4. ENERGY CONSERVATION IN THE NON-METALLIC MATERIALS INDUSTRY

4. ENERGY CONSERVATION IN THE NON-METALLIC MATERIALS INDUSTRY

4.1 Energy Conservation in the Glass Industry

4.1.1 Introduction

Glass factories fall into two categories according to the type of the melting furnace:

(1) Factories which produce glass products in large quantities using a tank furnace for melting the materials to form them into sheet glass, glass bottles, tubes, tableware and fabric fibers

(2) Factories which produce various kinds of glass products in small quantities using a pot furnace for melting the materials to make glass bottles, laboratory appliances, tableware, and so on through manual forming.

The characteristics of a glass factory with a tank furnace are that the largest amount of energy is consumed by the tank furnace and that a continuous forming machine is used for production.

On the other hand, a factory with a pot furnace features the ease of switching operations and suitability for multi-item small lot production.

This chapter describes energy conservation measures for each process in glass factories with tank furnaces.

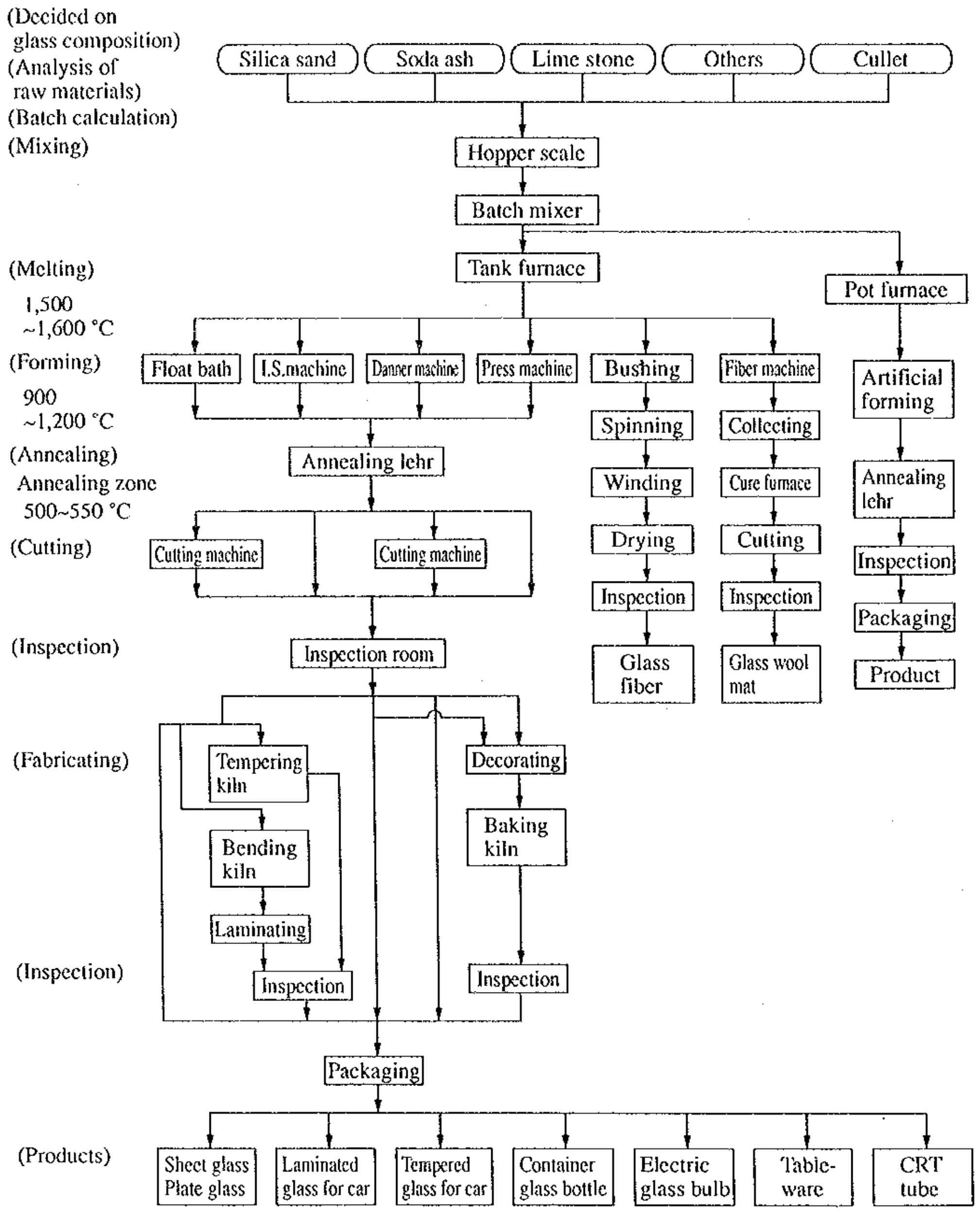
4.1.2 Overview of Glass Manufacturing Processes and Moving Ahead with General Energy Conservation

(1) Glass manufacturing process

Although glass manufacturing processes differ depending on the kind of glass, quality, and production volume, they basically consist of a series of standard tasks: determining the target components, mixing the materials, melting, forming and annealing.

Some kinds of glass require additional fabrication or processing. Figure 4.1.1 shows the glass manufacturing process flow.

Figure 4.1.1 Glass Manufacturing Process



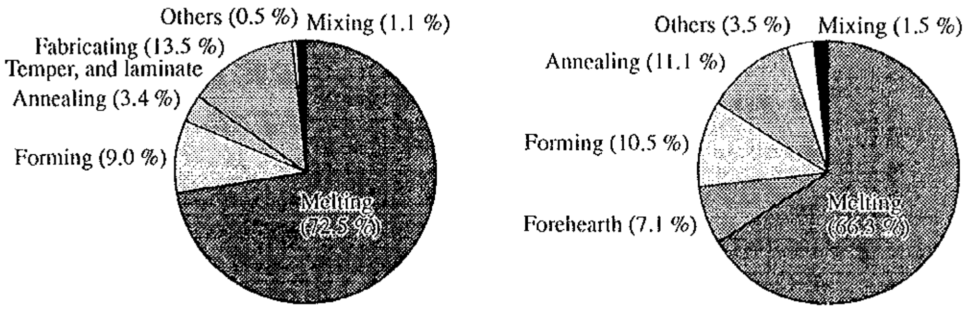
(2) State of energy use in glass manuacturing factories

Figure 4.1.2 shows the energy use percentages according to process in a glass manufacturing factory. As seen in the figure, a melting furnace accounts for approximately three-fourths of the total energy consumption. Hence, energy conservation efforts should be mainly focused on the melting furnace.

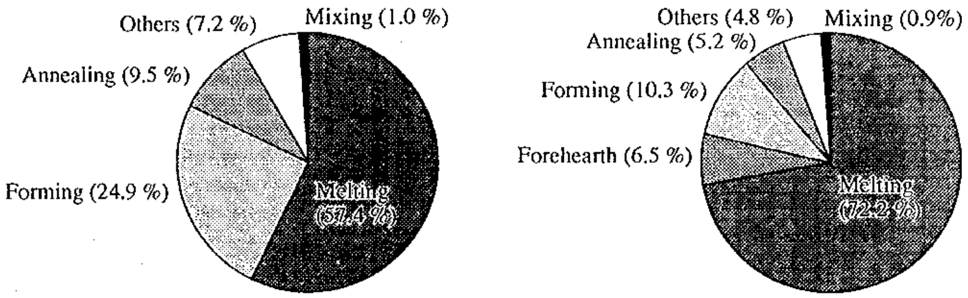
Figure 4.1.2 Share of Total Energy Consumption (10.258 kJ/kWh)

Ⓐ Flat glass : USA data in 1980
Ⓑ Container glass : USA data in 1980
Ⓒ Pressed and blow glass: USA data in 1980
Ⓓ Bottle glass : Average of bottle glass factories in Japan in 1984

Ⓐ Flat glass (15.4 MJ/kg)   Ⓑ Container glass (17.5 MJ/kg)



Ⓒ Pressed and blow glass (19.2 MJ/kg)   Ⓓ Bottle glass (10.6 MJ/kg)



(3) Energy conservation in the entire glass factory

a. Enhancement of control and energy conservation

Fundamentally, improving production management, quality control, plant maintenance and energy management in the entire glass factory will lead to stabilization of operation and equipment and enhancement of energy efficiency.

TQC and TPM approaches are employed in Japan for equipment and production management, achieving substantial results. It is recommended that these approaches or some similar management method should be introduced also in Poland in order to promote energy conservation.

Note: TQC: Total Quality Control

Company-wide activities in which all the members in all the departments of a company are involved to proceed with QC activities in order to achieve the company's operation target

TPM: Total Productive Maintenance

Maintenance of equipment and production as a total system in which all the employees of a company participate

To maximize the equipment's life cycle efficiency is the purpose of TPM, which is participated in by all the members of a company from the top management to the employees working at the first front.

b. Improvement of yield and energy conservation

Energy conservation is finally evaluated in terms of energy intensity per unit of production. Hence, improving the yield leads to energy conservation.

Generally, the yield in a narrow sense means the quantity of product for the quantity of pull total production amount, but the yield here refers to that in a broad sense including the operation rate.

In order to improve the yield, it is necessary to ensure a stable operation through reinforcement of TQC, decrease the accident loss through enhancement of TPM and improve the operation rate through reduction of color-change loss, etc.

c. Melting load and energy conservation

The molten amount per unit area is called melting load. Maximizing this melting load leads to energy conservation. This, however, requires a sufficient allowance of forming capacity and follow-up.

The standard of melting load differs depending on the product type. In the case of figured sheet glass, for example, melting load can be increased by about 40 % as compared with ordinary sheet glass and float glass. It can be increased by about as much as 90 % for bottle glass as compared with that for the ordinary sheet glass. Even for the same type of glass, melting load varies according to the difference in the required quality; for example, there is an about 10 % difference between glass for construction and glass for mirrors.

Melting load differs depending on melting capacity, which is determined based on the total of all the factors including the structure of a furnace, operating techniques, control techniques, raw materials, etc.

d. Scale merits and energy conservation

As the size of a furnace is larger, the molten glass amount per unit area increases. Increasing of the molten amount reduces the energy consumption per molten amount, leading to energy conservation.

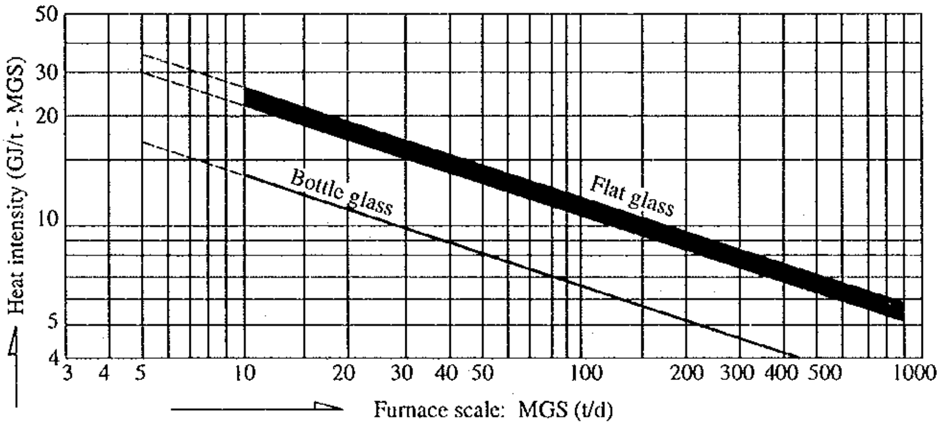
Tank furnaces widely range from small type furnaces with a melting capacity of about 5 ton per day to large furnaces for float glasses with a melting capacity of 800 ton per day.

The fuel intensity or fuel rate for melting also ranges widely, for example, from 50 GJ/t to 5 GJ/t.

A large amount of investment is required for making a furnace larger, that is, integrating small furnaces into larger ones, which may seem actually difficult. However, as shown in experiences of Japanese glass factories, for example, sheet glass factories, along with the introduction of the epoch-making forming method called "Floating Process", the number of furnaces decreased from 29 to 17 during the period of ten years from 1973. In other words, the molten amount of average 250 t/d per furnace increased to not less than 400 t/d. This leads to a 15 % decrease in energy intensity.

As a factor of melting furnace size, the standard amount of molten glass is plotted on the horizontal axis, while heavy oil intensity per molten amount is plotted on the vertical axis. As a result, an approximately straight line relationship between these can be obtained on the logarithmic scale. This is shown in Figure 4.1.3. For the floating process, see Figure 4.1.25

Figure 4.1.3 Relationship between Heat Intensity and Scale of Melting Furnace



Note: MGS means the amount of molten glass based on the cullet rate of 25 %. It is obtained using the following equation

$$MGS = \{(434 - C\ \%) / (400 + C\ \%)\} \times 1.04 \times MG$$

where

$$C\ \% = \{\text{Cullet (t/d)} / (\text{Batch} + \text{Cullet})(\text{t/d})\} \times 100$$

MG: Molten glass (t/d)

4.1.3 Processes in a Glass Manufacturing Factory and Moving Ahead with Energy Conservation

(1) Setting the target glass composition and energy conservation

Glass compositions vary widely depending on the kind of glass and need to be set according to the required physical property value, product quality, workability, and raw material cost.

It is advisable to set the basic compositions generally based on experience and practice, and perform melting on a trial basis to check the product physical property value, melting performance, devitrification temperature, temperature-viscosity curve, working temperature range, annealing point and strain point, and thereby determine the target composition after providing a necessary correction, if required. An appropriate oxidizing agent, melting accelerator, colorant, etc. should be determined and their amount to be added should be set according to the melting conditions and whether or not coloring is to be provided.

Table 4.1.1 shows typical compositions of various glass products.

Table 4.1.1 Compositions of Various Glass Products

	Flat glass and Container glass Soda-lime glass	Special glass Hard borosilicate Pyrex	CRT Tube panel	Glass fiber E	Glass wool Rotary	Lead glass Crystal
SiO_2	70 - 74	80 - 81	60 - 62	53 - 55	62 - 64	55 - 56
Al_2O_3	1.5 - 2.0	2.0 - 2.5	1.5 - 2.0	14 - 15	2 - 3	0.15 - 0.2
Fe_2O_3	0.1 - 0.5	0.0	0.0 - 0.1	0.2 - 0.3	0.2 - 0.3	0.0
CaO	7 - 12	0.0 - 0.5	1.5 - 2.0	21 - 23	8 - 9	1.5 - 2.0
MgO	1 - 4	0.0	0.5 - 1.0	0.4 - 0.5	2 - 3	0.0
Na_2O	13 - 16	4.0 - 4.5	7 - 9	0.3 - 0.4	16 - 17	3 - 4
K_2O	0.5 - 1.5	0.0	7 - 8	0.2 - 0.3	1.0 - 1.5	12 - 13
Li_2O	0.0	0.0	0.0 - 1.0	0.0	0.0	0.0
TiO_2			0.4 - 0.5	0.1 - 0.3		
ZrO_2			0.0 - 3.0			
BaO			5.5 - 10	0.5 - 0.6		
ZnO						
SrO			10 - 12			
PbO						24 - 26
CeO_2			0.2 - 0.4			
B_2O_3		12 - 13		7.5 - 8.5	4 - 5	0.5 - 1.0

To proceed with the energy conservation effort here, attention should be paid to melting performance to increase alkali content, add lithium, and add or increase boron within the basic range of each composition.

(2) Material mixing equipment

a. Material mixing process

Silica sand, soda ash, limestone, dolomite and so on are mixed in proportion to the glass composition of the product to be manufactured, and then small amounts of auxiliary materials, such as refining aids, colorant, decolorant, etc. and a proper amount of scrap glass (cullet) are blended into a composite material.

The type of energy used in the material mixing process is the electricity consumed by the crusher, mixer, belt conveyor, bucket elevator, etc. and it corresponds to approximately 1 % of the total energy consumption of the factory.
For the situation of energy usage in the glass manufacturing factory, refer to Figure 4.1.2 Share of Total Energy Consumption.

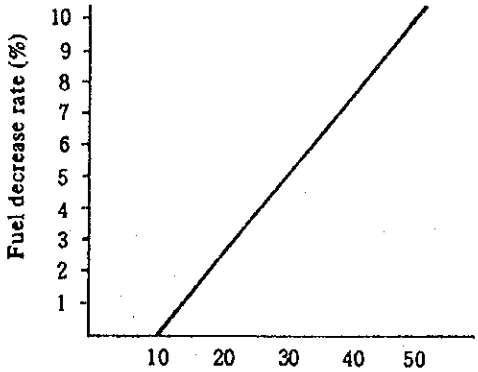
b. Energy conservation by improvement of operation and equipment

1) Operation management of equipment: Stopping the idling operation

2) Addition rate of cullet

The energy used for melting can be reduced if cullet is mixed in a larger percentage, provided that product quality will not be adversely affected by their increased percentage. The relationship between the percentage of cullet usage and fuel decrease rate is shown in Figure 4.1.4 and Table 4.1.2.

Figure 4.1.4 Addition Rate of Cullet vs Fuel Saving Rate



Addition rate of cullet (against the weight of molten glass) (%)

As shown in Figure 4.1.4, energy consumption can be decreased by 2.5 % if the cullet usage percentage is increased by 10 %.

Table 4.1.2 Heat Required for Production of Various Kinds of Glass (Theoretical Value)

Kind of glass	Temperature °C	Heat required for melting glass (kJ/kg glass) Cullet addition rate % 0	20	40	60	80	100
Tableware glass	1,400	2,411	2,273	2,135	1,997	1,859	1,721
	1,250	2,219	2,081	1,943	1,804	1,666	1,528
Sheet glass	1,500	2,604	2,456	2,308	2,159	2,011	1,863
	1,400	2,462	2,314	2,166	2,017	1,869	1,721
	1,150	2,110	1,962	1,814	1,665	1,517	1,369
Laboratory appliances	1,400	2,127	2,016	1,906	1,795	1,685	1,574
	1,300	1,997	1,887	1,776	1,665	1,555	1,444
Lead glass	1,400	2,077	1,976	1,876	1,775	1,675	1,574
	1,100	1,637	1,537	1,436	1,336	1,235	1,135

The cullet addition rate in the Japanese glass bottle manufacturing industry was 65 % in 1996, of which the cullet produced in factories is below 25 %, while the remaining 40% or more of cullet is the cullet recycled in the city. (These data above mentioned are calculated on a product base)

It should be noted, however, that impurities in the cullet could cause unmelting defects or coloring defects unless the recycled cullet is carefully selected. Additionally, the use of powder cullet should be avoided since it may increase foaming defects.

3) Proper use of refining aids

Batch melting heat varies depending on the composition of each product, but it does not necessarily follow that the composition requiring less heat leads to energy conservation. Specifically, reducing the alkali content lowers the melting heat theoretically, but actually it decreases the solubility. In this case, therefore, it is necessary to raise the melting temperature or to decrease the charging material quantity, which will not lead to energy saving.

Use of refining aids will shorten the refining time, and result in saving energy. A type and quantity of refining aids must be selected to suit the furnace conditions.

When the amount of refining aids is decreased, either the melting temperature must be increased or the amount to be melted must be decreased. Otherwise, defects will increase.

If the melting temperature is raised by 10 °C, energy consumption will increase by approximately 2 %.

4) Optimization of grain size distribution of silica sand

For silica sand—the principal material of glass—higher quality and lower impurities are required, but an additional amount of energy may be required for melting unless the granular size distribution is appropriate. The most suitable silica sand is empirically the one which has no coarse grains of 500 microns or more and has a peak of granular size distribution within a range of 177 to 250 microns.

In an actual example, grains of 500 microns or more had been removed in advance from silica sand containing 5 to 15 % coarse grains of 500 microns or more before it was used, thereby leading to a 2 to 8 % reduction in energy consumption.

(3) Melting facilities

a. Melting process

The composite material is charged into the furnace that is kept at about 1,500 °C, where the material is heated and melted by the radiating heat of flames in the upper space. Then the molten material is clarified and its bubbles are separated. The center part of the furnace is kept higher in temperature than the rest so that unmolten or low-temperature material in the furnace will not flow out to the working hearth.

Figures 4.1.5 and 4.1.6 show examples of an end-port type middle-size furnace for bottle glass and a side-port type melting furnace for figured sheet glass, respectively.

Figure 4.1.5 Outline Sketch of Middle-Size Tank Furnace (End-Port Type)

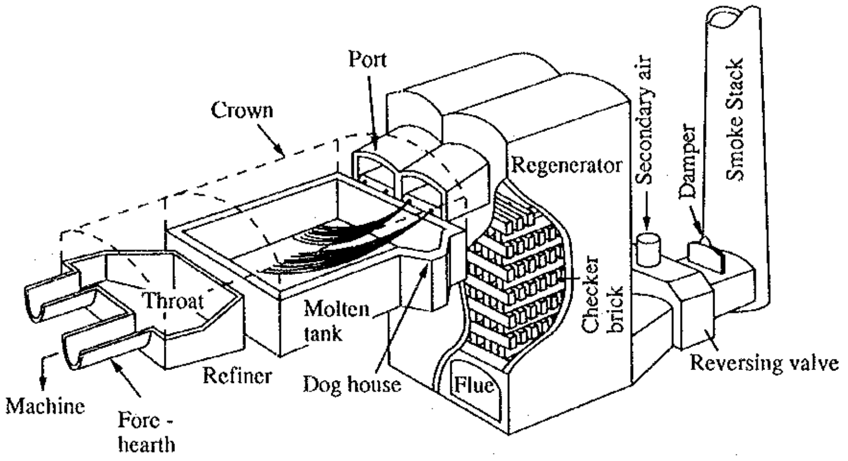
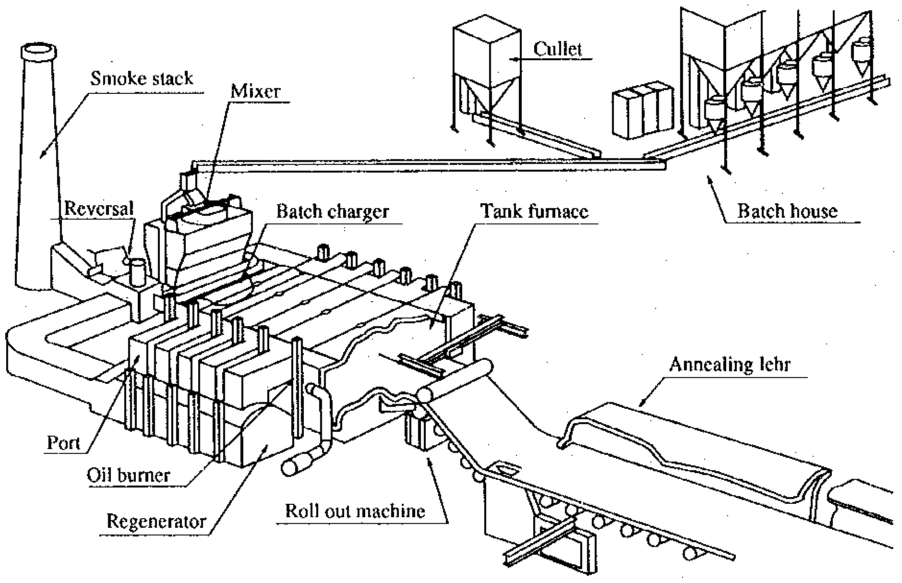


Figure 4.1.6 Outline Sketch of Tank Furnace (Side-Port Type)



A high temperature of about 1,500 °C is necessary to melt glass so that combustion air must be preheated by heat exchange with combustion exhaust gas. A regenerator or recuperator such as that shown in the figure is used for this preheating. Instead of heating with fuel, or as a complementary means, an electrode may be directly inserted into molten glass to directly heat it with electricity.

The melting furnace is lined with erosion-resistant electrofused cast bricks of ZrO_2–Al_2O_3–SiO_2 in the lower part which is exposed to molten glass, and with silica bricks in the upper part.

Burners in the large-size furnace are installed at the both sides of the furnace, while those in the middle-size furnace are installed at the blow-out ports arranged in the axial direction sticking out from the regenerator. Switching between the burner combustion sides is performed at regular intervals (usually 15 to 20 minutes). (See Figure 4.1.5 Outline Sketch for Middle-Size Tank Furnace.)

The regenerator on the side of the operating burners is used to preheat combustion air, and the other regenerator heats the checker bricks through combustion exhaust gas to store the heat in the bricks. Generally, the regenerator type has a higher rate of heat recovery than the recuperator. (For further details, see 4) Recovery of waste heat in this section.)

b. Energy conservation by improvement of operation and equipment

1) Optimization of air ratio

Glass is melted at a high temperature of about 1,500 °C. At such a high temperature, heat is transferred mainly by radiation. In other words, the higher the flame temperature is, the larger the heat transfer becomes. The flame temperature decreases as the volume of excess air increases. Therefore, the air ratio needs to be reduced as much as possible within a range where no imcomplete combustion will occur.

It is equally important to reduce the amount of exhaust gas since even the combustion exhaust gas after waste heat recovery has a temperature of around 500 °C.

Decreasing the air ratio leads to reduction in the amount of exhaust gas.

If the amount of exhaust gas decreases from G_1 to G_2 by improving the air ratio, the decreased heat loss by exhaust gas will reduce the amount of fuel to further decrease the amount of exhaust gas. In this case, the percentage of fuel saving can be expressed by the following equation.

$$\text{Fuel saving (\%)} = \frac{100R\,(1-\frac{G_2}{G_1})}{100-RG_2/G_1}$$

(there R is the percentage of the heat loss by exhaust gas before the improvement. (%))

Melting furnaces in Japan generally have the air ratio reduced down to the level where m = 1.05 to 1.10. Air ratio can be reduced by as much as about 70 % by manual combustion control alone as compared with automatic control although it can also be decreased by improvement of equipment and instrumentation management. Additionally, reduction of air ratio provides a substantial effect as a countermeasure for reduction of NOx.

Preventing air entering from the outside also serves as a measure for energy conservation. Air entering from the material charging port, the periphery of a burner, the peephole, and other similar parts not merely increases the amount of exhaust gas but also lowers the furnace temperature because the air is cold. In addition, the loss of radiation heat from the furnace through openings is substantial as well.

As a countermeasure for the above, the openings must be made as small as possible.

Moreover, it is necessary to completely seal the joints of bricks, gaps, etc.

From an operational viewpoint, a furnace pressure (> 0.05 mmAq at glass level) should be maintained at plus pressure by adjusting the flue damper.

2) Improvement of flame emissivity

In gas combustion, heat is transferred mainly by radiation from the clear flames of high-temperature carbon dioxide gas, water vapor, and other triatomic gas.

In fuel oil combustion, heat is transferred by luminous flame radiation, and solid radiation from the suspended carbon particles that are generated in the flames during combustion plays an important role.

As shown in Figure 4.1.7, emissivity ε of radiation heat transfer differs between fuel oil (0.6 – 0.8) and natural gas (0.3 – 0.4) in the initial phase of combustion. In actual furnaces, the effect will be less because there is re-radiation from the furnace walls in addition to radiation from the flames, but gas has less amount of radiation heat transfer than fuel oil.

If the fuel oil C used for combustion in a furnace is switched to natural gas, energy consumption usually increases by about 5 %.

Figure 4.1.8 shows an actual case, which has been reported so far. In this case, a baffle is provided halfway in the port. Fuel gas is injected in back of it to be burnt in a state of rather insufficient air so that fine carbon particles will be generated and they will be burnt into luminous flames in secondary combustion. This instance is not, however, regarded as a general method.

Figure 4.1.7 Relationship of Flame Emissivity and C/H Ratio in Fuel

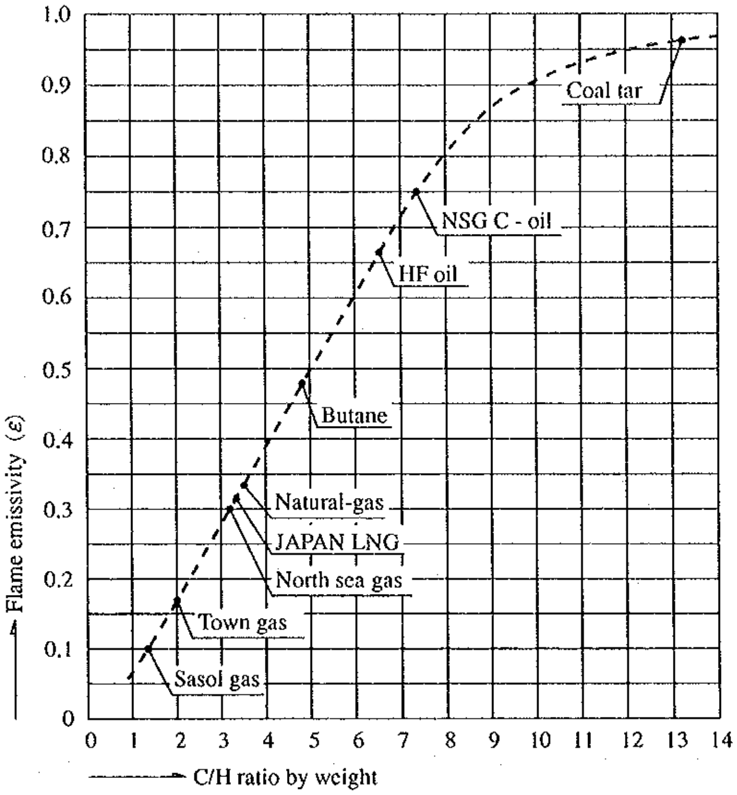
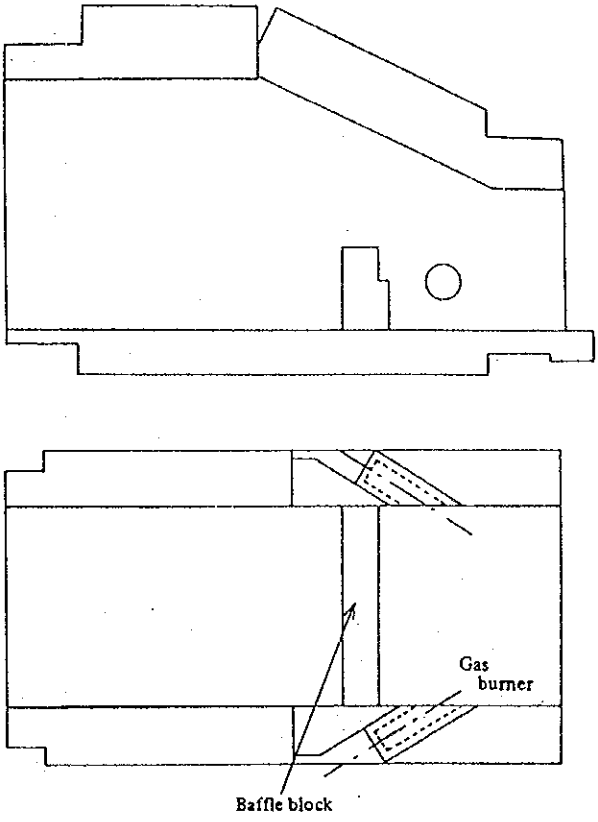


Figure 4.1.8 Baffle Block in the Port



3) Reinforcing heat insulation

The refractories of the melting furnace are exposed to very severe conditions in terms of temperature and corrosion by the glass. Consequently, they had not been sufficiently heat-insulated, and the outer surface of wall of molten glass level was cooled by air. As is clear from the heat balance chart, heat radiation from the furnace walls accounts for a large percentage of heat loss; therefore the furnace was being improved in heat insulation using high-grade refractories. Specifically, the furnace crown was lined with super-duty silica bricks having small alkali or alumina content; the tank block and bottom were lined with electrofused cast bricks of alumina, zirconium, silica inside and with fireclay bricks, insulating bricks, or ceramic fiber outside.

Heat loss from the furnace wall is either directly measured by a heat flowmeter, or it is obtained by measuring the temperature of the furnace wall outer surface and thereby calculating the dissipation heat caused by radiation and convection. The temperature of the furnace wall outer surface can be calculated by the material and thickness of the furnace wall refractory bricks and the furnace inner surface temperature.

Figure 4.1.9, 4.1.10 and Table 4.1.3 give examples showing the calculated values of radiation heat before and after reinforcing the heat insulation of the furnace wall.

Figure 4.1.9 Furnace Parts before and after Heat Insulation

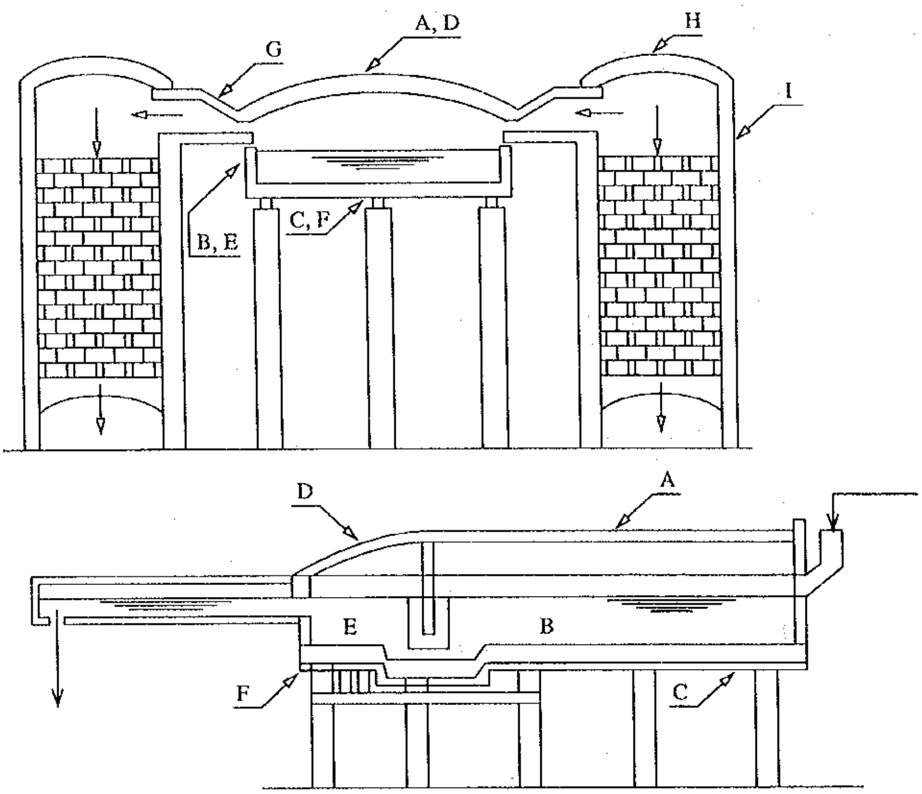


Figure 4.1.10 Comparison between Old and New Designs for Furnace Insulation

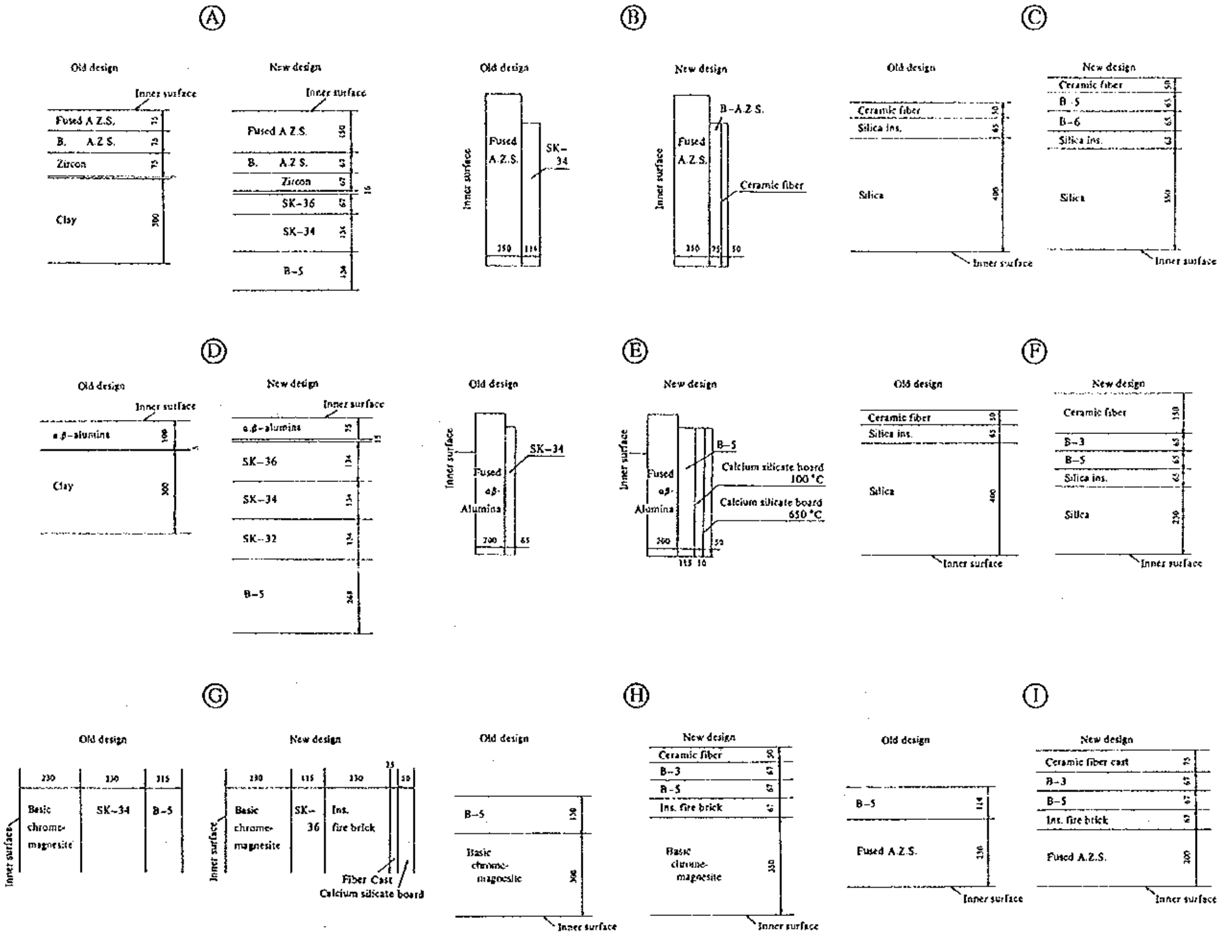


Table 4.1.3 Comparison of Heat Loss by Insulation

		Inner surface temperature (°C)	Outer surface temperature (°C)	Amount of heat loss (kJ/m^2h)	Wall heat loss reduction ratio (%)
Ⓐ Melting tank Crown	Old	1,550	132	5,066	42.8
	New	1,550	100	2,897	
Ⓑ Melting tank Side	Old	1,350	285	22,462	74.4
	New	1,350	141	5,761	
Ⓒ Melting tank Bottom	Old	1,350	225	17,966	72.6
	New	1,350	130	4,915	
Ⓓ Refining tank Crown	Old	1,250	115	3,860	67.8
	New	1,250	70	1,243	
Ⓔ Refining tank Side	Old	1,200	330	30,455	95.2
	New	1,200	74	1,457	
Ⓕ Refining tankBottom	Old	1,100	250	17,275	89.2
	New	1,150	80	1,867	
Ⓖ Port Crown	Old	1,500	155	6,896	62.3
	New	1,500	95	2,600	
Ⓗ Regenerator Crown	Old	1,450	128	4,802	67.8
	New	1,450	76	1,545	
Ⓙ Regenerator Side (Upper part)	Old	1,450	118	4,065	28.7
	New	1,450	100	2,897	
Average					66.8

The simply calculated mean value for heat loss reduction ratio in Table 4.1.3 amounts to 66.8 %, which indicates a substantial reduction of radiation heat loss from the refractory surface. Heat loss from the furnace includes a significantly large amount of heat loss from the joints of bricks and from support metals as well as heat loss from the refractory surface. Therefore, improvement effect of reduced radiation heat loss from the entire furnace is smaller than 66.85 %.

4) Recovery of waste heat

Because a melting furnace requires high temperature, the waste heat of burnt exhaust gas is recovered to preheat secondary air. Either a regenerator or recuperator is used as a waste heat recovery unit. Generally, a regenerator is used except for small-sized furnaces.

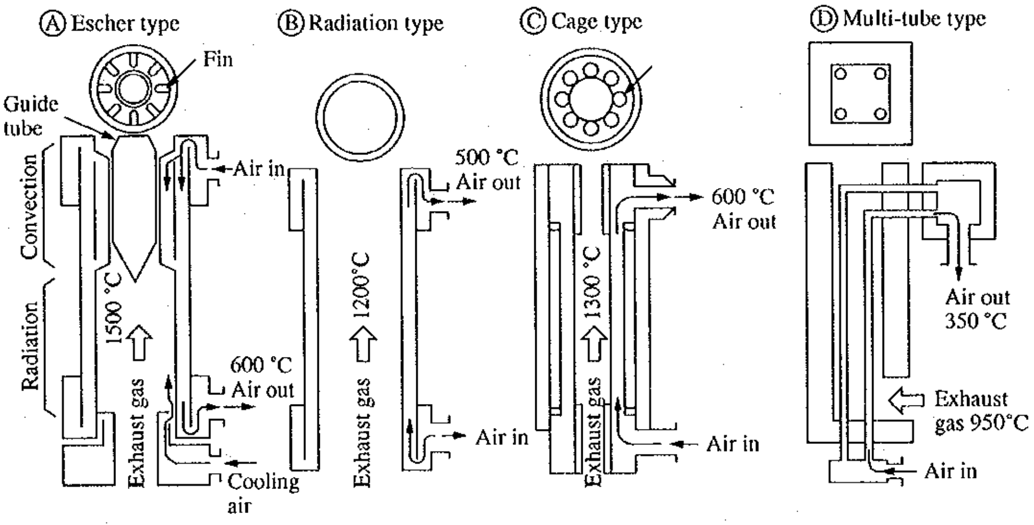
① Recuperator

Although a ceramic type recuperator is available, it is not widely used for the tank furnace because of air leakage from the junctions or blocking in the tube.

The type of metal recuperators that do not allow dust blocking is widely used. The air preheating temperature is not more than 800 °C and thus the heat recovery rate is low.

However, this type of compact and low-cost metal recuperator is used for small-size furnaces. Figure 4.1.11 shows various types of metal recuperator.

Figure 4.1.11 Various Types of Recuperator



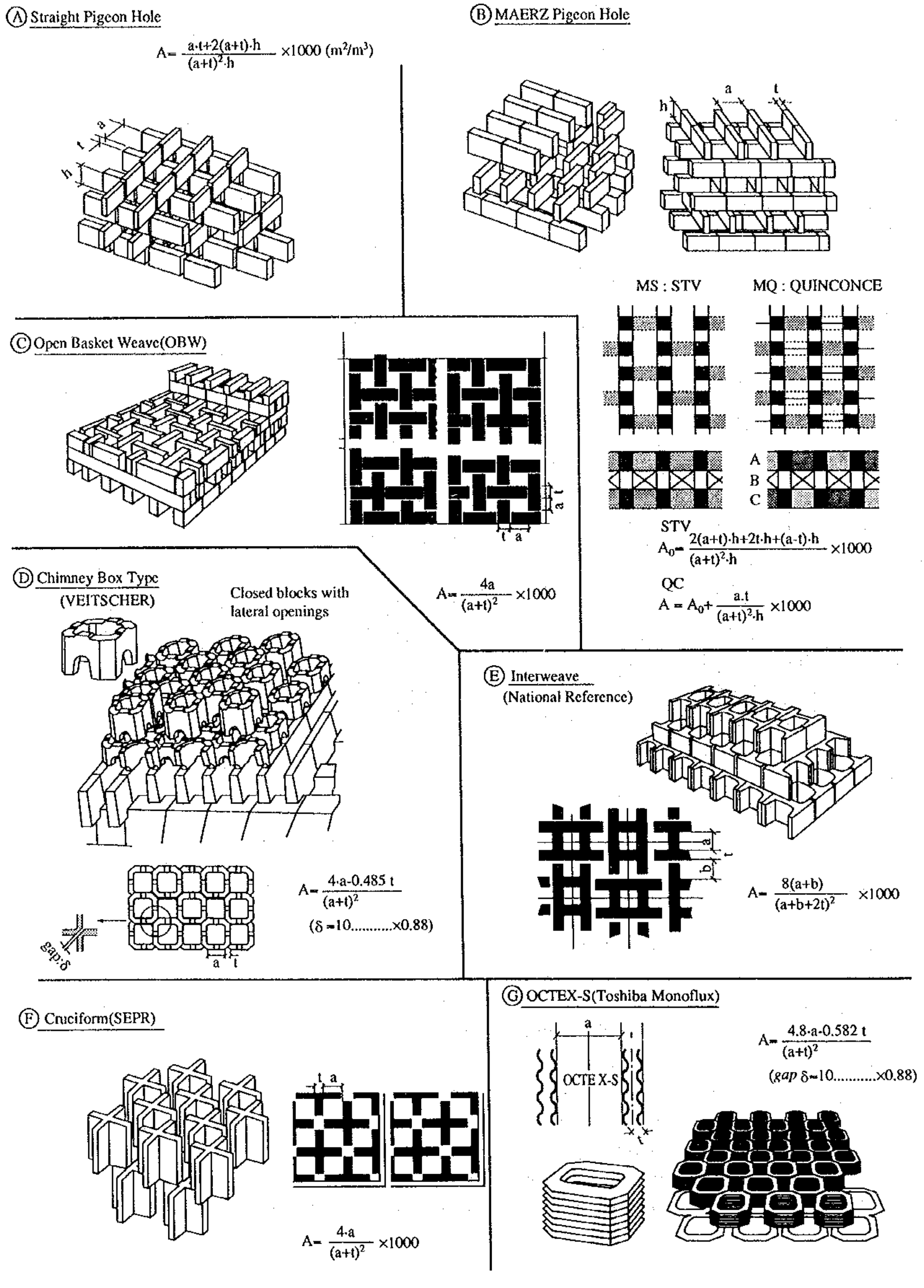
As shown in Figure 4.1.11, the air preheating temperature differs according to the type of the recuperator. Usually, however, the heat recovery rate by a recuperator is 20 % to 25 %, which is approximately half that by a regenerator described in the subsequent section.

② Regenerator

In the regenerator, secondary air is generally preheated to about 1,150 °C to 1,300 °C and the heat recovery rate is usually 35 % to 55 %.

The heat recovery ratio of the regenerator can be improved by decreasing the thickness of checker bricks, increasing the velocity of exhaust gas running through the checker bricks, and raising the height of the regenerator and thus increasing the amount of checker bricks. Figure 4.1.12 shows the types of checker work and the unit surface area for heat conduction.

Figure 4.1.12 Types of Checker Work and Unit Surface Area for Heat Conduction



Ⓐ Straight Pigeon Hole

$$A=\frac{a\cdot t+2(a+t)\cdot h}{(a+t)^2\cdot h}\times 1000\ (m^2/m^3)$$

Ⓑ MAERZ Pigeon Hole

STV

$$A_0=\frac{2(a+t)\cdot h+2t\cdot h+(a-t)\cdot h}{(a+t)^2\cdot h}\times 1000$$

QC

$$A=A_0+\frac{a.t}{(a+t)^2\cdot h}\times 1000$$

Ⓒ Open Basket Weave(OBW)

$$A=\frac{4a}{(a+t)^2}\times 1000$$

Ⓓ Chimney Box Type (VEITSCHER)

Closed blocks with lateral openings

$$A=\frac{4\cdot a-0.485\ t}{(a+t)^2}$$

(δ = 10..........×0.88)

Ⓔ Interweave (National Reference)

$$A=\frac{8(a+b)}{(a+b+2t)^2}\times 1000$$

Ⓕ Cruciform(SEPR)

$$A=\frac{4\cdot a}{(a+t)^2}\times 1000$$

Ⓖ OCTEX-S(Toshiba Monoflux)

$$A=\frac{4.8\cdot a-0.582\ t}{(a+t)^2}$$

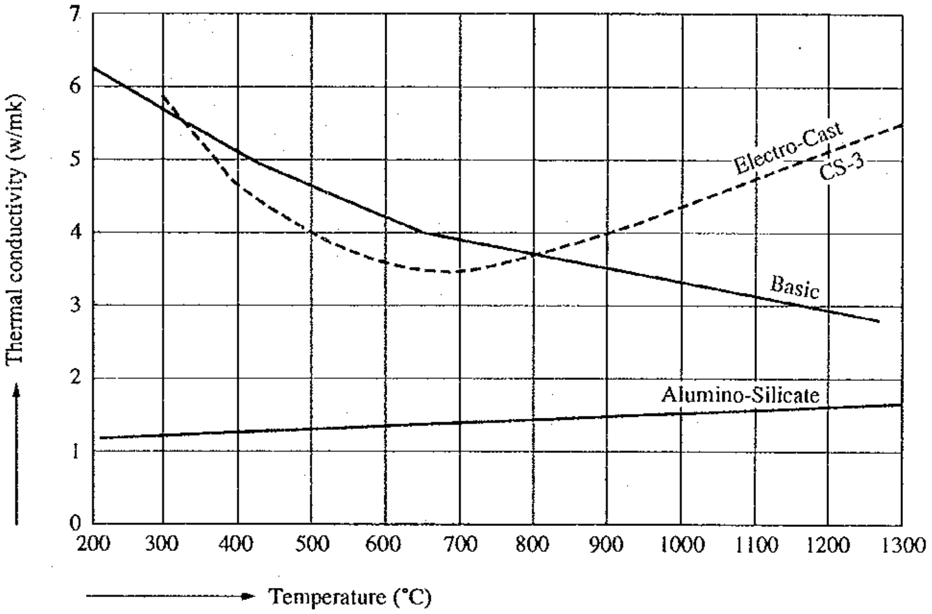
(*gap* δ ~ 10..........×0.88)

Conventional checker bricks without mortar bonding are mainly 75-mm thick bricks of the pigeon hole type. These are now being replaced by 40 to 50 mm thick bricks of OBW type, Chimney Box type and Cruciform type, which increase the unit surface area for heat transfer by about 60 %.

The materials of checker bricks are discussed below.

The checker bricks cause breaking down by reaction with the dust in exhaust gas over years of use, clogging up the gaps and holes, reducing the heat exchange area. Therefore, magnesite bricks and electrofused cast bricks of high corrosion resistance have come to be used to last as long as the melting furnace itself. The heat conductivity of magnetite bricks and electrocast bricks is two or more times as large as that of the conventionally used aluminosilicate bricks. (See Figure 4.1.13) This considerably contributes to improving the heat recovery rate (increasing the air preheating temperature).

Figure 4.1.13 Heat Conductivity of Checker Refractory



The regenerator configuration is outlined next.

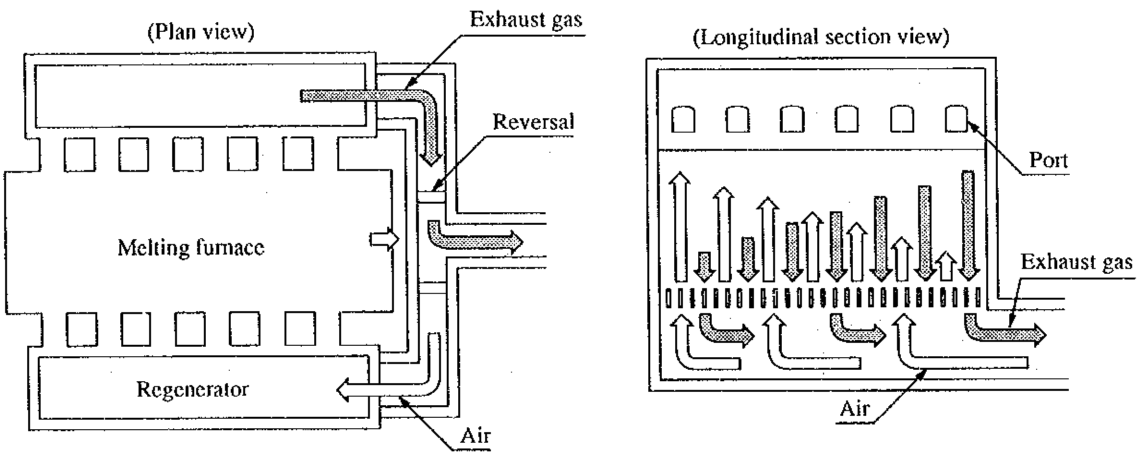
In a side port type tank furnace, the ports from No.1 to the last conventionally form one slender room without any partition wall between them. As a result, a large amount of exhaust gas flows toward the No. 1 port side, while a large amount of the preheated air tends to flow toward the final port side, thus causing an imbalance in the heat exchange rate and making it difficult to conrol the excess air rate.

To cope with this matter, a partition wall is provided between the ports to separate them so that each port can be controlled individually. A regenerator configured in this manner is called a separate regenerator, which increases the heat exchange rate between exhaust gas and secondary air and at the same time makes it easier to control excess air. Such a comparison is expected to bring about a 2 % to 5 % energy conservation.

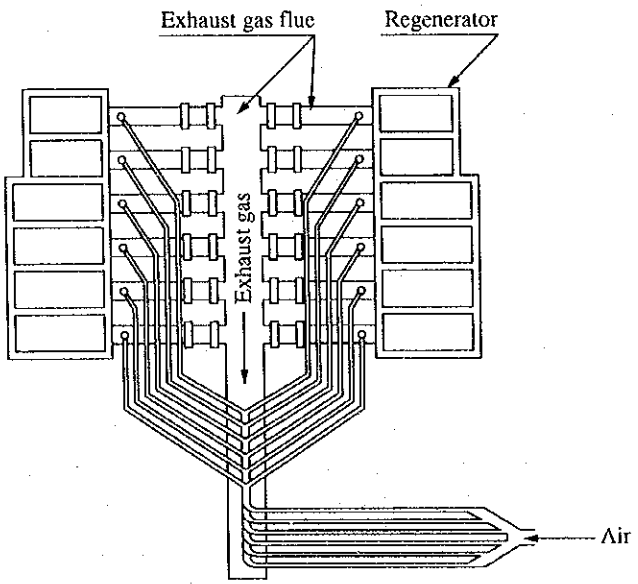
Figure 4.1.14 illustrates a conventional type regenerator and a new separate type one.

Figure 4.1.14 Old Type Regenerator and New Separate Regenerator

Ⓐ Old type regenerator



Ⓑ Separate regenerator



③ Waste heat boiler

The exhaust gas from the regenerator still contains sensible heat of about 500 °C, which can be recovered as steam or hot water by installing a waste heat boiler.

Many large-size furnaces for manufacturing sheet glass are equipped with a waste heat boiler to recover the waste heat as steam, which is then used for heating fuel oil or for atomizing.

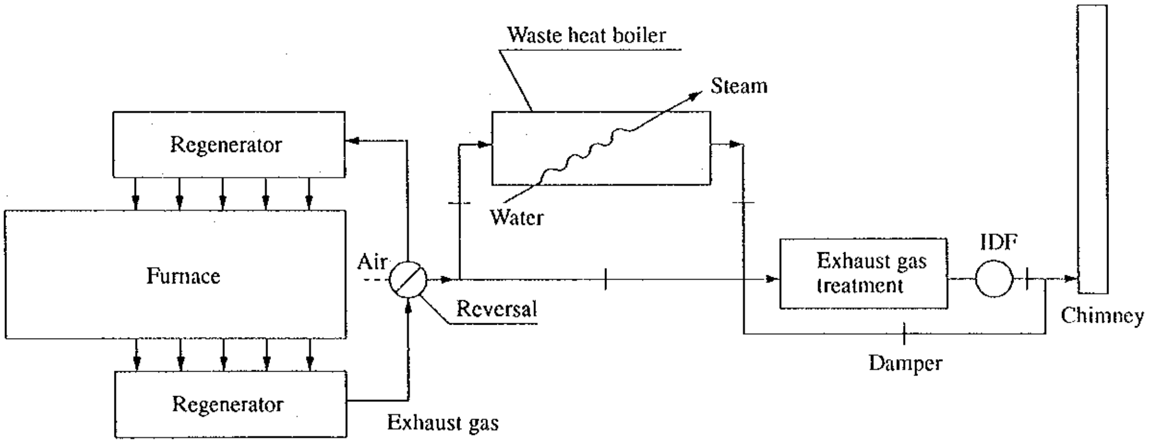
All the exhaust gas need not be used. A flue damper can be used to supply only the amount in proportion to the demanded steam to the waste heat boiler.

An implementation example is shown below.

Exhaust gas amount : 35,000 m^3/h
Inlet temperature : 483 °C
Outlet temperature : 223 °C
Heat recovery rate : 10 %
Feedwater temperature: 34 °C
Evaporation amount : 4.1 t/h
Steam pressure : 15 kg/cm^2
Steam temperature : 193 °C

Figure 4.1.15 shows the exhaust gas flow sheet and the location of a waste heat boiler.

Figure 4.1.15 Flow Sheet of Exhaust Gas and Waste Heat Boiler



5) Electric melting

① What is electric melting?

This method uses an electrode inserted in the melting furnace to apply electricity directly to glass to make it electro-conductive at about 800 °C. If it is used in a fuel-heating furnace as an auxiliary means to increase the quantity of pull and adjust the temperature inside the furnace, it is called a booster. About 100 kW of electricity is required for increasing the quantity of pull by 3 tons per day. If the fuel consumption rate is 7.3 MJ/kg-MG or more based on the assumption that the heat value per kW is 10,258 kJ, the use of a booster will contribute to energy conservation.

The subsequent description is mainly focused on all-electric melting.

② Economical limits of electric melting

Electric melting is more economical in small-sized furnaces. The limit point is obtained by the following equation.

$$y = 3.16x^{0.181x + 1.83}$$

where

y = Molten glass amount MG t/d

$$x = \frac{41{,}449 \times \text{Fuel price/kJ}}{\text{Electricty price/kWh}}$$

For example, if calculation is made on the assumption that y is equal to 65, all-electric melting is more economical when y is 65 t/d or less.

Furthermore, electric melting may emit less air pollution, make temperature control easier, and produce higher quality products more easily. As shown in Figure 4.1.16, the electric furnace is cold at the top and therefore the volatile loss is smaller as shown in Figure 4.1.17.

Figure 4.1.16 Heat Loss from Oil-/Gas-fired and Electrically heated Furnaces

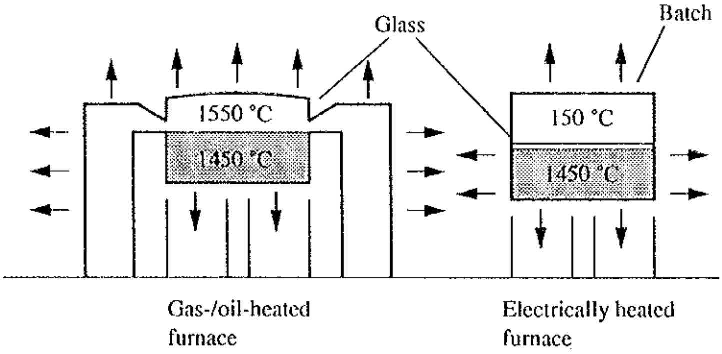
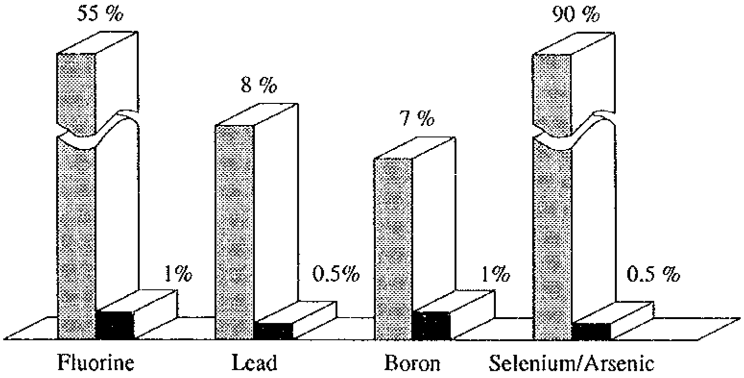


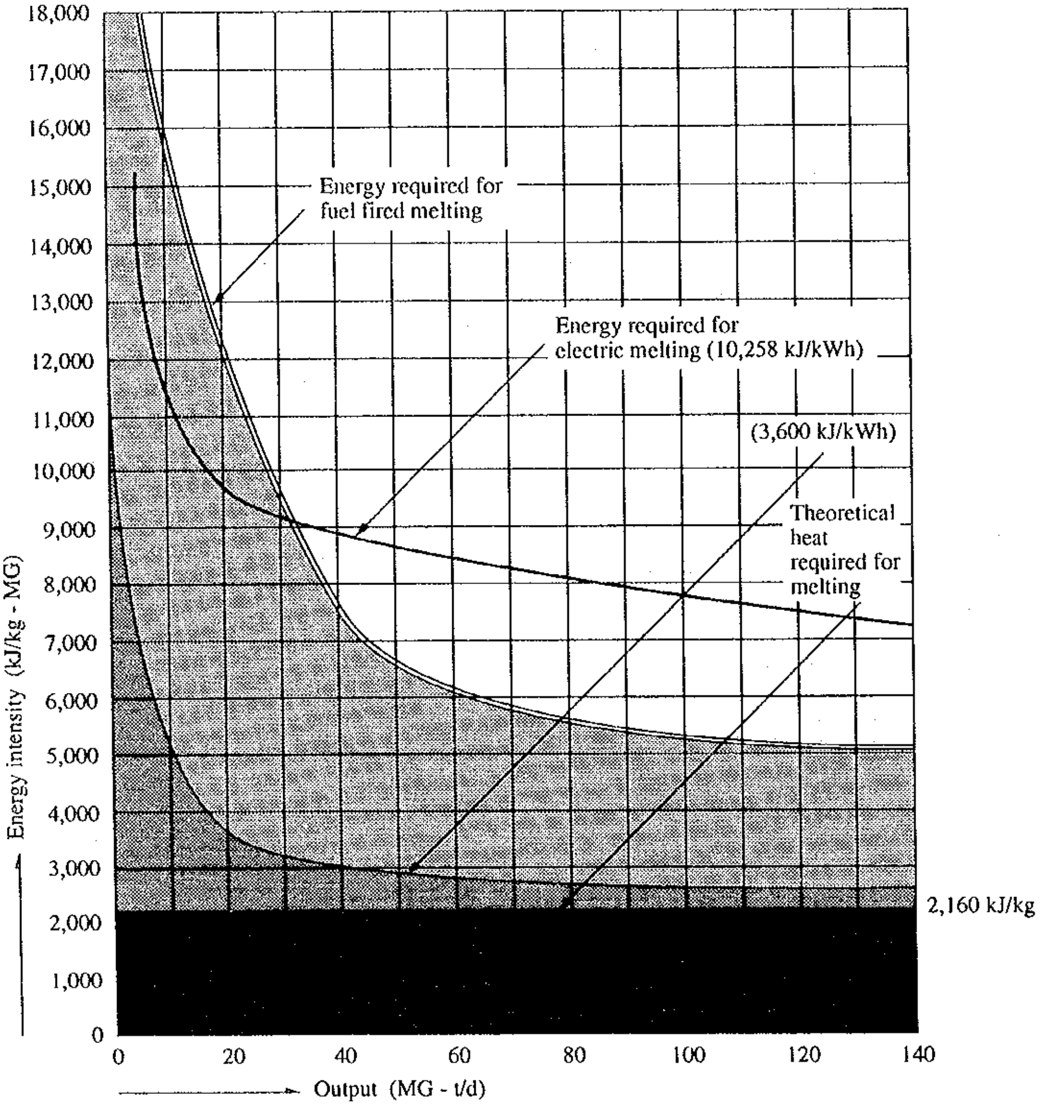
Figure 4.1.17 Comparison of Volatile Losses from Oil/Gas and Electrically heated Furnaces



③ Energy intensity for electrically-heated and oil/gas-fired furnaces

Figure 4.1.18 shows a comparison of energy intensity between electrically-heated furnace and oil/gas-fired furnace.

Figure 4.1.18 Comparison of Energy Requirements for Oil/Gas-fired and Electrically-heated Furnaces



④ Heat balance of electrical melting furnace

Table 4.1.4 shows an example of the heat output ratio in an electric melting furnace.

Table 4.1.4 Heat Output Ratio of Electric Melting Furnace

Capacity Molten glass	750 kg 400 kg/d		– 60 t/d	
	Heat output (kJ/h)	Rate (%)	Heat output (MJ/h)	Rate (%)
Heat loss from crown arch	334	0.07	513	2
Heat loss from furnace bottom	70,170	13.7	2,667	13
Heat loss from furnace side wall	62,023	12.1	–	–
Heat loss from throat wall etc.	93,631	18.2	3,077	15
Sub total	226,158	44.1	6,257	30
Heat for vitrification	–	–	616	3
Heat for glass heating	162,023	31.6	13,335	65
Sub total	162,023 (0.948 kWh/kg)	31.6	13,951 (0.544 kWh/kg)	68
Loss by water cooling for electrode	124,702	24.3	410	2
Total	512,883 (3.000 kWh/kg)	100.0	20,618 (0.804 kWh/kg)	100

The heat efficiency of an electric melting furnace is as much as 65 % even in 60 t/d scale furnaces, which is 44 % higher than that in oil/gas-fired furnaces of 264 t/d scale. (Refer to Table 4.1.4)

Additionally, as shown in Figure 4.1.18, for MG (Molten Glass) 60 t/d-scale furnaces, use of oil/gas-heated furnaces improves the energy intensity when electricity is converted into 10,258 kJ/kWh. The energy intensity of a MG 60 t/d-scale furnace is equal to that of an electric melting furnace.

⑤ Electrode material and refining aids

Electrode material used in electric melting furnaces is generally metal molibden.

The molibden electrode is corroded with salt cake, arsenic, etc. used as refining aids of glass and thus wears significantly. Therefore, care should be taken to the use. Hard glass is generally borosilicate glass and contains a large amount of B_2O_3. Therefore, the use of the refining aids mentioned above will cause foaming, thus posing the potentail danger of aggravating the product quality.

Salt is usually used as electrode material for hard glass. However, the use of salt can cause the corrosion of refractory bricks, and therefore care should be taken regarding this matter.

⑥ Actual example of electric melting furnace

Table 4.1.5 and Figure 4.1.19 show actual examples of an electric melting furnace.

The following electrode insertion methods are available:

Side electrode : Electrode is inserted from the furnace side as shown in Figure 4.1.19-Ⓐ, and Ⓒ

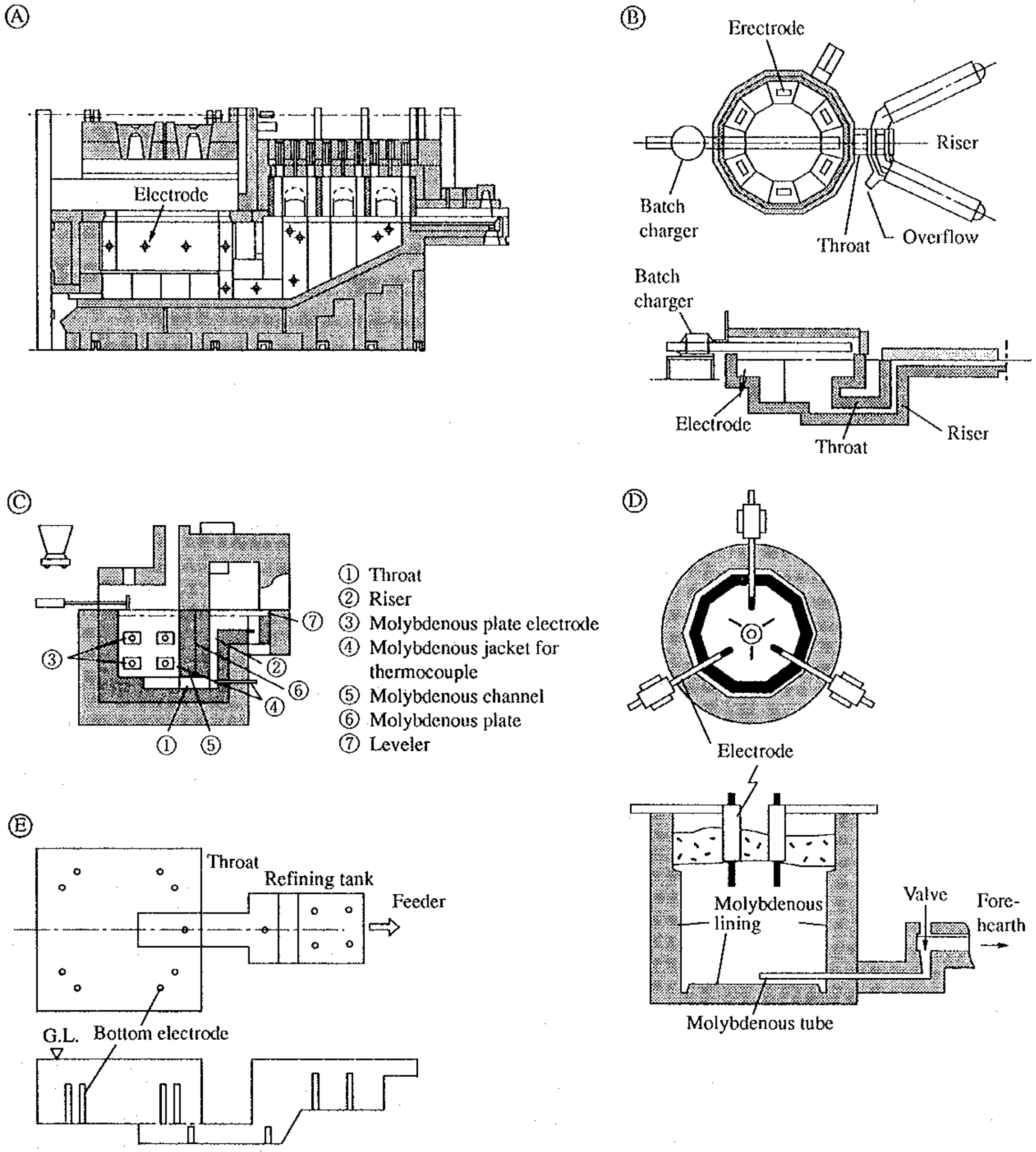
Bottom electrode: Electrode is inserted from the furnace bottom as shown in Figure 4.1.19-Ⓑ and the reference drawing Ⓔ

Top electrode : Special insertion method shown in Figure 4.1.19 Ⓓ

Table 4.1.5 Various Types of Electric Furnace

Maker	Glass	MG (t/d)	Melting load (t/m²·d)	Electric intensity (kWh/kg)
Ⓐ Staneck	Hard borosilicate	6	–	1.7
Ⓑ KTG	Hard borosilicate	72	2	–
Ⓒ (Old) USSR	Hard borosilicate	1.4 - 1.8	1.46 - 1.88	1.5
Ⓓ C.G.W	Pyrex	7.9	5	0.9 (Temperature 1,800 °C)
Ⓔ Reference figure – Bottom electrode				

Figure 4.1.19 Various Types of Electric Furnace



5) Oxygen combustion

There are two types of oxygen combustion: oxygen-enriched combustion where oxygen is added to air for combustion, and pure oxygen combustion where nearly 100 % concentration of oxygen is used for combustion. From the viewpoint of energy conservation, pure oxygen combustion is preferable.

① Characteristics of oxygen combustion

- Reduction in exhaust gas amount

  In pure oxygen combustion, the amount of exhaust gas becomes one fifth, reducing exhaust gas loss and eliminating the necessity of air preheating. As a result, a regenerator or recuperator is no longer necessary.

- Rise in flame temperature

  Combustion reaction heat is not deprived by nitrogen; therfore it produces a high temperature and improves melting efficiency.

- Rise in combustion speed

  Chances of collision between fuel particles and oxygen paticles increase, thus decreasing the excess air ratio and improving the combustion efficiency.

- Reduction in NOx

  The effect of reduction in gas amount is more significant than the rise in NOx due to the rise in flame temperatue, resulting in a reduction of NOx.

- Use of dissociation latent heat

  At flame temperatures of 2,000 °C or more, CO_2 and H_2O in combustion gas are dissociated and then re-linked on the surface of the object to be heated at a low temperature to produce high temperatures up to 4,000 °C.

② Energy conservation by oxygen combustion

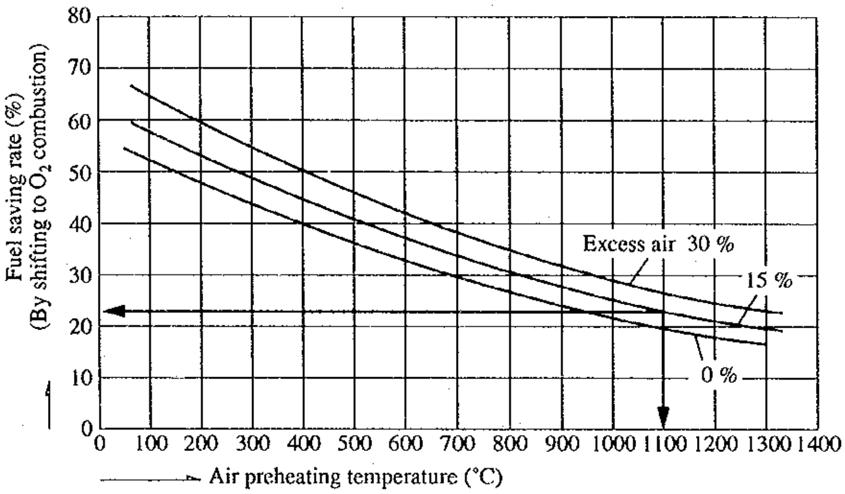
Oxygen combustion has a substantial energy conservation effect on small-size furnaces with a small combustion chamber, furnaces requiring a high melting temperature and furnaces with a recuperator of a relatively low temperature for preheating secondary air.

In an example in Japan, oxygen combustion was employed for a furnace with 450 °C of air preheating temperature and 30 % of excess air ratio, thereby reducing the fuel consumption rate by 50 %.

Next, the fuel saving rate for a furnace with a known relationship between air preheating temperature and excess air ratio when it is switched to oxygen combustion is obtained, the results of which is shown in Figure 4.1.20.

As shown in this figure, when oxygen combustion is used for a furnace where the air preheating temperature is 1,100 °C and the excess air ratio is 15 %, the energy saving rate will be 23 %.

Figure 4.1.20 Fuel Saving Rate by Oxygen Combustion

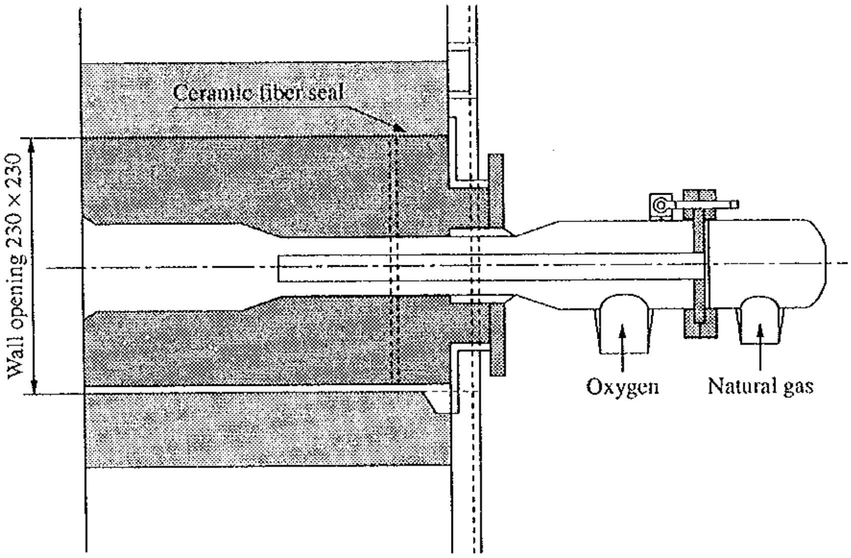


③ Oxygen burner (Oxygen/fuel burner)

Troidal burners and Dragon burners, which directly spray fire onto the surface of the object to be heated, are popular oxygen burners, but so far these burners have not been commercially available in the glass industry. In recent years, however, an Alglass burner developed by Air Liquid Company (France) has come to be widely used in the glass industry because it is very practical. The burner has the following features.

Figure 4.1.21 shows an example of the burner.

Figue 4.1.21 Sketch of Alglass Burner



④ Oxygen generator

Although liquid oxygen may be purchased and used as combustion oxygen, installing an oxygen generator is more economical.

There are various types of generators, of which the adsorption type is more suitable for oxygen burners.

Adsorption methods include the PSA (Pressure Swing Adsorption) and the VSA(Vacuum Swing Adsorption).

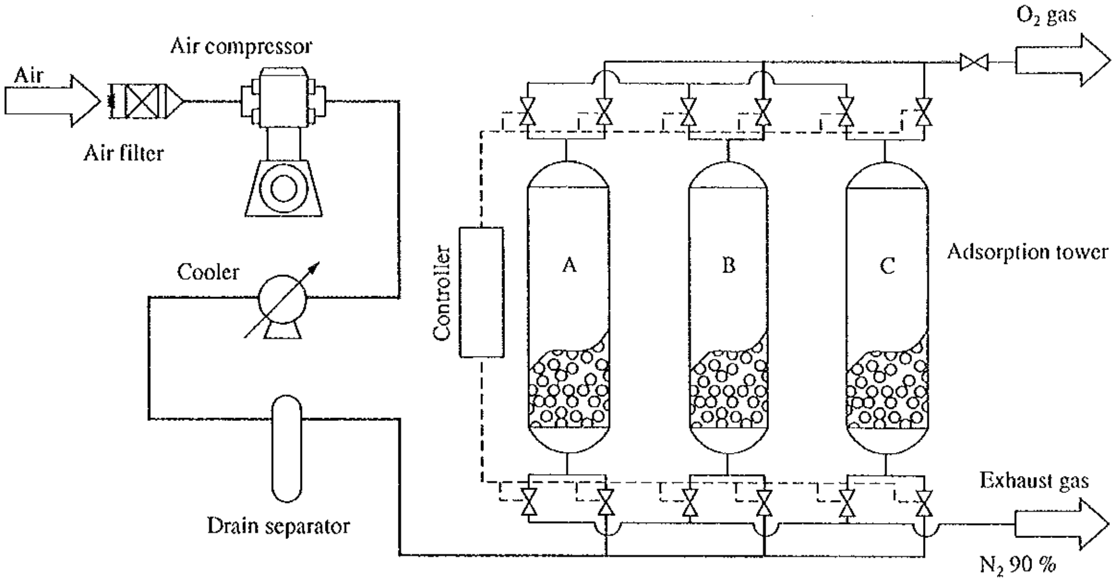
Figure 4.1.22 shows only the flow sheet of the PSA type since there is no significant difference between the VSA type and the PSA type.

Instead of the air compressor shown in the figure, a blower may be used for the VSA type; however, a compressor needs to be installed at the place where generated oxygen gas is pressure-fed, if necessary.

An adsorption tower is filled with molecular sieves and alumina gel, which adsorb N_2, H_2O, CO_2, and HC. To regenerate the adsorption tower for theVSA type, the exhaust gas is desorbed through pressure reduction by means of a vacuum pump to be released into the atmosphere.

The generator is operated fully automatically with a liquid oxygen generator as a backup unit, thus ensuring a safety supply system.

Figure 4.1.22 Flow Sheet of PSA System



Capacity : 20 t/d
O_2 Purity : 90 to 93 %
Pressure : 1.2 kg/cm^2
Electric consumption: 0.46 kWh/kg O_2

(4) Forehearth

a. Forehearth process

After being melted and refined in the working hearth via the molten tank and the throat, the glass is then supplied to the forehearth. Forehearth is the name used in the bottle furnace. In other glass furnaces, a similar part for feeding glass to the forming machine is provided, which is called forehouse, canal, feeder or the like.

The forehearth is used to adjust the glass temperature to suit bottle production. It is equipped with many small burners.

Electric heating may be performed in some cases by direct application of electricity.

b. Energy conservation by improvement of operation and equipment

Control of air ratio and reinforcement of heat insulation contribute to energy conservation for the forehearth as well as for the melting furnace.

Next, a succcessful example of achieving substantial energy conservation by changing the gas burner combustion system in the order of 1) → 2) → 3) is given below.

1) Ventury mixer, premix system:

The pre-mix burner system, which uses a ventury mixer to mix gas and air

The problem with this system is that an inter-zone interference occurs between gas and air. As a result, an adjustment performed in one zone may change the air ratio in other zones. This could cause a back fire.

2) Nozzle mix system:

Nozzle mix system, which uses burners to mix gas and air without using a mixer

The problem with this system is that there remains an interference between the zones of gas and air because gas or air is supplied by one pipe to multiple burners, and therefore adjustment of a specific burner affects other burners. This requires a lot of labor for adjustment although combustion can be made with excess air maintained at a low level since no back fire occurs.

3) Pre-mixer, premix system:

Pre-mix system, which uses a pre-mixer consisting of a mixing valve and a blower

The advantage of this system is that the burners in all the zones can be combusted using the same air/fuel ratio. The combustion volume per burner is larger and this prevents a backfire.

Compared with the system in the above item 1), an energy conservation of 64.7 % can be achieved.

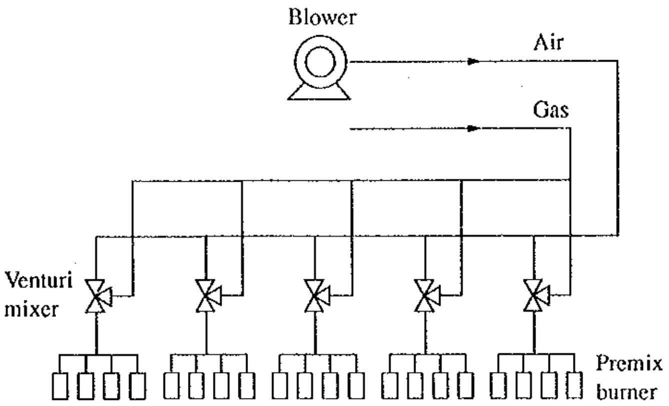
The energy conservation results are shown in Table 4.1.6 and comparison of combustion systems according to equipment is shown in Figure 4.1.23.

Table 4.1.6 Result of Energy Conservation in Forehearth

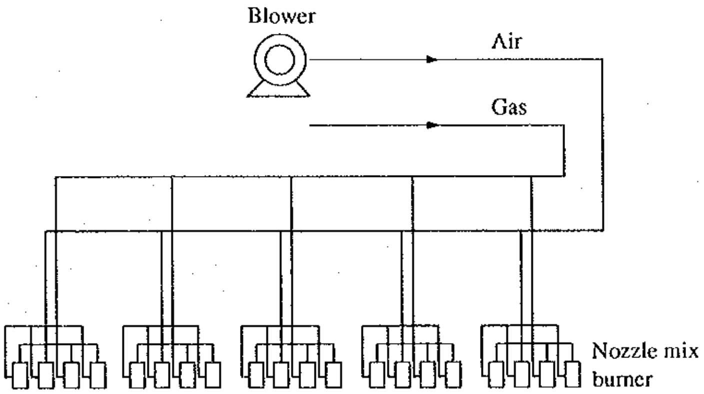
System	Oxygen in exhaust gas	Fuel gas consumption	Fuel saveing ratio
Ⓐ Venturi mixer and premix	8 %	85 m^3N/h	0
Ⓑ Nozzle mix	6 %	65 m^3N/h	23.5 %
Ⓒ Premixer and premix	1 %	30 m^3N/h	64.7 %

Figure 4.1.23 Various Types of Combustion System

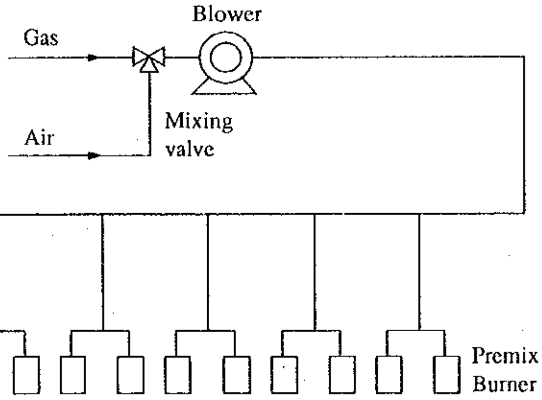
Ⓐ Venturi mixer and premix system



Ⓑ Nozzle mix system



Ⓒ Premixer and premix system



(5) Forming equipment

a. Forming process

The glass forming methods widely differ depending on the product type to be manufactured, and functionally they are roughly classified into pressing, blowing, drawing and rolling. These forming methods are used to produce various shapes of products at a high index.

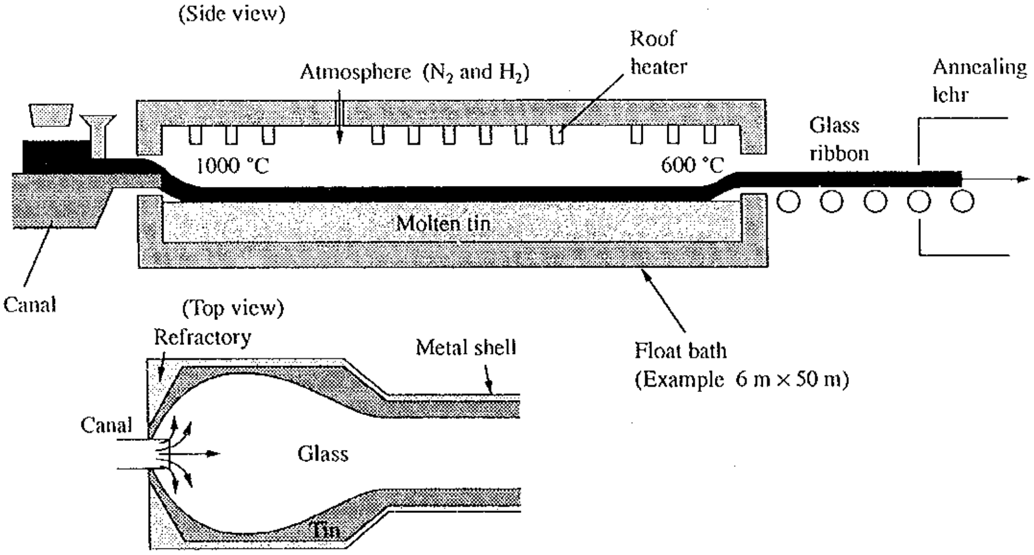
The glass viscosity sharply increases in the temperature zone ranging from high temperatures to normal temperature. The essence of glass forming lies in the utilization of this glass nature.

This section describes the float method and rollout method, which are mainly used for sheet glass, and the forming method using IS machine for bottle glass and the manufacturing method for small-size container glass, such as tableware glasses, among the container glass forming methods.

1) Float process

The float process is used for manufacturing float glass. In this process, the molten glass is introduced into the bath filled with molten metal (tin), where it floats and thereby is flattened. An example of this method is shown in Figure 4.1.24. The float bath is filled with reducing gas (N_2 + H_2) to prevent the oxidization of the molten tin.

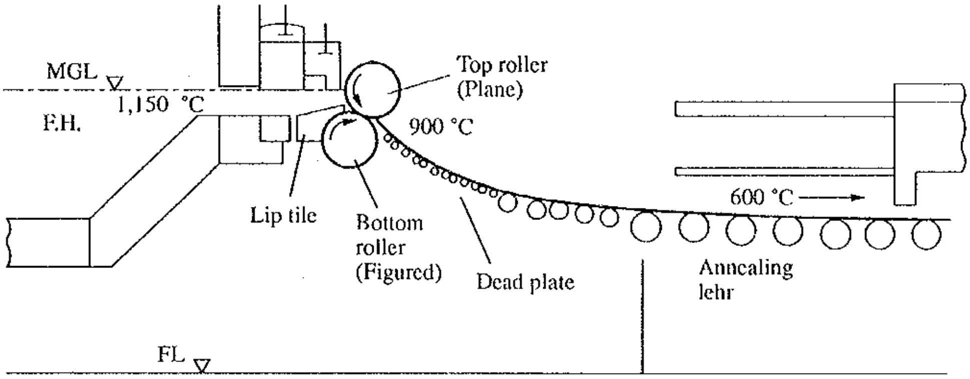
Figure 4.1.24 Float Process



2) Rollout process

The rollout process is used for manufacturing figured sheet glass and wired glass. In this process, the molten glass is introduced between a pair of rolls, to be rolled out for forming. Figure 4.1.25 shows an example of the rollout process. Usually, a pattern or a design is engraved on the lower roll and it is imprinted on the bottom surface of the glass while the glass is rolled between the rolls.

Figure 4.1.25 Rollout Process



3) Bottle glass forming process

Bottle glass forming processes are diverse and can be classified in many ways. They are roughly categorized into two processes: manual forming and mechanical forming.

The manual forming process is further divided into hand blowing and press molding.

The mechanical forming process is categorized into the gob feed system and the glass suction system depending on the material supply method. Either system is further divided into the rotary table type and the individual section type.

Forming of bottle glass is performed through the use of vitrification effected by cooling the molten glass while transferring it into the visco-elastic range. A bottle-manufacturing machine is one of the heat exchangers, for which the metal mold plays the role.

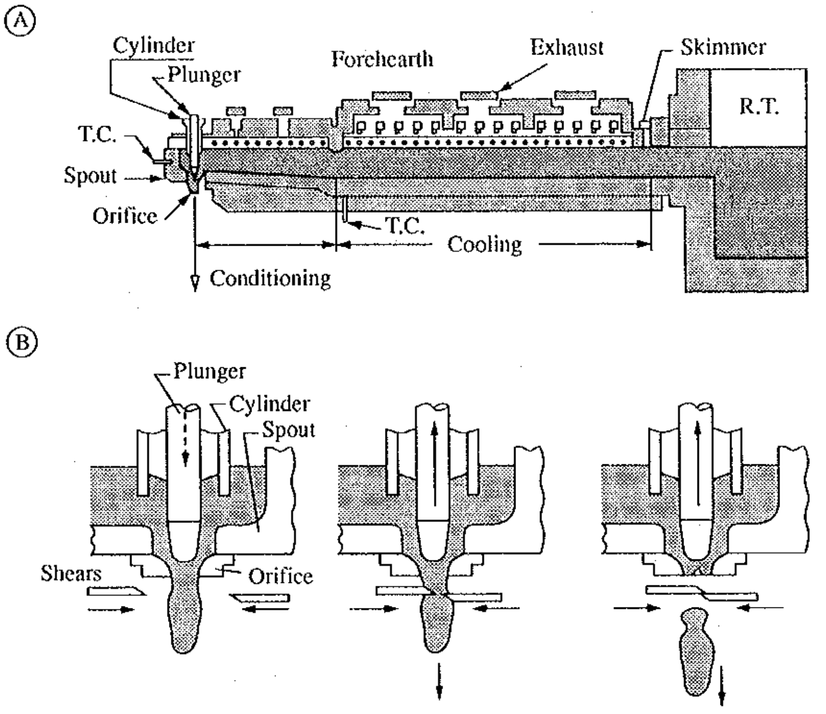
I.S. machine stands for Individual Section.

The I. S. machine is characterized by each section operating individually. When a metal mold is changed, only the corresponding section is stopped.

This machine had four sections at its initial stage, which then increased to 5, 6, and 8, until now, some machines have as many as 10 sections for use. Moreover, each section with single, double, triple or quadruple cavity allows four bottles to be manufactured at the same time by blowing, thus leading to a significant growth in the production volume. This IS machine is most widely used in the world.

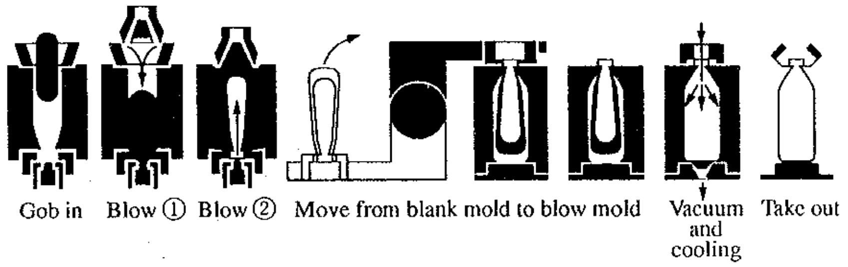
The forming process by the I.S. machine is shown in Figure 4.1.26 Ⓐ, Ⓑ, and Ⓒ. In this forming process, glass gob is fed into the blank mold by the feeder. Forming is started either by blowing first, or by the pressing operation of the mold. Then, the parison in an inverted position moves from the blank mold, rotates back into place and enters the blow mold, where it is subjected to finishing. In the meanwhile, forming of the next parison starts in the blank mold . The finished products are transferred to the stationary plate by the take-out unit to be partially cooled and fed all together to the annealing lehr by the conveyor.

Figure 4.1.26 IS Machine Process

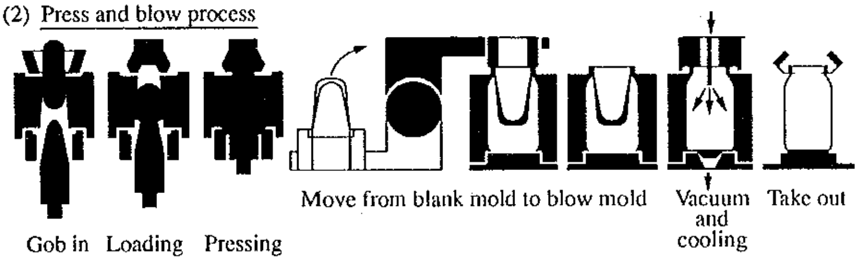


Ⓒ

(1) Blow and blow process



(2) Press and blow process



4) Tableware glass forming process

There are two types of tableware glass forming process: multi-item small lot type hand-made method and mass-production type mechanical method. Both, however, have the same manufacturing principle.

Glass material take-out and feed methods include the winding method (manual winding, autogatherer) and tube method (where the glass is made directly to flow down through the tube from the working hearth and put in the mold) in addition to the gob method used for the bottle forming.

Forming methods include the following:

① Blow molding: Popular method

② Blow molding (Blow-in): Thin glass products which are provided with complex polygonal designs on the surface

③ Pressing: Figured dishes, pots, thick glasses, and other products which have designs embossed by the engraved mold

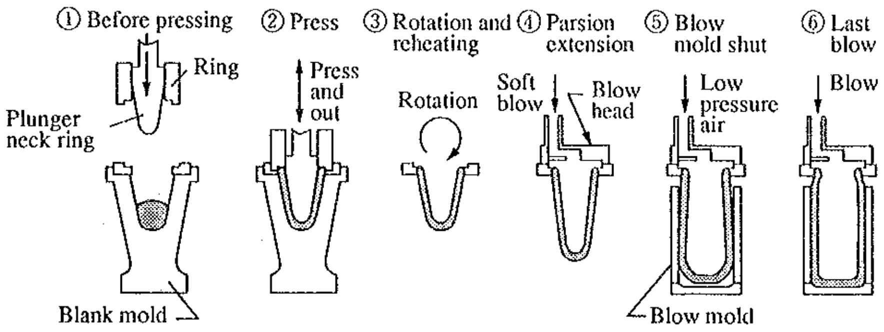
④ Centrifugal type (Spinning): The mold is rapidly rotated to flatten the poured glass along the mold by centrifugal force and to obtain a smooth internal surface.

⑤ Fully automatic forming machine: Among the typical forming machines are the H-28 model by Hartford Company for blow molding and the MDP model by Lynch for press molding. Special-purpose combination machines are also available for forming legged glasses.

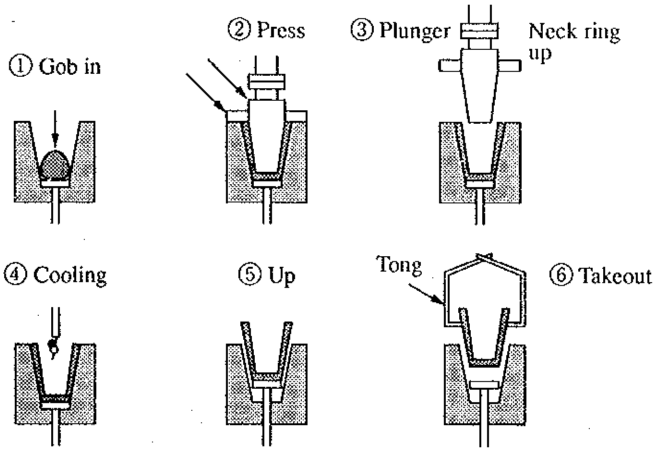
Next, Figure 4.1.27-Ⓐ,Ⓑ and Ⓒ show various types of forming processes.

Figure 4.1.27 Various Types of Forming Processes

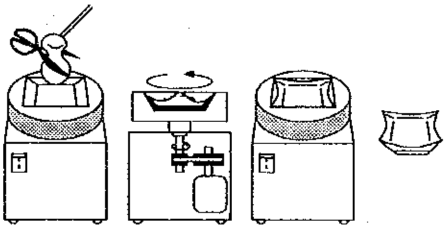
Ⓐ Hartford H - 28



Ⓑ Pressing



Ⓒ Spinning (Hand made)



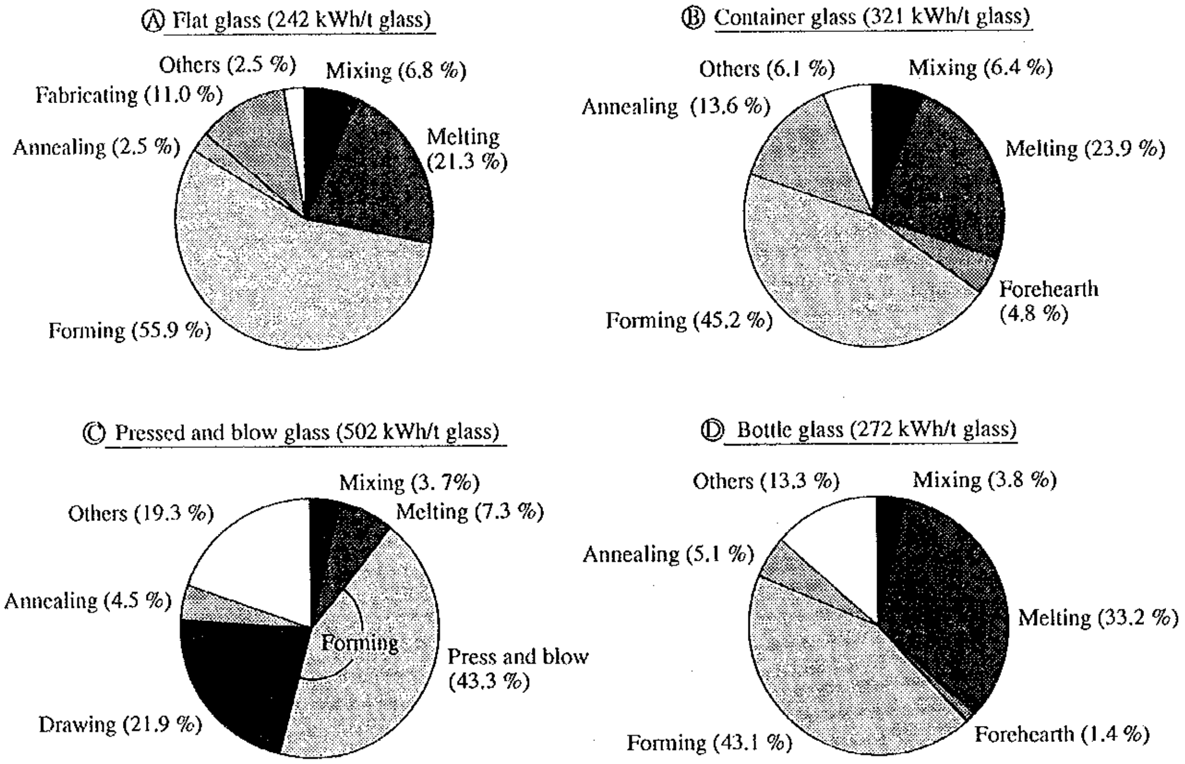
b. Energy conservation by improvement of operation and equipment

In the forming process, it is natural to place first priority on the function. Therefore, energy conservation tends to be the next consideration. The common consideration is the elimination of losses.

The forming process occupies nearly half or more of the total electricity consumption.

Figure 4.1.28 Sharing Electricity Consumption

Ⓐ Flat glass : USA data in 1980
Ⓑ Container glass : USA data in 1980
Ⓒ Pressed and blow glass : USA data in 1980
Ⓓ Bottle glass : Average of bottle glass factories in Japan in 1984



1) Saving electricity by effective layout of machines, equipment, compressor, blower, and so forth and enhancement of operational efficiency

2) Prevention of heat loss by reinforcement of heat insulation of float bath for sheet glass

3) Energy conservation by improvement of yield through enhancement of management and computerized control

(6) Annealing equipment

a. Annealing process

Formed products are annealed in an annealing lehr to remove thermal strain from the products. The annealing temperature and time differ depending on the glass composition, product thickness, etc. Generally, however, the annealing temperature ranges from 550 °C to 400 °C. The annealed glass is cooled and goes out of the annealing lehr.

The products from the annealing lehr are inspected and packed for shipping. Some of the products are transferred for further processing.

Although the annealing lehr includes a batch type furnace, a tunnel type continuous furnace with a mesh belt is used for container glass such as bottles and a roll type for sheet glass.

Annealing lehrs are conventionally brickwork structures, but there are some steel-plated lehrs lined with heat-insulating materials. Gas heating and electric heating methods are mostly used. A fuel oil firing type lehr is also available, but in this case an indirect heating system using a muffle and radiant tube is used.

b. Energy conservation by improvement of operation and equipment

1) Increase in the heat carried in

Formed products still have a temperature of over 600 °C and therefore, if they are taken into the lehr without losing this heat, heating should be theoretically unnecessary, provided that the following conditions are met.

- To shorten the distance between the forming machine and lehr
- To charge formed products from the forming machine into the lehr as quickly as possible.

2) Preventing heat radiation

While the glass is still at high temperature, it must be gradually cooled. For this purpose the following conditions must be met.

- Heat insulation of the high-temperature parts and prevention of hot air leakage
- Controlling cold air leakage into the lehr through the charging port
- A lehr sectional shape suited to product dimensions and production
- Shortening spaces of charged products

3) Use of direct heating method

In case of using fuel oil, the indirect heating method using muffles or radiant tubes was usually employed to prevent the burning gas from directly touching the products and possibly making their surfaces cloudy.

However, the lehr has a heating temperature range of less than 600 °C, and radiation heat transfer by indirect heating is inefficient. For this reason, direct heating should be employed when gas is used as fuel.

4) Lowering of mesh belt heat capacity

The example shown below indicates that the quantity of heat required to heat the mesh belt is larger than normally expected.

Product processing rate : 630 kg/h

Average specific heat of products : 0.252

Product temperature before entering lehr : 400 °C

Annealing temperature : 550 °C

In this case, the quantity of Q_1 required to heat the products can be calculated as follows:

$$Q_1 = 0.252 \times (550 - 400) \times 630 \times 4.1868 = 99{,}704 \text{ kJ/h}$$

Suppose that the products are conveyed on a 1,500 mm width belt into the lehr.

Belt weight : 20 kg/m²

Belt speed : 380 mm/min

Temperature before entering lehr : Room temperature 15 °C

Maximum heating temperature of belt in lehr : 550 °C

Average specific heat : 0.132

In this case, the quantity of heat Q_2 required to heat the belt will be:

$$Q_2 = 0.132 \times (550 - 15) \times 20 \times 0.38 \times 1.5 \times 60 \times 4.184 = 202{,}239 \text{ kJ/h}$$

As shown, more than twice as much heat is consumed to heat the belt as to heat the products. Possible measures to reduce this heat include decreasing belt wire diameter, decreasing wire pitch, and thus reducing belt weight per unit area.

Further, the mesh belt may be preheated by exhaust gas on the return way.

5) Energy conservation in the cooling area

The glass from the annealing zone is cooled in the cooling zone, where forced cooling is usually performed in order to cool the products as quickly as possible.

In an actual example of indirect cooling where many cooling fans are installed, as in the anealing lehr for float glass, energy conservation has been achieved by integration of fans and inverter control.

6) Heat consumption rate of an annealing lehr

The heat consumption rate of the lehr varies largely depending on the charging temperature of the products, their shape, thickness of products, the number of times these parameters change, operating time, processing quantity, and the type of lehr. For your reference, some of the lehrs used in Japan show a heat consumption rate ranging from 1,500 to 3,500 kJ/kg in most cases, and some large ones show an extremely low heat consumption rate of 200 kJ/kg.

Therefore, a comparison of the energy intensity between different types of products to be formed is meaningless.

Tables 4.1.7 and 4.1.8 show the annealing point and strain point of each type of glass and the required annealing time of each type.

Table 4.1.7 Annealing Point and Strain Point of Various Glasses

	Annealing point	Strain point
Alumino-Silicate glass (Example)	715 °C	665 °C
Boro-Silicate glass (Pyrex)	565 °C	520 °C
Soda-Lime glass	530 °C - 550 °C	480 °C - 510 °C
Lead glass (PbO 30 %)	440 °C	390 °C

Table 4.1.8 Standard Annealing Time of Various Products

Glass block (max. 95 mm × 145 mm × 300 mm)	240 minutes
Plate glass (25 mm × 250 mm × 250 mm)	120
Plate glass (19 mm thickness)	52 - 62
Tableware glass	30 - 50
TV bulb (14 inches)	45
Large size bottle	45
Electric bulb	15

4.1.4 Energy Conservation Effect of the Glass Industry in Japan

(1) Trend of energy intensity for sheet glass and bottle glass

Figure 4.1.29 and 4.1.30 show the changes in energy intensity of sheet glass and bottle glass which constitute the main components of the glass industry in Japan.

Figure 4.1.29 Trend of Energy Intensity Index in Sheet Glass Manufacturing

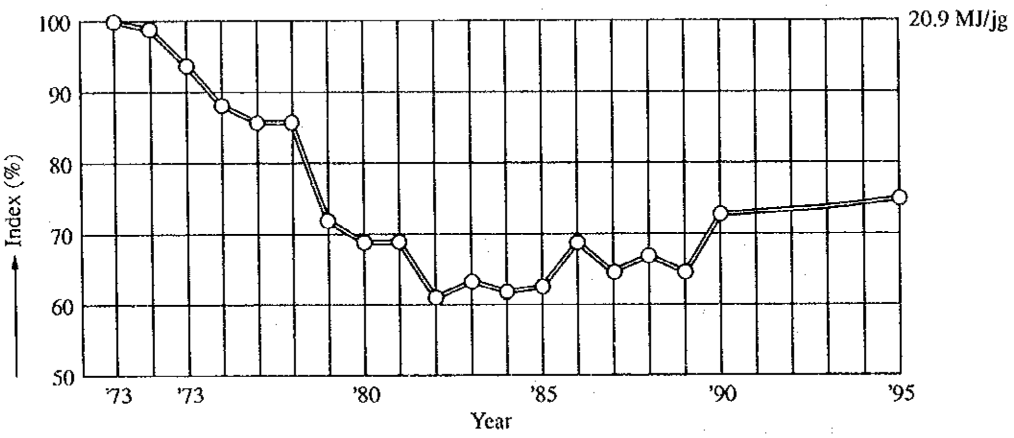
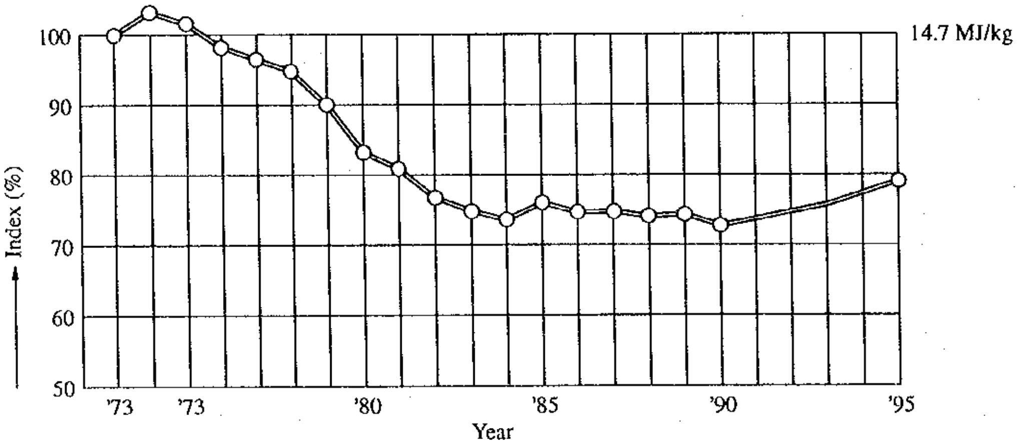


Figure 4.1.30 Trend of Energy Intensity Index in Bottle Glass Manufacturing



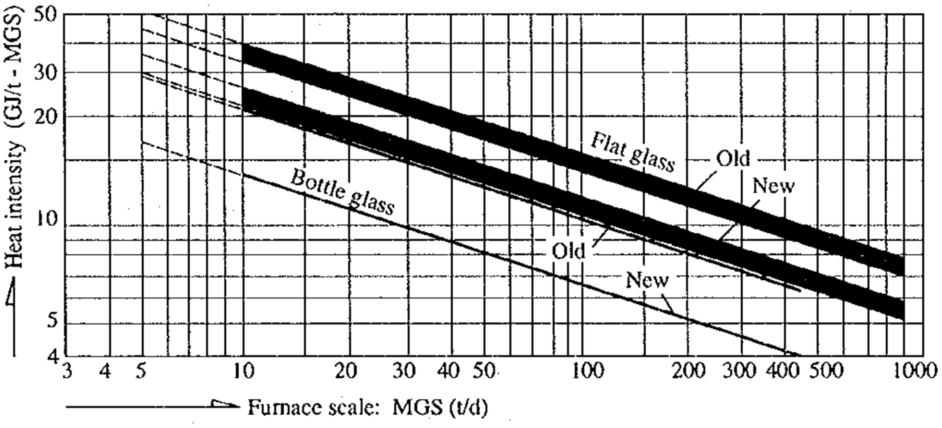
Note: Heat by oil: 41,449 kJ/L Light oil : 37,263 kJ/L
LPG, LNG : 50,242 kJ/L Electricity: 10,258 kJ/kWh

Energy intensity per kg of glass in 1983 was 65 for sheet glass and 75 for bottle glass on the basis of setting the 1973 level as 100. Thereafter, it has been showing a tendency to level off. Comparison of energy intensities for glass manufacturing industries on a global basis discloses that the energy intensities in Japan, Europe and U.S.A. are among the best, which show almost a similar level.

(2) Improvement of energy intensity for glass melting furnaces

The energy intensity for melting which requires the maximum amount of energy used in glass manufacturing is plotted based on Figure 4.1.3. The result is shown in Figure 4.1.31.

Figure 4.1.31 Relationship of Heat Intensity and Scale of Melting Furnace Old v.s. New



(3) Analysis of energy intensity improvement

a. Comparison of heat balance of glass melting furnace

The heat balance for a float glass melting tank and that for a bottle glass melting tank are compared between an old tank designed before implementation of energy conservation measures and a newly designed tank. The results of this comparison are shown in Figure 4.1.32, Figure 4.1.33 and Table 4.1.9.

Figure 4.1.32 Heat Balance Chart for Float Glass Melting Tank

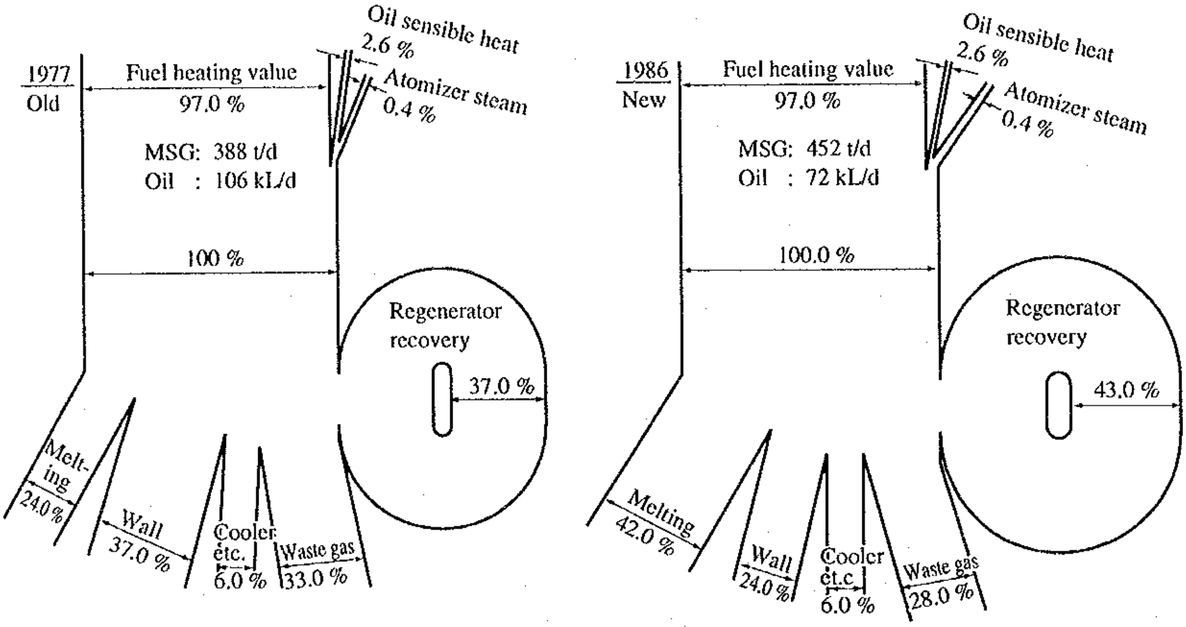
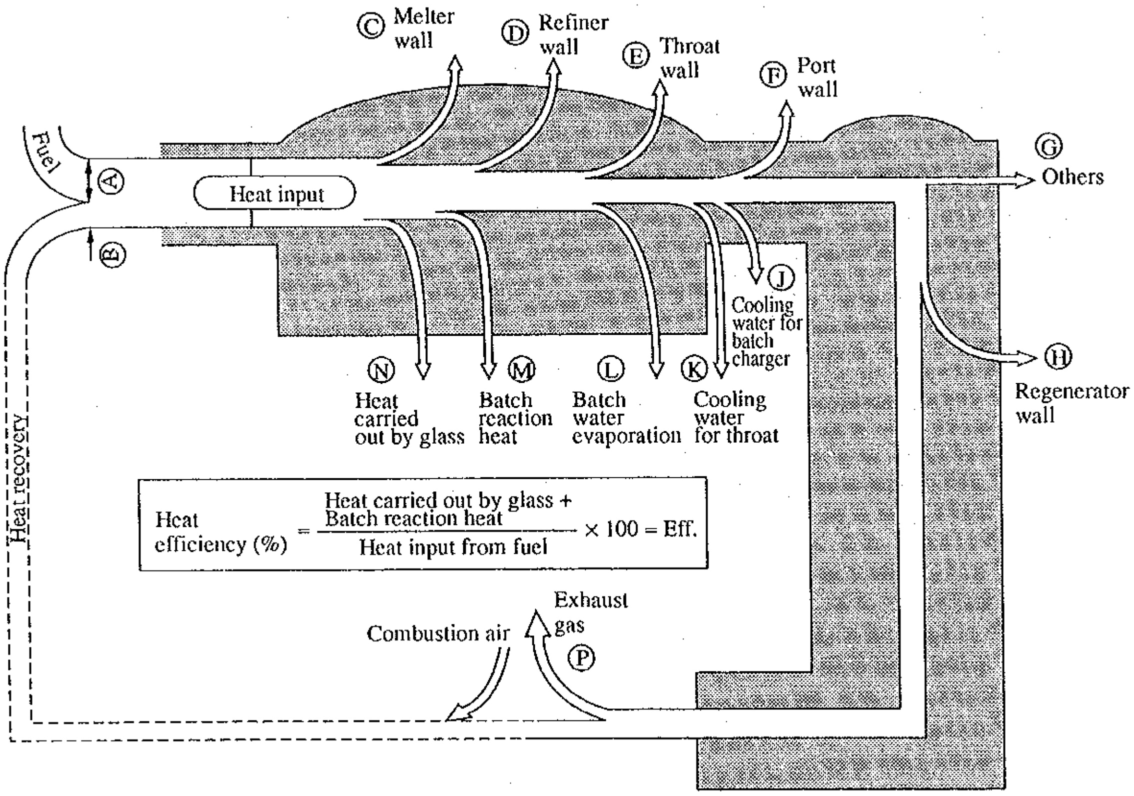


Figure 4.1.33 Heat Balance Chart for Bottle Glass Melting Tank



$$\text{Heat efficiency (\%)} = \frac{\text{Heat carried out by glass + Batch reaction heat}}{\text{Heat input from fuel}} \times 100 = \text{Eff.}$$

Table 4.1.9 Comparison of Heat Balance Data between Old Design and New Design

	Before	Old Design		New Design
	1973	1973	1973	1983
MG (t/d)		121	266	264
Fuel (GJ/h)		25.6	61.3	51.1
A Fuel input	100.0 %	100.0 %	100.0 %	100.0 %
B Regenerator recovery	46.6 %	54.0 %	50.7 %	56.6 %
C Melting tank Wall	27.2 %	10.8 %	12.0 %	5.8 %
D Refining tank Wall	2.8 %	2.1 %	2.0 %	0.8 %
E Throat Wall	0.0 %	0.1 %	0.1 %	0.1 %
F Port Wall	2.7 %	1.7 %	1.7 %	1.4 %
G Others	18.0 %	15.9 %	21.1 %	27.0 %
H Regenerator Wall	8.9 %	7.8 %	9.0 %	4.2 %
(Total of wall loss)	(59.6 %)	(38.4 %)	(45.9 %)	(39.3 %)
J Batch cooler	0.9 %	0.2 %	0.2 %	0.0 %
K Throat cooler, etc.	2.1 %	0.6 %	0.2 %	0.3 %
(Total of cooler loss)	(3.0 %)	(0.8 %)	(0.4 %)	(0.3 %)
L Batch water		1.4 %	2.3 %	2.5 %
M Batch reaction		11.3 %	6.7 %	12.6 %
N Glass carrid out		28.4 %	27.4 %	31.4 %
(Total: Efficiency)	(19.1 %)	(39.7 %)	(34.1 %)	(44.0 %)
P Exhaust loss	18.3 %	19.7 %	17.3 %	13.9 %

b. Summary of energy conservation potential

1) Energy conservation for sheet glass

Figure 4.1.29 shows an example of energy intensity index for three typical sheet glass manufacturing companies in Japan. As is clear from the figure, the energy intensity of sheet glass improved by approximately 35 % over the period of 10 years from 1973.

Thereafter, it has tended to level off because necessary energy conservation measures have been taken and the melting load has decreased due to supply and demand.

Next, the breakdown of the 35 % energy conservation is shown according to each factor.

Specifically for sheet glass, a new forming method called Float process which was first employed in that period together with the scale merit due to a larger sized tank substantially contributed to energy conservation.

- Scale merit due to integration of furnace tanks: 15 %
- Reinforcement of heat insulation of furnace tanks: 10 %
- Increase in heat recovery due to improvement of a regenerator: 5 %
- Increase in product yield due to improvement of management and technologies: 5 %

2) Energy conservation for bottle glass

As shown in Figure 4.1.30, the energy intensity for bottle glass improved by around 25 % for a period of 10 years from 1973

The subsequent level-off tendency is due to the same factors as those for the plate glass.

The reason why the improvement rate of energy intensity for bottle glass is smaller than that for plate glass is that bottle glass has a smaller scale merit effect and also larger energy percentages for sections other than melting.

The breakdown of the 25 % energy conservation is as follows.

- Reinforcing the heat insulation of tank furnaces: 10 %
- Increasing the heat recovery rate by improvement of a regenerator: 5 %
- Improvement of melting load and the scale merit: 5 %
- Increasing the amount of cullet to be used: 3 %
- Increasing the product yield by improvement of management and technologies: 2 %

3) Energy conservation efforts for other types of glass

The total annual output of products in the glass industry is about 5.30 million ton due to the recent leveling-off of demand.

On the basis of product type, sheet glass accounts for about 27% of the total production volume, followed by about 38 % for bottle glass (by 9 major companies), and about 13 % for glass fiber. The remaining 22 % fall into other types of glass products. Estimation of the energy intensity for other glass products allows the following results to be obtained.

- 19 MJ/kg for the average of all types of glass:
- 16 MJ/kg for sheet glass
- 11 MJ/kg for bottle glass
- 25 MJ/kg for glass fiber
- 33 MJ/kg for other types of glass.

Among other types of glass, some are produced using relatively large tank furnaces, but most of them are made in small furnaces of 100 t/d or less. For reference, most of melting furnaces used for glass fiber are tank furnaces that are unit melters of some 10 t/d.

Energy conservation measures taken for other types of glass are described below.

- Reinforcing the heat insulation

- Increasing the amount of heat recovery through improvement of regenerators and heat exchanging chambers

- Enhancing the management of operation, equipment and energy, improving the melting load and increasing the yield

These measures commonly apply to all types of glass, while the following measures produce a substantial effect particularly for small furnaces.

- Energy conservation by switching to electric melting furnaces

  As an actual case in Japan, this measure is taken even for the level of 20 t/d in view of product quality and prevention of pollution, though no economical merit is gained unless the melting amount is 10 t/d or less.

- Energy conservation through oxygen burner combustion

  In actual cases of oxygen burners, fuel consumption has been reduced just to half by the use of furnaces of 5 t/d.