With the heat exchanger for preheating, scale having desiliconizing product as the main component deposits on the heat exchange surfaces and drop in the heat transfer coefficient occurs. Therefore, upkeep and enhancement of the heat exchange efficiency by effective removal of scale is important in the management of the digestion process.

(2) Digestion residue (red mud) separation & washing process

Red mud is separated from the supersaturated sodium aluminate solution containing digestion residue (red mud), clear solution is obtained and is fed to the crystallization process. Accompanying sodium aluminate is recovered from the separated red mud, on the other hand. Sedimentation by gravity using thickeners is used in general for separation of red mud. For washing the red mud, it is usual that a number of thickeners are connected in series to perform counterflow multi-stage washing and dehydration is made in the final stage by vacuum filtration. As the liquid is in the supersaturated state in this process, it is important to prevent crystallization of aluminum hydroxide. Furthermore, effective washing should be made with washing water of as small quantity as possible.

Selection of suitable sedimentation agents is necessary to accelerate thickening of red mud in thickeners. Furthermore, such a method that the washing efficiency is increased using washing water of a small quantity through washing and filtration with a disk filter of large size, with washing using thickeners limited to around two stages was recently developed.

As red mud of small particle size is still remaining in the solution from which red mud was separated, filtration using a sand filter or a filter precoated with slaked lime is made in order to remove such residual red mud.

(3) Crystallization process

Seeds of aluminum hydroxide are added to sodium aluminate solution and agitation is made in the crystallization process for crystallization of aluminum hydroxide. The points of this process are;

a) Selection of type of crystallization tank

b) Production of aluminum hydroxide of coarse particle size that is suitable for sandy alumina and that is of large particle strength hardly crushed in the calcination process

c) Development of a method to increase the crystallization quantity per unit liquid volume

Regarding point a), advancement was made from mixing tanks with mechanical agitation vanes to air agitation (air lift pumps). Furthermore, draft mixers of such a system that agitation is made with the slurry in the crystallization tank fed downward through a draft tube with the axial flow pump located on top was developed. Now it is possible to fabricate crystallization tanks of capacity about 3,000 m³ per tank.

Regarding point b), increase of particle size caused by growth of crystals and coagulation of small particles is large in the high temperature state during the initial period of crystallization, and fine particles are produced as the temperature drops. In order to obtain aluminum hydroxide of large particle size and of high strength, the coagulating reaction and crystal growing reaction should be skillfully controlled by the temperature and also by the particle size and quantity of seeds. For this objective, classification of the aluminum hydroxide slurry taken out of the crystallization tank of the final stage is also important.

Regarding point c), the soda concentration of the circulated liquid is high, the alumina concentration of the solution fed to the crystallization process is also high, and in addition, aluminum hydroxide of small particle size is obtained with crystallization time of as long as 60 ~ 80 hours in the European type Bayer's process. In the American type Bayer's process, however, soda concentration of the circulating liquid is low, and aluminum hydroxide of coarse particle size is obtained at the rate of 50 kg (as converted to Al_2O_3) per m^3 in the crystallization time of about 30 hours from solution of low alumina concentration. Since a large portion of the quantity of the energy required in the liquid circulation system is proportional to the circulating liquid volume, to increase the production rate per unit liquid volume by satisfying the condition of point b) provides a large effect from the standpoint of energy conservation. A method for producing sandy alumina under the conditions of European type Bayer's process was recently developed.

(4)   Calcination of aluminum hydroxide

At a factory where a rotary kiln is used, the heat of the exhaust gas of the rotary kiln is used for drying the aluminum hydroxide and partly for dehydration. Furthermore, the heat of the calcined alumina is used for preheating of the combustion air for improving the fuel oil unit consumption. The fuel oil unit consumption was formerly 180 liters per ton of alumina. But it recently dropped to the order of 90 liters.

Use of fluidized bed calcinators became popular for new plants since the beginning of 1970's. Fluidized bed calcinators are suitable for production of sandy alumina, and those which were jointly developed by Lurgi and VAW of Germany and those which were developed by Alcoa of U.S.A. are operating. The fuel oil unit consumption dropped to 80 liters or less per ton of alumina. However, the fluidized bed calcinator is suitable only for calcinating raw material alumina but it is not for suitable for controlling particle growth.

The rotary kiln permits control of particle growth by changing the calcinating degree, so that it is possible to utilize a rotary kiln to produce alumina materials differing in the content of α-alumina particles. Therefore, this method is used not only for the production of materials for aluminum metal but also for the production of some kinds of chemical alumina.

(5) Unit consumption

Table 6.2 indicates typical progress of unit consumption for production of alumina in Japan. The unit consumption of bauxite and of caustic soda is determined by the grade of bauxite, but the unit consumption of steam and the unit consumption of fuel oil for calcination are determined by the equipment and technology. The steam unit consumption made rapid uplift in the 1950's by continuation of processes and recovery of heat from the liquid circulation system. The unit consumption was further uplifted by increase of productivity per unit liquid volume, exhaustive implementation of heat recovery and reduction of washing water by improvement of digested residue (red mud) and aluminum hydroxide washing methods.

Table 6.2 Unit consumption for production of alumina (per ton of alumina)

Year		1950	1955	1960	1970	Expected value for a new plant
Bauxite	kg	2,220	2,110	2,080	2,150	Determined by the grade of bauxite
Caustic soda	kg	—	73	63	101	Determined by the grade of bauxite
Fuel oil for calcination	ℓ	196	187	165	125	75
Steam	kg	5,280	2,280	1,580	1,830	1,100
Electric energy	kWh	505	280	220	210	170

6.2 Rationalization of use of thermal energy

6.2.1 Steps of implementation of energy conservation measures

It is recommended that energy conservation measures are implemented in the following steps.

Step 1: To improve the operation without large investment.

Step 2: To implement improvement that accompanies investment of a certain amount.

Step 3: To modify the production equipment and processes. Large equipment investment is naturally accompanied.

Make effective use of the current equipment and strengthen the management as the first step of promotion of energy conservation in steps. Start with judgment by data of whether energy is effectively used or not in this case.

It is necessary to recognize that all the data in the factory related to production control, quality control, control of raw materials and auxiliary materials besides heat balance exert influence over energy conservation.

6.2.2 Items of energy conservation measures

(1) Digestion process

Typical composition of bauxite produced in Hungary is shown below.

Table 6.3 Composition of Hungarian Bauxite

Boehmite	$Al_2O_3 \cdot H_2O$	27.2%
Gibbsite	$Al_2O_3 \cdot 3H_2O$	14.4%
Diaspor	$H \cdot AlO_2$	1.6%
Alumogoetite	AlOOH	0.9%
Kaolin		5.7%
TOTAL Al_2O_3		49.8%

Since this bauxite contains a lot of boehmite, which is monohydrate, the digestion temperature is about 240°C, which is higher than the digestion temperature for bauxite of gibbsite type, which is about 150°C. Accordingly, to make sufficient heat insulation is effective.

As multi-tube type heat exchangers require periodic washing, it is hard to apply permanent heat insulation to flanges, but it is recommended that heat resistant cloth with aluminum evaporation on the surface are suspended from hooks to cover up the flanges, instead of allowing heat radiation in the bare state. Although it is not complete heat insulation, it is effective to a certain extent, and it is also convenient for mounting and removal. It is recommended that removable molded heat insulation caps are provided for upper and lower covers.

If heat insulation is removed at the time of repair to digesters, flash tanks and pipelines, repair should be made promptly.

Steam leakage from steam lines, valves and flanges will, even if it is minor, when it is left unremedied, develop to major leakage because wear to the leaking point rapidly makes progress due to the steam of the jetting rate that exceeds the sonic speed. Therefore, repair to leaking points should be made without delay. For this objective, it is necessary to find points from which leakage often occurs, to prepare bypass lines, to keep a stock of packing materials and to train workers so that repair can be performed by anybody when leakage occurs.

Substances which are extremely hard to handle such as alkali solution of high temperature and slurry are handled at every alumina factory besides steam. From the standpoints of energy conservation, safety, resources conservation and of beautification of the factory, it should be formed into a habit to make routine checks for leakage and to make repair as soon as leakage was found.

In the case where the digesters are of indirect heating type, scale deposits on the heating surfaces as the working time elapses. As a result, the coefficient of heat transfer gradually drops and finally it becomes impossible to heat up to the set temperature level. Therefore, make changeover to another system for washing the interior. In order to make such changeover at a suitable timing, it is necessary that periodic inspection of temperature measuring instruments is implemented and attention is constantly paid to the progress of operating temperature and coefficient of heat transfer. The same thing can be said for heat exchangers used for heating low temperature liquid using flash steam.

The digestion process was usually of batch type before. Although it is easy to keep the process at the constant conditions with the batch type, this type involves such disadvantages that many operators are required, the capacity of the equipment is not effectively used during supply and discharge of liquid which are not related to the original reaction but heat radiation loss occurs in the mean time.

Continuous type, on the other hand, is excellent for energy conservation and also for stability of operation and of the product grade, as it is free of the disadvantages stated above. The same thing can be said also with the dilution process and crystallization process besides the digestion process.

To produce quality products by the specified quantity, within the specified time and at excellent energy unit consumption, it is necessary to prepare in writing an operation standard that incorporates important matters which should be observed and to make it generally known to the managers and workers. It should include points important for use, maintenance and management of equipment and measuring instruments besides operation.

(2) Calcination process

Of the energy applied to alumina processes, 24% is consumed at the calcination process as stated earlier. The energy conservation measures in this process include dehydration of feedstock, combustion control, recovery of heat from exhaust gas and recovery of heat from alumina.

a. Aluminum hydroxide, which is a raw material, is filtered with a vacuum continuous filter before it is fed to the calcinator. If the moisture content of the filtered cake is large, the fuel oil consumption at the calcinator increases. It is therefore necessary to reduce the moisture content to minimum. The consumption of the fuel oil for calcination can be reduced by 0.85% when the moisture content of the filtered cake is reduced by 1%. If the state where cake is partially attached to the filter cloth surfaces of the filter is produced or if cake is partially dropped off, air suction is made, the vacuum degree will not rise and the moisture content of the cake will increase. In such a case, check for excessive solid concentration in the aluminum hydroxide slurry. If the concentration is normal, wash the filter cloth using washing water after removing the entire cake, and perform filtration once again. If the cake thickness is increased, the vacuum degree rises. But if the cake thickness is excessive, the filtration capacity drops. It is therefore necessary to find the optimum point.

b. With the air ratio first of all regarding management of combustion of the calcinator, if the airflow is insufficient, incomplete combustion occurs and soot emission out of the smokestack is found, and accordingly, it is identified shortly. If the airflow is excessive, however, it is often overlooked unless an analyzer is used. When the airflow increases, the exhaust gas flow also increases, and accordingly, the calorific value taken away by the exhaust gas increases. Therefore, it is satisfactory if the air ratio is selected so that the total of the exhaust gas loss and the unburned combustion is the minimum in order to minimize the exhaust gas loss. As the unburned component rapidly increases in the vicinity of air ratio 1, air ratio 1.1 ~ 1.3 is the desirable level with liquid fuel.

With the furnace internal pressure next, the furnace internal gas makes outblow if the pressure is excessive. When the negative pressure is high, on the other hand, suction of fresh air occurs and the heat efficiency drops. In order to prevent occurrence of such problems, control the suction fan so that the pressure is 0 mmAq or is slightly on the minus level in the vicinity of the gap between the fixed part and the rotary part of kiln on the burner side.

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Furthermore, it is necessary to prevent drop of the system internal temperature and increase of the power of the suction fan by exhaustively plugging the air leaking points between the kiln and the smokestack so as not to allow suction of excessive air from the exterior.

c. As for heat recovery from the exhaust gas, provision of a multi-stage cyclone preheater to the rotary kiln is extremely effective, and it is also adopted in Hungary.

d. As for heat recovery from calcinated alumina, with a kiln equipped with planetary coolers, if alumina equally enters each planetary cooler and if cool air also equally enters it, satisfactory heat recovery is made and the sucked cool air is sufficiently preheated. It is recommended that the hot air obtained in such a manner is entirely used for combustion except for the primary air for burners.

The alumina that comes out of planetary coolers is then cooled in the fluidized cooler or the rotary cooler. With the fluidized cooler, it is a good idea to produce hot water by feeding water through the internal coil. But if the hot water remains unused, reduction of steam consumption can be made if heat recovery is made with sodium aluminate solution of low temperature fed instead of water.

e. It is hard to completely eliminate the hot air that comes upward as leaking through the gap between the fixed part and rotary part on the burner side of the kiln. It is recommended that a hood is provided on the upper side, the hot air is sucked with a fan and is blown into the kiln as primary air.

f. Before alumina is shipped through the alumina silo, it runs through many carrying equipment including chute, pneumatic conveyor, belt conveyor, screw conveyor or air slide. As alumina, that was produced through many processes, tends to scatter indoors and outdoors through the air, efforts should be made to prevent such scattering, because the energy, raw materials and auxiliary materials are wasted and loss to the factory is large, and external appearance of the factory is spoiled in addition.

(3) Water balance

The following water enters the process solution (sodium aluminate solution) circulated in the alumina processes.

a. Moisture attached to bauxite, which is a raw material

b. Moisture which accompanies caustic soda, which is an auxiliary raw material

c. Washing water for removing soda from red mud (insoluble digestion residue after extraction of alumina from bauxite)

d. Diluting water added to control to required concentration the sodium aluminate solution that comes out of the digester in the aluminum hydroxide crystallization process

e. Washing water for removing soda from aluminum hydroxide

f. Other miscellaneous water

On the contrary, there is water that goes out of the processes as attached to red mud and aluminum hydroxide. A concentration process is provided because the water incoming rate is larger than the outgoing rate in general and also because the process solution is used as circulated. Multi-effect vacuum evaporator heated with steam is used for concentration. Therefore, to reduce the water incoming rate leads to reduction of steam consumed by the evaporator, and large energy conservation is achieved. In addition, further energy conservation can be achieved if the evaporation efficiency of the evaporator is enhanced.

It is recommended that the following matters are implemented to reduce the water incoming rate.

a. To make distinction of the workshop cleaning water so as not to enter the cycle.

b. To use dry sealing pumps to eliminate sealing water.

c. To separate the system of the rainwater so as not to allow entry to the process solution.

d. To change the method for washing the aluminum hydroxide at the vacuum rotary drum filter from drip type to spray type.

6.2.3 Actual cases of energy conservation measures

The aluminum and alumina industries of Japan faced critical situations which threaten their existence because prices of crude oil rose extremely by two oil crises that occurred in 1973 and 1979. Under these circumstances, every company in these industries endeavoring for survival with full force concentrated on energy conservation as participated by all the employees. Some actual cases of energy conservation measures implemented by general workers are described below.

(1) Electric energy conservation in the bauxite crushing process

The slurry, which is obtained by wet crushing with crushers of bauxite, is fed to the electromagnetic vibration sifters with slurry pumps to remove portion of large particle size. The undersize portion sifted with the electromagnetic vibration sifters of opening 2 mm is fed to the digestion process with the slurry feed pumps. The oversize portion, on the other hand, is returned to the crushers for recrushing.

a. Improvement of electromagnetic vibration sifter

The solid concentration of the slurry fed to the electromagnetic vibration sifter is as high as 50% and screen is plugged early. Accordingly, cleaning was required six times a day, and it constituted a large factor for the drop in the sifting efficiency. The electromagnetic vibration sifter was of large size and heavy weight, and the power consumption was as much as 13kWh per unit.

To improve such situations, it was determined to replace them with electromagnetic vibration sifters of small size and light weight, and examination of screen inclination, vibration frequency and opening direction was made so as not to change the mean particle size of the undersize portion while securing the required capacity. The results of improvement are shown in Table 6.4.

The efficiency of the electromagnetic vibration sifters was increased and the electric energy required for the slurry feed pumps was reduced.

Table 6.4 Comparison between conventional electromagnetic vibration sifters and improved small size electromagnetic vibration sifters

	Conventional sifter	Small size sifter	Effect
Vibrator electric energy	12.25 kWh/unit	0.16 kWh/unit	−12.09 kWh/unit
Vibrator vibration frequency	3,600 RPM	1,800 RPM	
Screen area	2.47 m²	0.88 m²	−1.59 m²
Screen opening direction	Vertical	Horizontal	
Screen inclination	16 degrees	20 degrees	
No. of times of cleaning to eliminate plugging	6 times per unit per day	Once per unit per day	Reduced by 5 times per unit per day
Slurry pump electric energy	22.7 kWh/unit	22.0 kWh/unit	−0.7 kWh/unit

b. Electric energy conservaiton with slurry feed pumps

Next, improvement for saving the electric energy consumption of slurry feed pumps was made by deaeration of the slurry. When the bauxite slurry passes through crushers and vibration sifters, air of a large quantity is mixed into the slurry and such air remains in the slurry as bubbles. Accordingly, the capacity of the slurry feed pumps drops and it is a large obstacle for maintaining stable operation.

The electric energy consumption of the pumps decreased when the cushion tank level, which was formerly controlled to 20%±10%, was increased. It is considered to be because of increase of the pump suction head and also because of the deaeration effect produced by increase of the slurry stay time. However, since overflow of slurry with large bubble content occurs when the slurry level is 70% or higher, the control level is set at 50%±10%.

Furthermore, a deaeration tube shown in Figure 6.4 was installed between the tank and the pump and the tube top was connected to the vacuum system to apply negative pressure to the liquid surface in the tube. The bubble in the slurry was eliminated and the electric energy consumption of the pump was reduced as a result.
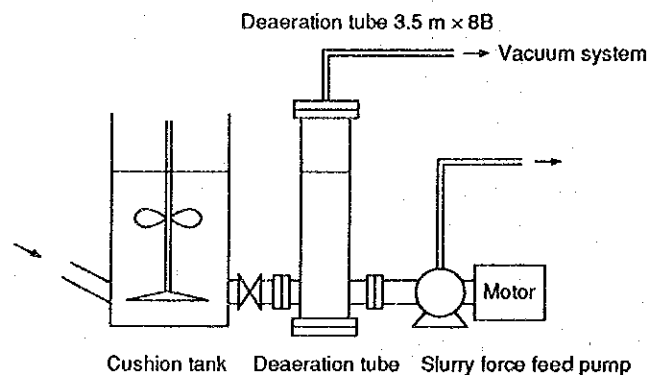

Figure 6.4 Sketch of deaeration tube

The electric energy conservaiton effect of the time when the slurry level rises and also in the case where a deaeration tube is additionally installed is shown in Figure 6.5.
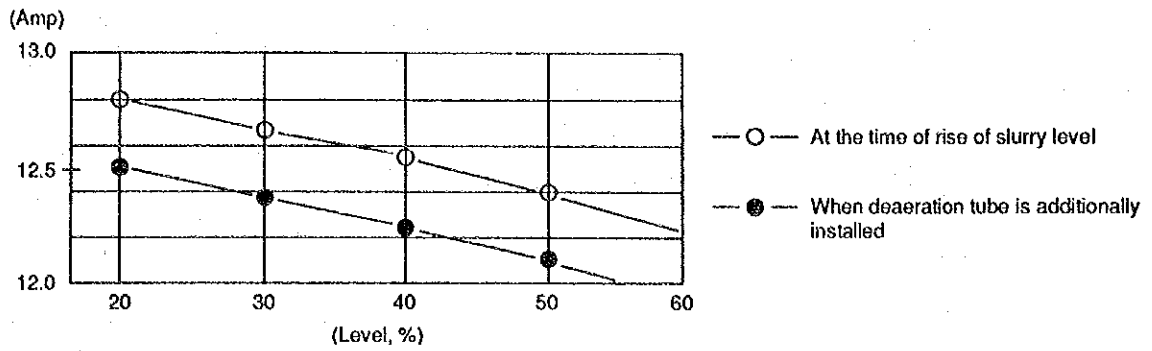
Figure 6.5 Electric energy conservation effect of rise of slurry level and of additional installation of deaeration tube

The following effect was obtained as a result of implementation of the improving measures stated above. The alumina production at this time was 370,000 tons a year.

Reduction of electric energy by reduction in size and weight of electromagnetic vibration sifters	2.324 M¥/year
Reduction of electric energy consumption of feed pumps by uplift of efficiency of electromagnetic vibration sifters	0.123 M¥/year
Reduction of electric energy consumption of slurry feed pumps by deaeration effect	0.694 M¥/year
Reduction of screen purchase expenses by reduction of screen area	0.77 M¥/year
Reduction of personnel expenses by reduction of frequency of screen cleaning	298 man-hour/year

(2) Saving of starch dissolving water

Sedimentation agents are used for the thickener for the purpose of acceleration of sedimentation of red mud and of thickening of red mud. High molecular coagulants such as polyacrylic soda and polyacrylic amide are often used as the sedimentation agent, but there also are cases where inexpensive starch is used.

What is described below is an example of improvement of the case where starch is used. Industrial water was used before for dissolving starch. But since this water enters the processes together with starch, it was determined to reduce the rate of use of industrial water and to use overflow liquid of the thickener instead. The industrial water consumption was reduced and steam consumption at the evaporator was also reduced as a result.

There is no problem when starch slurry is produced using industrial water and liquid of temperature higher than that of industrial water is added to it. When hot thickener overflow liquid is directly added to starch, however, many small lumps are produced and they cannot be suitably dissolved. Therefore, a small mixing tank of capacity 50 liters was installed before the starch dissolving tank, and starch slurry is produced using industrial water of a small volume (starch of 35 g is added to industrial water of 100 cc) in advance before mixing the starch slurry with the thickener overflow liquid. The dissolving equipment before and after improvement are shown in Figure 6.6.
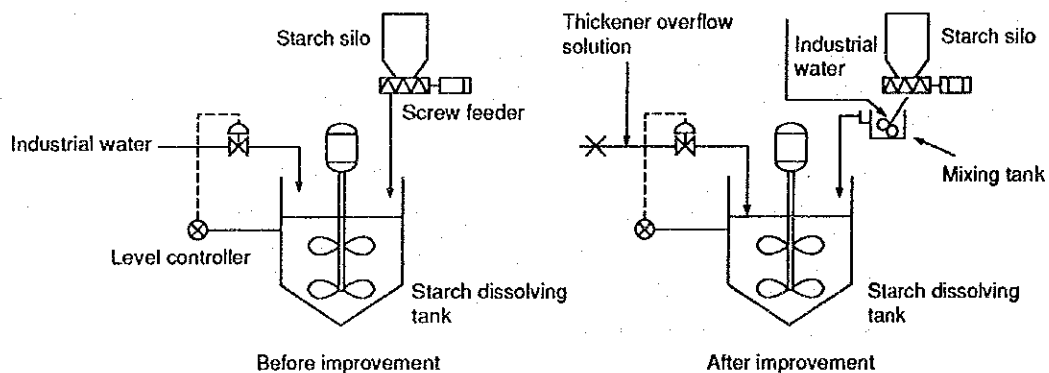

Figure 6.6 Starch dissolving equipment before and after improvement

Although the modified equipment was running satisfactorily at the beginning, lumps of starch were produced by a large quantity in the starch dissolving tank after a little while. It was considered that the viscosity increased as a result of alpharization of starch, bubble was produced due to air inclusion, starch rode on the bubble, solidified starch fell into the dissolving tank and lumps were produced.

Therefore, a diffusion plate shown in Figure 6.7 was mounted on top of the dissolving tank so as to permit quick contact of the overflow liquid with the starch slurry and also to permit quick discharge of the air in the overflow liquid. It has become possible to continue satisfactory operation as a result.
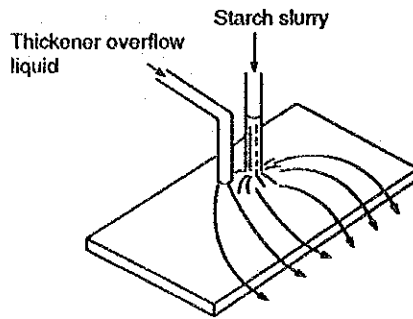
Starch slurry

Thickener overflow liquid

Figure 6.7 Diffusion plate

The following effect was obtained as a result of these measures for improving the starch dissolving method.

(At the time of alumina production 370,000 tons a year)

Saving of industrial water

Before improvement	3 m³/h × 24 h/d × 333 d/y = 23,976 m³/y
After improvement 400 t/d (starch consumption) × 100/35 =	1,143 m³/y
Water saved volume	22,800 m³/y
Saved amount	0.652 M¥/y

Saving of steam for concentration

Saved quantity	22,800 m³/y ÷ 3 m³/t-steam = 7,600 t/y
Saved amount	39.520 M¥/y

(3) Improvement of work to remove scale from limemilk line

Limemilk dissolved with diluted solution of the process is added by the rate of about 30 kg-CaO/t-Al$_2$O$_3$ in the alumina production process for separating by sedimentation as Ca salt the impurities such as Na$_2$C$_2$O$_4$ (sodium oxalate) contained in the process solution and also for caustification of Na$_2$CO$_3$.

The flow rate of this pipeline gradually drops due to scale formation, and water washing and cleaning are required once every two to three months. The entire volume of the industrial water used at this time enters the process solution and is added to the evaporation load.

The components of the scale are calcium oxalate, calcium carbonate and calcium aluminate, and it was found out that the scale can be dissolved at 90°C with 45% caustic soda. Accordingly, this washing method was implemented. The results of washing using caustic soda at a real pipeline are shown in Table 6.5.

Table 6.5 Results of washing using caustic soda at real pipeline

Time	h	0	1	2	3.5	4.5	5.5	6.5	7.5
Liquid temperature	°C	90	91	96	88	90	88	90	90
Flow rate	m³/h	4	6.6	7.8	8.0	8.4	8.6	9.0	9.0
Scale thickness	mm	8	—	—	4	—	—	—	2

Effect after implementation of the measure

a. Saving of industrial water

Use of industrial water has become unnecessary as a result of employees of caustic soda washing.

Saving by 2,125 m³/y (entry to the process: 1,075 m³)

b. Saving of steam for evaporation

1,075 m³/y ÷ 3 m³/t = 358 t-steam/y

c. Reduction of man-hour

3 men/day × 15 days/time × 5 times/year = 225 men/year

(4) Improvement of plate heat exchanger chemical washing work

The heat of red mud thickener overflow solutiuon is recovered with a plate heat exchanger and is used for heating the process solution after termination of crystallization.

Sulfuric acid washing is performed on the high temperature liquid side because the scale component is of sodalite type. Caustic soda washing is performed on the low temperature liquid side, on the other hand, as the scale components are aluminum hydroxide and soda oxalate. The frequency is once a month on both sides, and the washing conditions are as shown in Table 6.6.

Table 6.6 Conditions for chemical washing of plate heat exchanger

	Step	Concentration (%)	Temperature (°C)	Flow rate (m³/h)	Time (h)	Total flow (m³)
High temperature liquid side	Sulfuric acid washing	10	Normal temperature	45	4	10
	Hot water washing	—	80	45	2	20
Low temperature liquid side	Caustic soda washing	45	80	45	4	20
	Hot water washing	—	80	45	2	20

Specification for plate heat exchanger

Heat transfer surface area	284 m²/unit
Number of plates	201 plates/unit
Plate interval	5 mm
No. of units installed	8 units

It was found as a result of investigation of the situations of deposited scale on the high temperature side that monthly sulfuric acid washing is of excessive frequency. Therefore, the frequency was changed to once every three months.

The Na_2O concentration of the hot water washing waste liquid on the low temperature side is 20 g/ℓ, but liquid of high soda concentration comes out immediately after start of hot water washing because of residual liquid in the heat exchanger. It was therefore determined to recover as process solution the solution discharged in the period of five minutes (at pump delivery rate 0.7 m³/min) after start of hot water washing and to send the wastewater after elapse of this time to the wastewater treating process. The recovered liquid became Na_2O 95 g/ℓ, volume 3.5m³/unit, and the wastewater fed to the wastewater treating process became Na_2O 4 g/ℓ, volume 16.5m³/unit.

Effect after implementation of the measure

Low temperature liquid side

Reduction of steam for evaporation accompanying reduction of hot water washing discharge liquid entering the process solution

Reduction of water entry rate
16.5 m³/unit × 8 units/time × 12 times/y = 1,584 m³/y

Reduction of steam consumption
1,584 m³/y ÷ 3 m³/t-steam = 528 t/y

High temperature liquid side

a. Saving of industrial water by extension of washing period

20 m³/unit × 8 units/time × (12 − 4) times/y = 1,280 m³/y

b. Saving of sulfuric acid by extension of washing period

10 m³/unit × 8 units/time × (12 − 4) times/y × 1.08 × 10% ÷ 98% = 70 t/y

Increase in the neutralizing process

4 g/ℓ × 16.5 m³/unit × 8 units/time × 12 times/y ÷ 62 × 100 = 10 t/y

Saved weight 70 − 10 = 60 t/y

c. Saving of inhibitor (inhibitor of 0.5 vol% is added after sulfuric acid washing)

10 m³/unit × 8 units/time × (12 − 4) times/y × 0.005 = 3.2 t/y

(5) Saving of aluminum hydroxide washing water at Oliver filter

In the production of sandy alumina, the aluminum hydroxide slurry after completion of crystallization is fed through primary thickener, secondary thickener and tertiary thickener, and the aluminum hydroxide obtained with the primary thickener is used as the product.

The aluminum hydroxide obtained with the secondary thickener and tertiary thickener is added as seeds to the first crystallization tank. Soda oxalate ($Na_2C_2O_4$) is attached to the surface of the aluminum hydroxide from the tertiary thickener. Since it obstructs crystallization of aluminum hydroxide, it should be removed in advance.

As soda oxalate is easily soluble in hot water, the filtration cake of the Oliver filter is repulped with hot water in the seeds washing process to dissolve soda oxalate in the hot water, filtration is made once again, and the cake is fed to the crystallization tank as seeds.

The filtrate containing soda oxalate by a large quantity is fed to the oxalic acid removing process where it is made to react with slaked lime, and is removed with a thickener as calcium oxalate. The thickener's overflow solution is added by CaO and is returned to the oxalic acid removing process. A rough flow of this process is shown in Figure 6.8.

The relation with the soda oxalate removing rate was investigated in order to save the repulp hot water flow. The removing rate drops from 90~95% to 80~95% when the hot water flow is reduced by 20%, but there is no problem when the drop is of such an extent. If the hot water flow is reduced beyond this level, the NaO concentration in the liquid increases and the rate of reaction between soda oxalate and slaked lime rapidly drops. Therefore, it was determined to reduce the hot water flow by 20% only.
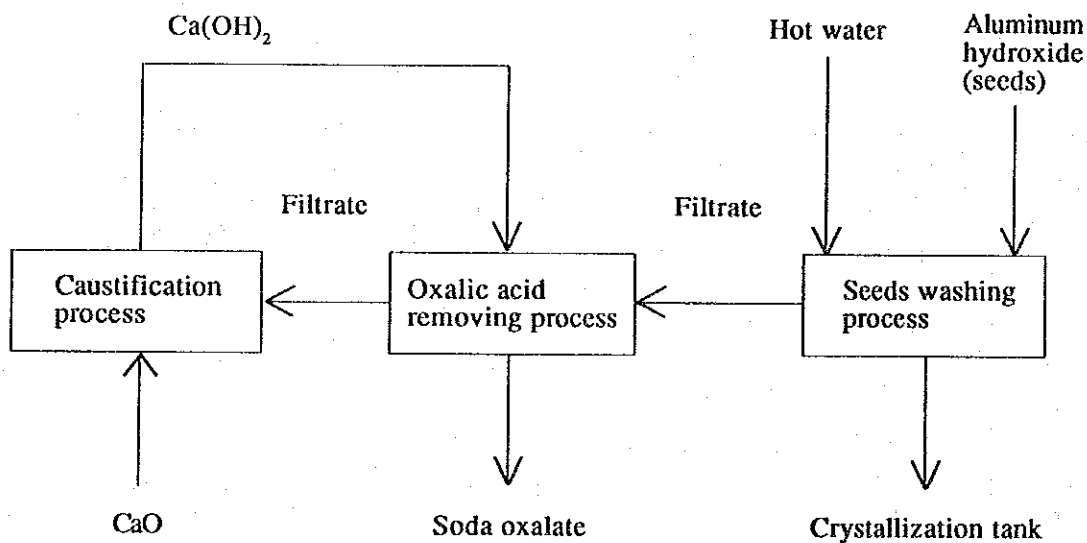

Figure 6.8   Rough flow of seeds washing process
and oxalic acid removing process

Effect after implementation of measures

Concentration steam saved volume 9,500 t/y (50.4 M¥/y)

(6) Saving of red mud washing water (Kelley filters)

The overflow solution from the red mud liquor thickener is filtered with eight pressure leaf filters (Kelley filters), and the filtrate is fed to the crystallization process at this factory.

The filters are stopped and opened, and the filtration media, red mud fine particles, etc. on the filter cloth surfaces are removed by water washing after use for about 20 hours. The industrial water used at this time is 7.2 m^3 per unit, and ten units are washed per day. This washing wastewater contains Na_2O of 40 g/ℓ and solid substance of 180 g/ℓ, and it enters the process solution. A number of measures were attempted to eliminate this water, it was finally found that improvement of water washing nozzle bore is effective, and this measure was implemented.

Twelve water washing nozzles are provided. It was found as a result of check that their bore is dispersed between 8 mm and 9.5 mm. Tests were conducted under these circumstances, and the relation among the bore, water flow rate and washing effect was checked. The results are shown in Table 6.7.

Table 6.7 Results of nozzle tests

Bore (mm)	Water flow rate (m^3/h)	Washing time (minute)	Water consumption (m^3/unit)	Feeling of water washing operator
9.5	10.5	45	7.9	—
9.0	9.2	48	7.4	—
8.0	7.8	50	6.5	—
7.0	6.8	53	6.0	No change at all.
6.0	3.9	70	4.6	Little change only.
5.0	2.5	—	—	Washing cannot be performed.

It was judged from the test results that it is totally good to set the bore of all the nozzles at 6 mm, although the washing time becomes slightly long, and this measure was implemented.

Effect after the measure

a. Saving of industrial water

Before improvement   7.2 m³/unit × 10 units/d × 333 d/y = 23,980 m³/y
After improvement   4.6 m³/unit × 10 units/d × 333 d/y = 15,320 m³/y
Water saved volume   8,660 m³/y

b. Saving of steam for evaporation

8,660 m³/y ÷ 3 m³/t-steam = 2,890 t/y

(7) Typical items of implementation of other measures

a. Change of slurry control valve from butterfly valve to ball valve

Steam, that is used for smoothing the operation of the butterfly, becomes unnecessary.

b. Review of chemical washing temperature for crystallization tanks

The steam flow was reduced by optimizing the temperature of chemical washing using caustic soda.

c. Repair to points of equipment, tanks, pipelines, valves, etc. where heat insulation is deteriorated or removed

It was determined to strengthen inspection and to implement repair beginning at points of large heat radiation. Furthermore, the standard for optimum heat insulation thickness was reviewed and was revised to what is matched with the present energy unit prices.

d. Improvement of process solution continuous specific gravity measuring instrument

The continuous specific gravity measuring instrument installed on the field was changed from water purge type to diaphragm type, to prevent entry of water to the process, and thus the steam for evaporation was reduced accordingly.

e. Intermittent running of agitators using timers

    The slurry of red mud fine particles, when the solid concentration is high, will not
    sediment immediately even if the agitator is stopped, unless sand is mixed in it. Even
    with slurry of low solid concentration, no troubles occur even if the agitator is stopped
    for a while. Timers were mounted to the red mud slurry tank, limemilk tank, miscella-
    neous water tank, etc. to perform intermittent running, and thus the electric energy
    required for agitation was reduced.

f. Change of resistance type indicator lamps to transformer type indicator lamps

    The voltage was reduced with a resistor to 18 volts for indicator lamps, but it was
    changed to a transformer type to save the electric energy.

g. Provision of top covers for large size outdoor crystallization tanks

    Top covers were provided for large size outdoor crystallization tanks to prevent heat
    radiation, to prevent entry of rainwater and also to prevent scattering of mist.

h. Uplift of fuel oil unit consumption by increase of the calcination capacity of the
    calcinators by stabilizing the operation or prevention of air infiltration

    The fuel oil unit consumption was improved by implementing centralized production
    with the calcination capacity per unit increased.

i. Reduction of calcinator leak air

    The points of air leakage between the kiln and the smokestack were exhaustively
    repaired, to uplift the combustion efficiency and to reduce the electric energy for the
    suction fan.

j. Reduction of steam blown into the electric precipitator

    Steam was blown into electric precipitators to increase the precipitation effect, but it
    was changed to water spraying using multiple nozzles. As the water evaporates by the
    heat of the gas, the steam consumption could be reduced to zero while maintaining the
    specified precipitation efficiency.

k. Uplift of ball mill's grinding efficiency

    The optimum combination of ball size was determined through testing with real machine,
    to save the electric energy. Wear resistant balls of small diameters were adopted.

l. Improvement of heating of fuel oil accepting line

Constant heating was discontinued, and it was determined to perform heating at necessary time only.

m. Review of illumination in the factory

The illumination was reviewed to obtain suitable illuminance. Furthermore, for the illumination required at the time of night patrol only, the locations of lamp switches were changed so that the lamps can be sequentially lit along the passage only and be turned off after passage.

7. Energy Conservation in the Cement Industry

7. ENERGY CONSERVATION IN THE CEMENT INDUSTRY

7.1 Introduction

The cement industry is capital-intensive and energy-intensive. It faces many problems including periodic variation of demand, low prices, competition with imported products, high energy cost and environmental control. Thus the cement industry is pressured in the aspect of improvement of efficiency and cost reduction issues.

The energy efficiency is high in the production of Portland cement. But the energy cost occupies over 40% of the direct cost. When the fuel cost rapidly rose in the 1970's, the cement trade promoted construction of new plants and modernization of plants including installation of preheaters and precalcinators and conversion of fuel into coal. Development of energy conservation equipment in the recent production of cement is in progress mainly in European nations and Japan.

However, low profits and high capital cost obstruct investment for modernization to satisfy the environmental standards and to improve the productivity.

(1) Fundamental points of consideration on energy conservation

The rough flow of heat in the production of cement, in the case where the heat consumption is assumed as 3,767 kJ/kg-cl, is shown in Table 7.1 and Figure 7.1.

Table 7.1 Heat Input/output

Heat input	(kJ/kg-cl)
Fuel oil heating value	3,767
Sensible heat of feedstock	126
Sensible heat of fuel	63
Heat output *	
Reaction heat of clinker	1,712 **
Sensible heat of exhaust gases	963
Sensible heat of clinker	126
Sensible heat of exhaust air	460
Heat radiation from furnace walls	837

Notes *: The heat exchanged between combustion gas and feedstock and the heat exchanged between clinker and cooling air is apparently internally recirculated heat.

**: The reaction heat is composed of endothermic decarbonizing heat of limestone and exothermic clinker-forming heat.

ENTHALPY FLOW DIAGRAM

Unit: kcal/kg-cl
s.h.: sensible heat

FUEL 900

Raw Meal s.h. 30

Fuel s.h. 15

IN

HEAT EXCHANGE

OUT

RECOUP (SECONDARY AIR)

Exhaust Air 110

Clinker s.h. 30

OUT GAS 230

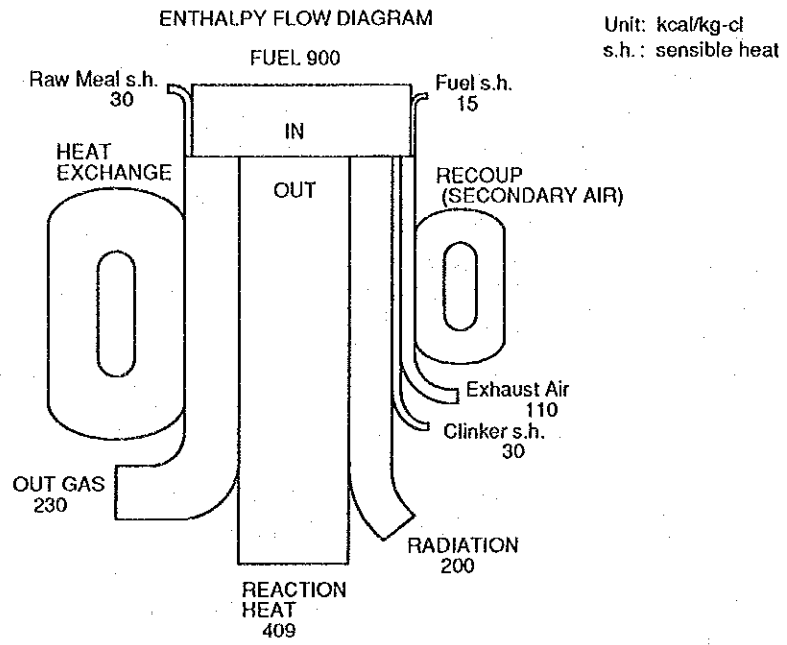RADIATION 200

REACTION HEAT 409

Figure 7.1 Heat flow diagram

The temperature profile of the system including preheater, kiln and cooler is shown in Figure 7.2.
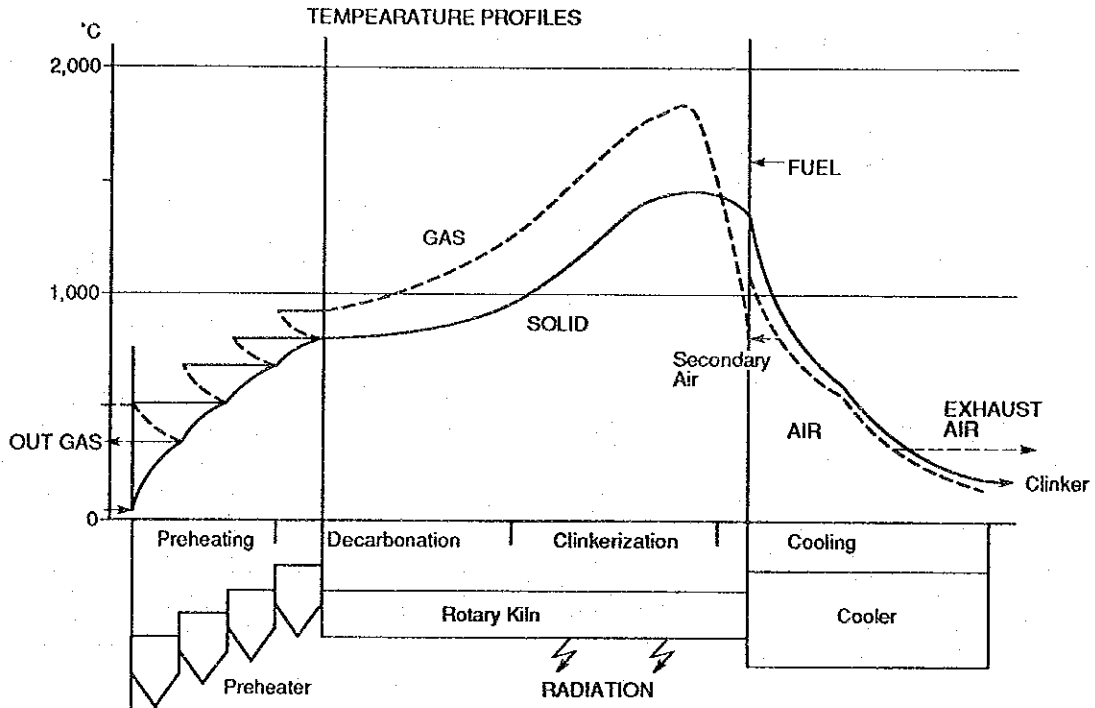

Figure 7.2 Temperature profile

Heat has two different values. One is heating value (kJ) and another is temperature (°C). The higher the temperature, the higher the serviceability of heat even with the same heating value. The product of heating value and temperature is called "heat value" (Wertigkeit der Wärme).

Table 7.2 indicates what were brought out from Table 7.1 and Figure 7.2. It indicates the fundamentals of the energy conservation measures in the cement industry. The ultimately required heating value is limited to Reaction Heat (1,712) + Radiation Loss (837) = 2,549 kJ/kg.

Table 7.2 Fundamentals of energy conservation measures

	Enthalpy	Temp	Characteristics	Countermeasures
Needed Heat	kJ/kg-cl	°C		
Reaction Heat	1,712		Definite	
Secondary Air	963	800	Temp: the higher the better	Cooler Operation
Heat Loss				
Radiation	837	100-350		Insulation, Coating
Exhaust Gas	963	400	Gas quantity: the less the better	Prevention of Air Infiltration
Exhaust Air	460	350	Air quantity: the less the better	Cooler Operation
Clinker	126	150	Temp: nearly definite	

The principal objects of energy conservation in the kiln system are losses caused by burnt exhaust gases and exhaust air, clinker sensible heat after cooling and heat radiation from furnace body.

The energy loss level varies by the process and running operation. Process in this case includes equipment and system, and running operation means frequency of shut-down and errors caused by carelessness such as air leakage.

It is possible to employ the optimum process depending on the investment amount at the time of construction of a new plant. At the time of modification, however, selection of process and equipment and examination of priority order of points of modification should be made in correspondence to the "cost performance". For this objective, it is important to study processes in detail and to listen to opinions of experts.

The running operation will become optimum if a suitable method is determined through full understanding of processes. Therefore, study of new technologies should be continued based on subject series. It is also important to uplift the consciousness of general employees regarding safety, quality control, production cost and energy conservation. United activities of all members of a task force organized under a good leader will help solving problems.

(2) Process and scale in the production of cement

Figure 7.3 and Figure 7.4 indicate data in U.S.A. They tell us the importance of the effect caused by differences in the process and scale.
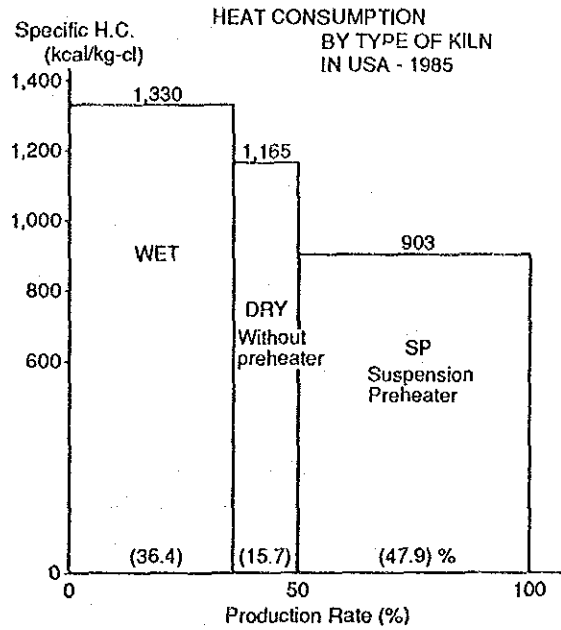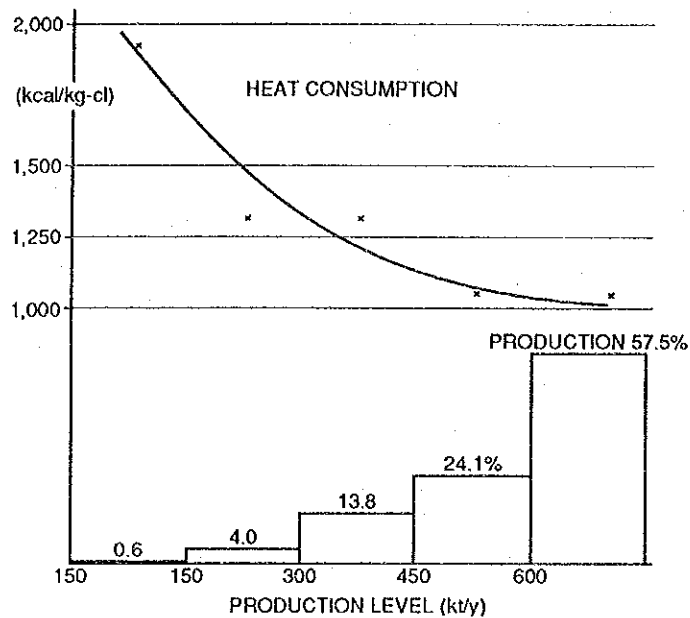

Figure 7.3 Energy unit consumption by process
in the cement industry in U.S.A.

**Figure 7.4 Energy unit consumption by scale
in the cement industry in U.S.A.**

What are observed in Japan, in which the cement industry is most advanced, are as follows. Since three NSP's (precalcinators) were developed and constructed about at the same time of 1973, kilns of this type were rapidly constructed by a large quantity as shown in Figure 7.5. Investment of a large amount is naturally required for conversion of the process. But since large "performance" can be anticipated against the "cost", many enterprisers in Japan made decision to make modification. The performance anticipated by them included the fact that kilns of this type are useful for solving environmental problems, in the reduction of NOx emission in particular.

Furthermore, these kilns are also convenient for use of refuse fuel, and they are directly effective for energy conservation and cost reduction.
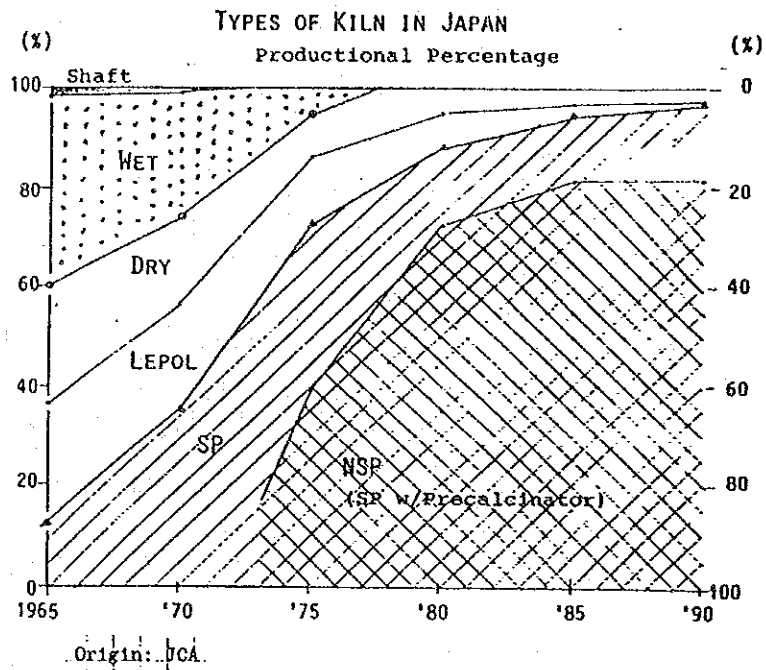
Figure 7.5 Types of Kiln in Japan

Also in Hungary, it is intended to modify three Lepol furnaces to one precalcinator at Vàc. This modification can be simply implemented by incorporating an equipment that is capable of burning 10~30% of the fuel in a part of the cyclone heat exchanger. The calcination capacity of the kiln will increase to a major extent, but there are cases where modification is required so that the capacity of the equipment in the upstream or downstream will not become a bottleneck.

The "productivity of kilns" in Japan rapidly increased by three folds in a short period of five years in the latter half of 1970's as shown in Figure 7.6. This period is matched with the time of employment of precalcinators.
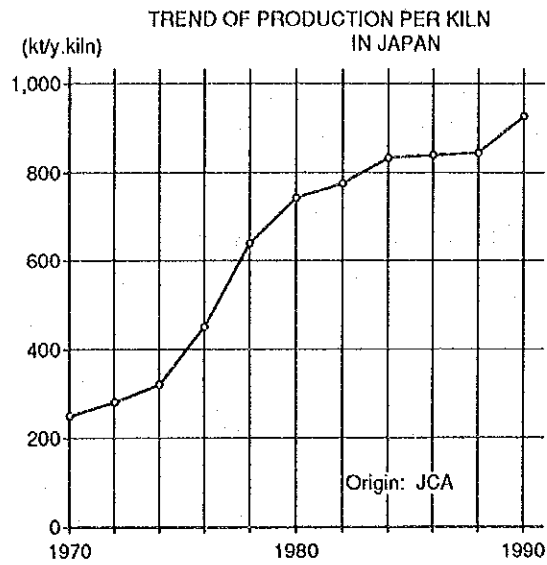
```
       TREND OF PRODUCTION PER KILN
(kt/y.kiln)            IN JAPAN
1,000

 800

 600

 400

 200
                         Origin: JCA

   0
   1970         1980          1990
```

Figure 7.6 Trend of Production per Kiln

(3)   Energy consumption and cost

Figure 7.7 indicates the trend of energy unit consumption in the cement industries in the world in the past ten years. The graph includes Japan and Korea as advanced nations, U.S.A. and England as worst nations as well as some European nations as middle. The statistics of Hungary indicate that their energy unit consumption was caught up by U.S.A. and England. But it is anticipated in the forecast up to 2000 that improvement will be made.
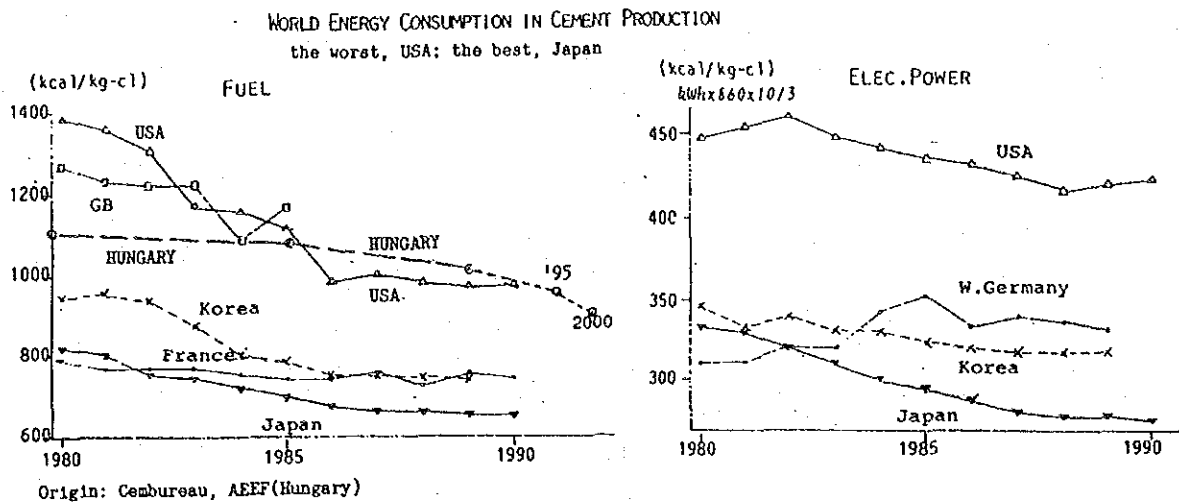
WORLD ENERGY CONSUMPTION IN CEMENT PRODUCTION
the worst, USA; the best, Japan

Origin: Cembureau, AEEF(Hungary)

Figure 7.7 World Energy Consumption in Cement Production

The cement production cost in Japan dropped drastically in the 1980's. The effect of improvement of equipment appeared at many factories in the first half of the 1980's, and the influence of the exchange rate between U.S. dollars and Japanese yen became conspicuous in the latter half of the 1980's.

Figure 7.8 indicates the composition of energy consumption in the cement industry of Japan twenty years ago and at the present time. The composition by process of feedstock preparation, pyroprocess and finish grinding (cement) is shown in the up-down positions and the composition of fuel and electric energy is shown in the right-left positions in this figure. Conversion of the electric energy into calorific value was made assuming the power generation efficiency as 30%.

Figure 7.9 indicates the progress of the component ratio of the cement production cost. Although fuel conservation made remarkable progress, the ratio of conservation of the electric energy is low.

It is noteworthy that little progress is observed in the finish grinding. But there is a possibility where improvement will occur in the near future.

ENERGY CONSUMPTION IN CEMENT PRODUCTION
IN JAPAN

-1970-

Total Energy
kcal/kg-cl

1,420.0
(100%)

Oil
19.6%

Elec. 80.4%

11.1 Raw
Material

Fuel Oil

Elec.

93.8

6.4

Clinker

78.5

Oil 1.2

Elec. 98.8

10.3 Cement

-1990-

kcal/kg-cl

1,002.7
(70.6%)

Coal 3.3%

Elec. 96.7%

8.5

Coal

Elec.

89.6

10.4

78.3

Coal
2.7

Elec. 93.3

13.2
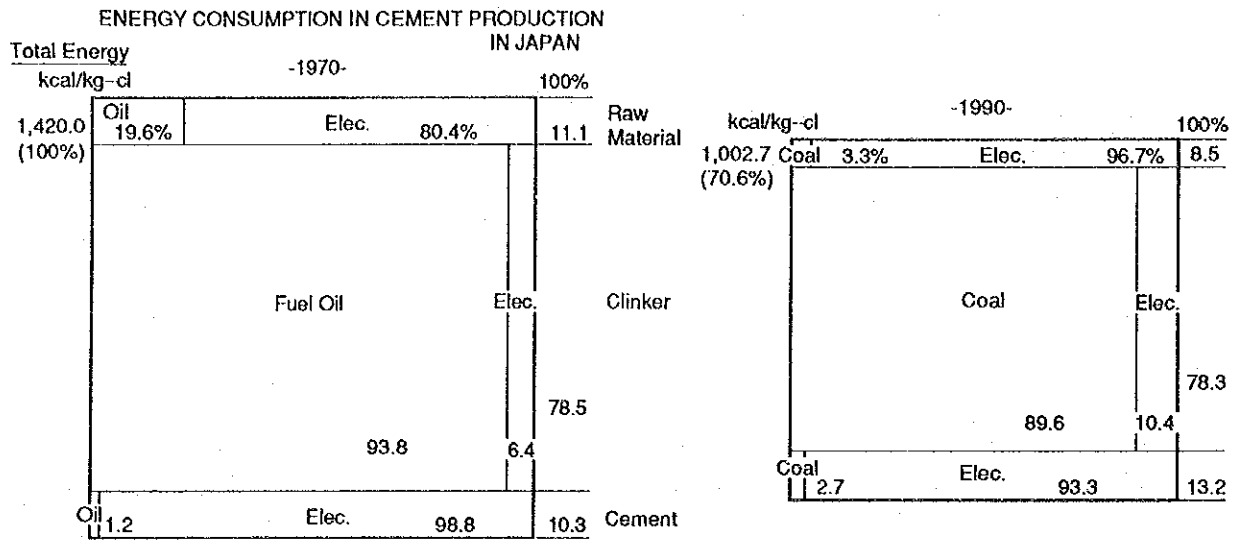
Figure 7.8 Energy Consumption in Japanese Cement Industry

TREND OF SOME ITEMS IN PRODUCTIOIN COSTS

(%) [IDEM]

(%)

100

0

Labor

80

20

Others

60

40

40

60

Elec. Power

20

80

Fuel

0

100

1981   '84   '87   '90

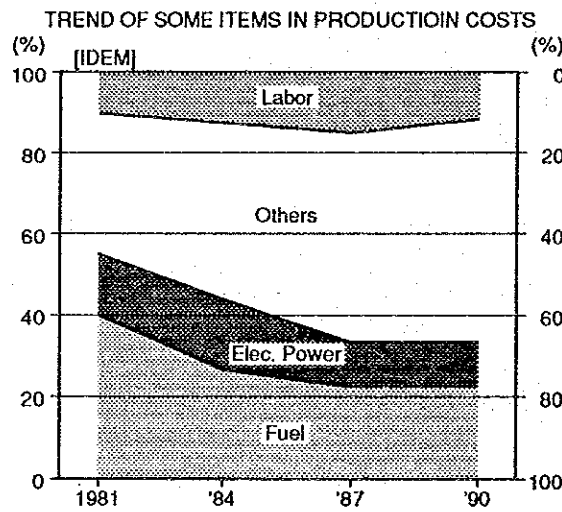**Figure 7.9 Composition of cement production cost**

Figure 7.10 indicates the progress of improvement of electric energy unit consumption by process, and Figure 7.11 indicates the ratio of electric energy to the entire energy consumption.

Employment of roller mills for grinding the feedstock began in 1975 and these mills made quick penetration. Use of roller mill and roll press also started partly for finish grinding since the latter half of the 1980's.
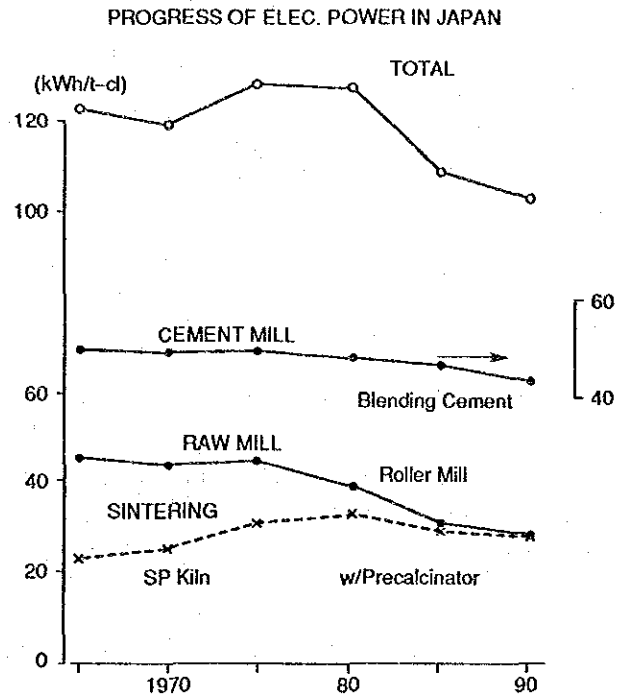
PROGRESS OF ELEC. POWER IN JAPAN

Figure 7.10 Progress of electric energy unit consumption

(kcal/t–cl)

CHANGE OF ELEC. POWER RATIO
IN JAPAN

1,500

Total Energy

1,000

Elec. Power Ratio

30

(%)

500

Elec. Power*

20

* kWh×860×10/3
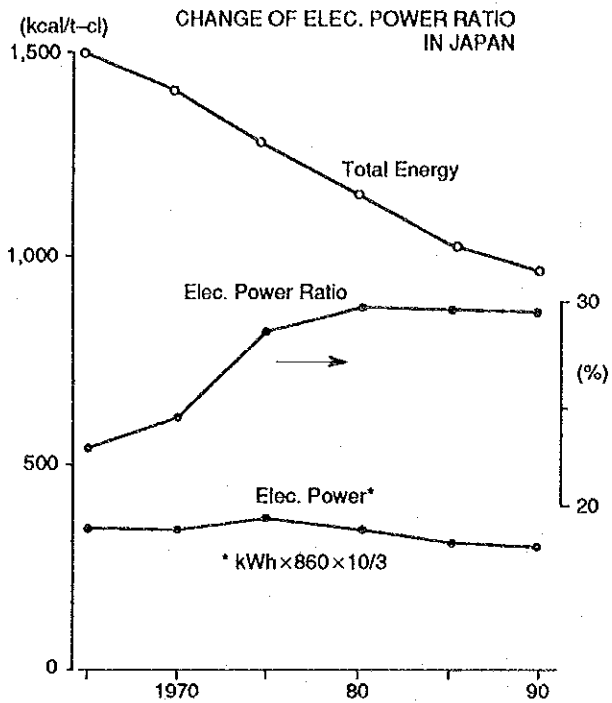
0

1970   80   90

Figure 7.11   Ratio of electric energy in energy consumption

The progress of labor productivity in the production of cement is shown in Figure 7.12 for reference. Uplift of labor productivity was powerfully promoted since the 1960's because of remarkable increase of the labor cost, and the productivity increased to over five folds in the period of last 25 years.

PROGRESS OF LABOR PRODUCTIVITY IN JAPAN
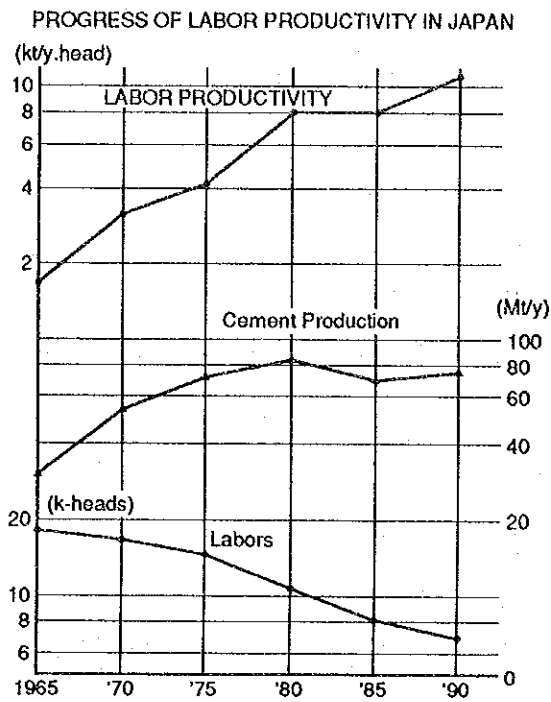
(kt/y.head)

Figure 7.12 Progress of labor productivity in the production of cement

(4) Fuel prices and conversion of fuel

a. Conversion of fuel

The energy prices in Hungary increased since the latter half of the 1980's and rapidly increased again in 1990/91 period to levels close to international prices, as shown in Figure 7.13.
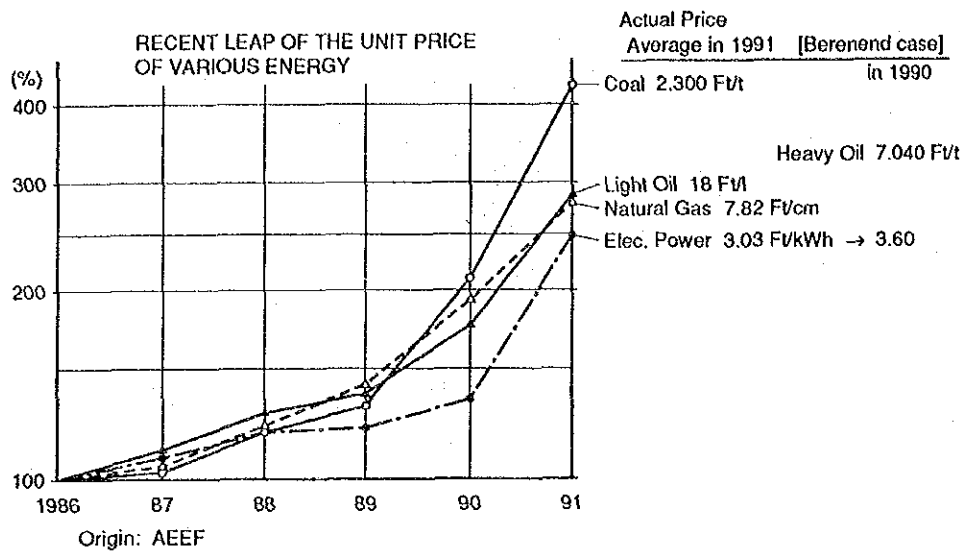
7-13

RECENT LEAP OF THE UNIT PRICE OF VARIOUS ENERGY

Actual Price
Average in 1991 [Berenend case]
in 1990

Coal 2,300 Ft/t

Heavy Oil 7,040 Ft/t

Light Oil 18 Ft/l
Natural Gas 7.82 Ft/cm
Elec. Power 3.03 Ft/kWh → 3.60

Origin: AEEF

Figure 7.13 Recent rise of energy unit prices in Hungary

Coal resources of a large quantity are available in Europe, and they require investigation in detail. Fuel of good quality and of good handlability is relatively of a high price, and fuel of inferior quality and of inferior handlability is available at a low price. In practice, the prices of fuel are in the order of gas, liquid fuel and solid fuel - the last is the lowest. To miss the opportunity to use closely located inexpensive resources due to being accustomed to conventional stable supply should be avoided. It is recommended that studies are made to convert the fuel to less expensive fuel, i.e., to liquid fuel or solid fuel if gas is currently used and to solid fuel if liquid fuel is currently used.

It is a pity that coal resources in Hungary is not of a large quantity, but attention should be paid to brown coal which is in existence in a larger quantity. Fortunately, economical and technical foundation regarding use of brown coal by a large quantity has already been established in Germany.

For use of brown coal, it is important to organize a project team between the supplier side and the user side first of all. It is desirable for the cement industry to tie with large users, thermal power plants for instance, and to establish an organization for cooperation in the aspects of prices, stability of supply, transport, shipping, storage and exchange of technical information.

Figure 7.14 and Table 7.3 indicate the distribution of energy resources and composition of fuel at thermal power plants in Hungary.
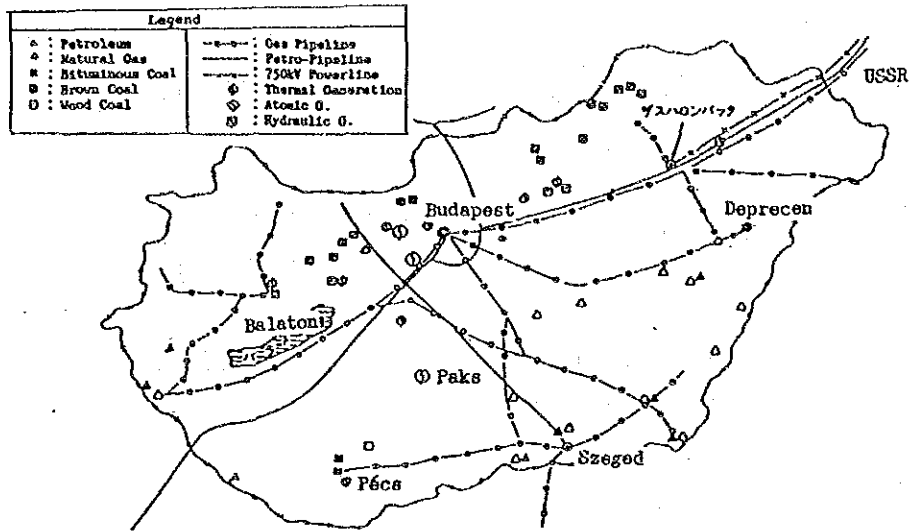

Figure 7.14 Distribution of energy resources in Hungary

Table 7.3 Fuel used at thermal power plants in Hungary [%]

	1970	1980	1985	1989
Bituminous Coal	9.6	6.9	5.3	7.3
Brown Coal	13.3	27.2	26.8	32.7
Wood Coal	12.8	17.1	16.5	15.5
Petroleum	19	13.9	21.2	8.9
Natural Gas	15.2	34.8	30.2	35.6

Origin: "Statistical Pocket Book of Hungary"

In Japan, since almost all of the energy except for hydraulic energy is dependent on import from foreign countries, the prices vary as linked with international prices. The management, therefore, is extremely sensitive on fuel prices. When it is anticipated that high prices will continue for a long time, measures are quickly taken. Typical example is conversion of fuel made twice in the past in the cement industry indicated in Figure 7.15. Conversion was made by over 90% in such a short time as two years, which is far shorter than before, toward the end of the 1970's based on the competition principle.
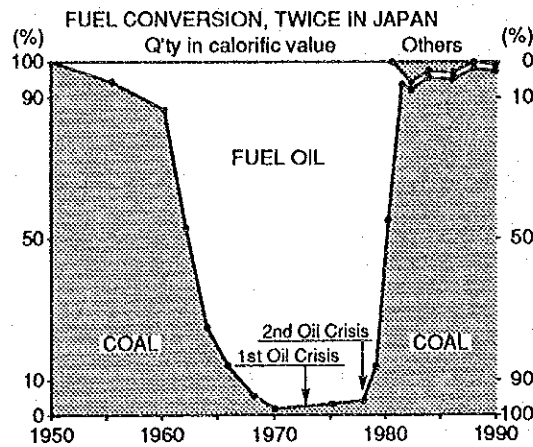
Figure 7.15 Conversion of fuel in the cement industry in Japan

b. Use of refuse

To make use of refuse as fuel has the following significance.

1) Substance which was abandoned as being valueless can be used for production.

2) Outstanding cost saving is brought to the cement factory.

The combustion zone of a rotary kiln requires high temperature, and it is necessary that at least one part of the fuel is high class fuel. But more lower fuel may be used if precalcinators are provided.

Use of refuse involves fear regarding equality of quality and stability of supply, and it also involves such problems that technical information and experience are minor and agreement of the neighboring areas is required.

A comparison of fuel prices in U.S.A. is shown in Table 7.4.

Table 7.4 Relative Costs of Fuels Used at Genstar's Redding Plant

Fuel	Relative Cost	Energy Content (kcal/kg)
Coal	1.0	7,100
Gas	2.5	570 /cu.ft
Rice Hulls	0.9	3,400
Wood Chips	0.7	4,100
Coke	0.6	8,300
Rubber Tires	0.6	7,800

(Segal 1984)

1) Petroleum coke

Petroleum coke is supplied in abundance from the petroleum industry and is inexpensive. But the combustibility is rather inferior. It is used in England, Norway, Japan, etc.

2) Urban refuse

Used at Blue Circle Cement Factory in England, and Wettekindt Factory in Germany

3) Chaff and wood refuse

In a case of implementation in U.S.A., problems of ring formation occurred when chaff and coal were fired in mixture because of high ash content.

4) Tyres

Use of tyres as fuel at a cement factory was commenced in Japan, and today tyres are used in the whole world.

5) Noxious refuse

Norcem Factory of Norway commenced combustion tests of noxious refuse in 1981. These tests include waste oil, aromatic compound, chlorinated organic compound, PCB, tar, and heavy organic compound. According to test results, it was indicated that these refuse were burnt by 99.99999% and that the quality of the product cement is not affected, although there are cases where dust emission increases by a minor extent.

6) Waste oil

Giant Portland Factory of U.S.A. used a mixture of the refuse from the hydrocarbon polymerization process and fuel oil. But coking occurred and the burner orifices were plugged when the fuel was superheated, and mechanical clean-up was required.

7) Sewage sludge

The sludge generated by a large quantity at a water treatment plant was dried by mechanical dehydration and by heating until the moisture content is reduced from 96% to 5 ~ 25%, and this sludge was burnt as blown into a 4-stage preheater. No problems occurred in the kiln running, air pollution or in the clinker quality.

Various refuse considered to be usable as fuel in the production of cement are indicated as classified in Table 7.5.

Table 7.5 Types of refuse considered to be usable as fuel in the production of cement [21]

Type	Example	Fuel Value (kcal/kg)
Brittle, Low Ash Content	Charcoal fines Rubber Char Petroleum Coke Brown or Lignite Coals (30% moisture)	5,000 - 7,000 5,000 - 7,000 6,200 - 7,500 4,000 - 4,500
Brittle, High Ash Content	Colliery minestone, shale or washery tailings High Carbon pulverized fly ash from coal-fired power stations Oil shales	500 - 4,000 1,000 500 - 2,500
Tough, Non-brittle Large Size	Domestic refuse, Municipal garbage Oil Palm shells (8% moisture) Peat (10% moisture) Vehicle rubber tires Acid battery cases Wood chips	1,500 - 2,500 4,800 4,000 - 4,500 5,000 - 7,000 3,000
Tough, Non-brittle Small Size Low density	Rice husks Saw dust Chopped straw	3,500 3,000 3,500
Fluid	Waste oils, oil refining residuals, waste organic chemicals, acid tars	5,000 - 10,000
Primary Fuel	Bituminous Coal (typical)	6,100

(5) Mixed cement

Mixed cement is produced by mixing and grinding Portland cement clinker and additives or by mixing after grinding separately. Since no calcination energy is required for additives, no energy conservation is achieved per ton of clinker, but large energy conservation is achieved per ton of cement. Therefore, mixed cement is what matches the social needs of refuse treatment and energy conservation.

In the advanced nations in the Western Europe and in the nations in the Eastern Europe in general, mixed cement of various types is used. Table 7.6 and Figure 7.16 shown below indicate the current situations in Europe.

It is important to investigate standards in each nation also in this case.

Table 7.6 Current situations of mixed cement

a) Blast-Furnace Cement		b) Regulation of Cement Additives	
Czechoslovakia	63%	20%	Czechoslovakia
Poland	40%		Poland
Rumania	35%		France
Russia	27%	15%	Austria
W. Germany	23%	10%	Greece
E. Germany	18%		Spain
Belgium	18%	1%	W. Germany
France	10%	0.5%	E.Germany
Italy	9%		

BLENDING CEMENT
actual and perspective

(%)

60

Luxemburg

40

France

Total
OECD

Japan

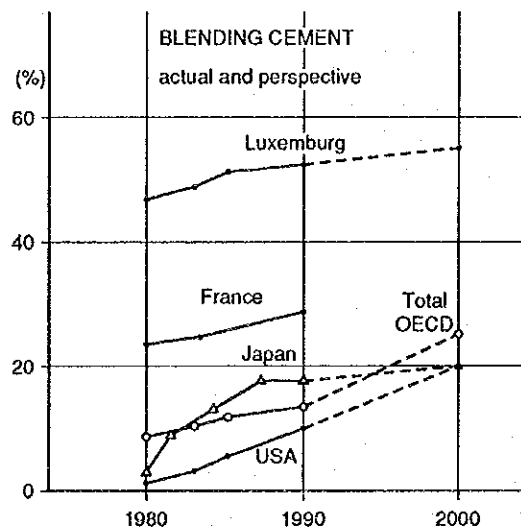20

USA

0

1980   1990   2000

Figure 7.16 Current situations of mixed cement

7-20

The additives used include industrial waste and bi-products (such as fly ash from coal firing thermal power plants and glassified granular blast furnace slag), dust of cement kilns and natural pozzolan.

① Fly ash

Fly ash is obtained with precipitators of fine coal combustion equipment of power plants and so forth, and is mainly composed of SiO_2, Al_2O_3, Fe_2O_3. When it is crushed to small particles, it can be mixed in cement without further treatment.

② Blast furnace slag

Blast furnace slag requires treatment such as quench glassification in order to permit full exhibition of its potential reactivity. There is such a trend that grinding of blast furnace slag is harder than Portland cement clinker. It has been reported (PCA, 1975) that more equal product of higher strength is produced when blast furnace slag and clinker are separately ground and are then mixed together, rather than grinding them together as mixed.

③ Kiln dust

Provisions are made at a cement factory to return as much kiln dust as possible to the kiln. Kiln dust is of the composition that is similar to that of kiln feedstock. But it usually contains alkali, chlorides and sulfate by considerably high rates, and accordingly, there is a limit in the recycling to the kilns. (Dust quantity is about 0.14 ton per ton of produced Portland cement.)

It has been proposed to use mixture of kiln dust and fly ash to suppress the alkali coagulating reaction when kiln dust is mixed in cement.

④ Natural pozzolan

Natural pozzolan such as pumice, volcanic ash, tufas and expanded shale are what are originated by volcanic activities. They do not require drying in usual cases, but it is necessary to crush them before mixing in almost all cases. Some of them (such as zeolite, clay and shale) require calcination, and are not attractive.

(6) Regulations

Regulations in the cement industry include what are related to environmental protection against air pollution, water pollution and noise and what are related to standard of cement products.

Regulations on air pollution include controls on sulfur oxides (SOx) and nitrogen oxides (NOx) besides dust. Fortunately, although cement kiln systems have some problems regarding alkali, they are of excellent sulfur oxides absorbers. Regarding nitrogen oxides, high temperature combustion gases are required to produce quality cement, and this condition is contrary to suppression of generation of nitrogen oxides. In order to suppress nitrogen oxides, 2-stage combustion method was developed for boilers, for instance. The NSP (precalcinator) system is also of typical dual stage combustion and generation of nitrogen oxides is minor. The NSP system is essential to cope with nitrogen oxides control.

Regarding product standards, the cement industry should keep paying attention to changes in the requirements of the society and to the progress of technology and should make efforts to make correction in order to adapt to such changes. However, there is a possibility where energy conservation can be achieved thanks to optimization of standards.

Regarding alkali in cement, for instance, there are cases where severe standards are specified because cracking occurs on concrete surfaces due to alkali coagulating reaction. In such a case, a part of kiln dust should be abandoned, and with an SP kiln that uses high alkali feedstock, a bypass system should be used. It is estimated that the energy consumption increases by about 200 MJ/t when 10% of the exhaust gases are bypassed. Therefore, improvement of the energy efficiency can be expected if application of alkali standards is limited to special cement or if deregulation is made.

There is such a trend in U.S.A. that cement of large initial strength is well accepted. But while Japanese ordinary cement is of about 3,000 cm^2/g-Blaine at average, grinding is made to 3,600 ~ 3,800 cm^2/g-Blaine in U.S.A. It indicates that electric energy is excessively consumed by about 20% for finish grinding. [22]

It is necessary to have understanding of users for revision of standards, but it is desirable that the standards which do not suit the current technology level and standards involving unnecessarily excessive regulation are corrected through associations and/or academic organs.

7.2 Itemized discussions

(1) Preparation of feedstock

    a. Dehydration of slurry (case of wet or semi-wet Lepol process)

        Today filter presses are broadly used in Europe, and slurry is dehydrated to about 20% and is then directly charged to a kiln or a grate type preheater.

        Slurry thinner reduces the moisture content of slurry from 30% to 24%, for instance, using surface active agent.

    b. Roller mills

        Roller mills are compact, require little power, the running noise level is low and equipment expenses are low. Furthermore, they are fully automated.

        A comparison between roller mills and ball mills is shown in Table 7.7.

Table 7.7 Comparison of roller mill and ball mill

Conditions	Roller Mill	Ball Mill
Maximum feedstock size (in.)	2 to 5	0.25 to 0.75
Maximum moisture content for grinding (%)	15 (*)	7
Roller wear cost (% of ball cost)	60	100

(*) Roller mill can dry and grind material of any moisture content

    c. High efficiency classifiers

        High efficiency classifiers of various types are used. Mitsubishi dual separator (MDS) shown in Figure 7.17 was developed for grinding feedstock. It has been reported that it is of good separation performance and of easy running and that its energy consumption is less by 10% and the equipment expenses are also less by 10%. O-Sepa developed by Onoda Cement Co., Ltd. has been run in Japan since 1979, and it has been reported that the energy consumption is reduced by 8~20% with this equipment.
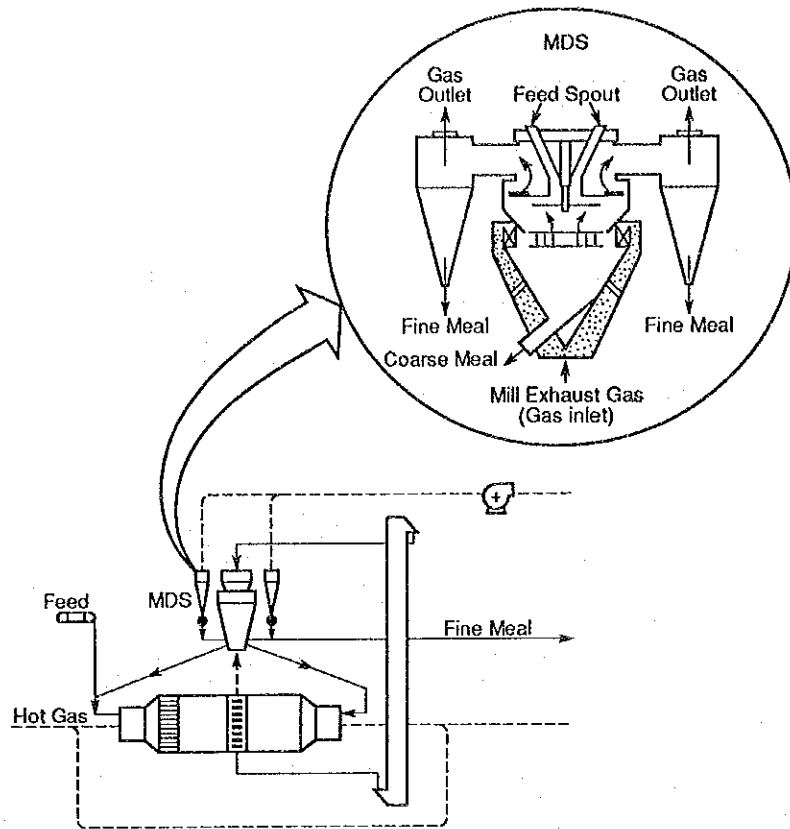
Figure 7.17 Mitsubishi dual separator (MDS)

d. Grinding media and mill liners

The grinding media motion pattern exerts major influence over the efficiency of grinding[1)2)]. It is determined by the following factors, but it can be corrected by the first three factors.

• Shape and surface configuration of the liners
• Size distribution of grinding media
• Load percent of the mill
• Resistance of the material against comminution
• Moisture content of the feed

Table 7.8 qualitatively indicates the factors which affect wear to a ball mill.

Table 7.8 Factors which affect wear to a ball mill

More wear	Less wear
Wet grinding	Dry grinding
High temperature grinding	Low temperature grinding
Corrosive material	Inactive material
Hard material	Soft material
Large supply rate	Small supply rate
Low pulp level	High pulp level
Large diameter mill	Small diameter mill
High speed rotation	Low speed rotation
Large grinding media	Small grinding media
Hard grinding media	Soft grinding media

e. Differential grinding

The distribution of the particle size of the feedstock plays an important role in the calcination energy. In general, it is said that as the feedstock is ground to small particle size, the temperature required for calcination becomes less or the reaction time at high temperature becomes short.

According to the experiments conducted at a laboratory, it was indicated that clinker is more easily produced when the clay particle size is smaller and that better result is obtained when limestone and clay are ground separately.

(2) Pyroprocessing - production of clinker

a. Conversion from wet process to dry process (case of wet or semi-wet Lepol process)

1) Conversion of a wet kiln directly to a dry long kiln

2) Conversion of a wet kiln to a kiln with preheater with the length shortened

3) Conversion of a wet kiln to a kiln with precalcinator with the length shortened

Table 7.9 indicates a comparison of heat balance among these processes.

Table 7.9 Comparison of heat balance between wet process and dry processes of good efficiency

	Wet	Dry		
		Long Kiln	Suspension Preheater	Precalciner
Heat Supplied				
Fuel	5.414	3.941	2.901	2.730
Raw Mix	0.072	0.048	0.048	0.048
Air	0.014	0.043	–	–
Total	5.500	4.032	2.949	2.778
Heat Required				
Clinker Formation	1.523	1.523	1.523	1.523
Clinker Sensible	0.040	0.056	0.072	0.086
Excess Air	0.137	0.308	0.390	0.350
Water Evaporation	2.206	0.022	0.022	0.022
Exhaust Gas	0.694	1.339	0.631	0.572
Dust	–	0.200	0.022	0.011
Radiat'n & Convect'n	0.900	0.584	0.289	0.214
Total	5.500	4.032	2.949	2.778

(MBtu/ton-clinker) (quoted from PCA 1975)

It is also necessary to pay attention to other factors such as the amount of investment for modification, production capacity and uplift of stability of operation regarding production of clinker. Stability of operation in particular is an important factor for quality, production rate, equipment utilization rate, refractories service life, production cost and number of workers. The stability of operation will uplift when the feedstock flash phenomenon that occurs accompanying carbon dioxide gas generating reaction in the calcination process in the first half of a rotary kiln is suppressed. In the case of a precalcinator, the decarbonating reaction that occurs in a rotary kiln is extremely minor.

b. Kiln's radiation loss and entry of air

Heat of a considerable quantity is lost from the shell, the portion located in the vicinity of the firing section in particular, of a rotary kiln. There are cases where the loss of radiated heat is as much as 8% to 15% of the heat input to the kiln. But this heat loss can be reduced by the use of insulating refractories. Refractories withstand heat, friction, thermal impact and chemical corrosion, extends the service life of the equipment and increases the efficiency. Bricks of alumina content 70% used for the lining of a kiln has thermal conductivity (K factor) of about 0.75.

Such a method that diatomaceous earth block bricks (of thermal conductivity about 0.18) are inserted to the back side of bricks of alumina content 70% is available as a method for reducing the heat loss[3].

Air infiltration from outside occurs at many sealed portions at both ends of the kiln and at the cyclone preheater between the kiln and the induced draft fan (IDF). The rate of air entry varies by the slit size and also by the difference in the pressure between the combustion gas and the outdoor air.

The radiated heat loss and entering air loss, when totaled, are equivalent to about 20% of the heat input to the calcination process.

c. Advanced kiln control method

Plant controls aims at uplift of running efficiency, reduction of production cost and strengthening of production capacity besides stabilization of many varying factors. Attention should be paid to the following points with the control system for a cement factory.

(1) Fuel unit consumption, heat recovery at the time of cooling of clinker, most economical running in the aspect of electric energy for the grinding process

(2) Production speed, and necessity of search and identification of process necks in the order of importance

(3) Temperature control of kiln firing zone, cooler discharge temperature, analysis of kiln exhaust gases, temperature of precipitator

(4) Firing zone temperature that is directly related to free lime, chemical composition, clinker density and kiln's temperature profile

(5) Stabilization of the process including chemical composition, feedstock supply rate, distribution of particle size, recycling of dust and airflow

Computers were introduced for controlling kilns beginning in the 1960's. But sufficient fruits were not obtained with early systems due to defects in the mathematical models and lack of reliability of sensors. Automatic kiln control systems of the second generation are used at the present time. They include fuzzy logic kiln control systems. The control programs of these systems are essentially what computerized kiln operation techniques of skilled operators by making use of fuzzy logic.

Each one of these programs takes such a general form that is indicated below.

IF [condition] ···· THEN [control action]

With a fuzzy controller, whether the firing conditions are optimized or not is monitored based on the statistical correlation between the level of nitrogen oxides in the kiln exhaust and the volume of the clinker discharged out of the cooler. Other parameters such as the temperature, combustible component and oxygen concentration of the exhaust gases from the preheater are used for routine checks. If the conditions are not optimum, either the suction rate of the induced draft fan or the fuel supply rate is adjusted. The kiln speed and the feedstock supply rate are kept at fixed levels.

d. Uplift of kiln internal efficiency

1) Low pressure loss cyclone

The new type small size cyclone of low pressure loss developed by FLS provides the following features.

① The outlet/cyclone diameter ratio is large.

② The center pipe is relatively short.

③ The overhang of the inlet is large.

A cyclone of this type was put into practical use for the first time in Spain in 1984. According to the running data, the pressure loss of the preheater is as low as 230 mmAq and the exhaust gas temperature is as low as 310°C, and accordingly, heat consumption is also as small as 3,056 kJ/kg-cl[4].

2) Fuel combustion system

The problems which are often observed at cement factories include generation of carbon monoxide and excessive air ratio due to faulty adjustment of burners and incomplete combustion.

Such a test result that energy conservation of about 4% was achieved as a result of lowering of the oxygen concentration in the kiln exhaust gases from 2% to 1% has been reported.

With newly developed burners, the flames are stable and are of high temperature, complete combustion is permitted and the flame form is also excellent. The importance of matching of burner design with kiln for increasing the combustion efficiency was recognized only recently.

3) Clinker cooler

Another large factor that contributes to heat losses at a cement factory is the heat loss from the clinker coolers. As the clinker coolers are run with heat recovery rate of 60% to 70%, a loss of 520 kJ/kg-cl occurs at maximum. Therefore, efforts are made to increase the heat transfer efficiency and to reduce the primary energy consumption of kilns. There are clinker coolers in which the heat recovery section and final cooling section are separated and cooling is made in dual stages in order to increase the heat recovery rate and to cool the clinker to the most possible extent in accordance with the old proverb, "a good heat recovery unit is an inferior cooler, and a good cooler is an inferior heat recovery unit".

According to references, there are cases where a heat exchanger is added to the exhaust system of the cooler to reduce air pollution. It is reported[5] that heat recovery rate increased by 5,020 MJ/h as a result of conversion of the cooler exhaust system to a closed circuit at Santa Cruz Factory (in California, U.S.A.) of Lone Start Corporation. Besides, various cases of improvement of cooler systems are discussed in the references[3,5,6,7,8].

(3) Finish grinding

a. Roller mill

Until 1987, cement mill of this type was developed only by Pfeiffer (West Germany) and Onoda-Kobe Steel (OK mill: Japan). It was reported by the latter that the electric energy consumed for finish grinding can be saved by 20% to 30%. Furthermore, since it is possible to keep the cement temperature at a low level during grinding with a roller mill, such advantages that no cement cooler is required, energy conservation is achieved and the equipment cost is reduced are obtained.

b. High pressure roll press

A press of this type is composed of twin rolls, and each roller is provided with a drive unit. The gap and pressure between rolls are kept at fixed levels by means of a hydraulic unit. This press is installed before the existing mill. The clinker's crystalline structure is fractured in the press, and reduction of particle size and particle size adjustment are made in the existing mill.

The communition with this press is achieved by means of compressive force, but the strain that occurs in particles by this force is five times as much as that caused by shearing force. As a result, when this press is used for crush of clinker lumps, the majority of the lumps are ground to such a particle size level that particles of 90μ or less occupy 30%. The production increases by 20 ~ 40% and the energy unit consumption decreases by 10 ~ 20%.

c. High efficiency classifier

Classifiers of high efficiency include new type vortex flow air classifiers. These classifiers are capable of achieving high separation efficiency with less power consumption and less capital cost compared to conventional classifiers.

Among side-draft type classifiers, O-sepa's (made by Onoda Cement) made broad penetration in the world and are achieving satisfactory results. In Japan, O-sepa's have been running since 1979, and the energy unit consumption decreased by 8~20% with them. O-sepa's are also used for ball mills for slag grinding besides mills for grinding of cement.

d. Grinding aids

Grinding aids are organic compounds and act as surface active agent for the clinker or the grinding media. These additives help dispersion of reduced-size feedstock to prevent formation of lumps. Grinding aids are used with the objective to increase the pulverization degree of the product or grinding throughput. The additives which are often used in the cement industry are ethanol amine and polyvalent alcohol. (Table 7.10)

Table 7.10 Additives used in Cement Industry Grinding Operations (adapted from Hartley, Priestry and Wick 1978)

Additive	% Added	Grinding Rate Factor
Water	0.04	1.3
Phenol & Polyphenol	0.01	—
Acetone	0.2	1.37
Sulfonic Acids	0.06	1.3
Sodium Stearate	0.15	1.2
Naphthenic Acid	0.1	1.33
Carbon Black	0.08	1.3

$$\text{Grinding Rate Factor} = \frac{\text{New surface produced with additive}}{\text{New surface produced without additive}}$$

(4) New type exhaust heat recovery power generation

Formerly, the heat of exhaust gases of 600~1,000°C from dry kilns was recovered with waste heat boilers and steam was used for power generation or as a utility for the factory. Since then, it has become possible to use low temperature gases or air for power generation as shown in Figure 7.18 thanks to progress of technologies.
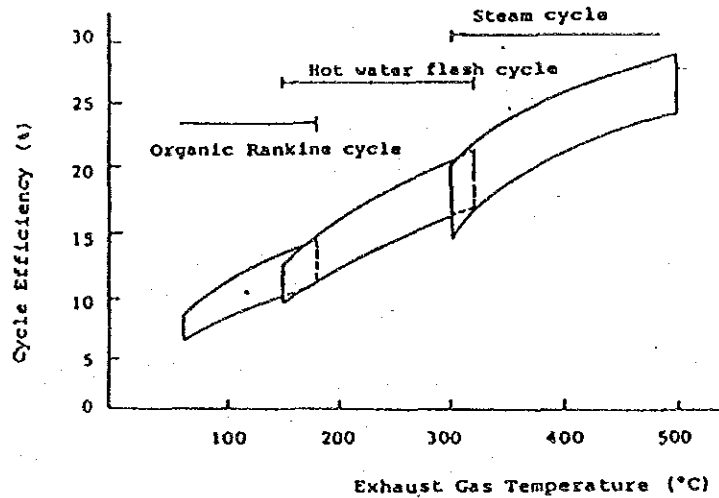
Figure 7.18 Relation between exhaust gas temperature and cycle efficiency

The maximum heat losses in a kiln system are sensible heat of kiln exhaust gases and sensible heat of cooler exhaust air as described earlier. These exhaust heats are partly recovered and used mainly for drying the feedstock or fuel, and in addition, they can be used to the maximum by the use of the sensible heat of gases or air of relatively low temperature for power generation. The number of embodiments of this new technology is still small in the world, but some cases are observed in Japan and all of them are extremely successful. The hot water flash cycle is more suitable than the organic media Rankine cycle as shown in Figure 7.18.

Equipment of this type requires investment of a huge amount and provision of engineers. But since the prices of electric energy in Japan are the highest in the world (about 13 Japanese yen per kWh, demand charge 3 Japanese yen per kWh, energy charge 10 Japanese yen per kWh), the ratio of profit to the investment is considerably high. It is anticipated that the investment can be recovered in 2 ~ 3 years and that about one third of the electric energy consumed for cement production becomes free thereafter.

The situations of implementation of exhaust heat recovery power generation in Japan are shown in Table 7.11.

Table 7.11 Achievements of exhaust heat power generation in Japan (1989)

	Total	Dry System	with Generator
Number of Kilns	80	69	31
Production (t/h) (%)	11,840 100	11,300 95	5,870 50
Generator (kW) (kWh/t-cl)			190,410 32.5

In the case the economy is examined generally, it is recommended that the figures shown in Table 7.12 and the following figures are used as a reference.

Table 7.12 Power gain from medium sized plant

	Temperature (°C) Inlet Outlet	Enthalpy Gain kJ/kg-cl	Power Gain kWh/t-cl
Exhaust Gas (from Kiln) Exhaust Air (from Cooler)	400 230 (*) 350 110	410 314	25 10
Total		724	35

In case of energy consumption of 3767 kJ/kg-cl
(*) This temperature is available for drying of material.

The construction expenses in Japan are as indicated below. They include boilers, turbines, generators and expenses for modification to existing equipment requiring about 1/3 to 1/4 of prices of new equipment. The 0.6'th power rule is established between the scale and the cost.

Power generation capacity	Unit price
10 MW	1,900 US$/kW
20 MW	1,500 US$/kW

Equipment of this type are in existence only in Taiwan besides Japan. It is because regulations that make it a duty to install power generation equipment of this type at a new factory were established by the government in Taiwan.

(5) Energy conservation effect

The effect of various energy conservation measures and typical implementation are shown in Table 7.13 and Table 7.14 as extracted from two reference.

Table 7.13 Estimates of the Energy-Conservation Potential of Current Technologies

Process Area	Ref. 9			Ref. 10
	% of Primary Energy Use(a)	State of (b) Development	Potential Impact(c)	Ref. No. in the next table
• Raw Material Preparation:				
1. Slurry Dewatering	1.3	Proven	Moderate	
2. Roller Mills	9.3	Proven	Moderate	11
3. High-Efficiency Classifiers	0.4	New	Moderate	
4. Grinding Media and Mill Liners	NA(d)	Developing	Low	12
5. Differential Grinding	0.7	Developing	-	
• Pyroprocessing:				
1. Wet/Dry Conversion 1)	3.6	Proven	-	
2)	16.6	Proven	Significant	
3)	20.0	Proven	Significant	13, 14
2. Kiln Radiation and Air Filtration	5.1	Developing	Moderate	
3. Advanced Kiln Control	2.3	Developing	-	15, 16
4. Kiln Internal Efficiency Enhancement	2.1	Proven	Moderate	3
• Finish Grinding:				
1. Roller Mills	1.1	New	Low	
2. Roll Press	2.4	Developing	Moderate	
3. High-Efficiency Classifiers	1.5	New	Moderate	17, 18
4. Grinding Aids	NA	Proven	Low	
• Waste Materials Utilization:				
1. Refuse-Derived Fuels(e)	3.6	Developing	Displace high-grade fuels	19
2. Blended Cements(e)	16.9	Developing		
• Waste Heat Utilization:				
1. Power generation	2.4-2.9	Developing	Moderate	20

(a) Elec. power consumption is converted with not 860 but 2625 kcal/kWh into the primary fuel savings.
(b) Proven: fully commercialized, New: newly demonstrated, Developing: under active investigation.
(c) Low: 0-10%, Moderate: 10-25%, Significant: 25-100%
(d) NA: not available
(e) Based on 20% substitution of a waste material for conventional fuel or cement.

Table 7.14 Examples of Recently Implemented Energy Conservation Measures In the Cement Industry

Measure	Ref. (#)	Company/Plant	Impacts
Grooved classifying liners and chromium-alloy cast ball charge for cement mill	12	Blue Circle-Atlantic/ Rovens, NY	• 28% power savings • 27% production increase • Liner life increase
High-efficiency separator for finish grinding	17	Lehigh Portland/Mason City, IA	• 26% power savings • 30% capacity increase
Roller mill for raw grinding replacing air-swept tube mill	11	. Not Available	• 24% power savings
High-efficiency classifier for finish grinding	18	Keystone Cement/Bath, PA	• 25-30% energy savings • 70% production increase
25 MW cogeneration with 2-waste heat boilers and a coal-fired CFB boiler	19	Calmat/Colton, CA	• Supplies all plant power needs • 62% savings in 10-fan power (used to cool kiln exhaust before filters)
Automatic computer kiln control using fuzzy logic	15	Ash Grove West/ Durkee, OR	• 3-4% fuel savings • 50% improvement in refractory life
Conversion of conventional suspension preheater to full precalcining system	13	Calmat/Rillito, AZ	• 13% fuel rate reduction • 29% capacity increase
Dry-precalciner plant (2700 tpd) replacing old wet process plant	14	Davenport/Davenport, IA	• 3.3 MMBtu/ton clinker fuel use • 125 kWh/ton cement power use
Precalciner with feed recirculation	23	Commercial plant test by Fuller Co.	• 2-8% energy savings depending on recirculation rate
Long-dry kiln improvements: Increase chains, semi-direct coal firing, install lifters, 1-stage preheater, increase kiln speed	3	• Not Available	• 23% fuel savings • 45% production increase
Kiln and precalciner excess - air supply control based on analysis of CO, NO and SO_2 in the exhaust	16	Ash Grove/Louisville, NE	• Reduction in fuel use • Production increase
Rice hulls, wood chips and rubber tyres as supplmenetary kiln fuel	20	Calaveros/Redding, CA	• 50% coal savings

References

1) Labahn, O. and B. Kohlhaas, Cement Engineers' Handbook, Bauverlag GMBH, (1983)

2) R.E. McIvor,
"Effects of Speed and Liner Configuration on Ball Mill Performance.".
Mining Engineering, June 1983

3) N.W. Biege, "Peck'Away at Rotary Kiln Inefficiencies",
World Cement, Dec. (1986), p.441

4) O.L. Jepsen and P.B. Nielsen,
"New Cyclone Design Improves Pyroprocessing Economics",
Proceedings of the 29th IEEE Cement Industry Technical Conference,
San Francisco, California, May 1987

5) G. Fisher and G. Unland,
"Upgrading Your Pyroprocessing System For Profitable Operation in Today's Market", ibid

6) W. Ruhland and K. von Wedel, "Air Jets Cool Clinker on Grate",
Rock Products, October 1985

7) H. Herchenbach, "Cooler Operation: Key to Stable Kiln Conditions and Good Clinker Quality",
Proceedings of the 21st International Cement Seminar,
Maclean-Hunter Publishing Corp., Chicago, Illinois, 1985

8) T.R. Nilsson, B. Sinner and O.A. Volden,
"Optimized Production and Energy Conservation".
IEEE Transactions on Industry Applications, Vol. 1A-22, No. 3, May/June 1986

9) "POTENTIAL FOR ENERGY CONSERVATION IN THE CEMENT INDUSTRY",
B.A. Garret-Price, Feb. 1985

10) "THE US CEMENT INDUSTRY: AN ENERGY PERSPECTIVE S.R.Venkateswaran, and H.E.
Lowitt, May 1988

11) R.S. Muhta, "Roller Mills vs. Tube Mills" Rock Products, Aug. 1984, p43

12) E.C. Irwin & M.F. Zoller, "Grooved Liners Cut Energy Cost",
Rock Products, Jun. 1985, p.43

13) L.A. Karls, "Upgrading Existing Preheater Systems for Energy Conservation and Increased
Capacity"
Proceedings of the 29th IEEE Cement Industry Technical Conference,
San Francisco, California, May 1987

14) H.E. Steuch, "Problems and Solutions in Setting UP a Cement Plant"
    Proceedings of the 21st International Cement Seminar,
    Maclean-Hunter Publishing Corp., Chicago, Illinois, 1985

15) S.E. Sheridan, "Automatic Kiln Control at Oregon Portland Cement Company's Durkee Plant
    Utilizing Fuzzy Logic"
    IEEE Transactions on Industry Applications, Vol. 1A-20, No. 3, May/June, 1984, pp542

16) E.R. Manswn, "The Use of Carbon Monoxide and Other Gases for Process Control"
    IEEE Transactions on Industry Applications, Vol. 1A-22, No. 2, Mar/Apr. 1986, p.338

17) C.D. Kellet, "Lehigh's Experiences with a High Efficiency Separator"
    Proceedings of the 21st International Cement Seminar,
    Maclean-Hunter Publishing Corp., Chicago, Illinois, 1985

18) R.H. Foust, "Experiences with the High Efficiency SD Classifier" ibid

19) "U.S.'s largest commercial CFB burns cleanly in California",
    Power, Oct. 1986, p. 43

20) R. Segal, "Kiln Fuel: Rice Hulls, Waste Oil"
    Rock Products, Apr. 1984, p.42

21) M.C. "Landfill Gas as a Viable Alternative Energy Source", World Cement, March, 1985

22) Portland Cement Association, "Energy Conservation Potential in the Cement Industry", Federal
    Energy Administrations, Washington D.C. 1975

23) A.J. Kreisberg "Recirculation improves Flash Calciner Efficiency"
    Proceedings of the 29th IEEE Cement Industry Technical Conference, San Francisco, California,
    May 1987

8. Energy Conservation in Steel Hot Rolling Reheating Furnace

8. ENERGY CONSERVATION IN STEEL HOT ROLLING REHEATING FURNACES

Steel production processes are shown in Figure 8.1. Reheating furnaces are what are used to reheat slabs, which were cogged at the blooming mill, or continuous-cast slabs to the temperature level that suits the objective, for rolling them to final products.

These furnaces can be roughly classified into batch furnaces and continuous furnaces, but hereinafter the description is limited to the continuous furnaces for plates, sheets and strips.
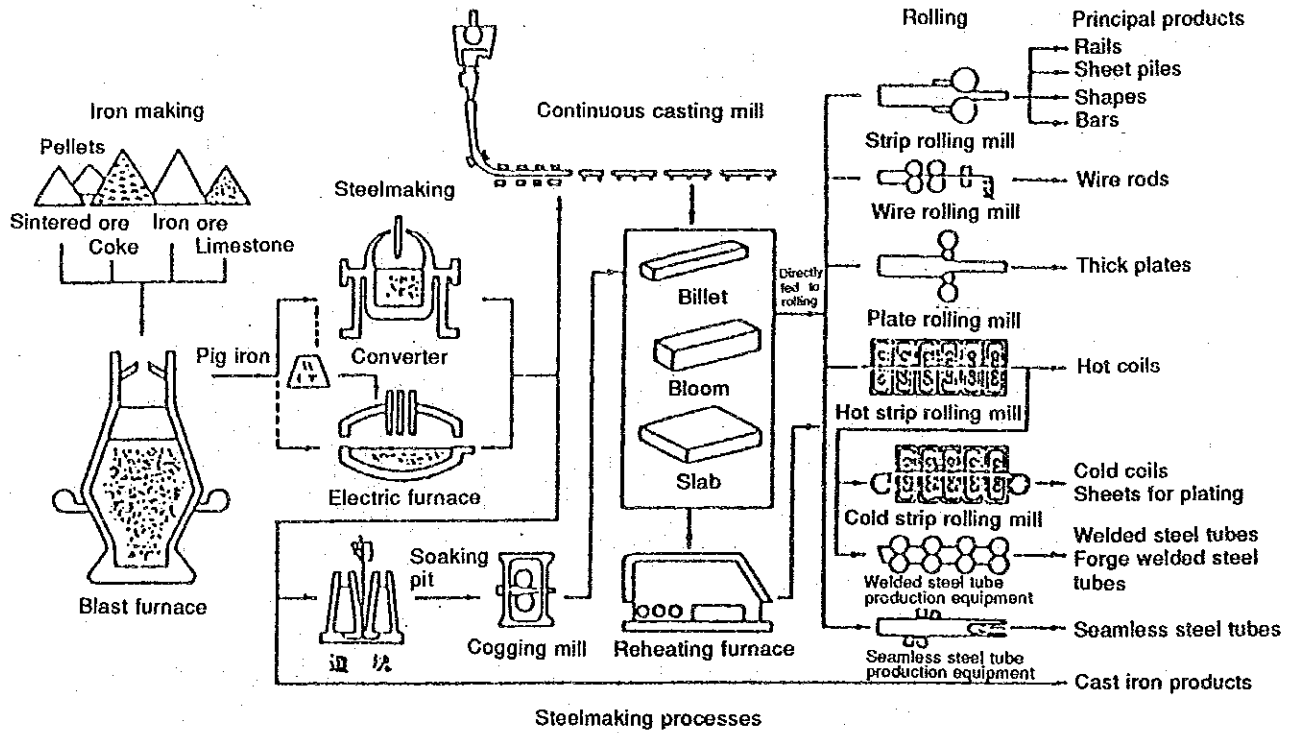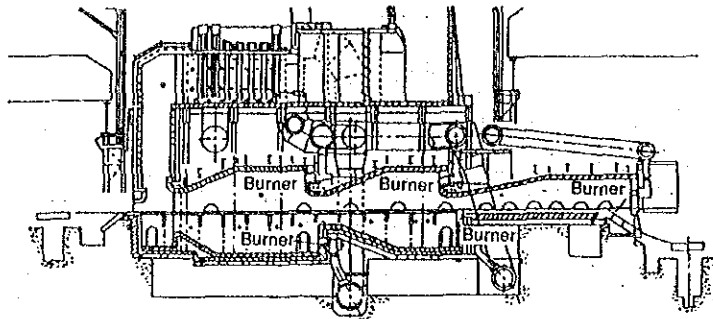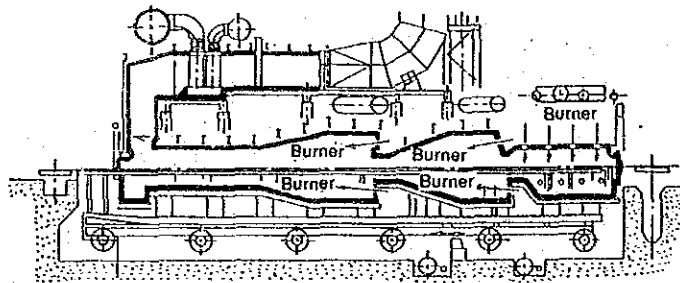

Figure 8.1 Manufacturing process of iron & steel

8.1 Furnace types

The types of continuous reheating furnaces include pusher furnaces and walking-beam furnaces. Typical views of furnaces of these two types are shown in Figure 8.2, and a comparison between them is shown in Table 8.1.

Pusher type 5-zone reheating furnace

Walking beam type reheating furnace

Figure 8.2 Typical section view of pursher f'ce & walking-beam f'ce

Table 8.1 Comparison of pusher furnace & walking-beam furnace

	Pusher furnace (PF)	Walking-beam furnace (WBF)
Application	1. Mass production	1. Mass production 2. Slabs of deformed sections to which PF is not applicable, and for quality products
Slab carrying method	The slab is pushed in with a pusher from the charge side and is made to move as sliding forward on the water-cooled skid.	The slab on the water-cooled fixed beam is carried by the water-cooled moving beam, which makes back-forth motions.
Advantage	1. Equipment cost is less than that of WBF. 2. Cooling water loss heat is less than that of WBF.	1. There is no restriction in the furnace length. 2. Skid mark is minor, and no scratches are produced. 3. The furnace can be easily emptied because the slabs in the furnace can be freely carried by the own power. 4. Slabs can be carried in suitable intervals.
Disadvantage	1. Skid mark and scratches are easily produced. 2. Buckling of slabs tends to occur in the furnace and there are restrictions in the furnace length. 3. Charge of slabs of extremely different thickness levels cannot be made. 4. It is hard to empty the furnace. 5. The frequency of maintenance of the soaking hearth is large.	1. The equipment cost is higher than that of PF. 2. As the number of skids is large, the cooling water loss is larger than that of PF.

8.2 Combustion

(1) Burners

The fuel used for reheating furnaces is heavy fuel oil, natural gas, C-gas (coke oven gas) and M-gas (mixture of coke oven gas and steel plant by-product gas such as blast furnace gas).

Binary fluid type burners using compressed air of high pressure or steam as the atomizing medium are used for fuel oil. Burners of this type are available in the following types.

① External mixing type that atomizes fuel oil by the atomizing medium of high velocity at the burner tip

② Internal mixing type that mixes fuel oil with air or steam in the mixing chamber in the burner and that blows this mixture out of nozzles

For gases, the following types are available.

① External mixing type that mixes gas and air outside of the burner for combustion

② Variable flame type that separates the gas into primary gas and secondary gas, causes the primary gas to jet out of nozzles of large hole diameter at the center, causes the secondary gas to jet out of nozzle of small hole diameter located along the external periphery and permits adjustment of the flame length by changing the flow rates of primary gas and secondary gas

③ Roof burner type that causes combustion nearly completed in the burner ports by accelerating mixture of gas with air by strong swirl flow in the burner interior and that performs heating by heat transfer by radiation from ports

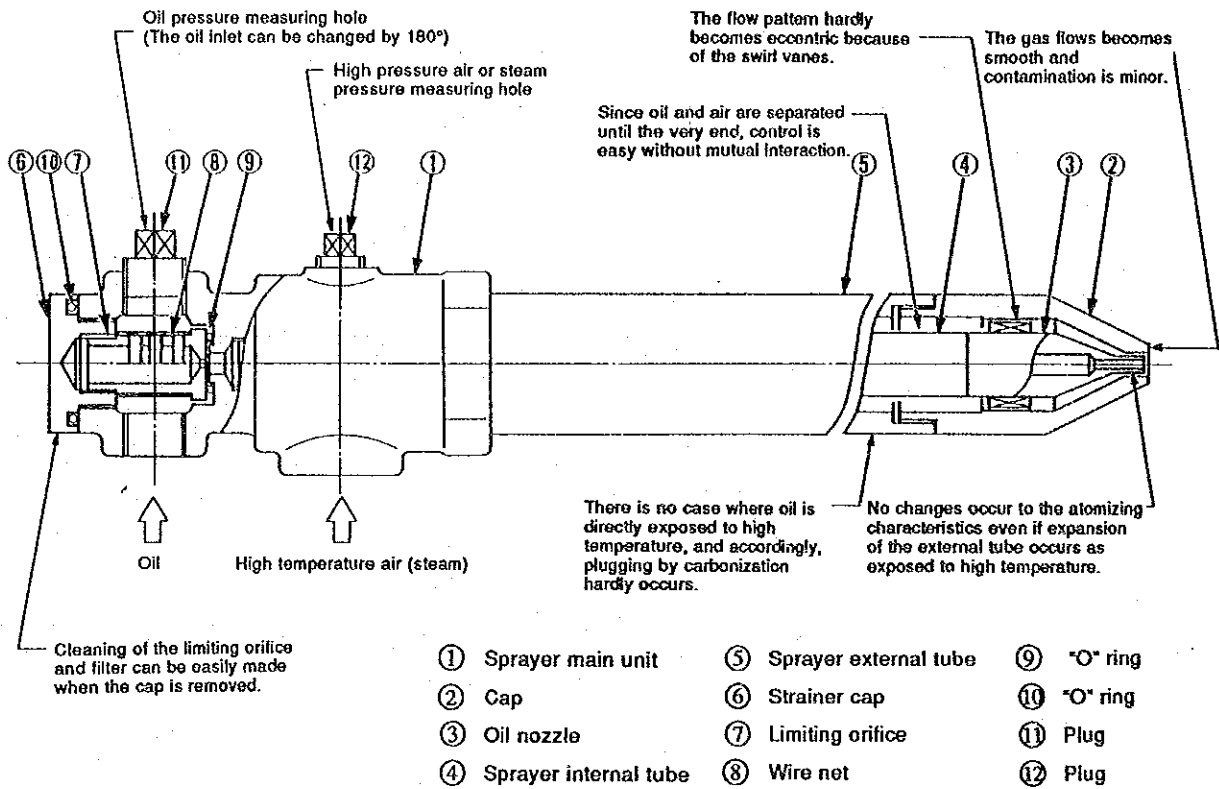Rough views of burners of these types are shown in Figure 8.3 ~ 8.7.

Oil pressure measuring hole
(The oil inlet can be changed by 180°)

High pressure air or steam
pressure measuring hole

The flow pattern hardly
becomes eccentric because
of the swirl vanes.

The gas flows becomes
smooth and
contamination is minor.

Since oil and air are separated
until the very end, control is
easy without mutual interaction.

⑥⑩⑦ ⑪⑧⑨ ⑫ ① ⑤ ④ ③②

↑ Oil   ↑ High temperature air (steam)

There is no case where oil is
directly exposed to high
temperature, and accordingly,
plugging by carbonization
hardly occurs.

No changes occur to the atomizing
characteristics even if expansion
of the external tube occurs as
exposed to high temperature.

Cleaning of the limiting orifice
and filter can be easily made
when the cap is removed.

① Sprayer main unit	⑤ Sprayer external tube	⑨ "O" ring
② Cap	⑥ Strainer cap	⑩ "O" ring
③ Oil nozzle	⑦ Limiting orifice	⑪ Plug
④ Sprayer internal tube	⑧ Wire net	⑫ Plug

Figure 8.3 View of external mixing oil burner

Sprayer internal tube   Mix chamber

Sprayer body   Sprayer external
tube   Oil nozzle   Sprayer cap

Oil inlet   Primary air (steam) inlet   (Determined by mounting
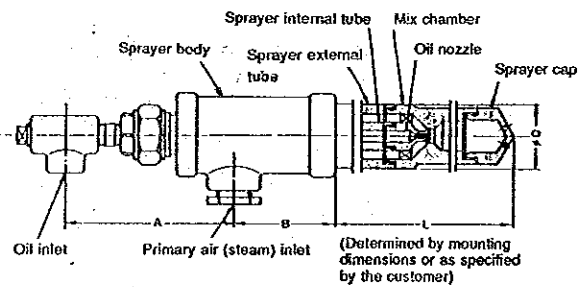dimensions or as specified
by the customer)

A ——— B ——— L

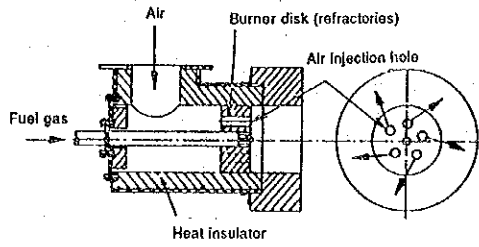**Figure 8.4 View of internal mixing oil burner**

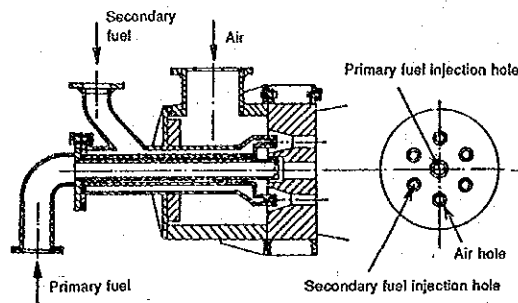**Figure 8.5 View of external mixing gas burner**

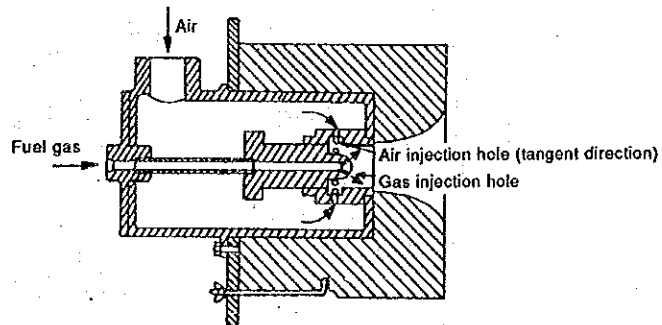**Figure 8.6 View of internal mixing gas burner**

Figure 8.7 View of roof gas burner

(2) Arrangement of burners

Arrangement of burners against the furnace is extremely important from the standpoint of heating characteristics of the furnace. Basically it is divided into three types, i.e., axial flow combustion, side combustion and roof combustion.

A comparison of characteristics of these types is shown in Table 8.2.

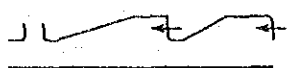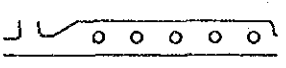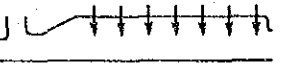### Table 8.2 Comparison of combustion method (1/2)

Item	Axial flow combustion	Side combustion	Roof combustion
Burner position			
Fuel	Fuel oil, C-gas, M-gas, natural gas	Fuel oil, C-gas, M-gas, natural gas	Fuel oil, C-gas, M-gas, natural gas
Burner type	External mixing type	External mixing type or variable flame burner	Roof burner
Flame form	Long flame	Short flame (variable flame)	Completion of combustion in ports
Combustion rate controllability	Broad control range	Narrow control range Operating number control is needed in correspondence to the combustion rate.	Relatively broad control range
Heating load	May be large with large capacity burner	May be large with large capacity burner	Not very large with small capacity burner
Restrictions by furnace internal dimensions	There are restrictions in the length per zone in the longitudinal direction.	There are restrictions in the widthwise direction.	None in particular. But lower combustion is not permitted.
Flow of combustion gas in the furnace	Flows without unnaturalness in the longitudinal direction.	Drift tends to occur because there is an angle between the burner direction and the longitudinal direction.	There is no unnaturalness in the flow because combustion is almost entirely completed in burner tiles.

Table 8.2 Comparison of combustion method (2/2)

Item	Axial flow combustion	Side combustion	Roof combustion
Mounting of burners	Nose section is required, and the furnace structure is complicated.	The furnace structure is simple.	The furnace structure is simple. But the piping is complicated because the number of burners is large.
Heat pattern	Equalization of the temperature in the width-wise direction is easy. The temperature drops in the longitudinal direction. The temperature at the nose section drops.	Equalization of the temperature in the width-wise direction is inferior. Equalization of the temperature drops in the longitudinal direction is easy.	Equalization of the temperature is easy in both of the widthwise direction and the longitudinal direction.
Workability	Relatively good. But no good at the periphery of the lower burners because of high temperature environment.	The working environment is good.	The workability is inferior because the number of burners is large and because of high temperature environment.

8.3 Heat transfer in the furnace

(1) Heat transfer mechanism

Figure 8.8 indicates the flow of heat in the case where the slabs in the furnace are heated with combustion gas. Heat is transmitted to the slabs by means of non-luminous flame radiation, luminous flame radiation and convection of combustion gas and by solid radiation from furnace internal walls. Heat transfer in the slabs is made from surface to the interior by heat conduction.
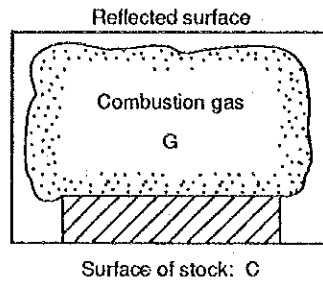
Reflected surface

Combustion gas

G

Surface of stock: C

Figure 8.8 Heat transfer within furnace

Since it may be regarded that the entire heat transfer is made by radiation in a reheating furnace, heat input q [kJ/m²/h] to slabs can be expressed by the following equation from the Stefan-Boltzmann law.

$$q = 4.88 \times \emptyset_{CG} \times [\{t_g + 273)/100\}^4 - \{(t_s + 273)/100\}^4] \tag{8-1}$$

where;

$\emptyset_{CG}$: Absorptivity

t_g : Combustion gas temperature [°C]

t_s : Slab surface temperature [°C]

Overall absorptivity $\emptyset_{CG}$ shown in the above equation is what totals various radiation heat transfer, that is, gas radiation, furnace wall radiation and so forth, and it is related to the angle relation between each face in the system and heat receiving face of the slab and also to the emissivity of furnace wall surface and combustion gas.

The value of $\emptyset_{CG}$ in the case that is shown in Figure 8.9 can be obtained by the following formula. It is preconditional with this model that each temperature in the system is equal respectively.

$$\frac{1}{\phi_{CG}} = \frac{1}{F_{CG}} + (\frac{1}{\varepsilon_C} - 1) \tag{8-2}$$

$$F_{CG} = \varepsilon_G (\frac{S_G}{S_T}) [1 + (\frac{S_R}{S_C}) / \{1 + \frac{\varepsilon_G}{(S_T / S_G) - \varepsilon_G} (\frac{1}{F_{RC}})\}] \tag{8-3}$$

where;

S   : Gas surface area [m²]

S_R : Reflection surface area [m²]

S_C : Heat receiving surface area [m²]

S_T : $S_T = S_R + S_C$ [m²]

ε_C, ε_G : Emissivity of heat receiving surface and gas

F_{RC} : View factor to observe face C from face R

F_{CG} : Coefficient of radiation from heat receiving surface to combustion gas with emissivity of combustion gas and reflection of reflection surface taken into account
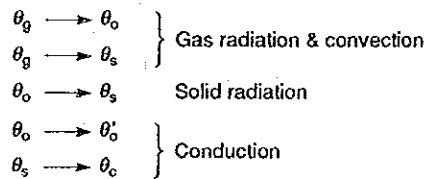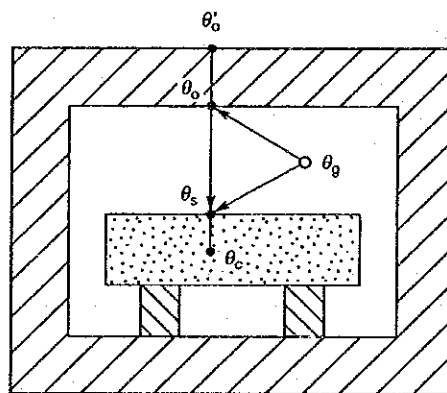

Figure 8.9 Mathematical model of heat transfer within furnace

With a section in the widthwise direction in a continuous reheating furnace, the temperature at portion is equal, and the value of $\emptyset_{co}$ remains unchanged in that section. In the longitudinal direction, however, the value of $\emptyset_{co}$ naturally changes by the location of the subject slab because the furnace internal combustion gas temperature, furnace internal wall temperature, slab surface temperature and angle relation change. It is therefore necessary to make division to a number of sections in the longitudinal direction and to calculate the value of $\emptyset_{co}$ in each one of these sections. By calculating the value of $\emptyset_{co}$, it may be used as material for judgment of whether the furnace shape is suitable or not. However, since an actual furnace is not of such a simple model that is shown in Figure 8, the calculation is extremely complicated. In practice, the value of $\emptyset_{co}$ is calculated based on the values of temperature measured in an actual furnace.

For calculation,

①　furnace internal gas temperature or furnace internal atmosphere temperature

②　surface temperature of heated slab

③　internal temperature of heated slab

are measured, and calculation is made using the following equation with the measured temperature rise curve divided into a number of zones.

$$\emptyset_{co} = \rho \times \Delta x (\Delta H / \Delta t) / [4.88 \times [\{(t_g + 273)/100\}^4 - \{(t_s + 273)/100\}^4]] \qquad (8\text{-}4)$$

where;
　ρ　：　Specific weight of slab [kg/m³]

　Δx：　Thickness of slab [m]

　ΔH：　Increment in zone of slab accumulated heat [kJ/kg]

　Δt　：　Heating time in the zone [h]

　t_g　：　Furnace internal temperature mean value at zone inlet and outlet [°C]

　t_s　：　Slab temperature mean value at zone inlet and outlet [°C]

The calculated values of $\emptyset_{co}$ in each zone in actual furnaces of several types are shown in Table 8.3 for reference. But the figures are dispersed to a considerable extent by the differences in the temperature measuring method, calculating method, etc. Since these values are of heavy fuel oil, it is considered that the value is less by about 0.1 in each zone in the case of gas firing, when the luminous flame radiation of fuel oil is taken into account.

Table 8.3 $\varnothing_{CG}$ of each zone

Preheating zone	Heating zone	Soaking zone
0.65 ~ 0.85	0.6 ~ 0.8	0.3 ~ 0.5

(2)   Calculation of heat transfer

Such a method that numeric value calculation is made with a differential equation of heat conduction converted into difference equation is broadly used as a method for theoretically seizing the heat transfer transient phenomena at the time of heating and cooling of a substance. With the approximate numeric calculation of difference equation, it is possible to solve the equation for the object of various forms under complicated boundary conditions. Furthermore, it is also possible to treat physical values of object as functions of temperature, and almost all the requirements against heat transfer calculation are satisfied.

A)   Differential equation of heat conduction

The differential equation of non-steady heat conduction is expressed by the following formula.

$$\frac{\partial H}{\partial \theta} = \frac{k_d}{\rho}\left(\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2}\right) + \frac{QI}{\rho} \qquad (8-5)$$

where;
H : Heat content

k : Thermal conductivity

θ : Time

ρ : Density

ϕ : Conversion temperature, $\phi = \int_{td}^{t} \frac{k}{k_d} dt$

t : Temperature

QI: Internally generated heat
       Subscript d means reference value (usually 0°C).

8-12

B) Calculation by difference equation of heat conduction

    a) A case of 2-dimensional rectangular coordinates is shown in Table 8.4 as an example of a difference equation of the case without internally generated heat.

    b) Q_{xy} expresses the thermal load on the boundary surface, and the following calculation method is available. But since the radiation heat transfer rate is proportional to fourth power of the temperature, it is recommended that Q_{xy} is calculated by expression (8-6) to correctly obtain the temperature transition in heating (cooling) process.

    ① Method to use Stefan-Boltzmann law

$$Q_{xy} = 4.88 \, \varnothing_{GC} \, [\{(t_g + 273) / 100\}^4 - \{(t_s + 273) / 100\}^4 + \alpha_c(t_g - t_s) \quad (8\text{-}6)$$

    ② Method to use mean heat transfer coefficient

$$Q_{xy} = (\alpha_r + \alpha_c)(t_g - t_s) \qquad\qquad (8\text{-}7)$$

where;

    $\varnothing_{GC}$: Furnace internal overall absorptivity

    t_g, t_s : Combustion gas temperature and slab surface temperature [°C]

    α_r, α_c: Radiation heat transfer coefficient and convection heat transfer coefficient [kJ/(m²·h·°C)]

    c) Physical properties (mean specific heat, heat content, thermal conductivity, conversion temperature) of principal steel grades are shown in Table 8.5.

    d) It is desirable that the number of divisions is 4 ~ 6 or larger when the heat transfer coefficient of the steel surface is around 840 ~ 1,670 [kJ/(m²·h·°C)]. The accuracy of calculation is better and the formula is simple when a square network is used in the x, y directions.

    e) As division time Δt, select a time that is 80 ~ 90% of the division limit time and at which the output data can be easily processed.

Table 8.4 Difference equation of heat conduction
(Rectangular coordinates of two-dimension)

(A) Internal point

$$H_{x \cdot y}' = H_{x \cdot y} + \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta x_1)(\Delta x_2)[(\Delta x_1)+(\Delta x_2)]}\left\{(\Delta x_1)\,\phi_{x+1 \cdot y} + (\Delta x_2)\,\phi_{x-1 \cdot y} - [(\Delta x_1)+(\Delta x_2)]\phi_{x \cdot y}\right\}$$

$$+ \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta y_1)(\Delta y_2)[(\Delta y_1)+(\Delta y_2)]}\left\{(\Delta y_1)\,\phi_{x \cdot y+1} + (\Delta y_2)\,\phi_{x \cdot y-1} - [(\Delta y_1)+(\Delta y_2)]\phi_{x \cdot y}\right\}$$

(B) Surface point (face)
Face x

$$H_{x \cdot y}' = H_{x \cdot y} + \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta x)^2}\left\{\phi_{\substack{x-1 \cdot y \\ (x+1 \cdot y)}} + \frac{Q_{x \cdot y}(\Delta x)}{k_d} - Q_{x \cdot y}\right\}$$

$$+ \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta y_1)(\Delta y_2)[(\Delta y_1)+(\Delta y_2)]}\left\{(\Delta y_1)\,\phi_{x \cdot y+1} + (\Delta y_2)\,\phi_{x \cdot y-1} - [(\Delta y_1)+(\Delta y_2)]\phi_{x \cdot y}\right\}$$

Face y

$$H_{x \cdot y}' = H_{x \cdot y} + \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta x_1)(\Delta x_2)[(\Delta x_1)+(\Delta x_2)]}\left\{(\Delta x_1)\,\phi_{x+1 \cdot y} + (\Delta x_2)\,\phi_{x-1 \cdot y} - [(\Delta x_1)+(\Delta x_2)]\phi_{x \cdot y}\right\}$$

$$+ \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta y)^2}\left\{\phi_{\substack{x-1 \cdot y \\ (x \cdot 1+y)}} + \frac{Q_{x \cdot y}(\Delta y)}{k_d} - Q_{x \cdot y}\right\}$$

(C) Convex angle

$$H_{x \cdot y}' = H_{x \cdot y} + \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta x)^2}\left\{\phi_{\substack{x-1 \cdot y \\ (x+1 \cdot y)}} + \frac{Q_{x \cdot y}(\Delta x)}{k_d} - \phi_{x \cdot y}\right\} + \frac{2 \cdot k_d \cdot \Delta t}{\rho(\Delta y)^2}\left\{\phi_{\substack{x-1 \cdot y \\ (x \cdot 1+y)}} + \frac{Q_{x \cdot y}(\Delta y)}{k_d} - \phi_{x \cdot y}\right\}$$

(D) Concave angle

$$H_{x \cdot y}' = H_{x \cdot y} + \frac{2 \cdot k_d \cdot \Delta t}{3 \cdot \rho(\Delta x)^2}\left[\phi_{x-1 \cdot y} + 2\phi_{x+1 \cdot y} + \frac{Q_{x \cdot y}(\Delta x)}{k_d} - 3\phi_{x \cdot y}\right] + \frac{2 \cdot k_d \cdot \Delta t}{3 \cdot \rho(\Delta y)^2}\left[\phi_{x \cdot y-1} + 2\phi_{x \cdot y+1} + \frac{Q_{x \cdot y}(\Delta y)}{k_d} - 3\phi_{x \cdot y}\right]$$

Division state

Internal point	Surface point
Division time $\Delta t \leq \dfrac{1}{2a\left[\dfrac{1}{(\Delta x_1)(\Delta x_2)} + \dfrac{1}{(\Delta y_1)(\Delta y_2)}\right]}$	$\Delta t \leq \dfrac{1}{2a\left[\dfrac{1}{(\Delta x)^2} + \dfrac{d_{x \cdot y}}{k_d(\Delta x)} + \dfrac{1}{(\Delta y)^2} + \dfrac{d_{x \cdot y}}{k_d(\Delta x)}\right]}$

Note: The maximum value in the heating temperature range was used as thermal diffusion rate $\alpha = k/\rho \cdot c$ in the division time calculation formula.

Table 8.5 Physical properties of some steel

Temperature °C	Mean specific heat [kJ/kg°C]				Temperature [°C]	Heat content [kJ/kg]				Coefficient of heat transmission [kJ/m·h°C]				Conversion temperature [°C]			
	Rimmed steel 0.06%C	Mild steel 0.23%C	Medium carbon steel 0.4%C	18-8 stainless steel		Rimmed steel 0.06%C	Mild steel 0.23%C	Medium carbon steel 0.4%C	18-8 stainless steel	Rimmed steel 0.06%C	Mild steel 0.23%C	Medium carbon steel 0.4%C	18-8 stainless steel	Rimmed steel 0.06%C	Mild steel 0.23%C	Medium carbon steel 0.4%C	18-8 stainless steel
0 ~ 50	0.469	0.469	0.469	0.494	0	0.0	0.0	0.0	0.0	235.3	186.7	186.7	57.4	0.0	0.0	0.0	0.0
50 ~ 100	0.486	0.486	0.486	0.511	50	23.4	23.4	23.4	24.7	226.1	185.5	185.5	57.4	49.0	49.8	49.8	50.0
100 ~ 150	0.502	0.502	0.502	0.528	100	47.7	47.7	47.7	50.2	216.9	181.7	181.7	58.6	96.1	99.0	99.1	100.5
150 ~ 200	0.519	0.519	0.511	0.536	150	72.8	72.8	72.8	76.6	208.1	179.2	179.2	60.3	141.2	147.3	147.5	152.4
200 ~ 250	0.536	0.536	0.528	0.536	200	98.8	98.8	98.4	103.4	200.5	175.0	173.3	62.0	184.7	194.7	194.7	205.7
250 ~ 300	0.553	0.553	0.553	0.553	250	125.6	125.6	124.8	130.2	191.3	167.5	168.7	63.2	226.3	240.7	240.5	260.2
300 ~ 350	0.569	0.578	0.569	0.553	300	153.2	153.2	152.4	157.8	183.8	159.9	164.1	66.2	266.1	284.4	285.1	316.6
350 ~ 400	0.594	0.594	0.586	0.569	350	181.7	182.1	180.9	185.5	175.0	157.0	159.9	69.5	304.3	326.8	328.5	375.7
400 ~ 450	0.628	0.628	0.611	0.586	400	211.4	211.8	210.2	213.9	167.5	153.6	150.7	72.4	340.7	368.4	370.1	437.6
450 ~ 500	0.662	0.662	0.653	0.594	450	242.8	243.2	240.7	243.2	156.6	147.8	144.9	75.4	375.1	408.8	409.6	502.0
500 ~ 550	0.703	0.703	0.687	0.628	500	276.3	276.3	273.4	273.0	147.8	141.5	137.3	78.3	407.4	447.5	447.4	569.0
550 ~ 600	0.754	0.745	0.712	0.653	550	311.1	311.5	307.7	304.3	141.5	135.6	129.8	82.9	438.2	484.6	483.2	639.2
600 ~ 650	0.804	0.787	0.728	0.628	600	348.8	348.8	343.3	337.0	135.6	128.1	122.2	85.8	457.6	520.0	516.9	712.8
650 ~ 700	0.862	0.846	0.770	0.628	650	389.0	388.1	379.7	368.4	129.8	122.2	116.0	88.8	495.8	553.5	548.8	788.9
700 ~ 750	1.105	1.432	1.583	0.620	700	432.1	430.4	418.3	399.8	122.2	114.7	108.4	92.1	522.6	585.2	578.9	867.7
750 ~ 800	0.871	0.954	0.620	0.645	750	487.3	502.0	497.4	430.8	114.7	102.6	98.0	95.0	547.8	614.3	606.5	949.3
800 ~ 850	0.804	0.737	0.511	0.645	800	530.9	549.7	528.4	463.1	108.4	93.4	88.8	96.3	571.5	640.5	631.5	032.7
850 ~ 900	0.837	0.645	0.544	0.645	850	571.1	586.6	553.9	495.3	99.6	93.4	88.8	95.0	593.6	665.5	655.5	116.1
900 ~ 950	0.662	0.653	0.628	0.645	900	612.9	618.8	581.1	527.5	98.0	95.0	92.1	96.3	614.6	690.7	679.5	199.5
950 ~ 1000	0.670	0.645	0.620	0.653	950	646.0	651.5	612.5	560.0	98.0	96.3	93.4	99.6	635.4	716.4	704.3	284.9
1000 ~ 1050	0.670	0.653	0.636	0.653	1000	679.5	683.7	643.5	592.4	99.6	98.0	96.3	100.9	656.4	742.4	729.7	372.3
1050 ~ 1100	0.670	0.645	0.628	0.662	1050	716.4	717.2	675.3	625.1	100.9	100.9	98.0	102.6	677.7	769.0	755.7	460.9
1100 ~ 1150	0.670	0.662	0.645	0.670	1100	746.5	748.6	706.7	658.2	102.6	102.6	100.9	103.8	699.3	796.2	782.3	550.9
1150 ~ 1200	0.670	0.662	0.653	0.670	1150	780.0	781.7	739.0	691.6	105.5	105.5	103.8	105.5	721.4	824.1	809.8	642.2
1200 ~ 1250	0.670	0.678	0.670	0.678	1200	813.5	814.8	771.6	725.2	107.2	107.2	107.2	107.2	744.0	852.6	838.0	734.9
1250 ~ 1300	0.670	0.687	0.687	0.678	1250	847.0	805.1	759.1	759.1	108.8	108.8	110.5	108.8	767.0	881.5	867.2	829.0
1300 ~ 1350	0.670	0.695	0.703	0.678	1300	880.5	883.0	839.4	793.0	110.5	110.5	113.9	110.5	790.3	910.9	897.2	924.6
1350 ~ 1400	0.670	0.703	0.720	0.678	1350	914.0	917.7	874.6	826.9	112.2	112.2	117.2	112.2	814.0	940.7	928.1	021.7
1400 ~ 1450	0.670	0.712	0.737	0.678	1400	947.5	952.9	910.6	860.8	113.9	113.9	120.5	113.9	838.0	971.0	966.0	120.3
					1450	981.0	988.5	947.5	894.7	115.6	115.6	123.9	115.6	862.4	001.7	992.7	220.3
Density [kg/m³]	7,871	7,859	7,854	7,916													

8.4 Heat balance

Heat balance is the technique implemented to decide the guideline for judgment of capacity and efficiency, improvement of operation standard and for improvement of equipment of a reheating furnace. The rough heat efficiency of a reheating furnace can be easily obtained from the fuel unit consumption. But the measured data obtained by heat balance and its results should be used for examination of improvement of operation standard and for improvement of equipment.

The outline of a heat balance method that conforms to Japanese Industrial Standards is described below.

8.4.1 Heat balance standard

a. During a shift is desirable as the period of implementation of heat balance. But a period equivalent to continuous charge of slabs twice as much as slabs in the furnace is required at minimum. Interruption of steady-state heating due to troubles with reheating furnace or on the rolling side shall not occur during the implementation period.

b. Implement heat balance with one ton of charged steel.

c. Use the low calorific value of the fuel at the time of use for heat balance.

d. Use fresh air temperature as the reference temperature for heat balance as a rule.

e. Implement heat balance with one furnace as a rule. Include the recuperating equipment in this case.

f. Indicate exchange of heat in the interior of the recuperating equipment separately as circulating heat.

8.4.2 Items of measurement

a. Test date and test staff

b. Weather, atmospheric pressure, fresh air temperature, room temperature and relative humidity

c. Consumption, pressure, temperature, composition and low calorific value of fuel by zone

d. Type of atomizer, and its consumption, pressure and temperature by zone

e. Consumption, pressure and temperature before and after preheating of secondary air by zone

f. Consumption, temperature at inlet and outlet and pressure of cooling water

g. Temperature and composition of combustion gas at furnace tail, recuperator inlet and outlet

h. Dimensions, weight, totally charged tonnage, charging temperature, extraction temperature, ignition loss weight and mean furnace stay time of slab to be heated

i. Furnace internal pressure

j. Surface temperature at various points of furnace zones (to be measured to the most possible extent)

8.4.3 Method for measurement

(1) Fuel

    a. Measurement of fuel consumption

        ① Measure the gaseous fuel flow rate with a differential pressure type flowmeter near the reheating furnace, and make correction by pressure, temperature, etc.

        ② Measure the liquid fuel flow rate with a tank or volumeric flowmeter, and convert it to weight by multiplying specific gravity to it.

    b. Measurement of pressure and temperature of fuel

        Take measurement before the combustion equipment.

(2) Atomizer

    a. Measurement of quantity of atomizer

        Take measurement with a differential pressure type flowmeter, and make correction by pressure, temperature, etc. as a rule.

    b. Measurement of pressure and temperature of atomizer

        Take measurement before the combustion equipment. Use the roughly calculated value if measurement cannot be taken, with an excuse in this case.

(3) Combustion air

  a. Measurement of airflow

     Measure the airflow with an orifice, Pitot tube or alike, or calculate it from the composition of fuel and combustion gas.

  b. Measurement of air temperature

     Take measurement at the inlet and outlet of the recuperator.

  c. Measurement of humidity in the air

     Calculate the absolute humidity upon decision of the relative humidity in the room with a draft type psychrometer.

(4) Cooling water

  a. Measurement of cooling water temperature

     Measure the cooling water temperature at the furnace inlet and outlet.

  b. Measurement of cooling water flow

     Measure the cooling water flow at the furnace inlet and outlet.

(5) Combustion gas

  a. Measurement of combustion gas temperature

     Measure the combustion gas temperature at the furnace tail, recuperator inlet and outlet. Make efforts to measure the mean temperature of the gas in the section of each passage. At the furnace tail in particular, a spot that is not affected by the entry from the charging opening should be selected.

  b. Sampling and analysis of combustion gas

     Implement sampling at the positions same as the points of measurement of combustion gas temperature.

(6) Slab to be heated

   a. Weight of slab to be heated

      Use a weighing equipment for measurement of the weight of slab to be heated. Regard the mass of the slab charged during the heat balance implementation period as the weight of slab to be heated. If the weight of the slab in the furnace changes to a major extent between the start and end of heat balance, correction should be made to the weight.

   b. Temperature of charged slab

      With hot slab, estimate the mean temperature from the surface temperature and so forth.

   c. Temperature of extracted slab

      Estimate the mean temperature of extracted slab with the surface temperature measured in the furnace immediately before extraction.

   d. Ignition loss

      Actually measure the weight of the test slab before charging and the weight of the test slab after extraction in the state where scale was removed, and calculate the ignition loss from the difference. Or, make calculation from the scale thickness and surface area and scale analyzed values.

(7) Furnace internal pressure

   Take the reading of the furnace internal pressure gauge, if available. Describe the location of the pressure gauge in this case. If no pressure gauge is available, obtain the zero line of each zone through observation.

(8) Surface temperature of various points of furnace proper

   Measure the furnace proper surface temperature with a surface pyrometer.

(9) Measuring interval

   Take measurement at fixed measuring intervals for other than those measured with recorders. This interval should be determined based on the variation of operation or of measured values. But it should be 30 [minutes] in the case where the variation is minor, and 10~15 [minutes] in the case where the variation is large, in general.

8.4.4 Preparations before testing

(1) Planning of time

As the capacity of a continuous reheating furnace is related to the rolling capacity, take measurement at the time when the rolling operation is matched with the objective of heat balance. Because heat accumulation loss to the furnace walls and hearth occurs immediately after installation or modification, measurement should be taken after the heat flow has reached the steady-state.

(2) Inspection of conditions of the furnace proper

Inspect various points of the furnace proper and record the conditions of the furnace proper under which measurement was taken.

(3) Consolidation of auxiliaries

Inspect combustion equipment, drafting equipment, automatic controller and other auxiliaries in advance so as not to allow occurrence of troubles during measurement.

(4) Consolidation of measuring instruments

Inspect the necessary measuring instruments in advance, accurately calibrate them and then locate them at specified positions.

(5) Arrangement of measuring staff

Arrange measuring staff with their positions determined in advance. Conduct a preliminary test before the final test if possible, and make preparation so that correct measurement can be started at the specified time.

8.4.5 Calculation

Divide the measuring time into time sections which are matched with the objective of heat balance, calculate the mean value of measured values by item, and make calculation per ton of slab.

(1) Case where the recuperator is included

A) Heat input

    a. Calorific value of fuel [kJ/t]

       = Fuel consumption per ton of slab [kg/t or Nm³/t]
       × Calorific value [kJ/kg or kJ/Nm³]   (8-8)

b. Sensible heat of fuel (when preheated with another heat source) [kJ/t]

= Fuel consumption per ton of slab [kg/t or Nm^3/t]
   × Mean specific heat of fuel [kJ/(kg·°C) or kJ/(Nm^3·°C)]
   × (Fuel temperature [°C] − Fresh air temperature [°C])   (8-9)

Assume the specific heat of fuel oil as 1.88 [kJ/(kg·°C)]. Calculate the value for a gaseous fuel from its composition.

c. Sensible heat of air (when preheated with another heat source) [kJ/t]

= Air volume per ton of slab [Nm^3/t] × Mean specific heat of air [kJ/(Nm^3·°C)]
   × (Air temperature [°C] − Fresh air temperature [°C])   (8-10)

① Use the following equation in the case where the air volume per fuel of 1 [kg] or 1 [Nm^3] is calculated from the composition of fuel and combustion gas.

Air volume [Nm^3] per fuel of 1 [kg or Nm^3]
= (Theoretical air volume) × (Air ratio)   (8-11)

② Theoretical air volume; A_0	
Liquid fuel [Nm^3/kg]	Gaseous fuel [Nm^3/Nm^3]
$A_0 = 8.89 \times C + 26.7 \times H - 3.33(O-S)$ (8-12)	$A_0 = 2.38 \times (H_2 + CO) - 4.76 \times O_2 + 9.52$ $\times CH_4 + 14.29 \times C_2H_4 + 35.80 \times C_6H_6$ (8-13)

③ Air ratio $m = 1 / [1 - 3.76 \times \{([O_2] - [O_0]) / ([N_2] - [N_2 \cdot D])\}$ (8-14)	
Liquid fuel [Nm^3/kg]	Gaseous fuel [Nm^3/Nm^3]
$D = ([CO] + [CO_2]) / (1.87 \times C)$ (8-15)	$D = ([CO] + [CO_2]) / (CO + CO_2 + CH_4 + 2$ $\times C_2H_4 + 6 \times C_6H_6)$ (8-16)

where;
   C, H, O, S   : Carbon, hydrogen, oxygen, sulfur in the fuel oil
                                           [kg/kg]

   H_2, CO, O_2, CH_4, C_2H_4, C_6H_6: Hydrogen, carbon monoxide, oxygen, methane,
                                           ethylene, benzene in the gaseous fuel [Nm^3/Nm^3]

$[CO], [CO_2], [O_2], [N_2]$: Carbon monoxide, carbon dioxide, oxygen, nitrogen content in exhaust gas of 1 Nm³ [Nm³/Nm³]

$[O_0]$: Theoretical oxygen flow required for complete combustion of incompletely burnt gas such as [CO] in exhaust gas of 1 Nm³ [Nm³/Nm³].

D   : Fuel volume equivalent to exhaust gas of 1 Nm³

d. Sensible heat of atomizer [kJ/t]

= Weight of atomizer per ton of slab [kg/t]
   × (Enthalpy of the atomizer in the working state [kJ/kg]
   − (Enthalpy of the atomizer at fresh air temperature [kJ/kg]   (8-17)

e. Heat content of charged slab [kJ/t]

= 1,000 [kg]
   × (Heat content of slab at mean charging temperature [kJ/kg]
   − Heat content of slab at fresh air temperature [kJ/kg])   (8-18)

f. Scale forming heat [kJ/t]

= Ignition loss Fe weight per ton of slab [kg/t]
   × Scale forming heat [kJ/kg.Fe]   (8-19)

① Scale forming heat [kJ/kg.Fe]

= {FeO forming heat [kJ/kg] × 0.777 × FeO [%] + Fe_2O_3 forming heat [kJ/kg]
   × 0.700 × Fe_2O_3 [%] + Fe_3O_4 forming heat [kJ/kg] × 0.724 × Fe_3O_4 [%]}
   ÷ T.Fe [%]   (8-20)

Oxidizing reaction heat [kJ/kg·Fe]		
FeO	Fe_2O_3	Fe_3O_4
4,814	7,317	6,668

However, it is permitted that 5,588 [kJ/kg.Fe] may be used when no scale analysis is made.

B) Heat output

a. Heat content of extracted steel [kJ/t]

$$= 1,000 \text{ [kg]} - \text{Ignition loss Fe weight [kg/t]}$$
$$\times \text{ (Heat content of slab at mean extraction temperature [kJ/kg]}$$
$$\times \text{ Heat content of slab at fresh air temperature [kJ/kg])} \qquad (8\text{-}21)$$

b. Sensible heat of scale [kJ/t]

$$= \text{Ignition loss Fe weight per ton of slab [kg/t]} \times 100 \text{ / T.Fe [\%]}$$
$$\times \text{ Mean specific heat of scale [kJ/(kg-°C)]}$$
$$\times \text{ (extracted surface temperature [°C]} - \text{Fresh air temperature [°C])} \qquad (8\text{-}22)$$

However, 0.900 [kJ/(kg·°C)] may be used as the specific heat of scale.

Furthermore, T.Fe = 75.5 [%] may be used in the case where no scale analysis is made.

c. Sensible heat of dry exhaust gas after recuperator [kJ/t]

$$= \text{Volume of dry exhaust gas after recuperator per ton of slab [Nm}^3\text{/t]}$$
$$\times \text{ Mean specific heat of dry exhaust gas [kJ/(Nm}^{3}\text{·°C)]}$$
$$\times \text{ (Exhaust gas temperature at recuperator outlet [°C]}$$
$$- \text{ Fresh air temperature [°C])} \qquad (8\text{-}23)$$

① The following equation is used when exhaust gas volume [Nm³] per fuel of 1 [kg] or 1 [Nm³] is calculated from the composition of fuel and combustion gas.

$$\text{Exhaust gas volume [Nm}^3\text{]} = \text{Theoretical exhaust gas volume}$$
$$+ \text{ (Air ratio} - 1)$$
$$\times \text{ Theoretical air volume} \qquad (8\text{-}24)$$

② Exhaust gas volume ; G_0	
Liquid fuel [Nm³/kg]	Gaseous fuel [Nm³/Nm³]
$G_0 = 8.89 \times C + 21.1 \times H - 2.63 \times O$ $+ 3.33 \times S + 0.8 \times N$ (8-25)	$G_0 = CO_2 + N_2 + 1.88 \times H_2 + 2.88 \times CO$ $+ 8.52 \times CH_4 + 13.28 \times C_2H_4 + 34.30$ $\times C_6H_6 - 3.76 \times O_2$ (8-26)

d. Retaining heat of water vapor after recuperator [kJ/t]

= Volume of water vapor after recuperator per ton of slab [Nm³/t]
   × Mean specific heat of water vapor [kJ/(Nm³·°C)]
   × (Exhaust gas temperature [°C] – Fresh air temperature [°C])
   + 2,512 × Weight of steam for atomization [kg/t.slab]   (8-27)

① Water vapor volume in exhaust gas [Nm³/kg or Nm³/Nm³ fuel]

= Generated water weight by fuel combustion
   + Moisture content of air [Nm³/Nm³ air] × A_0 × m
   + Weight of steam for atomization [kg/kg.Fuel] × 22.4/18   (8-28)

② Generated water weight by fuel combustion	
Liquid fuel [Nm³/kg fuel]	Gaseous fuel [Nm³/Nm³ fuel]
Mf = 11.2 × H + 1.25 × W (8-29)	Mf = H_2 + 2 × CH_4 + 2 × C_2H_4 + 3 × C_6H_6 (8-30)

where; W: Moisture content of fuel [kg/kg]

③ Moisture content of air [Nm³/Nm³ air]

= 0.622 × Ø × P_s / (101.325 - Ø × P_s) × 29/18   (8-31)

where;
   Ø : Relative humidity

   P_s : Saturated steam pressure at atmospheric temperature [kPa]

e. Heat loss due to unburned gas [kJ/t]

= Dry exhaust gas volume after recuperator per ton of slab [Nm³/t]
   × CO in exhaust gas [Nm³/Nm³] × 12,640 [kJ/Nm³]   (8-32)

f. Heat taken away by cooling water [kJ/t]

= Cooling water weight per ton of slab [kg/t] × (Outlet temperature [°C]
   – Inlet temperature [°C]) × 4.187 (kJ/(kg·°C)]   (8-33)

g. Other heat loss [kJ/t]

Difference in the calorific value between the total of heat input stated above and the total of heat output stated above.

h. Heat recovered with recuperator [kJ/t]

= Preheating air volume per ton of slab [Nm³/t]
× Mean specific heat of preheated air [kJ/(Nm³·°C)]
× (Air temperature at recuperator outlet [°C]
− Air temperature at recuperator inlet [°C])   (8-34)

(2) Case of furnace proper only

Implement calculations in section (1) with sensible heat of air, sensible heat of exhaust gas after recuperator and retaining heat of water vapor in exhaust gas after recuperator substituted by the calculations indicated below.

A) Heat input

c. Sensible heat of preheated air [kJ/t]

= Preheated air volume per ton of slab [Nm³/t]
× Mean specific heat of preheated air [kJ/(Nm³·°C)
× (Preheated air temperature before burner [°C]
− Fresh air temperature [°C])   (8-35)

B) Heat output

c. Sensible heat of dry exhaust gas at furnace tail [kJ/t]

= Volume of dry exhaust gas at furnace tail per ton of slab [Nm³/t]
× (Mean specific heat of dry exhaust gas [kJ/(Nm³·°C)]
× (Exhaust gas temperature at furnace tail [°C]
− Fresh air temperature [°C])   (8-36)

d. Retaining heat of water vapor at furnace tail [kJ/t]

= Volume of water vapor at furnace tail per ton of slab [Nm³/t]
× (Mean specific heat of water vapor [kJ/(Nm³·°C)]
× (Exhaust gas temperature at furnace tail [°C] − Fresh air temperature [°C])
+ 2,512 × Weight of steam for atomization [kg/t.Steel]   (8-37)

e. Other heat loss [kJ/t]

Difference in the calorific value between the total of heat input stated above and the total of heat output stated above.

(3) Case of recuperator only

A) Heat input

a. Sensible heat of air at recuperator inlet [kJ/t]

= Air volume per ton of slab [Nm³/t]
× Mean specific heat of air at recuperator inlet [kJ/(Nm³·°C)
× (Air temperature at recuperator inlet [°C] – Fresh air temperature [°C])   (8-38)

b. Sensible heat of dry exhaust gas at recuperator inlet [kJ/t]

= Volume of dry exhaust gas at recuperator inlet per ton of slab [Nm³/t]
× (Mean specific heat of dry exhaust gas at recuperator inlet [kJ/(Nm³·°C)]
× (Exhaust gas temperature at recuperator inlet [°C]
– Fresh air temperature [°C])   (8-39)

c. Retaining heat of water vapor in exhaust gas at recuperator inlet [kJ/t]

= Volume of water vapor in exhaust gas at recuperator inlet per ton of slab [Nm³/t]
× (Mean specific heat of water vapor at recuperator inlet [kJ/(Nm³·°C)]
× (Exhaust gas temperature at recuperator inlet [°C]
– Fresh air temperature [°C]) + 2,512
× Weight of steam for atomization [kg/t.Steel]   (8-40)

B) Heat output

a. Sensible heat of air at recuperator outlet [kJ/t]

= Air volume per ton of slab [Nm³/t]
× Mean specific heat of air at recuperator outlet [kJ/(Nm³·°C)]
× (Air temperature at recuperator outlet [°C] – Fresh air temperature [°C]) (8-41)

b. Sensible heat of dry exhaust gas at recuperator outlet [kJ/t]

= Volume of dry exhaust gas at recuperator outlet per ton of slab [Nm³/t]
× Mean specific heat of dry exhaust gas at recuperator outlet [kJ/(Nm³·°C)]
× (Exhaust gas temperature at recuperator outlet [°C]
– Fresh air temperature [°C])   (8-42)

c. Retaining heat of water vapor in exhaust gas at recuperator outlet [kJ/t]

= Volume of water vapor in exhaust gas at recuperator outlet per ton of slab [Nm³/t]
  × Mean specific heat of water vapor at recuperator outlet [kJ/(Nm³·°C)]
  × (Exhaust gas temperature at recuperator outlet [°C]
  − Fresh air temperature [°C]) + 2,512
  × Weight of steam for atomization [kg/t.Steel]   (8-43)

d. Other heat loss [kJ/t]

Difference in the calorific value between the total of heat input stated above and the total of heat output stated above.

8.4.7 Indication of test results

Table 8.6 Specifications of the furnace (1/2)

1	Plant name		
2	Process name		
3	Furnace number		
4	Furnace type		
5	Charging slab	Material	
6		Size	L[mm] × W[mm] × t[mm]
7		Weight	[kg]
8	Product		
9	Manufacturer name		
10	Installation year		
11	Nominal capacity		[t/h]
12	Furnace dimension		L[m] × W[m] × H[m]
13	Effective length & width		L[m] × W[m]

Table 8.6 Specifications of the furnace (2/2)

14	Nominal heating load			[kg/(m²·h)]
15	Kind of fuel & net calorific value			[kJ/kg or kJ/Nm³]
16	Burner type capacity & numbers	Upper zone	Soaking	[1 or Nm³] ×
17			Heating	[1 or Nm³] ×
18			Preheating	[1 or Nm³] ×
19		Lower zone	Soaking	[1 or Nm³] ×
20			Heating	[1 or Nm³] ×
21			Preheating	[1 or Nm³] ×
22	Fan capacity			[m³/min] × [mbar] × [kW]
23	Stack size			top/bottom D[m] × H[m]
24	Recuperator	Type		
25		Heating pipe area		[m²]
26		Material		
27	Skid pipe or Walking beam	Numbers		
28		Size		[mm]
29		Insulation		
30	Instrumentation			
31	Improvement history			
32	Operating situation	Operating methods		[shift/day]
33		Operating time		[h/shift]
34		Operating days		[day/year]

Table 8.7 Measuring data of furnace with recuperator (1/3)

1	Measuring time				
2	Ambient temperature [°C]			Relative humidity	[%]
3	Fuel	Kind			
4		Flow rate & ratio	Upper zone	Soaking zone	[kg or Nm³/h]
5				Heating zone	[kg or Nm³/h]
6				Preheating zone	[kg or Nm³/h]
7			Lower zone	Soaking zone	[kg or Nm³/h]
8				Heating zone	[kg or Nm³/h]
9				Preheating zone	[kg or Nm³/h]
11			Total		[kg or Nm³/h]
12		Pressure			[mbar]
13		Temperature			[°C]
14		Composition			[%]
15		Net calorific value			[kJ/Nm³ or kJ/kg]
16	2nd air	Flow rate	Upper zone	Soaking zone	[Nm³/h]
17				Heating zone	[Nm³/h]
18				Preheating zone	[Nm³/h]
19			Lower zone	Soaking zone	[Nm³/h]
20				Heating zone	[Nm³/h]
21				Preheating zone	[Nm³/h]
22			Total		[Nm³/h]

Table 8.7 Measuring data of furnace with recuperator (2/3)

23	2nd air	Pressure	Recuperator	Inlet			[mbar]
24				Outlet			[mbar]
25		Temperature	Recuperator	Inlet			[°C]
26				Outlet			[°C]
27	Cooling water	Flow rate					[kg/h]
28		Temperature		Inlet			[°C]
29				Outlet			[°C]
30	Waste gas	Temperature		Before recuperator			[°C]
31				After recuperator			[°C]
32		Pressure		Before recuperator			[mbar]
33				After recuperator			[mbar]
34		Composition		Soaking zone	CO_2 [%]	O_2 [%]	CO [%]
35				Before recuperator	CO_2 [%]	O_2 [%]	CO [%]
36				After recuperator	CO_2 [%]	O_2 [%]	CO [%]
37	Charged slab	Size	L [m] ×		W[mm] ×		t[mm]
38		Weight					[kg]
39		Total weight of charged slab					[t]
40		Temperature	Charge				[°C]
41			Discharge				[°C]
42		Decreased weight of slab by oxidization					[kg/t]

Table 8.7 Measuring data of furnace with recuperator (3/3)

43	Furnace temp.	Upper zone	Soaking	[°C]
45			Heating	[°C]
46			Preheating	[°C]
47		Lower zone	Soaking	[°C]
48			Heating	[°C]
49			Preheating	[°C]
50	Furnace pressure			[mbar]
51	Surface temperature of wall			[°C]

Table 8.8 Heat balance sheet of furnace with recuperator

HEAT INPUT			
Item		$\times 10^3$ kJ/t	%
1	Heat of fuel combustion		
2	Sensible heat of fuel		
3	Sensible heat of air		
4	Sensible heat of charged slab		
5	Heat of scale formation		
6	Recovered Heat by recuperator	( )	( )
	Total		
HEAT OUTPUT			
Item		$\times 10^3$ kJ/t	%
7	Sensible heat of discharged slab		
8	Sensible heat of scale		
9	Sensible heat of exhaust gas		
10	Heat loss by incomplete combustion		
11	Heat loss of cooling water		
12	Heat loss from furnace wall and others		
	Total		

Overall heat efficiency of furnace η_1

$$\eta_1 = [\{(7) - (4)\} / \{(1) + (2) + (3) + (5)\}] \times 100 \qquad (8\text{-}44)$$

Table 8.9 Heat balance sheet of furnace proper

HEAT INPUT		
Item	× 10³ kJ/t	%
1 Heat of fuel combustion		
2 Sensible heat of fuel		
3 Sensible heat of air		
4 Sensible heat of charged slab		
5 Heat of scale formation		
Total		
HEAT OUTPUT		
Item	× 10³ kJ/t	%
6 Sensible heat of discharged slab		
7 Sensible heat of scale		
8 Sensible heat of exhaust gas		
9 Heat loss of cooling water		
10 Heat loss from furnace wall and others		
Total		

Heat efficiency of furnace proper η_2

$$\eta_2 = [\{(6) - (4)\} / \{(1) + (2) + (3) + (5)\}] \times 100 \qquad (8\text{-}45)$$

Table 8.10 Heat balance sheet of recuperator

HEAT INPUT		
Item	**× 10³ kJ/t**	**%**
1 Sensible heat of inlet air		
2 Sensible heat of inlet waste gas		
Total		
HEAT OUTPUT		
Item	**× 10³ kJ/t**	**%**
3 Sensible heat of outlet air		
4 Sensible heat of outlet waste gas		
5 Heat loss from recupe. wall & others		
Total		

Heat recovery by recuperator η_3

$$\eta_3 = \{(3) - (1) / (2)\} \times 100 \qquad\qquad (8\text{-}46)$$

Heat conversion efficiency of recuperator η_4

$$\eta_4 = [(3) / \{(2) - (4)\}] \times 100 \qquad\qquad (8\text{-}47)$$

8.5 Energy conservation measures and their effect

A list of energy conservation measures at reheating furnaces is shown in Figure 8.10, and the contents of measures are explained by item.
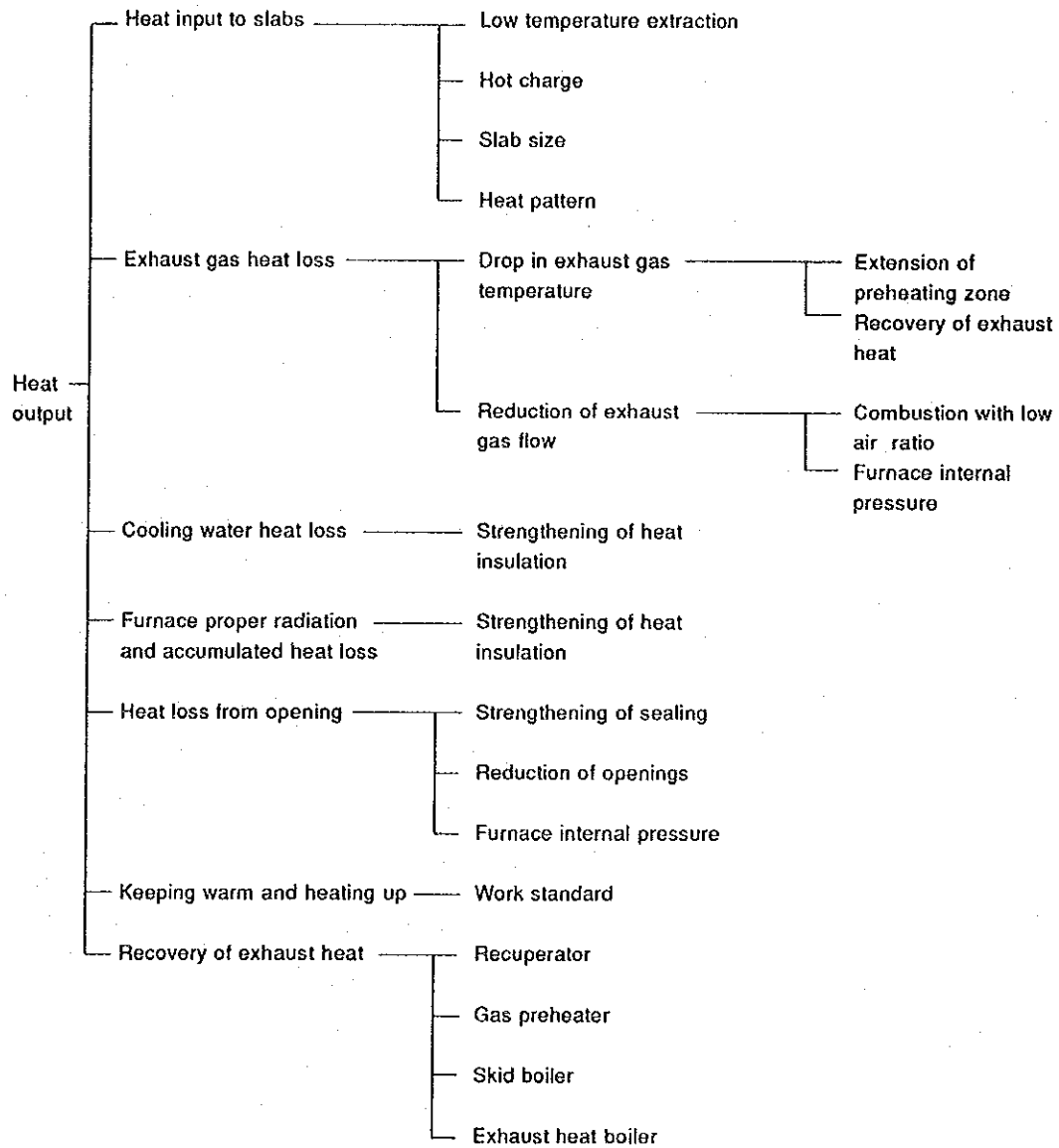
Heat output
- Heat input to slabs
  - Low temperature extraction
  - Hot charge
  - Slab size
  - Heat pattern
- Exhaust gas heat loss
  - Drop in exhaust gas temperature
    - Extension of preheating zone
    - Recovery of exhaust heat
  - Reduction of exhaust gas flow
    - Combustion with low air ratio
    - Furnace internal pressure
- Cooling water heat loss
  - Strengthening of heat insulation
- Furnace proper radiation and accumulated heat loss
  - Strengthening of heat insulation
- Heat loss from opening
  - Strengthening of sealing
  - Reduction of openings
  - Furnace internal pressure
- Keeping warm and heating up
  - Work standard
- Recovery of exhaust heat
  - Recuperator
  - Gas preheater
  - Skid boiler
  - Exhaust heat boiler

Figure 8.10 Energy conservation measures at reheating furnaces

8.5.1 Heat input to slabs

A) Low temperature extraction

It is desirable that slabs are extracted at low temperature as possible. In order to employ this measure, however, check of the following items is required.

① Power consumption of rolling mill caused by increase of rolling load

② Rolling capacity

③ Strength of equipment such as rolls and rolling mill motors

④ Problems such as flaws, dimensional accuracy of products and rolling finished temperature which exert influence over the quality

As the effect of low temperature extraction, energy saving by 96×10^3 [kJ/t] is obtained when the extraction temperature is reduced from 1,250 [°C] to 1,220 [°C]. On the other hand, the rolling mill power consumption increases when low temperature extraction is made. But the total energy unit consumption (total of fuel unit consumption and electric energy unit consumption) decreases as shown in Figure 8.10.
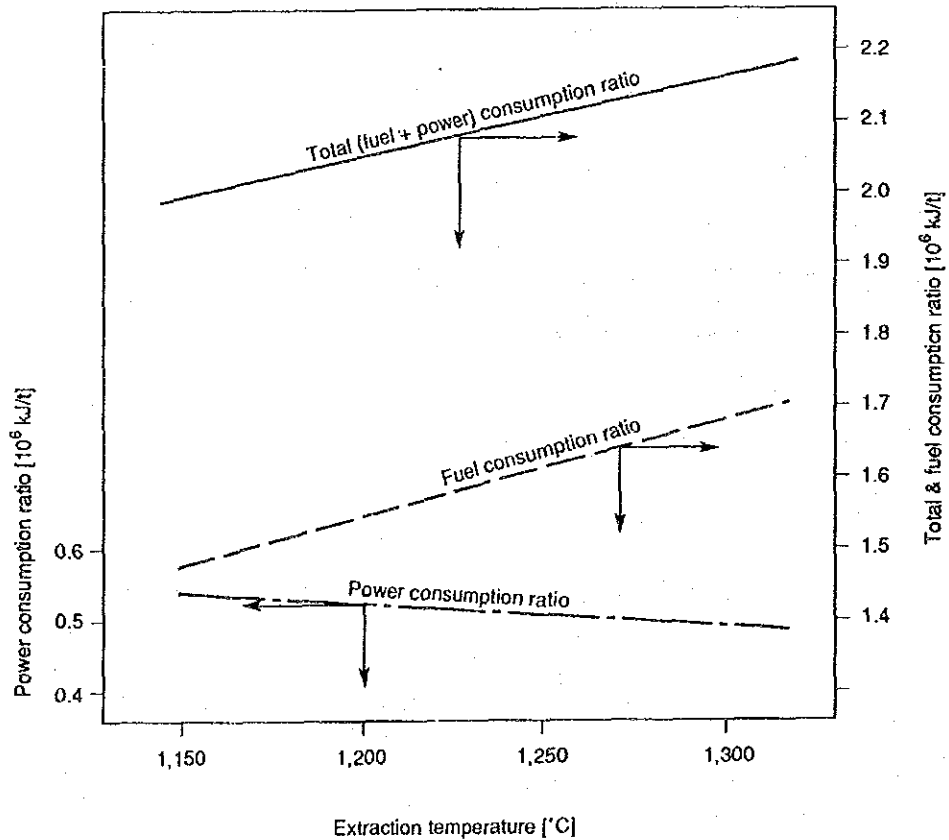

Figure 8.10 Relation of extraction temperature & total energy

B) Hot charge

The slab temperature after the continuous casting process is 900~1,100 [°C]. To make effective use of this sensible heat provides large effect in the reduction of fuel unit consumption. This effect is shown in Figure 8.11.

For this objective, it is desirable that slabs are charged into the reheating furnaces in hot state through uplift of technology for preventing occurrence of flaws in the continuous casting process, enhancement of process control system and uplift of the technology to prevent temperature drop during carriage between the continuous casting mill and the reheating furnace. To prevent temperature drop during carriage, carry the slabs on cars mounting slab boxes of heat insulation structure and make efforts to reduce the carrying time. In the case where hot slabs are placed temporarily under unavoidable circumstances, it is recommended that heat insulation boxes are installed to contain hot slabs to prevent temperature drop of the slabs. Heat insulation boxes are steel containers lined with a light weight heat insulator such as ceramic fibers of low thermal conductivity, and the tops are movable so as to permit bring-in/out of hot slabs.

What requires attention in the hot charge is to avoid charge of hot slabs and cold slabs in mixture. If charge is made in mixture, since heating is made based on cold slabs, the merits of hot charge are gone, and in addition, the hot slabs are overheated. Therefore, in the case where both of hot slabs and cold slabs are charged, charge cold slabs in a lot of as large quantity as possible, and with hot slabs, charge hot slabs of identical temperature level in a batch, or directly charge the hot slabs carried from the continuous casting mill. In any case, arrange the slabs in a lot of a considerable quantity and charge into the furnace alternately.

C) Slab size

When slabs of extremely different thicknesses are charged in mixture, heating in the furnace is made based on thick slabs as the reference. Therefore, thin slabs are overheated, and in addition, buckling may occur in a pusher furnace.

It is therefore desirable that the charge plan is established so that slabs of identical thicknesses are charged together, and if it is necessary to charge slabs of different thicknesses, charge is made so that changes in the thickness is minimized.

Furthermore, the furnace width utilization rate (slab length/furnace internal width) is related to the heat receiving area of the slabs in the furnace, and accordingly, it exerts effect over the fuel unit consumption and heating capacity. In the case where slabs of short lengths are charged in dual rows, the slabs should be combined so that the furnace width utilization rate becomes large for achieving energy conservation.
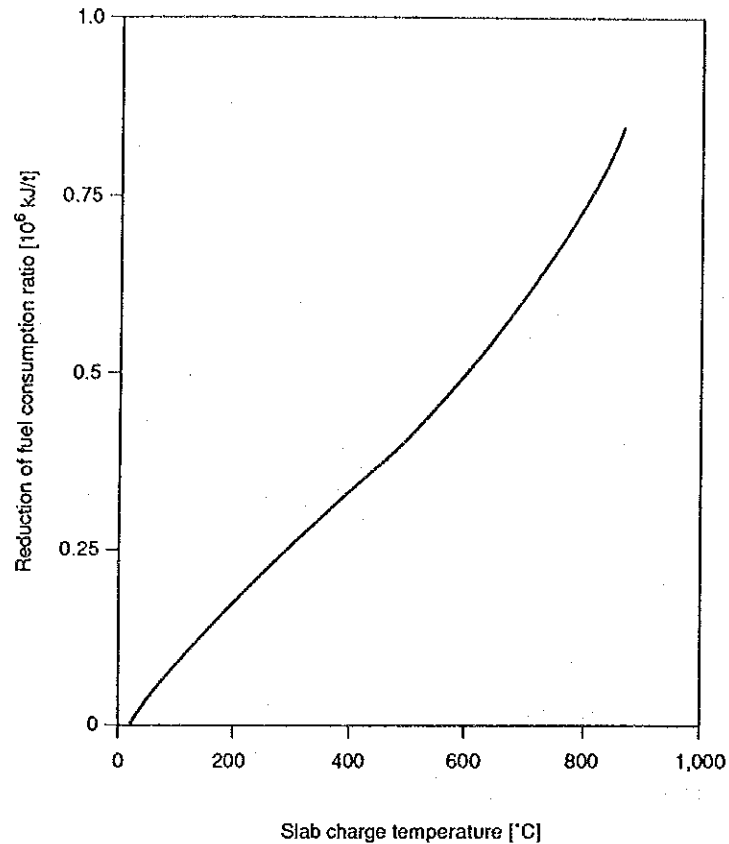
Figure 8.11 Effect of hot charge

D) Heat pattern

It is extremely important to adopt the optimum heat pattern in correspondence to changes in the heating load.

When the heating load decreases, the length of time slabs stay in the furnace becomes long, and accordingly, it is possible to heat the slabs to the specified temperature even if the heat input per unit area of the slabs or unit time is small. The necessity to make positive heating in the preheating zone decreases in this case. Therefore, change the heat pattern to the fuel distribution that lays emphasis on the heating in the heating zone accompanying reduction of the heating load, with the fuel flow reduced in the preheating zone or with burners put-off. When the load further decreases, adopt the heat pattern to implement positive heating also in the soaking zone in order to make quick heating on the extraction side. The exhaust gas temperature drops and the exhaust gas heat loss drops as a result.

Changes in the heat pattern that correspond to changes in the heating load are shown in Figure 8.12, and the relation between heating load and fuel unit consumption is shown in Figure 8.13.

Furnace position

θ_{H1}, θ_{H2}, θ_{H3} ; Heat pattern
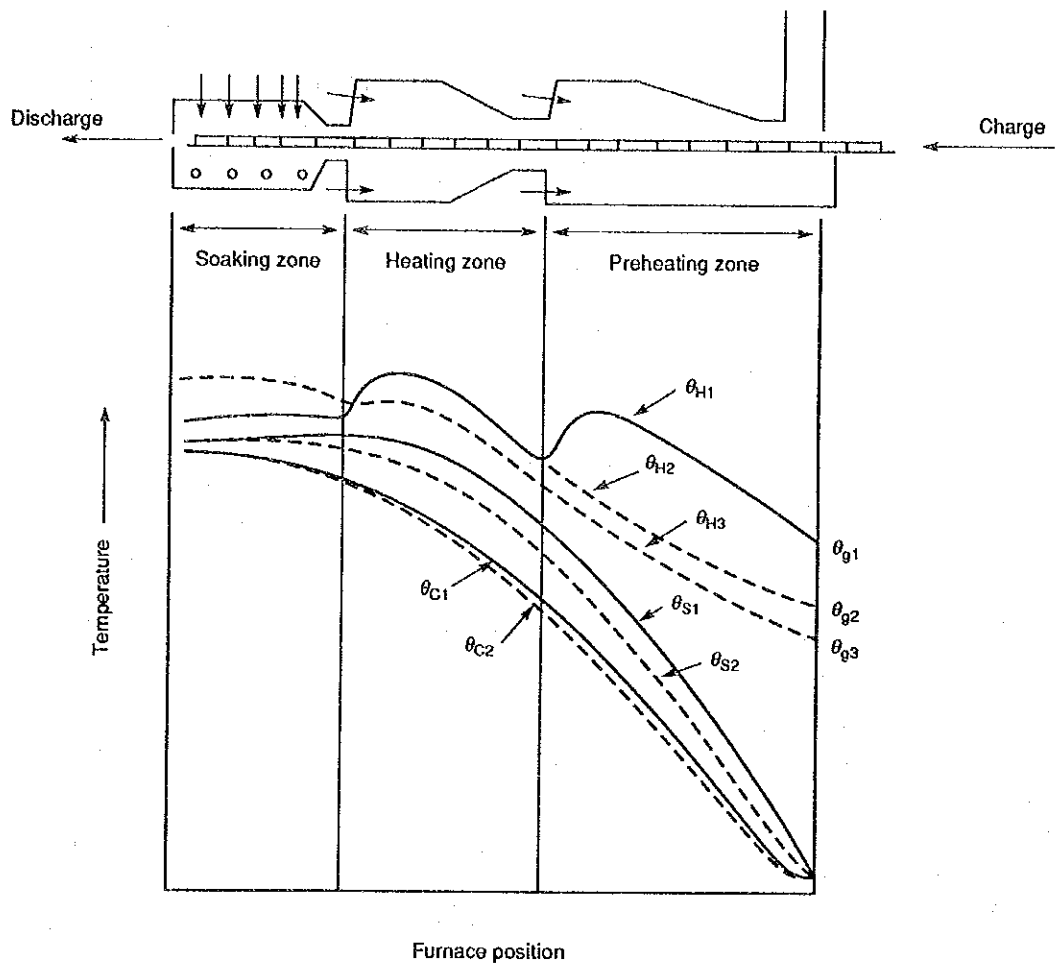
θ_{S1}, θ_{S2} ;   Slab surface temp.

θ_{C1}, θ_{C2} ;   Slab center temp.

θ_{g1}, θ_{g2}, θ_{g3} ; Furnace tail waste gas temp.

1; Nominal load, 2, 3; Light load
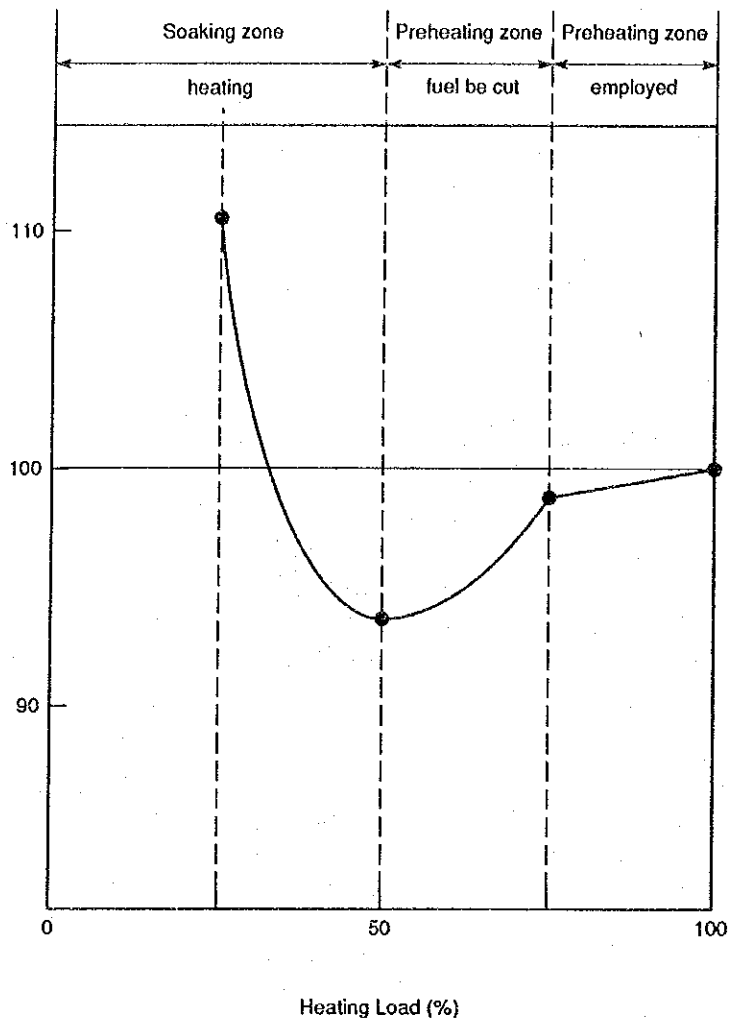
Figure 8.12 Suitable heat pattern for heating load

Figure 8.13 Heating load vs fuel consumption ratio

8.5.2 Exhaust gas heat loss

A) Extension of preheating zone

Extension of preheating zone provides large energy conservation effect with a furnace of large hearth load in particular because the exhaust gas temperature decreases due to increase of the area of heat transfer between combustion gas and slabs in the furnace.

As examples of the effect of extension of preheating zone, the relation between furnace length and fuel unit consumption is shown in Figure 8.14, and the relation among furnace length, exhaust gas temperature and preheated air temperature is shown in Figure 8.15.
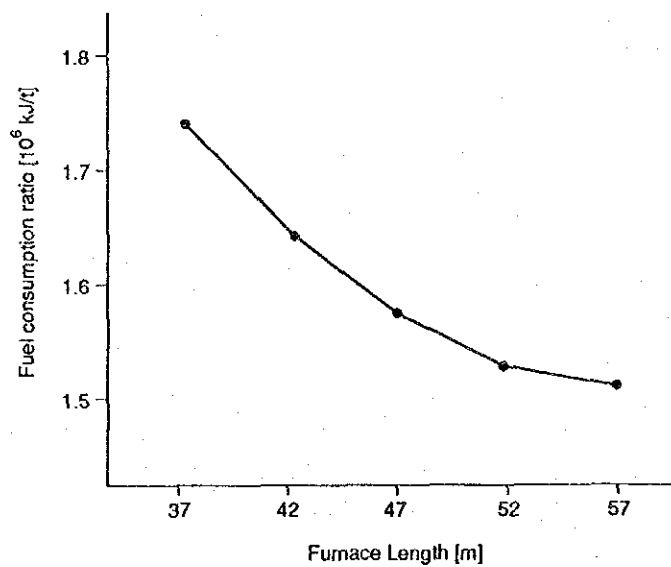

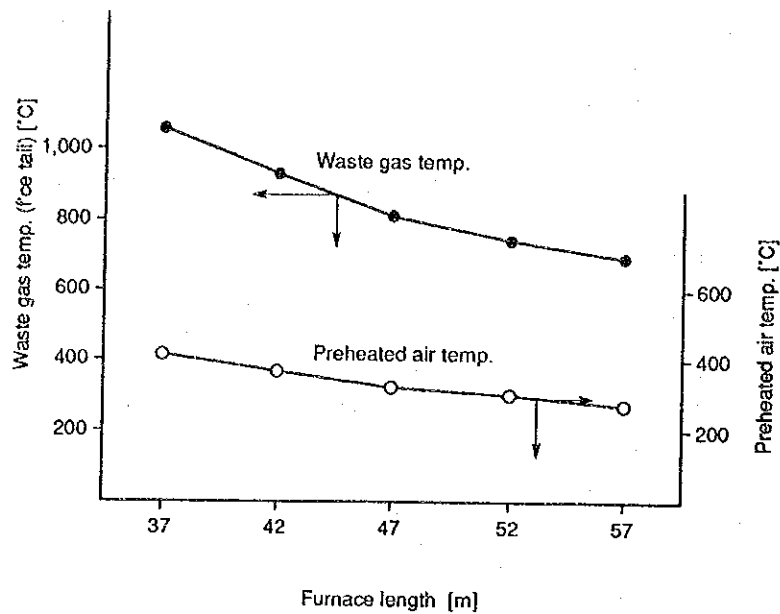**Figure 8.14 Furnace length vs fuel consumption ratio**

Figure 8.15 Furnace length vs temp. of waste gas & preheated air

B) Recovery of exhaust heat

a. Recuperator

A recuperator provides the function to elevate the combustion air temperature and to reduce the exhaust gas temperature. As the combustion air temperature rises, the flame temperature rises, the heat pattern is improved and the exhaust gas temperature at furnace tail drops.

Fuel conservation rate R [%] can be calculated with the following equation.

$$R = \{(P / (F - Q + P)\} \times 100 \tag{8-48}$$

where;

F : Fuel calorific value [kJ/kg or kJ/Nm³.Fuel]

P : Calorific value brought in by preheated air [kJ/kg or kJ/Nm³.Fuel]

Q : Calorific value taken away by combustion gas [kJ/kg or kJ/Nm³.Fuel]

The fuel conservation rate achieved by air preheating in the case of fuel oil is shown in Figure 8.16 as an example.

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