7	500	70	7.2	41.0	9.2	7.8	0	1.55
14	〃	〃	〃	75 m	O	1230	45 min/car (1.7)	4.6	12.38	50.0	370	73	41	4.1	480	100	10.0	50.5	10.6	6.1	0	1.38
15	〃	〃	〃	62.8 m	O	1250	44 min/car (1.8)	3.2	13.5	37.8	250	69	36	2.8	188	85	19.9	71.6	5.6	13.6	0	1.3
16	〃	〃	〃	88.4 m	O	1270	48 min/car (1.7)	3.6	12.9	41.7	333	79	37	3.2	238	193	16.9	70.3	4.2	15.6	0	1.3
17	〃	Gas	〃	33.2 m	O	1270	48 min/car (1.45)	1.13	4.6	11.5	246	70	79	2.5	290	221	12.0	42.0	4.0	15.6	0	1.2
18	〃	〃	Shuttle	8.6m³	O	1150	44 hrs.	2.8	2.8	9.24	1000	23	132	3.3	374	100	5.6	24.0	2.2	17.4	0	1.3

Table III-1-5 Heat Balancing of Pottery and Refractory Firing Tunnel Kiln

Item		Calculation Formula
1. Heat Input Q_1 〔kcal (kJ)〕	(1) Combustion heat of fuel Q_a 〔kcal (kJ)〕	$Q_a = m_f \times H_l$ where, mf: Fuel consumption per 1 ton of product (kg or m^{3}N) Ht: Low calorific value of fuel (kcal/kg) or (kcal/m^{3}N) Remark: For instance, in case of gas fuel of certain composition, it is possible to calculate the low calorific value of fuel Ht (kcal/m^{3}N) by the following equation: The parenthesized figure means a volume percentage of the composition of gas fuel. $H_l = 30.5(CO) + 25.7(H_2) + 85.5(CH_4) + 153.7(C_2H_6) + 222.8(C_3H_8) + 292(C_4H_{10})$
	(2) Sensible heat of fuel Q_s 〔kcal (kJ)〕	$Q_s = m_f \times C_f \times (t_f - t)$ where, *mf: Fuel consumption per 1 ton of product (kg or m^{3}N)* Cf: Specific heat of fuel (kcal/kg °C) or (kcal/m^{3}N °C) tf: Temp. of fuel t: Ambient temp (°C) Remark: The specific heat of liquid fuel shall be 0.45 kcal/kg °C and the specific heat of gas fuel be calculated based on its composition.

Table III-1-5 (2)

Item		Calculation Formula
1. Heat Input Q_1 [kcal (kJ)]	(3) Heat input by unfired product, saggar and tool Qc [kcal]	(a) Heat input by unfired product Q_{c1} [kcal] $Q_{c1} = M_m \times C_m \times (t_m - t)$ where, M_m: Weight of unfired product per 1 ton of fired product (kg) Cm: Average specific heat of unfired product [kcal/kg °C] tm: Temp. of unfired product at the inlet of kiln (°C) t: Ambient temp (°C) (b) Heat input by saggar and tool [kcal] $Q_{c2} = m_{st} \times C_{st} \times (t_{st} - t)$ where, Mst: Weight of saggar and tool per 1 ton of fired product (kg) Cst: Specific heat of saggar and tool [kcal/kg °C] tst: Temp. of saggar and tool at the inlet of kiln (°C) t: Ambient temp (°C) (c) Heat input by unfired product, saggar and tool Q_c [kcal] $Q_c = Q_{c1} + Q_{c2}$ where, Q_{C_1}: Heat input by unfired product [kcal] Q_{C_2}: Heat input by saggar and tool [kcal]
	(4) Heat input by car Q_d [kcal]	(a) Heat input by car (portion of refractor) Q_{d_1} [kcal (kJ)] $Q_{d1} = m_{cb} \times C_{cb} \times (t_{cb} - t)$ where, Mcb: Weight of car (portion of refractories) per ton of fired product (kg) Ccb: Specific heat of car (portion of refractories) [kcal/kg °C (kJ/kg °C)] tcb: Temp. (°C) of car (portion of refractories) at the inlet of kiln (°C) t: Ambient temp. (°C) (b) Heat input by car (iron part) Q_{d_2} [kcal (kJ)] $Q_{d2} = m_{cs} \times C_{cs} \times (t_{cs} - t)$ where, Mcs: Weight (kg) of car (iron part) per 1 ton of fired product Ccs: Specific heat of car [kcal/kg °C (kJ/kg °C)] tcs: Temp. (°C) of car (iron part) at the inlet of kiln t: Ambient temp. (°C) Remark: The specific heat of iron shall be 0.12 kcal/kg °C (0.50 kJ/kg °C) (c) Heat input by car Qd [kcal (kJ)] $Q_d = Q_{d1} + Q_{d2}$ where, Q_{d_1}: Heat input by car (portion of refractories) [kcal (kJ)] Q_{d_2}: Heat input by car (iron part) [kcal (kJ)]
	(5) Conbustion heat of combustible component contained in unfired product Q_e [kcal(kJ)]	$Q_e = m_e \times H_{lb}$ where, mc: Weight of combustible component contained in unfired product per 1 ton of fired product (kg) Hlb: Effective calorific value of combustible component [kcal/kg(kJ/kg)]
	(6) Total heat input Q_1 [kcal(kJ)]	$Q_1 = Q_a + Q_b + Q_c + Q_d + Q_e$ where, Qa: Combustion heat of fuel [kcal (kJ)] Qb: Sensible heat of fuel [kcal (kJ)] Qc: Heat input by unfired product, saggar and tool [kcal (kJ)] Qd: Heat input by unfired product, saggar and tool Qe: Combustion heat of combustible component contained in unfired product [kcal (kJ)]
2. Heat output Q_2 [kcal (kJ)]	(1) Heat output by fired product, saggar and tool Q_f [kcal (kJ)]	(a) Heat output by fired product Q_{f1} [kcal (kJ)] $Q_{f1} = 1000 + C'_m \times (t'_m - t)$ where, $C'm$: Average specific heat of fired product [kcal/kg °C (kJ/kg °C)] $t'm$: Temp. (°C) of fired product at the outlet of kiln (°C) t: Ambient temp. (°C). (b) Heat output by saggar and tool Q_{f_2} [kcal (kJ)] $Q_{f2} = m_{st} \times C'_{st} \times (t'_{st} - t)$. where, Mst: Weight of saggar and tool per 1 ton of fired product (kg) $C'st$: Specific heat of saggar and tool [kcal/kg°C(kJ/kg°C)] $t'st$: Temp. (°C) of saggar and tool at the outlet of kiln (°C) t: Ambient temp. (°C)

Table III-1-5 (3)

Item		Calculation Formula
2. Heat output Q_2 [kcal (kJ)]	(1) Heat output by fired product, saggar and tool Qf [kcal (kJ)]	(c) Heat output by fired product, saggar and tool Q_f [kcal (kJ)] $Q_f = Q_{f1} + Q_{f2}$ where, Qf_1 : Heat output by fired product Q_f [kcal (kJ)] Qf_2 : Heat output by saggar and tool [kcal (kJ)]
	(2) Heat output by car Qg [kcal (kJ)]	(a) Heat output by car (portion of refractories) $Q_{g1} = m_{cb} \times C'_{cb} \times (t'_{cb} - t)$ where, mcb: Weight (kg) of car (portion of refractories) per 1 ton of fired product $C'cb$: Specific heat [kcal/kg °C (kJ/kg°C)] of car (portion of refractories) $t'eb$: Temp. (°C) of car (portion of refractories) at the outlet of kiln t: Ambient temp. (b) Heat Qg_2 [kcal (kJ)] output by car (iron part) $Q_{g2} = m_{cs} \times C'_{cs} \times (t'_{cs} - t)$ where, mcs: Weight (kg) of car (iron part) $C'cs$: Specific heat [kcal/kg °C (kJ/kg °C)] of car (iron part) $t'cs$: Ambient temp. (°C) Remark: The specific heat of iron shall be 0.12 kcal/kg °C (0.50 kJ/kg °C) (c) Heat output by car Q_g [kcal (kJ)] $Q_g = Q_{g1} + Q_{g2}$ where, Q_{g1} : Heat [kcal (kJ)] output by car (portion of refractories) Q_{g2} : Heat [kcal (kJ)] output by car (iron part)
	(3) Heat output by cooling air Q_h [kcal (kJ)]	$Q_h = V_a \times C_a \times (t_a - t)$ where, Va: Volume of cooling air per 1 ton of fired product Ca: Specific heat of air [kcal/m³N °C(kJ/m³N °C)] t_a : Temp. (°C) of cooling air at the outtake part of klin t: Ambient temp. Remark: The specific heat of air shall be 0.31 kcal/m³N °C (1.30 kJ/m³N°C).
	(4) Heat output by combustion exhaust gas Q_t [kcal (kJ)]	(a) Sensible heat of dry comburtion exhaust gas Q_{t1} [kcal (kJ)] $Q_{t1} = m_f \times G' \times G_g \times (t_g - t)$ where, m_f : Fuel consumption per 1 ton of fired product G' : Volume of dry combustion exhaust gas per kg or/m³N of fuel Cg: Specific heat of combustion exhaust gas [kcal/m³N °C (kJ/m³N °C)] tg: Temp. of combustion exhaust gas (°C) t: Ambient temp. (°C) Remark: 1. Specific heat of dry combstion exhaust gas shall be 0.33 kcal/m³N °C when carrying out an approximate calculation. 2. When there is a combustible component of unfired product, calculate it separately. 3. When obtaining a volume of dry combustion exhaust gas G' (m³N) per 1 kg or 1 m³N of fuel based on a composition of combustion exhaust gas and a fuel composition use the following equation: (i) In case of liquid fuel $G' = (m - 0.21) A_0 + 1.867 \times \frac{c}{100} + 0.7 \times \frac{s}{100} + 0.8 \times \frac{n}{100}$ or $G' = \frac{1.867c + 0.7s}{(CO_2) + (CO)}$ $m = \frac{(N_2)}{(N_2) - 3.76\{(O_2) - 0.5(CO)\}}$ $A_o = \frac{1}{100}\left[8.89c + 26.7\left(h - \frac{o}{8}\right) + 3.33s\right]$

Table III–1–5 (4)

Item		Calculation Formula
2. Heat output Q_2 [kcal (kJ)]	(4) Heat output by combustion exhaust gas Q_1 [kcal (kJ)]	where, c : Mass percentage (%) of carbon in fuel s : Mass percentage (%) of combustible sulpher in fuel n : Mass percentage (%) of nitrogen in fuel o : Mass percentage (%) of oxygen in fuel h : Mass percentage (%) of hydrogen in fuel m : Air ratio A_o : Theoretical air volume (CO_2): Volume percentage (%) of carbon dioxide (including sulphur dioxide) in combustion exhaust gas (CO): Volume percentage (%) of carbon monoxide in combustion exhaust gas (O_2): Volume percentage (%) of oxygen in combastion exhaust gas (N_2): Volume percentage (%) of nitrogen in combustion exhaust gas For obtaining air ratio, theoretical air volume A_o (m^3N/kg) and volume of dry combustion exhaust gas G' (m^3N/kg) it is possible to use the following simple equations. Here the volume percentage (%) of a maximum volume of carbon dioxide (CO_2) max. in the combustion exhaust gas of liquid fuel *is put 15.3%*. $m = \frac{(CO_2)_{max}}{(CO_2)}$ $A_o = \frac{0.85}{1000} H_l + 2.0$ $G' = G_o + (m-1)A_o - \frac{22.4}{18}\left(\frac{w+9h}{100}\right)$ $G_o = \frac{1.11}{1000} H_l$ where, H_l : Low calorifice value of liquid fuel [kcal/kg (kJ/kg)] ω : Mass percentage (%) of moisture in fuel. h : Mass percentage (%) of hydrogen in fuel. Go: Volume of theoretical combustion exhaust gas (CO_2): Volume percentage (%) of carbon dioxide in combustion exhaust gas (ii) In case of gas fuel $G' = G - (H_2 + 2CH_4 + 3C_2H_6 + 4C_3H_8 + 5C_4H_{10})$ $G = 1 + m_{A_o} - 0.5(H_2 + CO - C_2H_6 - 2C_3H_8 - 3C_4H_{10})$ or $G' = \frac{CO + CO_2 + CH_4 + 2C_2H_6 + 3C_3H_8 + 4C_4H_{10}}{(CO_2) + (CO)} \times 100$ $m = \frac{(O_2) - 0.5(CO)}{(0.5H_2 + 0.5CO + 2CH_4 + 3.5C_2H_6 + 5C_3H_8 + 6.5C_4H_{10} - O_2)} \times \frac{1}{\frac{(CO_2) + (CO)}{CO + CO_2 + CH_4 + 2C_2H_6 + 3C_3H_8 + 4C_4H_{10}}} + 1$ $A_o = \frac{1}{0.21}(0.5H_2 + 0.5CO + 2CH_4 + 3.5C_2H_6 + 5C_3H_8 + 6.5C_4H_{10} - O_2)$ where, H_2 : Volume (m^3N) of hydrogen in $1m^3N$ of gas fuel CO: Volume (m^3N) of carbon monoxide in $1m^3N$ of gas fuel CH_4 : Volume (m^3N) of methane in $1m^3N$ of gas fuel C_2H_6 : Volume (m^3N) of ethane in $1m^3N$ of gas fuel C_3H_8 : Volume (m^3N) of propane in $1m^3N$ of gas fuel C_4H_{10} : Volume (m^3N) of butane in $1m^3N$ of gas fuel O_2 : Volume (m^3N) of oxygen in $1m^3N$ of gas fuel N_2 : Volume (m^3N) of nitrogen in $1m^3N$ of gas fuel CO_2 : Volume (m^3N) of carbon dioxide in $1m^3N$ of gas fuel (O_2): Volume per centage (%) of oxygen in combustion exhaust gas (CO_2): Volume percentage (%) of carbon dioxide in conbustion exhaust gas (CO): Volume percentage (%) of carbon monoxide in combustion exhaust gas

Table III−1−5 (5)

Item		Calculation Formula
2. Heat output Q_2 [kcal{kJ}]	(4) Heat output by combustion exhaust gas Q_t [kcal{kJ}]	m: air ratio A_0: Theoretical air volume (m^{3}N/m^{3}N) When calculating theoretical air volume A_0 (m^{3}N/m^{3}N) and volume of dry combustion exhaust gas G' (m^{3}N/m^{3}N) based on a low calorific value of gas fuel H_l [kcal/m^{3}N (kJ/m^{3}N)], it is possible to use the following simple equations: $A_o = \frac{1.09}{1000} H_l - 0.25$[in case $H_l = 4000$[kcal/m$^3{}_N${kJ/m$^3{}_N$}] or more] $G' = G_o + (m-1) A_o - (H_2 + 2CH_4 + 3C_2H_6 + 4C_3H_8 + 5C_4H_{10})$ $G_o = \frac{1.14}{1000} H_l + 0.25$[in case $H_l = 4000$[kcal/m$^3{}_N${kJ/m$^3{}_N$}] or more] where, G_0: Theoretical volume of combustion exhaust gas (m^{3}N/m^{3}N) H_2: Volume (m^{3}N) of hydrogen in 1 m^{3}N of gas fuel CH_4: Volume (m^{3}N) of methane in 1 m^{3}N of gas fuel C_2H_6: Volume (m^{3}N) of ethane in 1 m^{3}N of gas fuel C_3H_8: Volume (m^{3}N) of propane in 1 m^{3}N of gas fuel C_4H_{10}: Volume (m^{3}N) of butane in 1 m^{3}N of gas fuel (b) Sensible heat Q_{t2} [kcal(kJ)]of water vapor in combustion exhaust gas $Q_{t2} = m_f \times S_g \times C_{tg} \times (t_g - t)$ here, mf: Fuel consumption (kg or m^{3}N) per 1 ton of fired product S_g: Weight of water vapor (kg) in combustion exhaust gas per 1 kg or 1 m^{3}N of fuel Cig: Specific heat of vapor [kcal/kg°C{kJ/kg°C}] tg: Temp. (°C) of combustion exhaust gas t: Ambient temp. (°C) Remarks: 1. The specific heat of vapor shall be 0.45 kcal/kg °C (1.88 kJ/kg °C) 2. It is possible to obtain a volume of vapor S_g (kg) in combustion exhaust gas per 1 kg or 1 m^{3}N of fuel by the following equations: (i) In case of liquid fuel $S_g = \frac{29}{22.4} AZ + \frac{w}{100} + \frac{9h}{100}$ where, A: Air consumption (m^{3}N) per 1 kg of fuel Z: Absolute humidity w: Mass percentage (%) of moisture in heavy oil h: Mass percentage (%) of hydrogen in heavy oil (ii) In case of gas fuel $S_g = \frac{29}{22.4} AZ + \frac{18}{22.4} (H_2 + 2CH_4 + 3C_2H_6 + 4C_3H_8 + 5C_4H_{10})$ $A = mA_o$ $Z = \frac{0.62\varphi P_s}{P - \varphi P_s}$ where, A: Air consumption per 1 m^{3}N of fuel Z: Absolute humidity H_2: Volume (m^{3}N) of hydrogen in 1 m^{3}N of gas fuel CH_4: Volume (m^{3}N) of methane in 1 m^{3}N of gas fuel C_2H_4: Volume (m^{3}N) of ethane in 1 m^{3}N of gas fuel C_3H_8: Volume (m^{3}N) of propane in 1 m^{3}N of gas fuel C_4H_{10}: Volume (m^{3}N) of butane in 1 m^{3}N of gas fuel m: Air ratio A_0: Theoretical air volume [m$^3{}_N$/m$^3{}_N$] ϕ: Relative humidity P: Atmospheric pressure [mmHg{Pa}] Ps: Saturated vapor pressure [mmHg{Pa}] (c) Heat [kcal (kJ)] output by combustion exhaust gas where, Q_{i_1}: Sencible heat [kcal (kJ)] of dry combustion exhaust gas Q_{i_2}: Sensible heat [kcal (kJ)] of vapor in combustion exhaust gas

Table III-1-5 (6)

Item		Calculation Formula
2. Heat output Q_2 [kcal (kJ)]	(5) Heat loss by incomplete combustion Q_j [kcal (kJ)]	$Q_j = m_f \times G' \times \frac{(CO)}{100} \times 3050$ where, m_f : Fuel consumption (kg or m³N) per 1 ton of fired product G' : Volume of dry combustion exhaust gas (m³N) per 1 kg or 1 m³N of fuel (CO): Volume percentage (%) of carbon monoxide in combustion exhaust gas Remark: When measuring soot in combustion exhaust gas quantitatively, add its cclorific value of 8,100 kcal/kg (33,910 kJ/kg) to heat loss.
	(6) Heat output by vapor vaporing from moisture of unfired product Q_k [kcal (kJ)]	$Q_k = (m_x + m_y) \times (I - I')$ where, m_x: Moisture (kg) adhering to unfired product per 1 ton of fired product. m_y : Water of crystalization (kg) of unfired product per 1 ton of fired product. I : Enthalpy of water vapor at temp. of combustion exhaust gas. (°C) I' : Enthalpy of water at ambient temp.(°C)[kcal/kg {kJ/kg}]
	(7) Heat output by cooling water Ql [kcal (kJ)]	$Q_l = m_w \times 1 \times (t'_w - t''_w)$ where, m_w : Cooling water consumption (kg) per 1 ton of fired product. t'_w : Temp. (°C) of cooling water at outlet t''_w: Temp. (°C) of cooling water at inlet
	(8) Heat loss by radiation, conduction etc. Qm [kcal (kJ)]	$Q_m = Q_1 - (Q_f + Q_g + Q_h + Q_i + Q_j + Q_k + Q_l)$ where, Q_1 : Total heat input [kcal (kJ)] Qf : Heat output by fired product [kcal (kJ)] Q_g : Heat output by car [kcal (kJ)] Q_h : Heat output by cooling air [kcal (kJ)] Qi : Heat output by combustion gas [kcal (kJ)] Q_j : Heat loss by incomplete combustion [kcal (kJ)] Q_k : Heat output by vapor vaporizing from moisture of unfired product [kcal (kJ)] Q_l : Heat output by cooling water [kcal (kJ)] Heat loss from kiln wall. Qm_1 [kcal (kJ)] $Q_{m1} = \frac{Q_{m2}}{m_m'}$ $Q_{m2} = \Sigma(h_c + h_r)\Delta_t \cdot A$ $h_c = 2.1 \times \sqrt[4]{\Delta_t}$ (in case of horizontal roof wall) $h_c = 1.5 \times \sqrt[4]{\Delta_t}$ (in case of vertical wall) $h_r = 4.88\left\{\left(\frac{T_o}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right\} \times 0.8/\Delta_t$ where, $M'm$: Weight (t) of fired product per 1 hr. Qm_2: Quantity of heat [kcal (kJ)] release from the entire kiln wall per 1 hr. h_c : *Convective heat transfer coefficient* [kcal/m²h °C (kJ/m²h °C)] hr : Radiative heat transfer coefficient [kcal/m²h °C (kJ/m²h °C)] Δt : Difference between temp. of outer kiln wall and room air temp. (°C) A : Surfacial area of kiln wall (m²) T_o : Temp. of outer kilm wall indicated at absolute temp. (K) T_o : Room temp. indicated at absolute temp. (K) Remark: A calculation formula for heat loss from kiln wall in shown for reference.
	(9) Total Heat Output [kcal (kJ)]	$Q_2 = Q_f + Q_g + Q_h + Q_i + Q_j + Q_k + Q_l + Q_m$ where, Qf : Heat output by fired product [kcal (kJ)] Qg : Heat output by car [kcal (kJ)] Qh : Heat output by cooling air [kcal (kJ)] Qi : Heat output by combustion exhaust gas [kcal (kJ)] Qj : Heat loss by incomplete combustion [kcal (kJ)] Qk: Heat output by vapor vaporizing from moisture of unfired product [kcal (kJ)]

Table III−1−5 (7)

Item		Calculation Formula
2. Heat output Q_2 [kcal (kJ)]	(9) Total Heat Output	Ql : Heat output by cooling water [kcal (kJ)] Qm: Heat loss by radiation, conduction etc.
3. Circulating heat Q_3 [kcal (kJ)]	(1) Heat recovered by combustion air Q_n [kcal (kJ)]	$Q_n = V_{pa} \times C_{pa}(t_{pa} - t)$ where, Vpa : Volume of preheated air for combustion per 1 ton of fired product (m^{3}N) Cpa: Specific heat of air [kcal/m^3 N °C (kJ/m^3 C)] t : Ambient temp. (°C) Remark: The specific heat of air shall be 0.31 kcal/m^3 N °C (1.30 kJ/m^3 N °C)
	(2) Heat held by circulating combustion gas Q_o [kcal (kJ)]	$Q_o = V_{cg} \times C_{cg} \times (t_{cg} - t)$ where, V_{cg} : Volume of circulating combustion gas per 1 ton of fired product (m^{3}N) C_{cg} : Specific heat of combustion gas [kcal/m^3 N °C (kJ/m^3 N °C)] t_{cg} : Temp. of circulating combustion gas (°C) t : Ambient temp. (°C)
4. Effective heat Q_4 [kcal (kJ)]	(1) Effective heat per 1 ton of fired product when only fired product is considered Q_1 [kcal (kJ)]	(a) Heat required for evaporating moisture adhering to unfired product $Q_p = m_x \times (I_x - I'_x)$ where, m_x : Moisture (kg) adhering to unfired product per 1 ton of fired product Ix : Enthalpy of vopor vaporising from adhering moisture [kcal/kg (kJ/kg)] $I'x$: Enthalpy of moisture adhering to unfired product at the inlet of kiln [kcal/kg (kJ/kg)] Remark: Enthalpy of vapor vaporizing from adhering moisture shall be the enthalpy of vapor of 648 kcal/kg (2713 kJ/kg) at 125°C (b) Heat required for evaporizing water of crystalization of unfired product Qg [kcal (kJ)] $Q_q = m_y \times (I_y - I'_y)$ where, m_y : Water of crystalization (kg) of unfired product per 1 ton of fired product Iy : Enthalpy of vapor vaporizing from water of crystalization [kcal/kg (kJ/kg)] $I'y$: Enthalpy of water of crystalization of unfired product at the inlet of kiln. [kcal/kg (kJ/kg)] Remark: Enthalpy of vapor vaporizing from water of crystalization shall be the enthalpy of vapor of 859 kcal/kg (3,596 kJ/kg) at 550°C. (c) Heat required for decomporing clay Qr [kcal (kJ)] $Q_r = m_{cl} \times q_p$ where, m_{cl} : Quantity (kg) of clay in unfired product per 1 ton of fired product. q_p : Heat required for decomposing 1 kg of clay [kcal/kg (kJ/kg)] Remark: Heat required for decomposing clay shall be 260 kcal/kg (1,088 kJ/kg). (d) Heat required for firing product Qs [kcal (kJ)] $Q_s = 1000 \times G''_m \times (t''_m - t_m)$ where, $G''m$: Specific heat of fired product [kcal/kg °C(kJ/kg°C)] $t''m$: Firing temp. (°C) tm: Temp. (°C) of unfired product at the inlet of kiln (e) Effective heat per 1 ton of fired product Qq [kcal (kJ)] $Q_1 = Q_p + Q_q + Q_r + Q_s$ where, Qp: Heat required for evaporizing moisture adhering to unfired product [kcal (kJ)] Qq: Heat required for evaporizing water of crystalization of unfired product [kcal (kJ)] Qr: Heat required for decomposing clay [kcal (kJ)] Qs: Heat required for firing product [kcal (kJ)]

Table III–1–5 (8)

Item		Calculation Formula
4. Effective heat Q_4 [kcal (kJ)]	(2) Effective heat per 1 ton of fired product when saggar and tool are included Q_{tt} [kcal (kJ)]	(a) Heat required for heating saggar and tool Qt [kcal (kJ)] $Q_t = m_{st} \times C''_{st} \times (t''_{st} - t_{st})$ where, mst : Weight of saggar and tool per 1 ton of fired product (kg) $C''st$: Average specific heat of saggar and tool [kcal/kg °C (kJ/kg °C)] $t''st$: Firing temp. of saggar and tool (°C) tst : Temp. (°C) of saggar and tool at the inlet of kiln (b) Effective heat per 1 ton of fired product when saggar and tool are included Q_{tt} $Q_{tt} = Q_1 + Q_t$ where, Q_1 : Effective heat per 1 ton of fired product [kcal (kJ)] Q_t : Heat required for heating saggar and tool [kcal (kJ)]
5. Thermal efficiency η (%)	(1) Thermal efficiency of fired product η_1 (%)	$\eta_1 = \frac{Q_1}{m_f \times H_l} \times 100$ where, Q_1 : Effective heat per 1 ton of fired product [kcal (kJ)] mf : Fuel consumption per 1 ton of fired product (kg or m^3N) Hl : Low calorific value of fuel [kcal/kg (kJ/kg) or kcal/m^3N (kJ/m^3N)] Remark: When fuel and combustion air are preheated by other heat source, add their quantity of heat to the denominator of the above equation.
	(2) Thermal efficiency included saggar and tool η_2 (%)	$\eta_2 = \frac{Q_{tt}}{m_f \times H_l} \times 100$ where, Q_1 : Effective heat per 1 ton of fired product when saggar and tool are included [kg or m^3N) mf : Fuel consumption per 1 ton of baked product (kg or m^3N) Hl : Low calorific value of fuel [kcal/kg (kJ/kg) or kcal/m^3N (kJ/m^3N)] Remark: When fuel and combustion air are preheated by other heat source, add its quantity of heat to the denominator of the above equation.

Remark: m^3N means a unit of volume in a standard condition of gas [0°C, 760 mmHg (101.3 kPa)]

Table III–1–6 Example of Heat balance sheet of tunnel kiln

(%)

Product		Biscuit	Tile	Table-ware (tray)	Table-ware	Table-ware (mixed)	Table-ware (mixed)
Heat input	Combustion heat of fuel	97.4	99.5	99.4	99.6	99.9	99.8
	Sensible heat of fuel	0.1	0.2	0.2	0.1	0.1	0.1
	Heat carried in by product and tools	1.0	0.2	0.2	0.1	–	0.0
	Heat carried in by car	1.5	0.1	0.2	0.2	–	0.1
	Total	100.0	100.0	100.0	100.0	100.0	100.0
Heat output	Heat carried out by product and tools	4.0	2.3	3.3	2.3	0.7	1.1
	Heat carried out by car	4.3	1.1	3.8	4.0	0.4	2.4
	Heat carried out by cooling air	52.6	43.2	47.3	40.9	19.6	24.0
	Heat carried out by exhaust gas	18.7	15.6	19.8	19.5	22.4	27.0
	Heat loss by incomplete combustion	–	–	–	–	–	1.8
	Heat loss by heat radiation and transfer	15.9	36.7	24.7	32.6	55.7	42.8
	Heat loss by evaporation of moisture unfired product	4.5	1.1	1.1	0.7	0.7	0.4
	Total	100.0	100.0	100.0	100.0	100.0	100.0
Heat efficiency	Product only	31.2	10.6	8.8	4.8	–	6.0
	(including tools)	69.2	39.4	28.0	19.8	–	18.6
Weight ratio	Product: tools	1 : 4	1 : 3.5	1 : 4.5	1 : 6	–	1 : 6.5

Table III–1–7 Heat balance of tile etc.

(%)

	Item	Glazed tile	Ceramic tube	Sanitary ware	Tile (wet forming)	Tile
Heat input	(1) Combustion heat of fuel	98.86	99.77	99.44	98.93	99.39
	(2) Sensible heat of fuel	0.16	0.01	0.00	–	0.02
	(3) Heat brought in by unfired product, sagggar and tool	0.73	0.13	0.15	0.64	0.35
	(a) Heat brought in by unfired product	0.49	0.12	0.05	0.54	0.32
	(b) Heat brought in by saggar and tool	0.24	0.01	0.10	0.10	0.03
	(4) Heat brought in by car	0.25	0.09	0.41	0.43	0.24
	(a) Heat brought in by car *(refrectory part)*	0.16	0.08	0.34	0.39	0.19
	(b) Heat brough in by car (iron part)	0.09	0.01	0.07	0.04	0.05
	(5) Combustion heat brought in by combustible components contained in unfired product	n d	n d	n d	n d	n d
Heat output	(1) Heat carried away by fired product, saggar and tool	3.62	2.60	1.88	3.49	3.46
	(a) Heat carried away by fired product	2.30	2.36	0.68	3.08	3.23
	(b) Heat carried away by saggar and tool	1.32	0.25	1.20	0.41	0.23
	(2) Heat carried away by car	2.01	2.19	5.47	2.25	1.54
	(a) Heat carried away by car *(refractory part)*	1.46	1.89	4.77	2.03	1.26
	(b) Heat carried away by car (iron part)	0.55	0.30	0.70	0.22	0.28
	(3) Heat carried away by cooling air	–	–	–	14.79	–
	(4) Heat carried away by combustion exhaust gas	12.85	10.85	23.58	19.73	12.15
	(a) Sensible heat of dry combustion exhaust gas	12.19	10.39	–	18.66	11.49
	(b) Sensible heat of vapor of combustion exhaust gas	0.66	0.46	–	1.07	0.66
	(5) Heat loss by incomplete combustion	–	–	1.40	–	–
	(6) Heat carried away by vapor evaporated from moisture of unfired product	7.04	3.11	26.25	4.57	8.13
	(7) Heat loss by radiation, conduction and others	74.47	81.25	41.42	55.17	74.71
	Total	100.00	100.00	100.00	100.00	100.00
Effective heat	(1) Effective heat per one ton of fired product when only fired product is considered	42.60	26.74	12.04	29.61	40.55
	(a) Heat required for evaporation of moisture adhering to unfired product	1.40	0.46	0.28	0.71	3.57
	(b) Heat required for evaporation of water of crystalization in unfired product	7.57	3.69	1.48	4.86	6.13
	(c) Heat required for decomposition of clay	12.15	7.75	3.06	8.25	8.97
	(d) Heat required for firing of product	21.48	14.84	7.22	15.79	21.87
	(2) Effective heat per one ton of fired product when saggar and tool are included	56.43	29.12	26.43	32.99	42.83
	Heat required for heating of saggar and tool	13.83	2.38	14.40	3.39	2.28
Heat efficiency	(1) Thermal efficiency of fired product	42.60	26.74	12.04	29.61	40.55
	(2) Thermal efficiency when saggar and tool are included	56.43	29.12	26.43	33.00	42.83
	Unit fuel consumption rate l/t	92.76	132.53	384.22	134.83	94.64

Table III-1-8 Average Constant Pressure Specific Heat of Various Gasses (standard 0° C)

Unit kcal/m³N °C(kJ/m³N° C)

Temp. t(°C)	CO_2	H_2O	Air	CO	N_2 in air	Combustion gas	
						Heavy oil	Coal
0	0. 387 {1. 619}	0. 356 {1. 490}	0. 311 {1. 301}	0. 311 {1. 301}	0. 310 {1. 297}	0. 326 {1. 364}	0. 326 {1. 364}
100	0. 411 {1. 720}	0. 359 {1. 502}	0. 312 {1. 305}	0. 312 {1. 305}	0. 311 {1. 301}	0. 331 {1. 385}	0. 331 {1. 385}
200	0. 432 {1. 807}	0. 363 {1. 519}	0. 313 {1. 310}	0. 313 {1. 310}	0. 311 {1. 301}	0. 334 {1. 397}	0. 335 {1. 402}
300	0. 450 {1. 883}	0. 368 {1. 540}	0. 315 {1. 318}	0. 315 {1. 318}	0. 313 {1. 310}	0. 338 {1. 414}	0. 340 {1. 422}
400	0. 467 {1. 954}	0. 373 {1. 561}	0. 318 {1. 331}	0. 318 {1. 331}	0. 315 {1. 318}	0. 343 {1. 435}	0. 345 {1. 443}
500	0. 482 {2. 017}	0. 379 {1. 586}	0. 321 {1. 343}	0. 321 {1. 343}	0. 318 {1. 331}	0. 348 {1. 456}	0. 350 {1. 464}
600	0. 494 {2. 067}	0. 385 {1. 611}	0. 324 {1. 356}	0. 325 {1. 360}	0. 320 {1. 339}	0. 352 {1. 473}	0. 354 {1. 481}
700	0. 506 {2. 117}	0. 391 {1. 636}	0. 328 {1. 372}	0. 328 {1. 372}	0. 324 {1. 356}	0. 357 {1. 494}	0. 360 {1. 506}
800	0. 516 {2. 159}	0. 397 {1. 661}	0. 331 {1. 385}	0. 332 {1. 389}	0. 327 {1. 368}	0. 361 {1. 510}	0. 364 {1. 523}
900	0. 525 {2. 197}	0. 403 {1. 686}	0. 334 {1. 397}	0. 335 {1. 402}	0. 329 {1. 377}	0. 365 {1. 527}	0. 367 {1. 536}
1000	0. 533 {2. 230}	0. 410 {1. 715}	0. 337 {1. 410}	0. 338 {1. 414}	0. 332 {1. 389}	0. 369 {1. 544}	0. 372 {1. 556}
1200	0. 547 {2. 289}	0. 422 {1. 766}	0. 343 {1. 435}	0. 344 {1. 439}	0. 339 {1. 418}	0. 378 {1. 582}	0. 380 {1. 590}
1400	0. 558 {2. 335}	0. 434 {1. 816}	0. 348 {1. 456}	0. 349 {1. 460}	0. 344 {1. 439}	0. 384 {1. 607}	0. 387 {1. 619}
1600	0. 568 {2. 377}	0. 445 {1. 862}	0. 352 {1. 473}	0. 353 {1. 477}	0. 348 {1. 456}	0. 390 {1. 632}	0. 392 {1. 640}
1800	0. 576 {2. 410}	0. 455 {1. 904}	0. 356 {1. 490}	0. 357 {1. 494}	0. 352 {1. 473}	0. 395 {1. 653}	0. 397 {1. 661}
2000	0. 583 {2. 439}	0. 465 {1. 946}	0. 359 {1. 502}	0. 360 {1. 506}	0. 354 {1. 481}	0. 399 {1. 669}	0. 401 {1. 678}

Remarks 1. The source of the average constant pressure specific heat of CO_2, H_2O, air, CO and N_2 in the above Table is W. Heiligenstaedt: Wärmetechnishe Rechnungen für Industrieöfen, 4 Auflage, Stahleisen-Bücher Band 2, p.58 (1966).

The specific heat of N_2 shown in the Table is not a specific heat of pure N_2 but a specific heat of the remainder (containing Ar, etc.) after removing O_2 from air.

The specific heat of combustion gas means a value calculated when C is equal to 86 % H 12%and m 1.0 for heavy oil, and when w is equal to 2% a 14% c 70% h 5% o 2% n 2%and fuel ratio 1.25.

2. When above table is used, average specific heat $\overline{C}_p$ is

$$\bar{C}_p = \frac{\int_0^t C_p d_t}{t}$$

And when carrying out a heat balance based on ambient temperature (t_p).

$$\bar{C}_p = \frac{\int_0^t C_p d_t - \int_0^{t_R} C_p d_t}{t - t_R}$$

Shall be used. However, for simplicity, here $\overline{C}$ (0° C standard) is used.

Table III-1-9 Specific Heat of Raw Materials for Ceramics and Refractory

	Average Secific Heat kcal/kg [kJ/kg]																				
Kind \ Temp. t °C	0	100	200	300	400	500	600	700	800	900	1000	1050	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Zetoritzkaolin		0.201 [0.841]	0.203 [0.850]	0.213 [0.891]	0.219 [0.916]	0.249 [1.043]	0.413 [1.729]	0.430 [1.800]	0.426 [1.783]	0.433 [1.813]	0.429 [1.796]		0.421 [1.763]	0.414 [1.733]	0.410 [1.717]	0.405 [1.696]						
Feldspar		0.161 [0.674]	0.162 [0.678]	0.163 [0.682]	0.172 [0.719]	0.191 [0.800]	0.202 [0.846]	0.211 [0.883]	0.222 [0.929]	0.229 [0.959]	0.246 [1.030]		0.260 [1.089]	0.262 [1.097]								
Quartz		0.190 [0.795]	0.206 [0.862]	0.217 [0.909]	0.228 [0.955]	0.239 [1.001]	0.256 [1.072]	0.257 [1.076]	0.260 [1.089]	0.263 [1.101]	0.267 [1.118]											
English China clay		0.369 [1.545]	0.393 [1.645]	0.410 [1.716]	0.438 [1.834]	0.487 [2.039]	0.538 [2.252]	0.508 [2.127]	0.493 [2.064]	0.493 [2.064]	0.495 [2.072]											
North Carolina clay		0.381 [1.595]	0.402 [1.683]	0.426 [1.783]	0.451 [1.888]	0.477 [1.997]	0.532 [2.227]	0.517 [2.165]	0.505 [2.114]	0.505 [2.114]	0.507 [2.123]											
Cristobalite		0.194 [0.812]	0.212 [0.887]		0.236 [0.988]		0.248 [1.038]		0.257 [1.076]		0.266 [1.113]											
Calcined alumina		0.199 [0.833]	0.202 [0.846]		0.223 [0.933]		0.250 [1.047]		0.268 [1.122]		0.305 [1.277]											
Corundum		0.203 [0.850]	0.211 [0.883]	0.223 [0.933]	0.231 [0.967]	0.248 [1.038]	0.251 [1.051]	0.259 [1.084]	0.272 [1.139]	0.287 [1.201]	0.304 [1.273]											
Sillimanite		0.161 [0.674]	0.161 [0.674]	0.163 [0.682]	0.167 [0.699]	0.170 [0.712]	0.173 [0.724]	0.174 [0.729]	0.175 [0.733]	0.174 [0.729]	0.175 [0.733]		0.196 [0.821]	0.199 [0.833]	0.203 [0.850]	0.205 [0.858]						
Spinel		0.200 [0.837]	0.235 [0.984]		0.248 [1.038]		0.258 [1.080]		0.260 [1.088]		0.262 [1.097]											
Magnesia		0.234 [0.980]			0.253 [1.059]		0.264 [1.105]		0.273 [1.143]		0.280 [1.172]			0.285 [1.193]		0.289 [1.210]	0.291 [1.218]		0.294 [1.231]	0.295 [1.235]		
Zirconia											0.157 [0.657]			0.167 [0.699]		0.175 [0.733]						
China clay		0.382 [1.600]	0.435 [1.821]		0.463 [1.938]		0.557 [2.332]		0.506 [2.118]		0.487 [2.039]											

Remarks 1. The specific heat shown in this table indicates an average specific heat ranging from 20°C of room temperature to t°C.

2. *The values of this table are based on values provided by W.H. Cohn (1928), A.E. MacGee (1926),* G.R. Wilkee (1934), (1926), A.T. Green (1923). etc.

Table III-1-10 Specific Heat of Ceramics

	Average Specific Heat kcal/kg [kJ/kg]																				
Kind \ Temp. t °C	0	100	200	300	400	500	600	700	800	900	1000	1050	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Ceramics (high-temp. firing)		0.189 [0.791]	0.195 [0.816]	0.203 [0.850]	0.212 [0.887]	0.222 [0.929]	0.232 [0.971]	0.245 [1.026]	0.264 [1.105]	0.273 [1.143]	0.304 [1.273]		0.337 [1.411]									
Ceramics (low-tep. firing)			0.218 [0.913]		0.230 [0.963]		0.243 [1.017]		0.255 [1.068]		0.268 [1.122]			0.281 [1.176]		0.293 [1.227]						
Ceramic glaze (unfired product)		0.170 [0.712]	0.174 [0.729]	0.183 [0.766]	0.193 [0.808]	0.203 [0.850]	0.246 [1.030]	0.239 [1.001]	0.259 [1.084]	0.278 [1.164]	0.280 [1.172]		0.291 [1.218]	0.299 [1.251]	0.307 [1.285]	0.292 [1.223]						
Ceramic glaze (fired product)		0.179 [0.749]	0.181 [0.758]	0.189 [0.791]	0.197 [0.825]	0.199 [0.833]	0.202 [0.846]	0.204 [0.854]	0.211 [0.883]	0.218 [0.913]	0.230 [0.963]		0.245 [1.026]									
Ceramic body (unfired)		0.181 [0.758]	0.183 [0.766]	0.198 [0.829]	0.201 [0.842]	0.215 [0.900]	0.291 [1.218]	0.288 [1.206]	0.280 [1.172]	0.281 [1.176]	0.290 [1.214]		0.311 [1.302]	0.323 [1.352]	0.344 [1.440]							
Ceramic body (fired)		0.186 [0.779]	0.192 [0.804]	0.203 [0.850]	0.212 [0.888]	0.223 [0.934]	0.234 [0.980]	0.275 [1.151]	0.286 [1.197]	0.296 [1.239]	0.307 [1.285]		0.324 [1.357]									

Remark: The specific heat shown in this table indicates an average specific heat ranging from 20° C of room temperature to t° C.

Table III-1-11 Specific Heat of Refractory Brick

	Average Specific Heat kcal/kg [kJ/kg]																				
Kind \ Temp. t °C	0	100	200	300	400	500	600	700	800	900	1000	1050	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Silica brick 1							0.228 [0.955]				0.263 [1.101]			0.282 [1.181]		0.293 [1.227]						
Silica brick 2		0.189 [0.791]	0.210 [0.879]		0.236 [0.988]		0.240 [1.005]		0.250 [1.047]		0.266 [1.114]			0.272 [1.139]								
Silica brick 3						0.240 [1.005]		0.249 [1.042]		0.258 [1.080]		0.263 [1.101]										
Silica brick 4	0.190 [0.795]		0.206 [0.862]		0.222 [0.929]		0.236 [0.988]		0.243 [1.017]		0.259 [1.084]			0.268 [1.122]		0.276 [1.156]						
Clay brick (unfired)		0.191 [0.800]	0.194 [0.812]		0.211 [0.883]		0.347 [1.453]		0.311 [1.302]		0.343 [1.436]			0.384 [1.608]		0.414 [1.733]						
Clay brick (fired)		0.197 [0.825]	0.202 [0.846]		0.220 [0.921]		0.238 [0.996]		0.251 [1.051]		0.277 [1.160]											
China clay brick						0.230 [0.963]		0.247 [1.034]		0.258 [1.080]		0.263 [1.101]										
Ordinary clay brick	0.190 [0.795]		0.203 [0.850]		0.217 [0.909]		0.232 [0.971]		0.247 [1.034]		0.258 [1.080]			0.267 [1.118]		0.275 [1.151]						
Sillimanite brick 1		0.161 [0.674]	0.161 [0.674]		0.167 [0.699]		0.173 [0.724]		0.175 [0.733]		0.175 [0.733]			0.199 [0.833]		0.205 [0.858]						
Sillimanite brick 2					0.229 [0.959]		0.246 [1.030]		0.255 [1.068]		0.258 [1.080]			0.263 [1.101]		0.268 [1.122]	0.270 [1.130]					
Sintered sillimanite brick						0.232 [0.971]		0.247 [1.034]		0.259 [1.084]		0.264 [1.105]										
Fused magnesia brick						0.265 [1.109]		0.276 [1.156]		0.285 [1.193]		0.290 [1.214]										
Magnesia brick 1			0.223 [0.934]		0.254 [1.063]		0.266 [1.114]		0.264 [1.105]		0.277 [1.160]						0.296 [1.239]					
Magnesia brick 2							0.265 [1.109]		0.274 [1.147]		0.285 [1.193]											
Magnesia brick 3	0.220 [0.921]		0.237 [0.992]		0.264 [1.105]		0.260 [1.088]		0.260 [1.088]		0.230 [0.963]			0.290 [1.214]		0.295 [1.235]						
Chrome brick 1			0.178 [0.745]		0.210 [0.879]		0.221 [0.925]		0.218 [0.913]													
Chrome brick 2						0.206 [0.862]		0.214 [0.896]		0.221 [0.925]		0.227 [0.950]										
Chrome magnesia brick						0.224 [0.938]		0.235 [0.984]		0.245 [1.026]		0.250 [1.047]										
Dolomite brick						0.237 [0.992]		0.247 [1.034]		0.256 [1.072]		0.261 [1.093]										
Zirconia brick						0.165 [0.691]		0.272 [1.139]		0.170 [0.712]		0.181 [0.758]										
Sintered periclite brick						0.234 [0.980]		0.249 [1.043]		0.260 [1.088]		0.265 [1.110]										
Diatomaceous earth brick						0.232 [0.971]		0.245 [1.026]		0.254 [1.063]		0.259 [1.084]										
Silicon carbide brick 1		0.838 [3.509]									0.780 [3.265]											
Silicon carbide brick 2		0.200 [0.837]									0.186 [0.779]											

Remarks 1. The specific heat shown in this table indicates an average specific heat ranging from 20°C to t °C of room temperature to t° C.

2. *The values of this table are based on values provided by W.H. Cohn (1928), A.E. MacGee (1926), G.R. Wilkee* (1934), Bradohaw and Energy (1920), F. Neumann (1925), Tadokoro (1926), A.T. Green (1923), etc.

Table III-1-12 Heat Balancing of Pottery and Refractory Firing Periodic Kiln

Item		Calculation Formula
1. Heat Input Q_1 〔kcal {kJ}〕	(1) Combustion heat of fuel Q_a 〔kcal {kJ}〕	$Q_a = m_f \times H_l$ Here *mf*: Fuel consumption per 1 ton of fired product. (kg or m^3N) *Ht*: Low calorific value of fuel (kcal/kg)(kJ/kg) or kcal/m^3N(kJ/m^3N) Remark For instance, in case of gas fuel of certain composition, it is possible to calculate a low calorific value of fuel $H\ell$ [kcal/m^3N (kJ/m^3N) by the following formula. Here the parenthesized value shows volume percentage (%) of the composition of gas fuel. $H_l = 30.5(CO) + 25.7(H_2) + 85.5(CH_4)$ $+ 153.7(C_2H_6) + 210(C_3H_8) + 292(C_4H_{10})$
	(2) Sensible heat of fuel Q_b 〔kcal {kJ}〕	$Q_b = m_f \times C_f \times (t_f - t)$ Here *mf*: Fuel consumption per 1 ton of fired product (kg or m^3N) *Cf*: Specific heat of fuel [kcal/kg °C (kJ/kg° C) or kcal/m^3N {kJ/m^3N}] *tf*: Fuel temp. (°C) *t*: Ambient temp. (° C) Remark: The specific heat of liquid fuel is considered at 0.45 kcal/kg °C (1.88 kJ/kg° C). while that of gas fuel is calculated on its composition.
	(3) Heat input by combustion air Q_c 〔kcal {kJ}〕	$Q_c = \frac{Q_{c1}}{m_0}$ $Q_{c1} = \Sigma[V_c \times C_c \times (t_c - t)]$ Here Q_{cl}: Heat input by combustion air [kcal (kJ)] m_0: Weight of fired product (t) V_c: Each combustion air volume during the period from the start to the completion of firing (m^3N) C_c: Specific heat of each combustion air [kcal/m^3N° C{kJ/m^3N}] ° C)] t_c: Temp. of each combustion air (° C) t: Ambient temp. (° C) Remark: Heat input by combustion air represents the integration of each heat content of combustion air at an interval of fixed time during the period from the start to the completion of firing.
	(4) Heat input by unfired product, saggar, tool and car, and combustion heat of combustible components Q_d 〔kcal {kJ}〕	(a) Heat input by unfired product Q_{d1} [(kcal (kJ)] $Q_{d1} = m_m \times C_m \times (t_m - t)$ Hear m_m: Mass of unfired product per 1 ton of fired product. *Cm*: Average specific heat of unfired product [kcal/kg° C (kJ/kg° C)] t_m: Temp. of unfired product when charged into kiln (° C) *t*: Ambient tep (° C) (b) Heat input by saggar and tool Qd2 [kcal (kJ)] $Q_{d2} = m_{st} \times C_{st} \times (t_{st} - t)$ Hear m_{st}: Mass of saggar and tool per 1 ton of baked product C_{st}: Specific heat of saggar and tool [kcal/kg °C (kj/kg°C)] t_{st}: Temp. of saggar and tool when charged into kiln (°C) *t*: Ambient temp. (° C) (c) Heat input by car Qd3 [kcal (kj)] $Q_{d3} = m_{cb} \times C_{cb} \times (t_{cb} - t)$ Here *mcb*: Mass of car per 1 ton of fired product (kg) C_{cb}: Specific gravity of car [kcal/kg ° (kJ/kg ° C)] t_{cb}: Temp. of car when charged into kiln (°C) *t*: Ambient temp. (° C) (d) *Combustion heat of combustible component contained in unfired* product Qd4 [kcal (kj)] $Q_{d4} = m_l \times H_{lb}$ Here m_l: Mass of combustible component contained in unfired product per 1 ton of fired product (kg) *Hℓb*: Effective calorific value of combustible component [kcal/kg (kJ/kg)] (e) Heat input by unfired product, saggar, tool and car, and combustion heat of combustible component Q_d 〔kcal {kJ}〕 $Q_d = Q_{d1} + Q_{d2} + Q_{d3} + Q_{d4}$

Table III-1-12 (2)

Item		Calculation Formula
1. Heat Input Q_1 [kcal (kJ)]	(5) Heat accumulated in kiln body Q_e [kcal (kJ)]	$Q_e = \frac{Q_{e1}}{m_e}$ $Q_{e1} = \Sigma[m_r \times C_r \times (t_r - t)]$ Here Q_{e1}: Gross calorific value accumulated in kiln body [kcal (kJ)] m_e: Gross mass of fired product(t) m_r: Mass of refractories of each part (ceiling, side wall and bottom) in kiln body (kg). Cr: Average specific heat of refractories of kiln body [kcal/kg °C(kJ/kg°C)] t_r: Average temp. of inner and outer surfaces of kiln body (°C) t: Ambient temp. (°C) Remarks 1. The heat accumulated in kiln body, shall be calculated dividing into the ceiling, side wall and bottom 2. The average temp.'s of inner and outer surfaces of kiln body *shall be those measured when fuel begins to be burned.*
	(6) Total heat input Q_1 [kcal (kJ)]	$Q_1 = Q_a + Q_b + Q_c + Q_d + Q_e$ Here Qa: Combustion heat of fuel [kcal (kJ)] Qb: Sensible heat of fuel [kcal (kJ)] Qc: Heat input by combustion air [kcal (kJ)] Qd: Heat input by unfired product, saggar and car, and combustion heat of combustible component [kcal (kJ)] Qe: Heat accumulated in kiln body [kcal (kJ)]
2. Heat output Q_2 [kcal (kJ)]	(1) Heat output by vapor evaporating from moisture adhering to unfired product Q_f [kcal (kJ)]	$Q_f = m_x \times (I_x - I'_x)$ Here mx: *Amount of moisture adhering to unfired product per 1 ton of* baked product. Ix: Enthalpy of vapor evaporating from moisture adhering to unfired product [kcal/kg (kJ/kg)] $I'x$: Enthalpy of moisture adhering to unfired product [kcal/kg (kJ/kg)] Remark: Enthalpy of vapor evaporating from moisture adhering to unfired product shall be enthalpy 648 kcal/kg (2713 kJ/kg) of vapor at 125°C.
	(2) Heat output by vapor evaporating from water of crystalization of unfired product Q_g [kcal (kJ)]	$Q_g = m_y \times (I_y - I'_y)$ Here my: Water of crystalization of unfired product per 1 ton of fired product (kg) I_y: Enthalpy of vapor evaporating from water of crystalization of unfired product [kcal/kg (kj/kg)] $I'y$: Enthalpy of water of crystalization of unfired product [kcal/kg (kJ/kg)] Remark: Enthalpy of vapor evaporating from water of crystalization of unfired product shall be enthalpy 859 kcal/kg (3596 kJ/kg) of vapor at 550 °C.
	(3) Heat required for decomposition of clay Q_h [kcal (kJ)]	$Q_h = m_{cl} \times Q_p$ Here m_{cl}: *Amount of clay (kg) in unfired product per 1 ton of fired product* Q_p: Heat required for decomposition of 1 kg of caly [kcal/kg (kJ/kg)] Remark: Heat required for decomposition of clay shall be 260 kcal/kg (1088 kJ/kg).
	(4) Heat required for firing Q_i [kcal (kJ)]	$Q_i = 1000 \times C'_m \times (t'_m - t_m)$ Here $C'm$: *Average specific heat of fired product* [kcal/kg °C (kJ/kg °C)] $t'm$: Firing temp. (°C) of fired product. t_m: *Temp. of unfired product when charged into kiln* (°C)
	(5) Heat required for heating saggar and tool Q_j [kcal (kJ)]	$Q_j = m_u \times C'_u \times (t'_u - t_u)$ Here m_u: Mass of saggar and tool per 1 ton of fired product C'_u: Average specific heat of saggar and tool [kcal/kg °C (kJ/kg °C) t'_u: Firing temp. of saggar and tool (°C) t_u: Temp. of saggar and tool when charged into kiln. (°C)

Table III-1-12 (3)

Item		Calculation Formula
2. Heat output Q_2 [kcal {kJ}]	(6) Heat accumulated in kiln body Q_k [kcal {kJ}]	$Q_k = \frac{Q_{k1}}{m_o}$ $Q_{k1} = \Sigma[m_r \times C'_r \times (t'_r - t)]$ Here Q_{k1}: Heat content accumulated in kiln body [kcal (kJ)] m_o: Gross mass of fired product (kg) m_r: Mass of refractories of each part of kiln body (kg) C'_r: Specific heat of refractories of kiln body [kcal/kg °C (kJ/kg °C)] $t'r$: Average temp. of inner and outer surfaces of kiln body (°C) t: *Ambient temp.* (°C) Remarks: 1. Heat accumulated in kiln body shall be calculated dividing into the ceiling, side wall and bottom. 2. The average temp. of inner and outer surfaces of kiln body shall be obtained from the temperature when fuel combustion is completed. 3. When refractories of different specific heat are used in combination in kiln body, it is better to calculate heat accumulated layer by layer and to sum up them. Thus a more accurate value can be obtained.
	(7) Heat output by combustion *exhaust gas* Q_t [kcal {kJ}]	(a) *Sensible heat of dry combustion exhaust gas* $Q_{t1} = \frac{Q_{t11}}{m_o}$ $Q_{t11} = \Sigma[G' \times F \times C_g \times (t_g - t)]$ Here Q_{t11}: Gross sensible heat of dry combustion exhaust gas [kcal {kJ}] m_o: Gross mass of fired product (t) G': Volume of dry combustion exhaust gas per 1 kg of fuel or per 1 m^3N. F: Consumption (kg or m^3N) of fuel (vaporized gas in case of gas fuel) c_g: Specific heat of combustion exhaust gas t_g: Temp. of combustion exhaust gas t: Ambient temp. Remarks 1. When calculating approximately the specific heat of combustion exhaust gas, use the value of 0.33 kcal/m^3N °C (1.38kJ/m^3N °C). In other case, obtain required number from *attachment* 1. 2. Obtain the sensible heat of combustion exhaust gas through *separate calculation* of a value obtained at an interval of fixed time and summing up them. 3. In case the combustible component is included in an unfired product, calculate it separately and obtain the sum of such calculations. 4. When volume of dry combustion exhaust gas (m^3N)G′ per 1 kg or 1 m^3N of fuel is obtained from the composition of combustion exhaust gas and the composition of fuel use the following equation: $G' = (m - 0.21)A_o + 1.867 \times \frac{c}{100} + 0.7 \times \frac{s}{100} + 0.8 \times \frac{n}{100}$ or $G' = \frac{1.867C + 0.7s}{(CO_2) + (CO)}$ $m = \frac{(N_2)}{(N_2) - 3.76[(O_2) - 0.5(CO)]}$ $A_o = \frac{1}{100}\left[8.89c + 26.7\left(h - \frac{o}{8}\right) + 3.33s\right]$ Here e: Mass percentage of carbon in fuel (%) s: Mass percentage of combustible sulphur in fuel (%) n: Mass percentage of nitrogen in fuel (%) m: Air ratio h: Mass percentage of hydrogen in fuel (%)

Table III-1-12 (4)

Item		Calculation Formula
2. Heat output Q_2 [kcal (kJ)]	(7) Heat output by *combustion* exhaust gas Q_t [kcal (kJ)]	o: Mass persentage of oxygen in fuel (%) Ao: Theoretical air volume (m^3N/kg) (CO_2): Volume percentage of carbon dioxide in combustion exhaust gas (%) (CO): Volume percentage of carbon monoxide in combustion exhaust gas (%) (O_2): Volume percentage of oxygen in combustion exhaust gas (%). (N_2): Volume percentage of nitrogen in combustion exhaust gas (%) For the air ratio m theoretical air volume Ao (m^3N/kg) and volume of dry combustion exhaust gas G' (m^3N/kg) per 1 ton of fired product, it is possible to calculate these by using the following simple equation. In this case, the volume percentage (%) of a maximum volume of carbon dioxide in the combustion exhaust gas of liquid fuel shall be 15.3%. $m = \frac{(CO_2)_{max}}{(CO_2)}$ $A_o = \frac{0.85}{1000} H_l + 2.0$ $G' = G_o + (m-1)A_o - \frac{22.4}{18}\left(\frac{W + 9h}{100}\right)$ $G_o = \frac{1.11}{1000} H_l$ Here H_l: Low calorific value of liquid fuel [kcal/kg (kJ/kg)] W: Mass percentage of water in fuel (%) h: Mass percentage of hydrogen (%) G_o: Theoretical volume of combustion exhaust gas (m^3N/kg) (CO_2): Volume percentage (%) of carbon dioxide in combustion exhaust gas (ii) In case of gas fuel $G' = G - (H_2 + 2 \cdot CH_4 + 3 \cdot C_2H_6 + 4 \cdot C_3H_8 + 5 \cdot C_4H_{10})$ ($m^3{}_N/m^3{}_N$) $G = 1 + mA_o - 0.5(H_2 + CO - C_2H_6 - 2 \cdot C_3H_8 - 3 \cdot C_4H_{10})$ ($m^3{}_N/m^3{}_N$) or $G = (m - 0.21)A_o + CO_2 + CO + H_2 + 3 \cdot CH_4 + 5 \cdot C_2H_6 + 7 \cdot C_3H_8 + 9 \cdot C_4H_{10} + n_2$ ($m^3{}_N/m^3{}_N$) G' can also be obtained from the results of analysis of combustion exhaust gas by the following equation: $G' = \frac{CO + CO_2 + CH_4 + 2C_2H_6 + 3C_3H_8 + 4C_4H_{10}}{(CO_2) + (CO)} \times 100$ $m = 1 + \frac{(O_2) - 0.5(CO)}{(0.5H_2 + 0.5CO + 2CH_4 + 3.5C_2H_6 + 5C_3H_8 + 6.5C_4H_{10} - O_2)} \times \frac{(CO_2) + (CO)}{CO + CO_2 + CH_4 + 2C_2H_6 + 3C_3H_8 + 4C_4H_{10}}$ $A_o = \frac{1}{0.21}(0.5H_2 + 0.5CO + 2CH_4 + 3.5C_2H_6 + 5C_3H_8 + 6.5C_4H_{10} - O_2)$ ($m^3{}_N/m^3{}_N$) Here H_2: Volume of hydrogen in 1 m^3N of gas fuel Co: Volume of carbon monoxide in 1 m^3N of gas fuel CH_4: Volume of methane in 1 m^3N of gas fuel C_2H_4: Volume of ethane in 1 m^3N of gas fuel C_3H_8: Volume of propane in 1 m^3N of gas fuel C_4H_{10}: Volume of butane in 1 m^3N of gas fuel O_2: *Volume of oxygen in 1 m^3N of gas fuel* N_2: Volume of nitrogen in 1 m^3N of gas fuel CO_2: Volume of carbon dioxide in 1 m^3N of gas fuel (O_2): *Volume percentage of oxygen in combustion exhaust gas* (CO_2): Volume percentage of carbon dioxide in combustion exhaust gas (CO): Volume percentage of carbon monoxide in combustion exhaust gas m: Air ratio A_o: Theoretical air volume (m^3N/m^3N) *When calculating a theoretical air volume Ao* (m^3N/m^3N) and a quantity of dry combustion exhaust gas G' (m^3N/m^3N) from a low calorifici value H_l [kcal/kg (kJ/kg)] of gas fuel, it is possible to use the following simple equations: In the case of H_l = *4000* kcal/m^3N [*16,740* kJ/m^3N] *or more*

Table III-1-12 (5)

Item		Calculation Formula
2. Heat output Q_2 [kcal {kJ}]	(7) Heat output by combustion exhaust gas Q_t [kcal {kJ}]	$A_o = \frac{1.09}{1000} H_l - 0.25$ $G_o = \frac{1.14}{1000} H_l + 0.25$ $G' = G_o + (m-1) A_o - (H_2 + 2CH_4 + 3C_2H_6 + 4C_3H_8 + 5C_4H_{10})$ Here Go: Theoretical volume (m^3N/m^3N) of combustion exhaust gas H_2: Volume (m^3N) of hydrogen in 1 m^3N of fuel gas CH_4: Volume (m^3N) of methane in 1 m^3N of fuel gas C_2H_6: Volume (m^3N) of ethane in 1 m^3N of fuel gas C_3H_8: Volume (m^3N) propane in 1 m^3N of fuel gas C_4H_{10}: Volume of (m^3N) of butane in 1 m^3N of fuel gas *(b) Sensible heat of water vapor in combustion exhaust gas* $Q_{t2} = \frac{Q_{t21}}{m_o}$ $Q_{t21} = \Sigma[F \times S_g \times C_{tg} \times (t_g - t)]$ Here, Q_{t21} Gross sensible heat of vapor in combustion exhaust gas [kcal {kJ}] m_o: Gross mass of fired product (t) F: Fuel consumption at an interval of fixed time (kg or m^3N) S_g: Volume of vapor in combustion exahust gas per 1 kg or m^3N of fuel C_{sg}: Specific heat of vapor [kcal/kg°C{kJ/kg°}] tg: Temp. of combustion exhaust gas (°C) t: Ambient temp. (°C) Remarks: 1. When the combustible portion of unbaked product is included, calculate it separately and obtain the sum of such calculations. 2. The specific heat of vapor shall be 0.45 kcal/kg (1.88 kJ/kg). 3. For the sensible heat of vapor in combustion exhaust gas, calculate it at an interval of fixed time and obtain the sum of such calculations. 4. It is possible to obtain a vapor volume Sg (kg) in combustion exhaust gas per 1 kg or 1 m^3N of fuel by the following equation: (i) In case of liquid fuel $S_g = \frac{29}{22.4} A \cdot Z + \frac{w}{100} + \frac{9h}{100}$ where A: Air consumption per 1 kg of fuel (m^3N) Z: Absolute humidity w: Mass percentage of moisture of fluid fuel (%) h: Mass percentage of hydrogen of liquid fuel (%) (ii) In case of gas fuel $S_g = \frac{29}{22.4} A \cdot Z + \frac{18}{22.4}(H_2 + 2CH_4 + 3C_2H_6 + 4C_3H_8 + 5C_4H_{10})$ $A = mA_o$ $Z = \frac{0.62\varphi P_s}{P - \varphi P_s}$ where A: Air consumption per 1 m^3N of fuel (m^3N) Z: Absolute humidity H_2: Volume of hydrogen in 1 m^3N of gas fuel (m^3N) CH_4: Volume of methane in 1 m^3N of gas fuel (m^3N) C_2H_4: Volume of ethane in 1 m^3N of gas fuel (m^3N) C_3H_8: Volume of propane in 1 m^3N of gas fuel (m^3N) C_4H_{10}: Volume of butane in 1 m^3N of gas fuel (m^3N) m: Air ratio Ao: Theoretical air volume (m^3N/m^3N) ϕ: Relative humidity P: Atmospheric pressure (mmHg{Pa}) P_s: Saturated vapor pressure [mmHg{Pa}]

Table III-1-12 (6)

Item		Calculation Formula
2. Heat output Q_2 〔kcal{kJ}〕	(7) Heat output by combustion exhaust gas Q_l 〔kcal{kJ}〕	(c) Heat output by combustion exhaust gas Q_l $Q_l = Q_{l1} + Q_{l2}$ where Q_{l1}: Sensible heat of dry combustion exhaust gas [kcal{kJ}] Q_{l2}: Sensible heat of vapor in combustion exhaust gas [kcal{kJ}]
	(8) Heat loss by incomplete combustion Q_m 〔kcal{kJ}〕	$Q_m = \Sigma[m_f \times G' \times \frac{(CO)}{100} \times 3050]$ where mf: Fuel consumption per 1 ton of fired product at an interval of fixed time (kg or m^3N) G': Volume of dry combustion exhaust gas per 1 kg or 1 m^3N of fuel (m^3N) (CO): Volume percentage of carbon monoxide in combustion exhaust gas Remarks 1. In case soot in combustion exhaust gas is measured quantitatively, add its calorific value of 8,100 kcal/kg (33,100 kj/kg) to heat loss. 2. For heat loss by incomplete combustion, calculate it at an interval of fixed time and obtain a total of such calculations. 3. When a combustible portion is contained in unfired product, calculate it separately and obtain a total of such calculations.
	(9) Heat loss by radiation and others Q_n 〔kcal{kJ}〕	$Q_n = Q_1 - (Q_f + Q_g + Q_h + Q_i + Q_j + Q_k + Q_l + Q_m)$ where Q_f : Heat output by vapor vaporizing from moisture adhering to unfired product. [kcal{kJ}] Q_g : Heat output by vapor vaporizing from water of crystalization of unfired product. Q_h : Heat required for decomposing clay. Q_i : Heat required for firing product. Q_j : Heat required for heating saggar and tool. Q_k : Heat accumulated in kiln body. Q_l : Sensible heat of combustion exhaust gas. Q_m: Heat loss by incomplete combustion. Heat loss by radiation etc, from kiln wall $Q_{n1} = \frac{\Sigma Q_{n2}}{m'_o}$ $Q_{n2} = \Sigma(h_c + h_r)\Delta_t \cdot A_r \cdot t_m$ $h_c = 2.1\sqrt[4]{\Delta t}$ (in case of horizontal roof wall) $h_r = 1.5\sqrt[4]{\Delta t}$ (in case of vertical roof) $h_r = 4.88\left[\left(\frac{T_o}{100}\right)^4 - \left(\frac{T_o}{100}\right)^4\right] \times 0.9/\Delta_t$ where m'_o: Mass of fired product (t) $Qn2$: Quantity of heat release from kiln wall at an interval of fixed time. [kcal{kJ}] hc: Coefficient of convection heat transfer [kcal/$m^2h°C${kJ/$m^2h°C$}] hr: Coefficient of radiative transfer of heat [kcal/$m^2h°C${kJ/$m^2h°C$}] Δt: Difference between temp. of outer kiln wall and temp. of indoor air (°C) Ar: Surfacial area of kiln wall (m^2) Ta: Ambient temp. around the kiln indicated at absolute temp. (k) t_m: Time interval of measurement (h) T_o: Temp. of outer kiln wall indicated at absolute temp. (k) Remakrs 1. A calculation formula for heat loss by the radiative transfer of heat from kiln wall is shown for reference. 2. The ambient temp. around the kiln shall be a value of measurement obtained at a position 1 meter apart from the side wall of kiln. 3. Calculate heat loss by the radiative transfer of heat from kiln wall at an interval of fixed time and obtain a total of such calculations.
	(10) Heat output Q_2 〔kcal{kJ}〕	$Q_2 = Q_f + Q_g + Q_h + Q_i + Q_j + Q_k + Q_l + Q_m + Q_n$ where Qf: Heat output by vapor vaporizing from moisture adhering to unfired product. Q_g: Heat output by vapor vaporizing from water of crystalization of unfired product. Qh: Heat required for decomposing clay. Qi: Heat required for firing product. Qj: Heat required for heating saggar and tool.

Table III-1-12 (7)

Item		Calculation Formula
2. Heat output Q_2 [kcal {kJ}]	(10) Heat output Q_2 [kcal {kJ}]	Qk: Heat accumulated in kiln body Ql: Sensible heat of combustion exhaust gas. Qm: Heat loss by incomplete combustion. Qn: Heat loss by radiative transfer of heat and others
3. Thermal efficiency η (%)	(1) Thermal efficiency of fired product η_1 (%)	$\eta_1 = \frac{Q_1}{m_h \times H_l} \times 100$ where Q_l: Effective heat per 1 ton of fired product. [kcal{kJ}] m_h: Fuel consumption per 1 ton of fired product (kg or m^3N) H_l: Low calorific value of fuel [kcal/kg (kJ/kg)] [kcal/m^3N (kJ/m^3N)] Remarks 1. In case fuel and combustion air are preheated by other heat source, add its quantity of heat to the denominator of the above equation. 2. Obtain an effective heat Q_1 [kcal(kJ)] per 1 ton of fired product by the following equation: $Q_1 = Q_f + Q_g + Q_h + Q_i$ where Qf: Heat output by vapor vaporizing from moisture adhering to unfired product. [kcal {kJ}] Q_g: Heat output by vapor vaporizing from water of crystalization of unfired product. Qh: Heat required for decomposing clay. Q_i: Heat required for firing product. 3. In case heat accumulated in another kiln under cooling process is utilized, and waste heat of other kiln under firing process is utilized, it is desirable to obtain the under-mentioned η_3 in addition to η_1. $\eta_3 = \frac{Q1}{m_f \text{ x } H_l + \text{heat recovered from other kiln}} \text{ x } 100$
	(2) Thermal efficiency of fired product including saggar and tool η_2 (%)	$\eta_2 = \frac{Q_{ll}}{m_f \times H_l} \times 100$ where Q_{ll}: Effective heat per 1 ton of fired product including saggar and tool mf: Fuel consumption per 1 ton of fired product (kg or m^3N) H_l: Low calorific value of fuel [kcal/kg (kJ/kg)] or [kcal/m^3N (kJ/m^3N)] Remarks 1. In case fuel and combustion air are preheated by other heat source, add its quantity of heat to the denominator of the above equation. 2. Obtain Effective heat per 1 ton of fired product when including saggar and tool. Q_1 [kcal (kJ)] by the following equation: $Q_{ll} = Q_f + Q_g + Q_h + Q_i + Q_j$ where Qf: Heat output by vapor vaporizing from moisture adhering to unfired product. Qg: Heat output by vapor varporizing from water of crystalization of unfired product. Qh: Heat required for decomposing clay. Q_i: Heat required for firing unfired product. Q_j: Heat required for heating saggar and tool. 3. In case heat accumulated in other kiln under cooling process is utilized and waste heat of other kiln under firing process is utilized, it is desirable to obtain the under-mentioned η_4 in addition to η_2. $\eta 4 = \frac{Q_{ll}}{mf \text{ x } Hl + \text{heat recovered from other kiln}} \text{ x } 100$

Remark m^3N indicates a unit of volume in standard condition of gas [0 °C, 760 mmHg (101.3 kPa)]

Table III–1–12 ⑧ Heat balance table

Item			Heat input		Heat output	
			10^3kcal (10^3kJ)	%	10^3kcal (10^3kJ)	%
Heat input	*(1) Combustion heat of fuel*	Q_a				
	(2) Sensible heat of fuel	Q_b				
	(3) Heat carried in by air for burning	Q_c				
	(4) Heat carried in by unfired product, saggar, tool and car, and combustion heat of combustible component	Q_d				
	(5) Heat accumulated in the main body of kiln	Q_e				
	(6) Total heat input	Q_1				
Heat output	(1) Heat carried out by vapor evaporated from moisture sticking to unfired product	Q_f				
	(2) Heat carried out by vapor evaporated from moisture of crystallization of unfired product	Q_g				
	(3) Heat required for decomposing clay	Q_h				
	(4) Heat required for firing product	Q_i				
	(5) Heat required for heating saggar and tools	Q_j				
	(6) Heat accumulated in the main body of kiln	Q_k				
	(7) Sensible heat of exhaust gas	Q_l				
	(8) Heat loss by incomplete burning	Q_m				
	(9) Heat loss by heat radiation, transfer and other factors	Q_n				
	(10) Total heat output	Q_2				
Total						
Heat efficiency	Heat efficiency of fired product	η_1				%
	Heat efficiency of fired product including saggar and tools	η_2				%
	Heat efficiency of fired product including recovered heat	η_3				%
	Heat efficiency including recovered heat (of fired product including saggar and tools)	η_4				%

2.2.2 *Glass industries (bottle and glass tableware manufacturing)*

In the glass factory, energy consumption is broken down as follows:

Purpose	Facilities	Energy source
Glass melting	Melting tank	Heavy oil, Electric power
Refining	Refiner	Diesel oil, LPG, Heavy oil
Cooling	Feeder	LPG
Annealing	Annealing furnace	Heavy oil
Air compression	Compressor	Electric power
Illumination, others		Electric power

The energy consumption ratio by purpose is as shown in Fig. III-1-7 as an example.

From this Fig., it is understood that energy saving procedures for the melting tank and other furnaces are important.

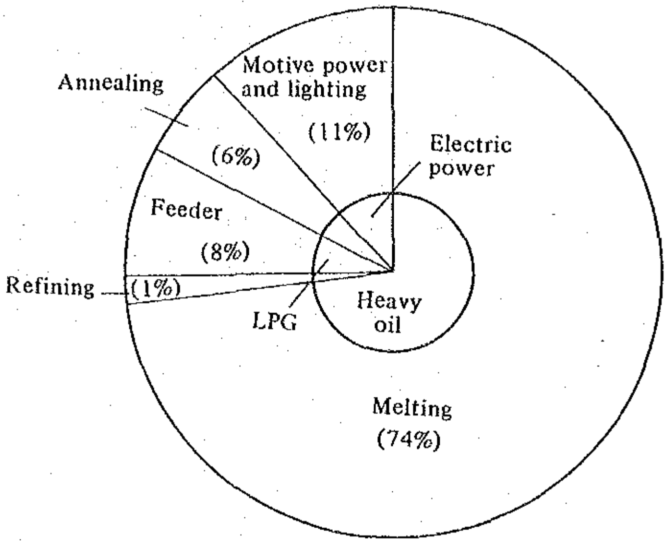


Fig. III–1–7 Ratio of energy consumption of glass factory per use purpose

(Note) 1 KWH = 860 Kcal

For reference, the heat balance chart based on the survey on a middle-capacity tank in Japan is shown in Fig. III-1-8. The thermal efficiency of this tank is approx. 40%; approx. 20% of heat is lost into the combustion exhaust gas and the rest through kiln walls, etc.

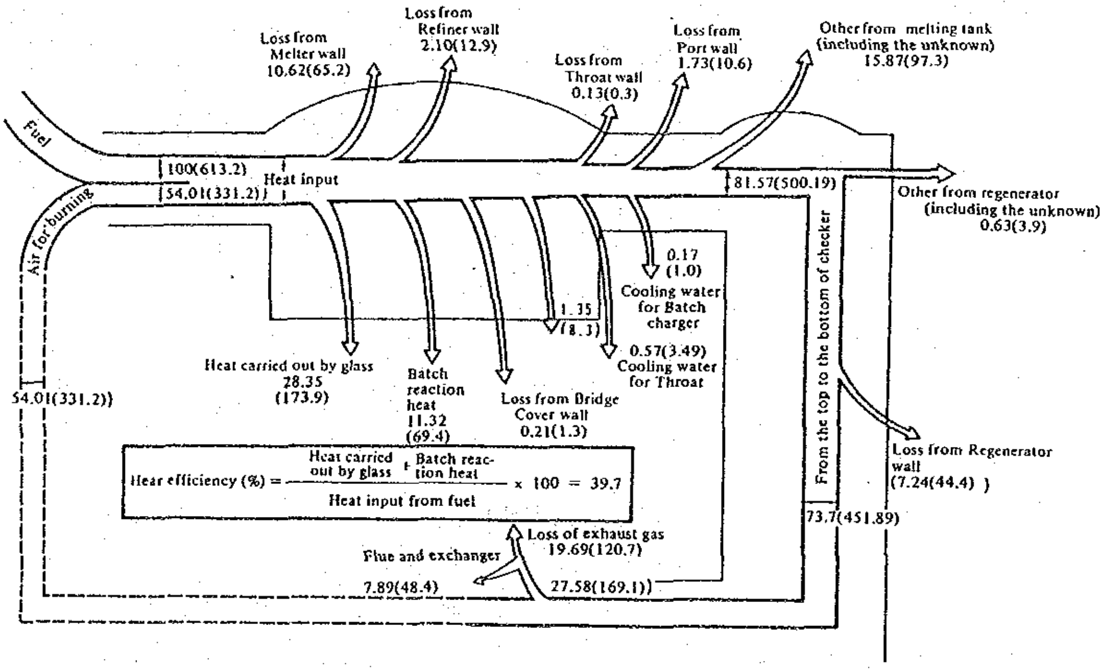


Fig. III–1–8 Heat balance chart for glass melting tank

With regard to factories diagnosed by us in The Kingdom of Thailand, the unit fuel consumption rate for melting and thermal efficiency of the tank being operated continuously are as shown in Fig. III-1-9.

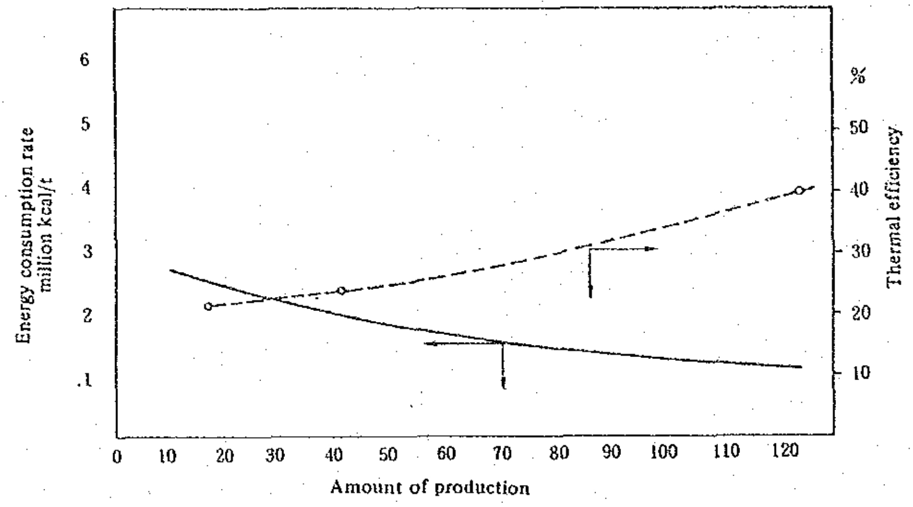


Fig. III–1–9 Melting energy consumption rate and efficiency

Concerning the unit total energy consumption rate for glass bottle manufacturing including electric power energy, it is impossible to make a simple comparison because such factors as kind of glass, availability of molding machine, existence of printing process, etc. are involved. In the above-mentioned factory examples, the figures such as 230,000, 288,000 and 347,000 kcal/ton are given respectively (conversion rate: 1 kWh of electric power = 2,450 kcal)

To cite an example of the total energy consumption in Japan for reference, the unit consumption rate had been improved approx. 25% through 1982 based on 1975 as shown in Fig. III-1-10.

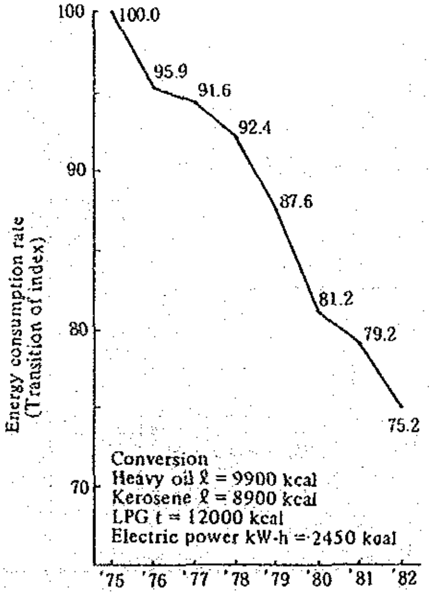


Fig. III–1–10 Manufacturing energy consumption rate for glass bottle (data by the members of the Bottle Manufacturers Association of Japan)

Although the figures by production scale had not been published, the average total energy consumption in 1982 was 2,580,000 kcal/ton in the industry, and the newly established highest-efficiency kiln (200 tons/day) was 1,820,000 kcal/ton (unit melting energy consumption rate: 950,000 kcal/ton - energy source breakdown; 1,140,000 kcal/ton of heavy oil, 170,000 kcal/ton of LPG and 510,000 kcal/ton of electric power).

To look at data of the Kingdom of Thailand based on these figures it, is recognized that the performance of the 120 t/d kiln in Fig. III-1-9 is at high level.

The breakdown of electric power consumption is as shown by a certain Japanese firm below.

Facilities	Purpose	Ratio
Large-size fan	Cooling of kiln wall, feeding of air for burning	28%
Compressor	Drive and cooling of bottle manufacturing machine	27%
Electric booster	Melting	21%
Other motors		21%
Illumination		3%

In the factories of the Kingdom of Thailand, the electric power consumption for compressor accounts for 30 to 78% or a large proportion of the total electric power consumption.

3. How to Manage Energy

In order to improve the efficiency of energy consumption, productivity and product quality as well as raise their overall level, it is essential first to use facilities well adjusted and maintained to the purpose and to operate them correctly. It is most effective for energy conservation to reduce the incidence of equipment failure and increase product yield. Secondly, it is required that those engaged in energy management study the possibilities of further improving the existing facilities and operating method and pursue better means through repeated surveys and factory experiments.

Accordingly, it is not exaggerating to mention that the consciousness and willingness of the total factory employees would influence the actual performance of the factory. And it is important to raise the level of factory management which encourages the employees to have such consciousness and willingness. It is defined that energy management is a systematic effort to achieve energy conservation.

3.1 Clarification of Management Policy

Following the soaring of energy prices, the factory owner and manager have grown more concerned about energy conservation. In order to promote this tendency on a company level instead of letting it merely stay within the frame of the owner's mind as a desire, it needs to be clarified toward all the employees that the top management has the intention to tackle the energy conservation problem seriously as a company policy. In positive terms, the target should be clarified quantitatively; such as what percentage of energy consumption per ton of finished product should be reduced. Simultaneously the restrictions such as the ceiling of annual investment and deadline for pay back time should be clarified.

As explained above, the top management should clearly show the way to proceed on to the employees. Then in turn, the latter become confident about their jobs meeting the direction set by the former. Further, both can develop a smooth collaborative relationship because everybody involved is spiritually aligned in a unified direction.

Since the target of the top management is shown as a comprehensive one for the whole factory, each section and department should set concrete subtargets which do not require too much time and try their best effort to achieve these subtargets. These subtargets should be set concerning items for which any counter-measures can be taken by section and department personnel within their own responsibility range to attain the target set by the top management. As the said target is shown in a familiar and understandable form, it is easy to expect even employees of the lowest rank to fully understand the subtargets and extend their cooperation in attaining them.

When setting subtargets for each section and department, it is suggested that the committee described later or others study if such subtargets would be appropriate for achieving the overall target.

3.2 Arrangement of System for Promotion

In a campaign, for energy conservation where various classes of people take part, persons who play a part to promote the activities of all as a nucleus. If the factory is small, an individual person may be a promoter, but if the factory is large, a section for promotion is sometimes established.

This position should be occupied by a top-notch person and he should always be careful about a progress in energy conservation status and look into a cause, if there is a delay, then try to treat problem.

In concrete terms, the assignments of the position are as follows: the grasping of actual energy consumption, comparison of actual energy consumption with plans, invitation and checking of ideas about improvement, budgetary distribution, management of work progress and evaluation of actual works, mapping-out of education programs, preparations for committee meetings, etc.

The committee is effective for adjustment so that inter-disciplinary understanding may be realized among sections and departments such as manufacturing, sales, raw material purchasing, equipment maintenance and servicing, and accounting, and countermeasures may be put into practice smoothly. At the committee meeting, any possible influence of energy conservation measures to be performed on each section and department should be studied to make sure that no profit is reduced on an entire factory basis.

It is important that a general manager of the factory or a person next to the former in rank who has responsibility and authority in production assume the chairmanship of the committee. Otherwise, no decision would be made, neither would such a decision be implemented.

Even if certain energy measures were based on an excellent idea, any fruitful results would not be expected unless the operator fully understands what the measures mean and applies them to the actual work. There are many cases where the QC (quality control) circle which is effective for quality control is utilized successfully for energy conservation with noteworthy results. The QC circle is an activity of improving human relationship in the job, stimulating people to become more conscious about independence endowed intrinsically to humans and providing them with the pleasure of working actively. However, it is necessary to prepare conditions which make the operator find it easier to conduct activities such as education and incentive granting before he can recognize the advantages and necessity of the circle activities. It is the operator on the front line that is always in touch with energy consuming equipment and sensitive enough to grasp any phenomenon appearing according to a change in the operating conditions. It is extremely effective for energy conservation to make the best of information obtained by the operator and to squeeze out a good idea for improvement.

3.3 *Scientific and Systematic Activities*

It is an indispensable condition to obtain an exact status of energy consumption when energy conservation is carried out. If data such as change of the unit consumption rate per production, difference in the unit, variation of product grade and difference in raw materials are not available, it would be impossible to formulate plans which guide you toward an area requiring the implementation of immediate procedures. In other words, it is factory data that provide numerous ideas for improvement. If studies are made of these data with a consciousness about problems, it would be able to find something leading to such ideas. Therefore, it is suggested that a measuring instrument be installed at necessary spots, record its readings and obtain information through their periodical arrangement. In this case, such data should be processed from the viewpoint of mathematical statistics to determine if the difference is significant.

Next, it should be made sure that the results are followed up, if improvement plans were implemented. Efforts should be made to enhance the quality of operations according to the PDCA circle advocated by Dr. Deming. The function of the PDCA circle is such as explained below as shown in Fig. III-1-11:

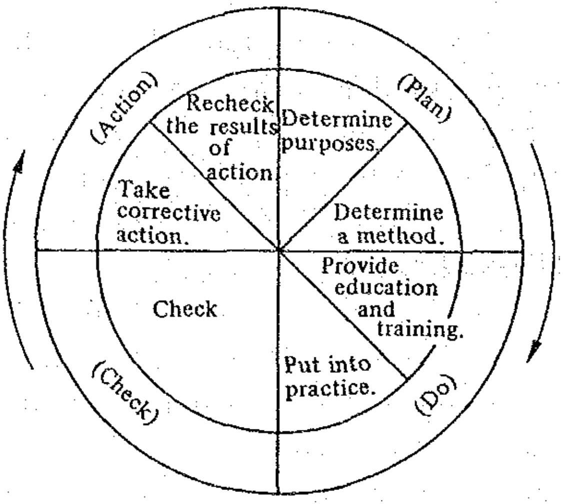


Fig. III–1–11 Deming circle

First, plans should be formulated; that is, a purpose will be set for a certain theme and means decided. This represents "P" for PDCA. People will be trained concerning how to perform these means and given an opportunity to actually do them. This represents "D". The results of the performance will be checked. This represents "C." Results of the check will be evaluated to determine if they are satisfactory. Action will be to standardize the results, if they are satisfactory and to take corrective measures if there is still a problem yet to be resolved. If one step was completed, the function of "PDCA" will be set to work towards a target of higher level. In this way, people proceed with their assignments. This method will be helpful for not only energy conservation but also heightening the quality of jobs in every field.

With regard to the part concerned with "Plan," it is recommended that "improvement plans invitation system" be actively utilized because items to propose can be found rather easily during an early stage. It should be so arranged that proposals may be made by whosoever he may be, an individual or a member of a working place, the QC circle or staff. Proposals presented should not be left alone, but should be examined promptly by the committee and others. The proposals presented should be adopted as far as circumstances allow after being modified on advice depending on the occasion. It is also suggested that a prize be presented to people for their proposals and further, a commendation be given to those whose proposals brought about fruitful results. These measures will be an incentive for people to deepen their consciousness about participation. For proponents whose proposals were not adopted, it is suggested that they be explained about the reasons why the proposals were not taken up and at the same time, be properly guided over better ideas.

In the stage of "D", it is suggested that satisfactory explanation be provided to employees of the lowest rank regarding an intention for improvement, and their cooperation in an effort toward the improvement be solicited. They are also encouraged to report even on minor abnormalities during operation so that they may be able to make scrupulous adjustments. This consideration is necessary to eliminate any possible cause for error.

"Check" should be conducted periodically and at the same time, the results be reported to the committee and the senior official. Along with this procedure, the results also should be made known to the operator so that he may deepen his concern. In this case, it is important to clarify an evaluation criterion from the beginning; it is not desirable to change it easily halfway.

If satisfactory results can be expected following the implementation of an improvement plan, they should be incorporated into the operation standard. Simultaneously necessary measures for the improvement of equipment should be taken so that any extra load may not be brought to bear on the operator. This is a condition for continued favorable results of energy conservation.

In case considerable results have been accomplished continuously as a result of the above, their summarized processes should be published as references. At the same time, those concerned should be officially commended so that they may be motivated for next activities.

3.4 Furnishing of Education and Information

Even if employees are willing to cooperate, any improvement can hardly be expected, unless they have knowledge as to how they should do it. They would become more positive to participate in the energy conservation campaign, if they are capable of presenting their own improvement proposal without being limited to merely pointing out problems. In order to realize this target, an internal education program sponsored by the company itself is important; that is, programs such as seminars and distribution of guide books should be provided. In the Kingdom of Thailand, a considerable number of companies are enthusiastic about education and also numerous cases where their staffers are sent for participation into external seminars are noticed. To our regret, however, such staffers sent for the external seminar tend to keep their acquired knowledge only to themselves instead of passing it on to other staffers or general operators. If it is arranged so that those who received external seminar training become lecturers for internal education and provide training to other people based on their acquired knowledge, it is expected that the entire level of employees' professional quality will be raised and staffers participating in the external seminars will be able to make sure that their obtained knowledge is practically useful.

Next, it is desired that information exchange with other companies of the same industry or raw material suppliers or finished product buyers be activated. Although it is naturally important that competition should take place among different companies of the same industry, it is recommended that technical information be exchanged to some extent on a give and take basis. This is because the technical level of the entire company can be heightened resulting in stronger international competing power and subsequent mutual benefit. For instance, the publishing of actual unit consumption rates will be instrumental for the motivation of commercial competition.

4. Rationalization of the Utilization of Thermal Energy

4.1 Ceramic Industries

4.1.1 Rationalization of Fuel Combustion

In order to increase flame temperature, reduce exhaust gas loss and lessen loss by incomplete combustion it is desired that the air ratio be as close to 1 as possible.

For obtaining an appropriate air ratio, it is necessary to be careful about the following points:

(1) Maintenance of fuel oil temperature at an appropriate level. (see P. III-1-61)

(2) Inspection and maintenance of the burner.

To make sure that fuel equipment functions normally, inspect and maintain the under-mentioned items periodically.

a. Clogging of oil strainer

b. Clogging, wear and assembling of burner tip

c. Holding direction of burner and distance from burner tile

d. Damage on burner tile and carbon deposit

e. Oil leakage from oil valves and pipe joints

(3) Maintenance of air pressure for atomizing at proper level

Adjust the air pressure to a rating per burner.

(4) Blocking of air intrusion.

In the case of tunnel kiln, pay your attention to the following points:

a. Adjust kiln pressure so that air invasion from the cooling zone to firing zone may not be in excess.

b. Adjust the fuel volume and the combustion air volume according to burner location.

c. The opening of the entrance and exit door for a car fluctuates pressure in the kiln. Therefore, operate the door in as short a period as possible or provide a dual door.

d. Maintain seal in good condition so that air suction from under a car may be blocked. In addition, provide more effective thermal insulation to the car thus reducing the cooling air volume under the car.

e. Reduce the number of openings and arrange so that the kiln pressure may not be negative. In this way, the air suction will be minimized. The same is true about the shuttle kiln. That is, it is necessary to block air invasion from under the car and openings.

(5) Adjustment of the Air Ratio for Batch Kiln

Early after ignition, the combustion tends to be incomplete because of low kiln temperature. Therefore, it is necessary to keep the air ratio at a rather higher level. For this reason, it is required to make minute adjustments such as reducing the air ratio proportional to a rising of kiln temperature. There is a case where fuel was saved approx. 15% by a method of burning heavy oil exclusively after the ceiling temperature reached higher than 600 to 700° C through the joint use of gas fuel of high combustibility (LPG, etc.) only during a low kiln temperature.

(6) Measurement

In order to make sure that the quality of finished product is stable and energy is saved, it is essential to take appropriate measures by grasping intra-kiln condition all the time. In so doing, the following items need to be measured and the measurements be recorded:

Item	Subject	Measurement Spot		
Temperature	Intra-kiln temperature	Tunnel kiln		
			Ceiling	Both sides (upper/middle lower)
		Preheating zone	3 points	3 points
		Firing zone	5	3
		Cooling zone	5	3
	Exhaust gas Combustion air Under the car Kiln-loaded product Kiln-discharged product Fuel oil			
Pressure	Intra-kiln pressure	1 to 3 spots in each zone (upper/middle/lower)		
	Combustion air Fuel			
Composition	Combustion exhaust gas			
Weight	Kiln-discharged product			

(7) Standard for Air Ratio

In the firing of ceramic products, the oxidizing property and reductibility of flame are sometimes required depending on the kind and manufacturing method of finished product. In addition, the air ratio needs to be changed in accordance with a progress in the firing in the batch kiln. The Japanese standard does not provide value for the air ratio of the ceramic kiln.

Here it is suggested that the air ratio of the boundary between the firing zone and the preheating zone be set at 1.3 only where the tunnel kiln operated steadily in the oxidizing atmosphere is concerned.

4.1.2 Rationalization of Heating, Cooling and Heat Transfer

(1) Increase in Firing Rate

In the tunnel kiln, the fixed released heat loss accounts for a large percentage of the total loss, so that more production per unit time is increased, more energy saving. Fig. III-1-12 shows one example of the relationship between firing rate and thermal efficiency. In order to increase the car sending speed, it is required to raise the technological level as a whole including the following procedures:

a. Measure a thermal analytical curve of materials and set an appropriate heating-up curve based on the former.
b. Minimize the temperature difference in the upper and lower parts of the kiln.
c. Reduce the weight of casing other than fired product to the allowable minimum extent.
d. Consider the compounding of materials at the best ratio so that the product may be fired even at low temperatures.
e. Try to increase car sending speed according to plans over the examination of product quality.
f. Use the rapid firing kiln of low height with an even temperature distribution of a heated product.

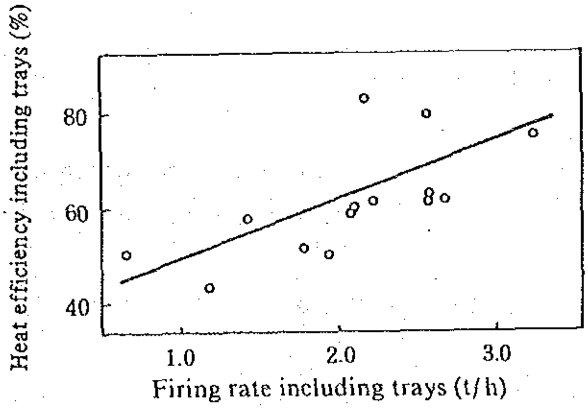


Fig. III−1−12 **Relationship of firing rate including trays and heat efficiency including trays**

Table III-1-13 shows the results of heat conservation realized at a tile factory manned by 38 employees. The principal performance items are as follows:

(First step)

- The space between the car and product was expanded to allow a smoother flow of gas.

- The ceiling was insulated with 50-mm calcium silicate and 100-mm glass wool to reduce the external surface temperature at less than 100° C.
- A drying chamber utilizing exhaust gas from the cooling zone was established.
- The oxygen content of preheating zone gas was maintained at 7%.

Table III–1–13 Example of improved consumption rate at tile factory

A	B	C	D	E	F	G	H	I
Step	Date	Car sending time min.	No. of cars sent/day	No. of loaded cases/car	Production ft^2/day	Fuel consumption kℓ/day	Consumption rate	
							mℓ/ft^2	Contrast
Start	1977 1	55	26	882	8,026	3,912	487	100.0
1	5	40	36	756	8,164	2,957	392	74.3
2	1978 8	〃	〃	〃	9,797	2,705	276	56.6
3	1979 3	38	38	714	9,767	2,723	279	57.2
4	11	35	41	732	10,804	3,046	282	57.8
5	1980 5	〃	〃	750	11,070	2,838	256	52.6
6	7	〃	〃	768	11,335	2,671	236	48.5

(Second step)

- A door was provided at the outlet side of tunnel kiln.
- LPG was jointly used in the low temperature section.

(Third step)

- The space over the car was expanded to 17 cm.

(Fourth step)

- Asbestos was sprayed a 50-mm thickness on the side walls. Thus the insulation effect was increased.
- A dual inlet door was provided at the tunnel kiln and consequently the kiln pressure fluctuation was well controlled. As a result, the oxygen content of exhaust gas was reduced to 4.5%.
- The primary air temperature was raised from 60° C to 80° C.

(Fifth step)

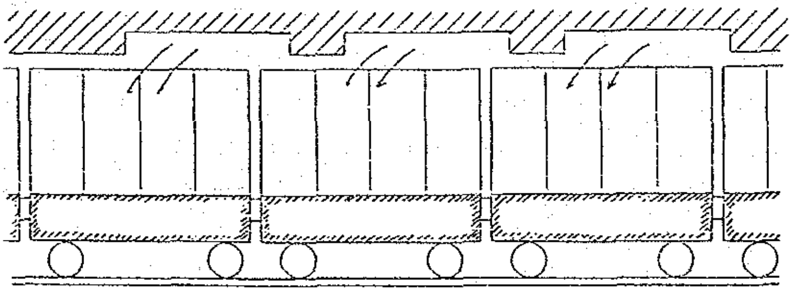
- The car top was insulated with 30-mm ceramic fiber. Thus the insulation effect has been increased.
- It was arranged so that heat from the cooling zone might be recovered more effectively so as to raise the temperature of the drying tunnel.

As a result of the above-mentioned various steps, not only energy consumption is now reduced, but also the firing is uniform with a yield improved. Although the cost involved was ¥15.5 million, the annual spending curtailment has now reached ¥35 million. Thus, the funds invested have been recovered in a brief period.

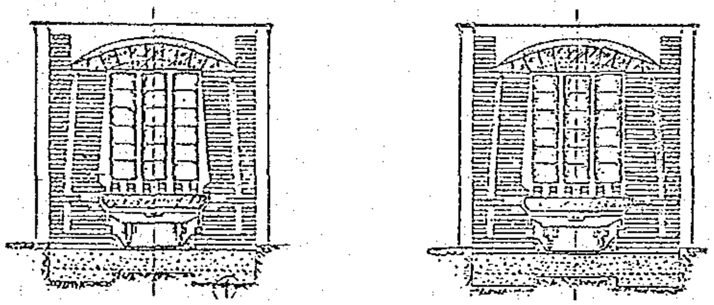
(2) Improvement of Heat Transfer

The interior of the kiln is filled with products to be heated, and the internal space is small, so that convection heat transfer plays an important role in the kiln. For this reason, it should be arranged so that an intra-kiln gas may contact a product to be heated as uniformly as possible.

a. To restrict a gas flow in the longitudinal direction of the kiln, and to promote circulation vertically make the internal wall surface of kiln uneven or make the upper and lower widths different from each other. (refer to Fig. III-1-13)



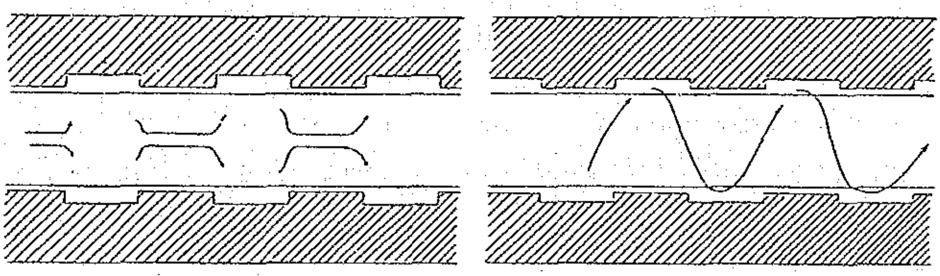
(a) Drop arch



(1) Part showing expanded walls on both sides

(2) Part showing an expanded wall on one side only

(b) Cross-section of Harlop-type tunnel kiln



(c) Expandable/Contractable passage of tunnel

(d) Zigzag passage of tunnel

Fig. III-1-13

b. Load products into the kiln so that the clearance from the ceiling may not be wide. Provide a gate of the same form as the internal cross section of kiln in front of the entrance of tunnel kiln and check a clearance between the ceiling and a car when the latter passes.

c. Improve a gas flow inside the kiln by using a top fire from the ceiling or a high-speed burner (in case the fuel is gas or kerosene).

d. In case there is no qualitative problem, change from the indirect kiln such as muffle or radiant tube to the direct heating kiln.

(3) Reduction of Heat Capacity of Other Than Finished Product

a. The batch kiln repeats the cycle of heat regeneration and release in the kiln wall per each time of firing. Hence the so-called accumulated heat loss is significant. Therefore, energy can be saved significantly by lining light-weight insulation materials such as ceramic fiber. In addition, this lining has characteristic of allowing a wide range of ascending and descending temperature rates and also a high firing rate.

For ceramic fiber, use it at a temperature lower by approx. 100° C than that specified per grade as a permissible maximum temperature. Further, install the fiber in such a way that its cross section may touch an atmosphere, thus retarding its degradation and pulverization.

The example of energy conservation on the periodic kiln using alumina fiber is introduced below:

This kiln is a shuttle kiln with an internal volume of 6 m^3. On account of a high intra-kiln temperature of 1,350 to 1,450° C, crystallizing alumina fiber which is less susceptible of degradation was used. As means to install it, there are two methods available, one of using metal fittings and the other of lining with mortar. As a result of a few months' tests, the mortar method was adopted. One hundred eighty pieces of 305 × 305 × 51-mm alumina fiber block were lined over the entire area of 17 m^2 inside the kiln. When installing the fiber, attention should be given to the following points:

- First, clean the wall surface to be lined with the fiber.
- Scrape off any projection on the wall surface.
- Rub mortar into the fiber surface scrupulously.
- Apply a thick layer of mortar over the fiber surface.
- Adhere the fiber tightly against the kiln wall by means of a flat plate.

If the temperature is slowly increased up to approx. 800° C during initial firing after complete drying following the installation, unloaded burning need not be performed.

Unless the operating procedures are changed after the installation, a drastic increase in the intrakiln temperature would sometimes occur, resulting in a soaring exhaust gas temperature and subsequent fuel consumption not being reduced as originally expected. In order to cope with this situation, it is required that the firing time be shortened over the checking of finished product quality and the exhaust gas temperature be lowered by decreasing a draft pressure and adjusting a fuel volume (refer to Fig. III-1-14).

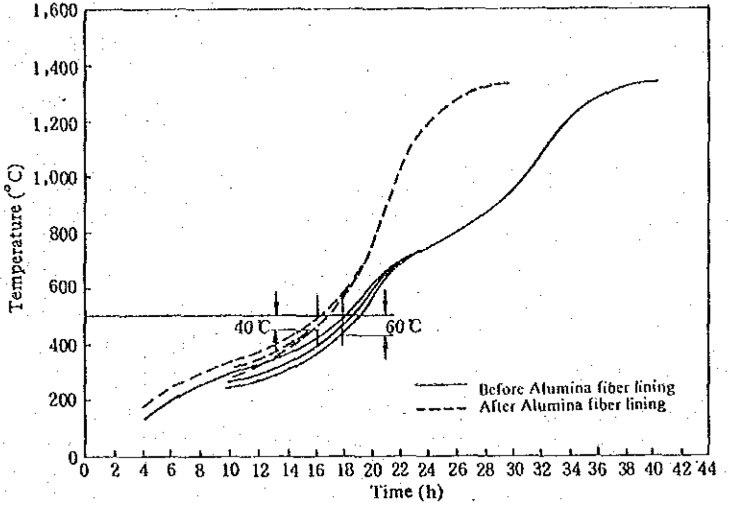


Fig. III−1−14 Temperature ascending curve for each intrakiln part

Measurement after adjustment of these operating conditions revealed that the external wall temperature dropped at approx. 50° C at the arch part, the door surface at 52° C and the wall surface at 41° C. In addition, the application of lining helped reduce gas leakage through kiln wall.

The heat balance prior to and after installation is as shown in Table III-1-14 and Table III-1-15. These tables apparently indicate a decrease in the heat loss attributed to a regenerated heat and heat release. The fuel conservation value is as shown in Table III-1-16. The fuel conservation rate now stands at 19%.

Table III−1−14 Heat balance of shuttle kiln prior to the use of alumina fiber

Item		Heat input		Heat output	
		10^3 kcal	%	10^3 kcal	%
Heat input	Combustion heat of fuel	3,715.3	98.4		
	Sensible heat of fuel	1.8	0.0		
	Heat carried in by air for burning	14.9	0.4		
	Heat regenerated in the main body of kiln	45.6	1.2		
	Total heat input	3,777.6	100.0		
Heat output	Heat required for firing			370.5	9.8
	Heat regenerated in the main body of kiln			1,000.1	26.5
	Sensible heat of exhaust gas			1,529.6	40.5
	Heat loss by heat radiation and transfer and other factors			877.4	23.2
	Total heat output			3,777.6	100.0
Heat efficiency of fired product		10.0%			

Table III–1–15 Heat balance of shuttle kiln after the use of alumina fiber

Item		Heat input		Heat output	
		10^3 kcal	%	10^3 kcal	%
Heat input	Combustion heat of fuel	2,838.9	96.9		
	Sensible heat of fuel	1.4	0.0		
	Heat carried in by air for burning	11.5	0.4		
	Heat regenerated in the main body of kiln	80.1	2.7		
	Total heat input	2,929.8	100.0		
Heat output	Heat required for firing			370.5	12.7
	Heat regenerated in the main body of kiln			949.1	32.4
	Sensible heat of exhaust gas			1,161.6	39.6
	Heat loss by heat radiation and transfer and other factors			448.6	15.3
	Total heat output			2,929.8	100.0
Heat efficiency of fired product		13.1%			

Table III–1–16 Comparison of fuel prior to and after use of Alumina fiber

Alumina fiber	Firing weight	Fuel used	Fuel per 1 kg of product	Ratio
Prior to use	1,333 kg	398 kg	0.299 kg/kg	100
After use	1,220 kg	294 kg	0.241 kg/kg	81

Table III–1–17 Energy saving by more effective insulation system for car

Finished product	Sanitary ware
Insulation material	Refractories → Insulative refractories
Car weight	1,900 → 1,400 kg/car
Regenerative heat	169 → 70 × 10^3kcal/car
Reduced fuel consumption	308 kℓ/y

The annual fuel conservation amounts to approx. 6.7 tons or approx. ¥470,000 in value. In the meantime, the installation cost invested was approx. ¥1 million. This means that the investment could be paid back in approx. a couple of years.

b. Insulation of the car top with light-weight insulation material would be effective for diminishing energy for heating the car and also preventing heat release into under the car. The insulation would also be helpful for expediting the car sending speed.

Table III-1-17 is an example of energy conservation by the insulation of the car top. This factory used to adopt ceramic fiber, but suspended its use because of deformation and pulverization and switched to an insulation with refractories.

c. The same is true about casings and shelf boards; that is, the reduction of a heat capacity would be effective for energy conservation.

Table III-1-18 Details of reduction of car weight

Item	Prior to weight	After weight	Factor of reduction
Weight of car top	1,404 kg	943 kg	32.8%
Weight of shelf board	730 kg	520 kg	28.8%
Total	2,134 kg	1,463 kg	31.4%

Table III-1-18 is an example of weight reduction for the car and shelf boards. The car before modification weighed 140 kg on account of refractories used. However, it was modified to a car with refractories arranged in the periphery only and covered with thin refractories on the surface using pearlite buried inner part. Further, a support of honeycomb structure was provided in the part where the weight of shelves rests. Thanks to this modification, the weight of the car top was reduced approx. 33%. For the shelf board, the 60-mm thick cordelite was replaced with the 35-mm thick mulite. At the same time, for the shelf support, refractories were replaced with the light-weight support of honeycomb structure. Thus the weight of the support was reduced 29%.

As a result, when the car sending speed was the same as before and the weight reduction was applied to 75% of the total number of cars, a 22% reduction of fuel consumption was realized as shown in Table III-1-19. In the meantime, the cost breakdown for weight reduction was ¥95,000 for car top and ¥125,000 for shelf board per car respectively totaling ¥220,000. This investment can be completely paid back in one-odd year, according to calculation.

Table III-1-19 Energy saving effect by reduction of car weight

Item	Fuel consumption	No. of pcs. of tile for firing	Factor of energy saving
Prior to weight reduction	3,378 l/day	3.41 pcs./l	–
When the weight of 75% of cars has been reduced	2,628 l/day	4.38 pcs./l	22.2%

For rapid firing thin products, a base plate push-out kiln not using a car, a belt conveyor kiln, a walking beam kiln, a roller hearth kiln, etc. are partly employed in practical work.

4.1.3 Prevention of Heat Release through Radiation, Transfer etc.

(1) Adoption of More Effective Insulation of Kiln Walls

a. As mentioned in the preceding paragraph, for the periodic kiln, light-weight insulation material is lined on the internal surface for an additional purpose of preventing a regenerated heat loss. However, when it goes to the continuous kiln, in which the regenerated heat loss is not important role, insulation is, in the most case, applied with rock wool sprayed on the external surface. The coating is 50 to 100 mm thick except for the metal part. The insulation effect is that the surface temperature comes down below 100° C and as low as 40° C depending on part. Thus the energy conservation reaches the level of 5 to 15%.

To look at a certain tile factory, a 50-mm-thick rock wool was sprayed on the side wall for both preheating zone and firing zone of the tunnel kiln, and the car top was also insulated. As a result, the unit fuel consumption rate was improved from 173 liters/ton to 143 liters/ton. The investment was recovered within one year. When applying a surface insulation, first of all, it is required to check if the internal brick temperature exceeds the tolerable temperature limit of brick.

b. Let's consider heat transfer in the kiln wall as shown in Fig. III-1-15. Here *l* represents the thickness of each brick, λ the heat conductivity of each brick, ha hb the coefficient of heat transfer of inner- and outer-surface of kiln and A the average heat transfer area.

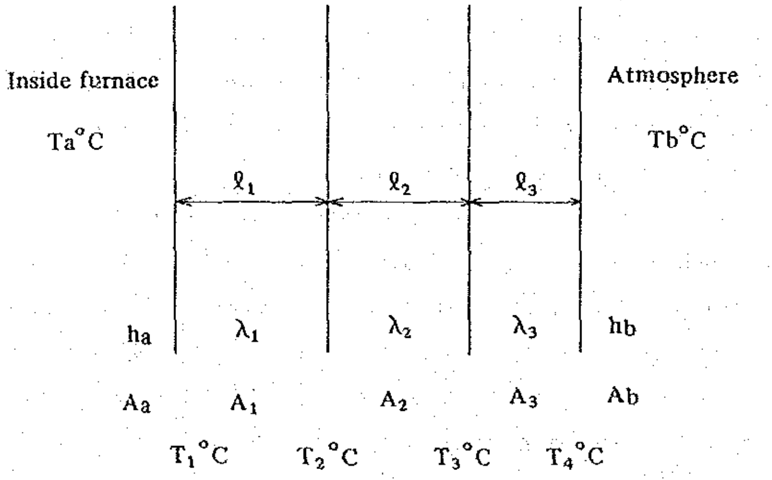


Fig. III–1–15 Heat transfer in the kiln wall

The heat flux Q flowing through this kiln wall is expressed by the following equation at R of heat transfer resistance.

$$Q = \frac{T_a - T_b}{R}$$

R is the sum of heat transfer resistance values of various parts as is the same as the case where resistances are arranged in series in the electric current.

$$R = \frac{1}{h_a A_a} + \frac{l_1}{\lambda_1 A_1} + \frac{l_2}{\lambda_2 A_2} + \frac{l_3}{\lambda_3 A_3} + \frac{1}{h_b A_b}$$

In the ceramic kiln at high temperature, normally the first term shall be ignored and Ta be regarded as equal to T_1 in calculation. In the flat wall, the equation $Aa = A_1 = A_2 = A_3 = Ab = A$ is established. Since the heat flux Q' passing through each surface is the same, the temperature of each surface can be obtained by the following equation:

$$Q' = \frac{T_1 - T_2}{l_1/\lambda_1} = \frac{T_2 - T_3}{l_2/\lambda_2} = \frac{T_3 - T_4}{l_3/\lambda_3} = \frac{T_4 - T_b}{1/h_b}$$

Establish an equation applicable to the case where more effective insulation has been installed and make sure that obtained T_1, T_2, etc. are not higher than the working safety temperature of each brick.

Fig. III-1-16 shows the heat conductivity of metal material. Table III-1-20 shows the Japan Industrial Standard for refractories. In this table, a temperature not exceeding 2% of the reheated shrinkage percentage is a criterion for working temperature. When using the brick as an internal wall directly, it is desirable to allow for approx. 200°C as a safety factor. Class A represents the brick of low heat conductivity and Class C the brick of high compression strength. Table III-1-21 shows an example of the quality of ceramic fiber felt. The λ value of the above-mentioned equation is obtained based on these tables.

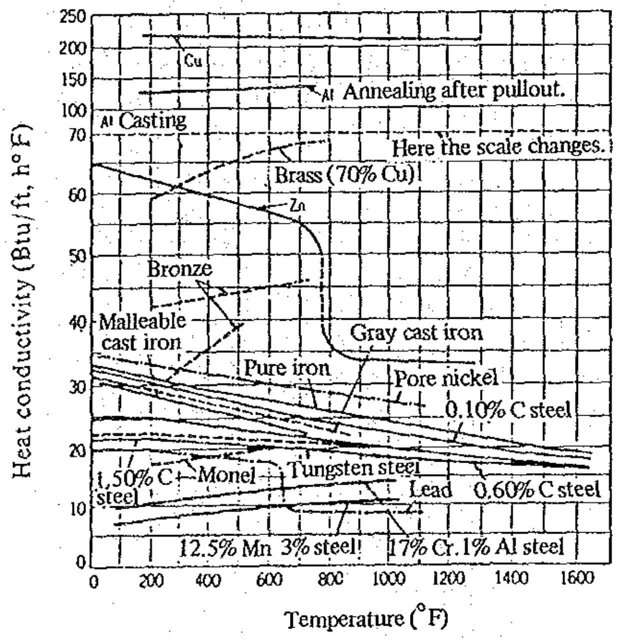


Fig. III–1–16 Relationship between heat conductivity of metal material and temperature

Table III–1–20 Japan industrial standard for refractories (JIS R 2611)

Classification		Code	Temp. shrinkage not exceeding 2% after reheating (°C)	Bulk density	Compression strength (kg/cm^2)	Heat conductivity (average temp. of 350 ± 10°C kcal/m.h.°C)
Class A	Type 1	A 1	900	0.50 max.	5 min.	0.13 max.
	Type 2	A 2	1,000	0.50 max.	5 min.	0.14 max.
	Type 3	A 3	1,100	0.50 max.	5 min.	0.15 max.
	Type 4	A 4	1,200	0.55 max.	8 min.	0.16 max.
	Type 5	A 5	1,300	0.60 max.	8 min.	0.17 max.
	Type 6	A 6	1,400	0.70 max.	10 min.	0.20 max.
	Type 7	A 7	1,500	0.75 max.	10 min.	0.22 max.
Class B	Type 1	B 1	900	0.70 max.	25 min.	0.17 max.
	Type 2	B 2	1,000	0.70 max.	25 min.	0.18 max.
	Type 3	B 3	1,100	0.75 max.	25 min.	0.20 max.
	Type 4	B 4	1,200	0.80 max.	25 min.	0.22 max.
	Type 5	B 5	1,300	0.80 max.	25 min.	0.23 max.
	Type 6	B 6	1,400	0.90 max.	30 min.	0.27 max.
	Type 7	B 7	1,500	0.90 max.	30 min.	0.31 max.
Class C	Type 1	C 1	1,300	1.10 max.	50 min.	0.30 max.
	Type 2	C 2	1,400	1.20 max.	70 min.	0.38 max.
	Type 3	C 3	1,500	1.25 max.	100 min.	0.45 max.

Table III–1–21 Example of quality of Ceramic fiber felt

Item \ Name of article		A	B	C
Usual max. working temp. °C		1,100	1,200	1,400
Bulk density g/cm^2		0.16	0.16	0.13
Factor of ignition loss %		6	6	7
Modulus of linear shrinkage %	at 800 °C	0.0	–	–
	at 900 °C	0.4	0.0	–
	at 1,000 °C	1.1	0.5	–
	at 1,100 °C	1.2	0.9	0.0
	at 1,200 °C	–	1.4	0.4
	at 1,300 °C	–	–	0.7
	at 1,400 °C	–	–	1.5
Thermal conductivity kcal/m-h-°C	at 700 °C	0.14	–	–
	at 800 °C	0.17	0.17	–
	at 900 °C	0.20	0.20	–
	at 1,000 °C	0.23	0.23	0.26
	at 1,100 °C	0.28	0.28	0.30
	at 1,200 °C	–	0.32	0.36
	at 1,300 °C	–	–	0.42

The h_b value is the total of radiation heat transfer value and convection heat transfer value. The experimental value of Langmure is shown in Table III-1-22. In addition, it is accepted that when it is windy, the said value will be increased at a mutiplying factor of Table III-1-23.

Table III–1–22 Surfacial heat transfer coefficient

$T_4 - T_b$	h_b	$T_4 - T_b$	h_b	$T_4 - T_b$	h_b
40	10.	150	16.6	275	25.0
60	11.5	175	17.5	300	27.0
80	12.3	200	19.3	325	29.0
100	13.3	225	21.1	350	31.3
125	14.6	250	23.1	375	33.5

Table III–1–23 Mutiplying factor

Wind velocity m/sec	$T_4 - T_b$		
	38 °C	98 °C	149 °C
1.1	1.46	1.43	1.40
2.2	1.74	1.69	1.64
4.5	2.16	2.10	2.02
6.7	2.50	2.42	2.33
8.9	2.76	2.69	2.58

In order to obtain a heat release value of the surface without using the h_b value, use the following calculation.

In case a small object exists in a large room, the radiation heat transfer value of the surface of the small object is expressed by the following equation:

$$Q_r = 4.88\,\epsilon\,A_b\left\{\left(\frac{273 + T_4}{100}\right)^4 - \left(\frac{273 + T_b}{100}\right)^4\right\}$$

Where ϵ means "emissivity" which changes according to the kind of material, surface temperature and physical property of surface.

Table III-1-24 shows the emissivity of various kinds of surfaces.

As regards convection heat transfer under natural convection conditions such as steam piping and kiln wall arranged in the room, simple equations are available.

$Q_c = h\,A_b\,(T_4 - T_b)$

In the case of horizontal upward surface,

$h_c = 2.2(T_4 - T_b)^{1/4}$

In the case of horizontal downward surface,

$h_c = 1.1(T_4 - T_b)^{1/4}$

In the case of a vertical surface,

$h_c = 1.5(T_4 - T_b)^{1/4}$

The relationship among Qr, Qc and h_b obtained in this way will be as shown by the following equation:

$$h_b = \frac{Q_r + Q_c}{A_b(T_4 - T_b)}$$

When the surficial temperature T_4 has not yet been measured, it is possible to calculate a heat release amount by obtaining T_4 at which a heat flux passing through refractories is equal to heat loss of the surface on the following equation:

$$\frac{T_a - T_4}{\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} + \frac{l_3}{\lambda_3}} = 4.88\,\epsilon\left\{\left(\frac{273 + T_4}{100}\right)^4 - \left(\frac{273 + T_b}{100}\right)^4\right\} + h_c(T_4 - T_b)$$

It is to be noted, however, that, in order to resolve this equation, the use of a computer and by methods such as Newton is required.

Table III–1–24 Emissivity of various surfaces

Surface	Emissivity
Wood	0.98
Water	0.95 ~ 0.96
Fiber	0.93
Glass/Concrete	0.94
Stone/Paper/Oil paint	0.91 ~ 0.93
Plastic/Oil paint	0.90 ~ 0.96
Refractories	0.80 ~ 0.90
Steel (Oxidized surface)	0.65 ~ 0.75
(Polished surface)	0.14 ~ 0.38
Molten iron	0.30 ~ 0.45
Aluminium	0.04 ~ 0.06

(2) Heat insulation of surface on the car

As mentioned in the preceding paragraph, decrease the heat capacity of the car and at the same time, minimize heat release under the car.

(3) Reduction of surface area of the kiln body

Reduce the surface area by making smaller the combustion chamber of tunnel kiln or letting a combustion take place between the cars like a downward combustion.

(4) Prevention of heat release from the entrance of shuttle kiln

Prevent heat release through the entrance by speeding up the switchover of cars, shortening a unloaded time of kiln through improvement of operating arrangement and shutting the door during an unloaded time.

(5) Prevention of heat release from the drying chamber

The same is true about the drying chamber; provide more effective surface insulation and seal openings. In addition, insulate a hot air pipe of heat source sufficiently.

(6) Standard for heat insulation

The following standard for heat insulation is applied in Japan. With regard to newly established kilns, the standard temperature of external surface of kiln wall is as shown by Table III-1-25.

Table III–1–25 Standard of external surface temperature of kiln

Kiln Temp. (°C)	Standard of external surface temperature of kiln (°C)	
	Ceiling	Side wall
1,300	140	120
1,100	125	110
900	110	95
700	90	80

However, the value shown in the said table represents the case where the kiln is constantly operated at an ambient temperature of 20°C. Further, as a rule, this standard is not to be applied to the kiln at a rated capacity of not more than 200,000 kcal/h. In the case of the Kingdom of Thailand, it is recommended that the atmospheric temperature condition be 30°C which is close to an actual status and that therefore, the standard temperature be the above-mentioned value plus 7 to 8°C.

Regarding some kilns at more than 500°C of kiln temperature of newly built batch kilns, under the standard for insulation in Japan, the insulation conditions should be satisfied either by meeting the value of Table III-1-25 or constituting more than 50% of the internal surficial area of kiln walls excluding the kiln bottom with insulation material having a bulk specific gravity of less than 1.3.

In the case of the Kingdom of Thailand, the above standard shall be applied as it is only by correcting a difference of the atmospheric temperature.

4.1.4 Recovery and Utilization of Waste Heat

(1) Exhaust of hot air from cooling zone

The quantity of heat of hot air exhausted from the cooling zone of tunnel kiln reaches even 20 to 50% of the heat input. In addition, the content of impurities is small. Therefore, it is important to make efficient use of the hot air. The conceivable applications are for drying and preheating of material or molded products, or for combustion air. In the Kingdom of Thailand, the hot air is now being used for drying and preheating, but it is not yet being fully utilized.

An application to combustion air is almost not noticed, but energy conservation effect of it is estimated as follows:

Q: Quantity of heat brought out by combustion exhaust gas
kcal/kg − fuel

P: Quantity of heat brought in by preheated air
kcal/kg − fuel

F: Combustion heat of fuel
kcal/kg − fuel

H: Available heat and required fixed quantity of heat
kcal/kg − fuel
$= F - Q$

When not preheating air,

$H_A = F - Q$

When preheating air,

$H_B = F - Q + P = H_A + P$

Suppose that the required quantity of heat for the kiln is X kcal/h, the fuel consumption will be

$$\frac{X}{H_A} \text{kg} - \text{fuel/h},$$

when the air is not preheated.

However, the fuel consumption will be

$$\frac{X}{H_B} = \frac{X}{H_A + P} \text{kg} - \text{fuel/h}$$

when the air is preheated.

Accordingly, the fuel conservation rate will be as follows.

$$\frac{\dfrac{X}{H_A} - \dfrac{X}{H_A + P}}{\dfrac{X}{H_A}} = \frac{P}{H_A + P}$$

The fuel conservation rate at an air ratio of 1:2 is shown in Fig. III-1-17. If the air is preheated, the following merits are expected in addition to the energy conservation effect due to an increase in the heat brought in: The reduction of air ratio as a result of the improvement of ignition and flame stabilizing properties and the increasing of a burning rate, and a rise of flame temperature.

In the meantime, when preheating the air, attention must be given to the increase of nitrogen oxide generation due to a soaring flame temperature and the heat resistance of burners. Further, a control device is required to have a function correcting the effect of an air volume fluctuations because the air volume supplied to the burner changes in accordance with preheated air temperature fluctuations.

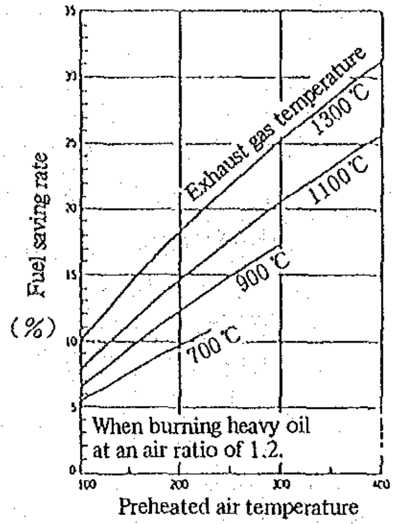


Fig. III−1−17 Fuel saving rate after air preheating

(2) Combustion exhaust gas

Combustion exhaust gas from the tunnel kiln is utilized for preheating the materials to be fired. Accordingly, it is not utilized for any more on account of acid dew point.

If fuel containing sulphur is burned, sulphur dioxide is generated and part of it is changed to sulphur trioxide. Consequently, if a combustion exhaust gas contacted the low-temperature wall of devices such as heat exchanger, reaching lower than the dew point, sulphur trioxide and water react, resulting in the production of sulphuric acid (H_2SO_4) of high concentration. Thus the heat exchanger or the duct is corroded.

Fig. III-1-18 shows the relationship between the sulphur content of fuel and the SO_2 percentage of exhaust gas. Fig. III-1-19 shows the conversion rate of SO_2 to SO_3. Fig. III-1-20 shows the relationship between the SO_3 concentration and the acid dew point.

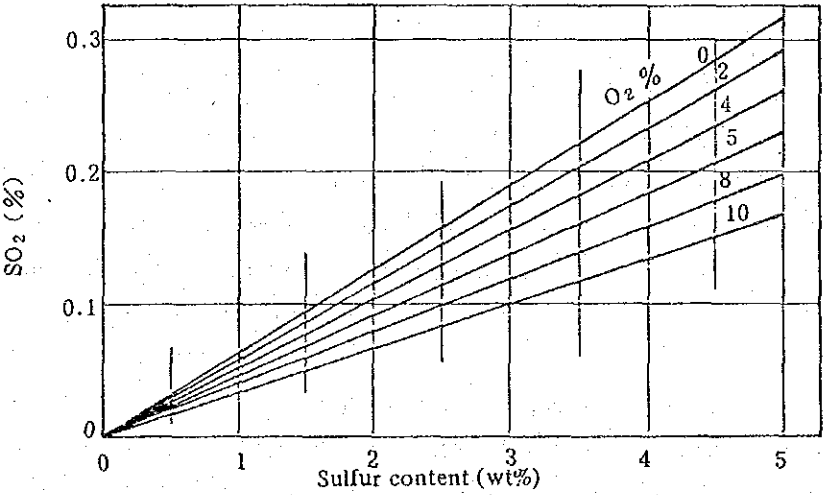


Fig. III−1−18 Relation between sulfur content in fuel and SO_2 content in fuel gas

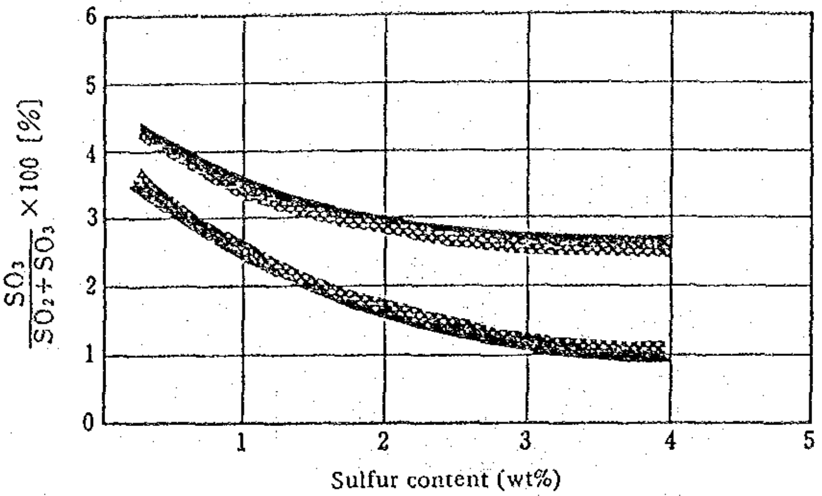


Fig. III–1–19 Relation between sulfur content in fuel and conversion ratio from SO_2 to SO_3

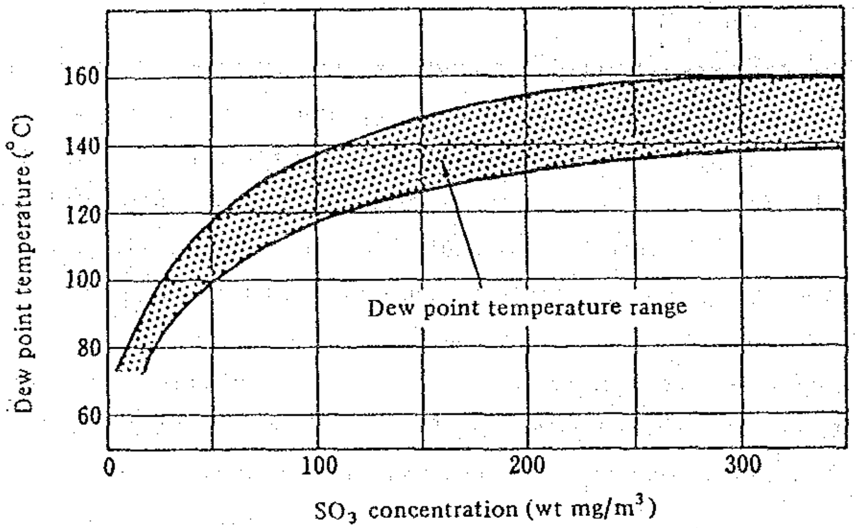


Fig. III–1–20 Relation between SO_3 concentration in exhaust gas and dew point temperature

In the neighborhood of the low-temperature fluid inlet of the heat exchanger, some part comes at low temperatures, so that it is necessary to maintain the gas at a slightly higher temperature than the acid dew point temperature as shown in the Fig.

If glass or lead-coated pipe is used as a material for the heat exchanger, it is possible to recover heat to lower temperatures. In the case of ceramic industries, the application of recovered exhaust heat is limited, and therefore, it is not necessary to apply such expensive equipment.

In the case of the batch kiln, it is possible to use an exhaust gas for preheating the air, heating fuel or for drying the molded product directly, because the exhaust gas is generally at high temperature. In this case, however, do not forget about cleaning the heat exchanger and duct periodically.

An example of the installation of a recuperator for heating the secondary air on the round kiln for manufacturing silica refractories is shown.

The kiln is a round, down draft type, 11-m in diameter and capable of receiving each combined charge of 330 tons of products and tools. As energy saving measures, the following steps were taken:

- Provision of more effective heat insulation on the ceiling.
- Installation of measuring instruments for fuel oil and air by burner.
- Increase in the number of charge tonnage in the kiln.
- Installation of recuperator for recovering the heat of cumbustion exhaust gas.

Fig. III-1-21 shows the installation layout of a recuperator. Table III-1-26 shows the specifications of a recuperator. Table III-1-27 shows the heat balance prior to and after energy conservation measures and the chart of heat balance.

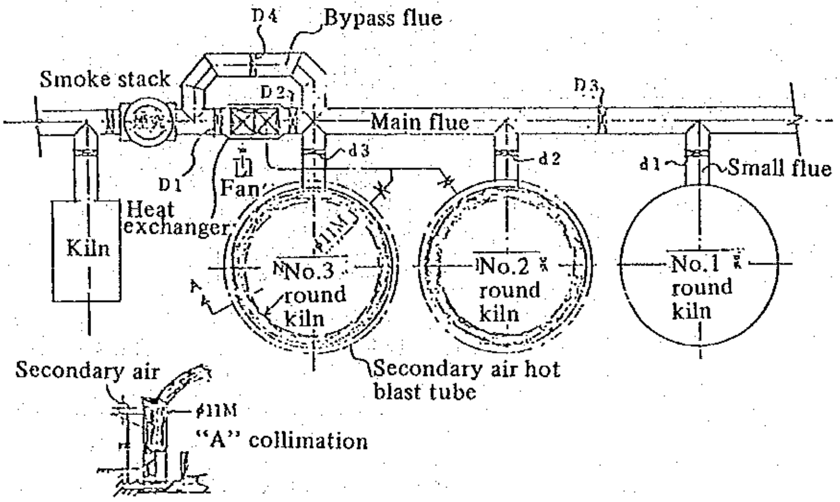


Fig. III–1–21 Layout of recuperator in flue of round kilns

Table III–1–26 Specifications of recuperator

	Item	Unit	(max)
Exhaust gas side	Exhaust gas amount	Nm^3/Hr	10,000
	Temp. of recuperator inlet	°C	800(900)
	Temp. of recuperator outlet	°C	650
Preheated air	Air amount	Nm^3/Hr	4,500
	Temp. of recuperator inlet	°C	20
	Temp. of recuperator outlet	°C	400(450)
Pressure loss	Pressure loss on exhaust gas side	mmH_2O	8
	Pressure loss on preheated air side	mmH_2O	150

Table III-1-27 An example on heat balance of down draft kiln before and after adoption of energy saving measures (Example)

(Example of "Before energy saving measures")

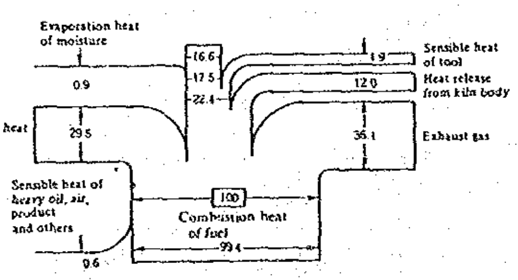
Preconditions

(1) Kiln loading : Finished product 260.15 t
Sagger 77.07 t
(2) Oil consumption: 68.18 kℓ
(3) Temperature : Heavy oil 73°C, air 5°C, finished product 10°

Heat Balance

			X10⁴ kcal	X10⁴ kcal/t	%
Heat input	Heavy oil	combustion heat Q_0	67,089.0	257.9	99.4
		sensible heat	203.6	0.8	0.3
	Air for burning	sensible heat	142.8	0.5	0.2
	Finished *product* and tools	sensible heat	74.2	0.3	0.1
	Total		67,509.6	259.5	100
Heat output	Finished product	sensible heat Q_1	11,191.8	43.0	16.6
	Evaporation heat of moisture in product	Q_2	618.5	2.4	0.9
	Sagger	sensible heat Q_3	3,315.5	12.7	4.9
	Heat carried out by exhaust gas		24,382.9	93.7	36.1
	Heat *release from kiln* body		8,085.4	31.1	12.0
	Regenerated heat of kiln body and others		11,915.5	76.6	29.5
	Total		*67,509.6*	*259.5*	*100*
Heat efficiency	Finished product (η_1)	$(Q_1 + Q_2/Q_0)$			17.6%
	Finished product + tools(η_2)	$(Q_1 + Q_2 + Q_3/Q_0)$			22.5%

Heat balance chart



(Example of "After energy saving measures")

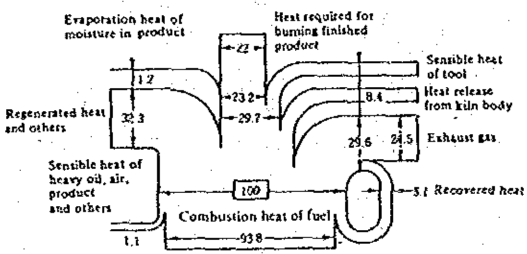
Preconditions

(1) Kiln loading : Finished product 290.00 t
Sagger 87.34 t
(2) Oil consumption: 60.70 kℓ
(3) Temperature : Heavy oil 73°C, air 15°C, finished product 15°

Heat Balance

			X10⁴ kcal	X10⁴ kcal/t	%
Heat input	Heavy oil	combustion heat Q_0	54,353.0	183.6	93.8
		sensible heat	179.0	0.6	0.3
	Air for burning	sensible heat	354.0	1.2	0.6
	Recovered heat of exhaust gas		2,956.4	10.0	5.1
	Finished *product* and tools	sensible heat	126.5	0.4	0.2
	Total		57,968.9	195.8	100
Heat *output*	Finished product	sensible heat Q_1	12,733.7	43.0	22.0
	Evaporation heat of moisture in product	Q_2	703.8	2.4	1.2
	Sagger	sensible heat Q_3	3,757.4	12.7	6.5
	Sensible heat of exhaust gas		17,170.0	58.0	29.6
	Heat *release from kiln* body		4,851.0	16.4	8.4
	Regenerated heat of kiln body and others		18,753.0	63.4	32.3
	Total		*57,968.9*	*195.8*	*100*
Heat *efficiency*	Finished product (η'_1)	$(Q_1 + Q_2/Q_0 \times 100)$			24.7%
	Finished product + tools(η'_2)	$(Q_1 + Q_2 + Q_3/Q_0 \times 100)$			31.6%

Heat balance chart



It is estimated that the unit fuel consumption rate will be reduced 18 to 22% and that the investment in equipment of ¥23 million will be completely paid back in slightly less than a couple of years.

(3) Heat release from the kiln body

It is a basic procedure to minimize heat release by providing more effective heat insulation to the kiln body. When it is difficult to carry out insulation it may be considered to make use of the released heat for other purposes instead.

As means for such a utilization, the heat can be used to preheat fuel oil in a tank provided atop the kiln either directly or through the intermediary of water, to dry the product in the drying chamber atop the kiln as in the roofing tile industry or to preheat the air by laying an air duct for burning along the kiln.

Apart from the subject of the heat of the kiln body, when the fired product is at