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HANDY MANUAL

GLASS INDUSTRY

Output of a Seminar on Energy Conservation in Glass Industry

Sponsored by

United Nations Industrial Development Organization (UNIDO)

and

Ministry of International Trade and Industry (MITI), Japan

Hosted by

Ministry of Science, Technology and Environment, Thailand

The Department of Energy, Philippines

Organized by

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1993

Thailand **Philippines**

PREFACE

The conservation of energy in an essential step we can all take towards overcoming the mounting problems of the worldwide energy crisis and environmental degradation. In particular, developing countries are interested to increase their awareness on the inefficient power generation and energy usage in their countries. However, usually only limited information sources on the rational use of energy are available.

The know-how on modern energy saving and conservation technologies should, therefore, be disseminated to governments and industrial managers, as well as to engineers and operators at the plant level in developing countries. It is particularly important that they acquire practical knowledge of the currently available energy conservation technologies and techniques.

In December 1983, UNIDO organized a Regional Meeting on Energy Consumption as well as an Expert Group Meeting on Energy Conservation in small- and medium-scale industries for Asian countries. During these meetings, it was brought out that, for some energy intensive industries, savings up to 10% could be achieved through basic housekeeping improvements, such as auditing and energy management.

All these experiences brought UNIDO to prepare a regional programme on the promotion and application of energy saving technologies in selected subsectors, since the rational use of energy calls for a broad application of energy conservation technologies in the various industrial sectors where energy is wasted. One of these energy intensive industrial sectors to be considered to improve efficiency through the introduction of modern energy conservation technologies is the glass industry, which has a high level of energy consumption and therefore CO_2 production. In recent years, CO_2 generated in huge amounts is said to cause global warming, and the impact on the earth environment is getting serious. To cope with this situation, efforts have been made throughout the world to reduce the amount of CO_2 generated with the target placed on the year 2000.

In the glass industry, significant improvements in the level of energy efficiency could be achieved by combustion control, furnace wall insulation, exhaust heat recovery, heat balancing, use of electric booster and bubbling, electric heating of forehearth, using a great number of cullet and by low melting temperature batch technique.

Currently, UNIDO is implementing this Programme with the financial support of the Japanese Government, in selected Asian developing countries. This programme aims at adopting these innovative energy conservation technologies, developed in Japan, to the conditions of developing countries.

In this programme, we are considering that the transfer of these technologies could be achieved through:

(i) Conducting surveys of energy usage and efficiency at the plant level;

(ii) Preparing handy manuals on energy management and energy conservation/saving technologies, based on the findings of the above survey;

(iii) Presenting and discussing the handy manuals at seminars held for government officials, representatives of industries, plant managers and engineers;

(iv) Disseminating the handy manuals to other developing countries for their proper utilization and application by the industrial sector.

The experience obtained through this programme will be applied to other programmes/projects which involve other industrial sectors as well as other developing countries and regions.

UNIDO has started this programme with the project US/RAS/90/075 - Rational Use of Energy Resources in Steel and Textile Industry in Malaysia and Indonesia. This was followed by project US/RAS/92/035 - Rational Use of Energy Saving Technologies in Pulp/Paper and Glass Industry in Philippines and Thailand.

The present Handy Manual on Glass Industry was prepared by UNIDO, with the cooperation of experts from the Energy Conservation Center (ECC) of Japan, on energy saving technologies in the framework of the above mentioned UNIDO project. It is based on the results of the surveys carried out, the plant observations and the recommendations and suggestions emanating from the Seminars on Energy Conservation in the Glass Industry, held under the same project in January and February 1993 in Bangkok, Thailand and Manila, Philippines respectively. The handy manual will not only be interesting for government and representatives from industry, but it is, in particular, designed for plant-level engineers and operators in developing countries as a help to improve energy efficiency in the production process.

Appreciation is expressed for the valuable contribution made by the following institutions to the successful preparation and publication of the manual mentioned above:

The Department of Energy, Philippines

Ministry of Science, Technology and Environment, Thailand

Ministry of International Trade and Industry (MITI), Japan

The Energy Conservation Center (ECC), Japan

July 1993

CONTENTS

1. Production process of the glass industry

The glass industry consumes much energy. Fuels are burnt to create a high temperature inside the furnace, where the batch is reacted, vitrified, degassed, homogenized, and taken out as products (e.g. glass bottles, tableware). The products are put into the lehr for annealing, and the surfaces are printed as required. Then they are placed into the baking furnace. Thus, each of these processes uses a furnace which consumes much energy. The typical manufacturing process of a bottle is shown in Figure 1.

The fossil fuels (coal, petroleum, natural gas) as energy resources are limited resources which must be left for the people of next generations as much as possible. SOx and NOx are discharged into the atmosphere by the combustion of fuels, thereby affecting the human health. This has raised serious problems. In recent years, CO_2 generated in huge amounts is said to cause global warming, and the impact on the earth environment is getting serious. To cope with this situation, efforts have been made throughout the world to reduce the amount of CO_2 generated with the target placed on the year 2000.

Energy saving or energy conservation efforts in industrial activities are directly connected to the effect of controlling the cost increase due to the reduction of unit energy consumption in industry, leading to intensified competition. At the same time, such efforts provide an essential means for the improvement of the global environment so that the human being will maintain its health for a long time to come. It is imperative for the industrialist to understand that the energy conversation is one of the most important policies for industry, the nation and the world.

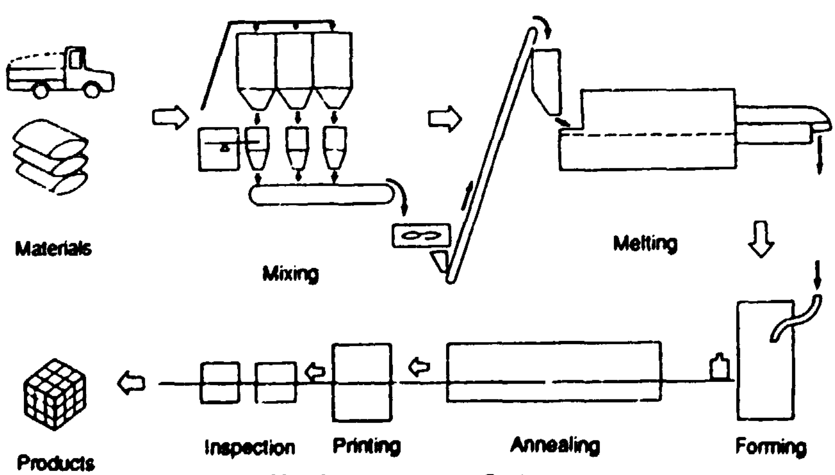


Figure 1

2. Characteristics of energy consumption in the glass production process

Figure 2 illustrates the ratio of the energy cost on the total manufacturing cost at glass bottle manufacturing plants in 1973 immediately before the first oil shock, in 1981 after the second oil shock and in 1989. Despite the energy conservation efforts, the ratio rose from 9% in 1973 to 16.7% in 1981 mainly due to spiraling oil cost. The ratio reduces to 8.6% in 1989 due to energy conservation efforts and lower oil price.

The energy cost in 1981 can be broken down as follows:

Heavy oil	11%
Electric power	4%
LPG	2%

Energy conservation for each energy source is a major task to be solved for cost reduction. Figure 3 shows the energy consumption for each process.

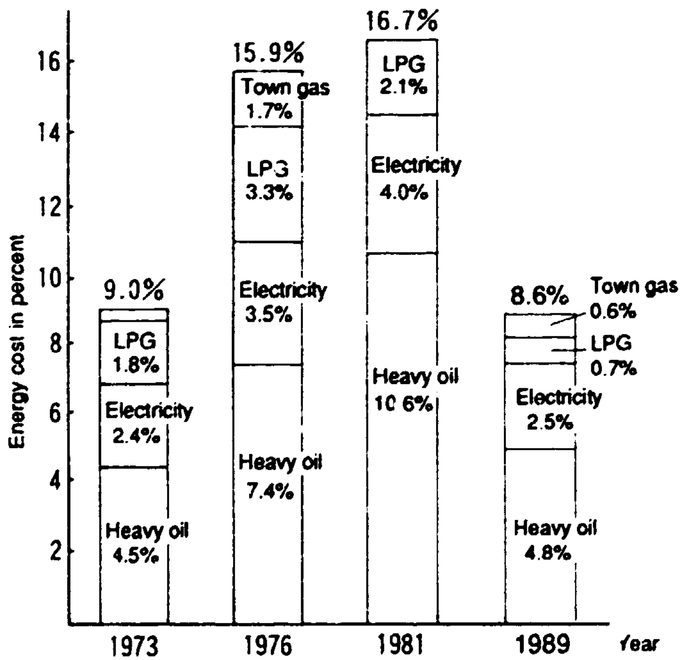


Figure 2 Energy cost distribution for total manufacturing cost in glass bottle

Source: New Glass Tech Vol. 3 (1983), No. 4
Industrial Statistics (1989)
Oil Consumption Statistics (1989)

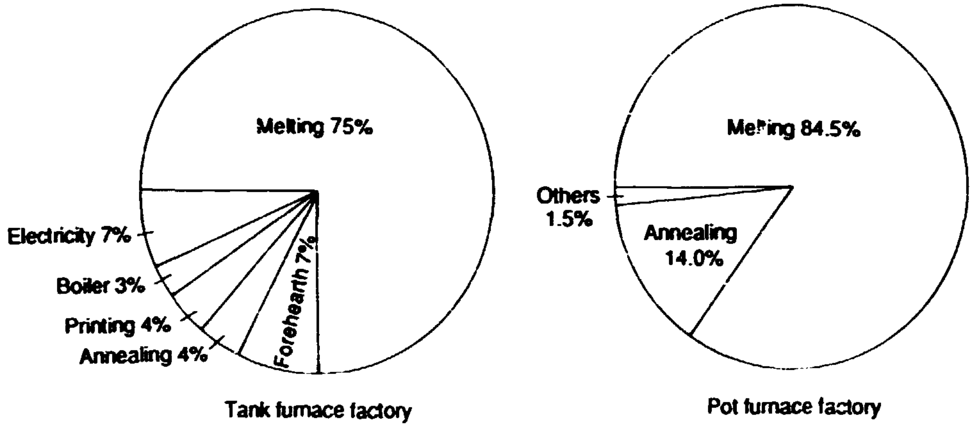


Figure 3 Share of total energy consumption

The situation differs according to the product types and scales; Figure 3 gives examples of the glass bottle manufacturing plant equipped with the tank furnace and the small-scale plant provided with the pot furnace.

The melting process is the greatest energy consumer in both the plant provided with the tank furnace for continuous production and the plant provided with the pot furnace for small quantity production of multiple product types.

The figure records 75% on the tank furnace; it even reaches close to 82% when 7% for forehearth is added. More energy, nearly 85%, is consumed in the case of the pot furnace.

Thus, when energy conservation efforts are made, top priority must be placed on the furnace, then on the lehr.

The unit energy consumption means the energy required to make the product of unit amount (1 kg or 1 ton). It is expressed either by unit energy consumption if energy is used as the unit or by unit fuel consumption if the amount of fuel is used as the unit.

Basically, energy conservation in the glass factory is to reduce the unit energy consumption.

To reduce unit energy consumption, it is necessary to reduce the amount of fuels used, while it is important as well to increase production without increasing the amount of fuels, and to reduce the failure rate of production, thereby ensuring production increase in the final stage.

Specific energy consumption includes all the energy used to manufacture the product — oils such as heavy oil, LPG and kerosine oil, electric power used for transportation, etc.

Table 1 shows an example of energy consumption for each process and fuel in the glass bottle making plant. The management is required to get a total picture of this situation. Each process of the plant must grasp the unit fuel consumption or unit electricity consumption at each section.

Table 1 Distribution of energy consumption for glass bottle manufacture

× 10^4 kca/ton glass

	Heavy oil	Kerosene	LPG	City gas	Electricity	Total	%
Batch					1.47	1.47	0.58
Melter	161.80				16.96	178.76	71.03
Forehearth	1.77		14.76		0.8	19.33	6.89
Forming				0.08	26.85	26.93	10.70
Lehr			9.59		2.86	12.45	4.95
Printing, working			6.32	0.09	1.54	7.95	3.16
Package					0.47	0.47	0.19
Others	0.05	0.02	0.32	0.14	3.58	4.11	1.63
Total	163.61	0.02	30.99	0.31	56.74	251.68	
(%)	65.01	0.01	12.31	0.12	22.54		100

Regarding the furnace, it is necessary to get correct data on the unit energy consumption (or unit fuel consumption). It corresponds to the energy consumption for the amount of glass taken out of the furnace. It may be expressed in calories or in the value converted into the amount of heavy oil. When the electric booster is used, the amount should include the electric energy used for that booster.

This applies also to the annealing furnace. In this case, the value is expressed in the amount of energy consumption for the amount of annealed glass.

Unit energy consumption varies greatly depending on the production scale. It also depends on the kinds of glass because it is related to the quality level. Figure 4 illustrates the differences in the tableware plant and the glass bottle plant. The smaller scale and the higher product quality level of the tableware manufacturing plant than those of the glass bottle making plant explain the reasons for considerably higher unit energy consumption in the tableware manufacturing plant.

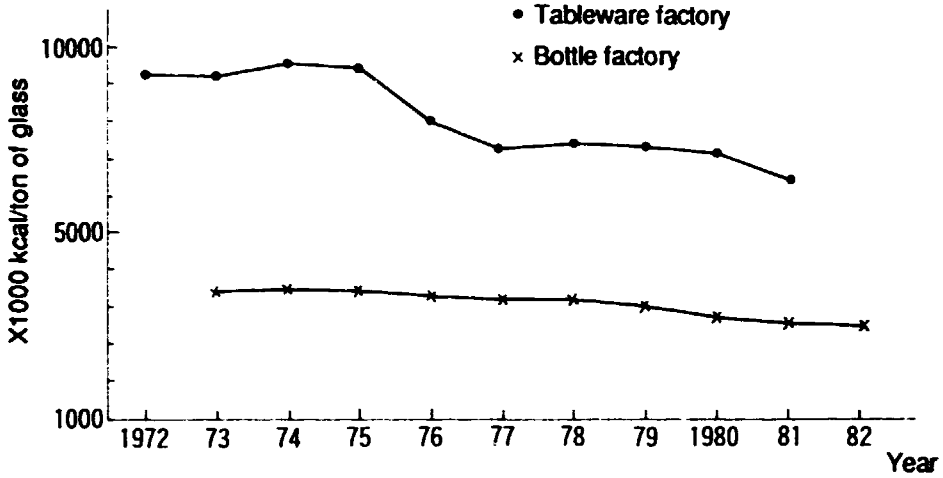


Figure 4 Unit energy consumption for factories

For the pot furnace factory of small quantity production of multiple product types, only the unit energy consumption in the furnace is clear; it is 4,000 to 8,000 kcal/kg. The difference depends on the kinds of glass, such as bolosilicate glass, soda lime glass and crystal glass, and furnace size.

Table 2 represents the situation of the unit consumption for the lehr. Big differences are observed according to heating method, operation time, heat of the glass to be loaded, amount of the glass loaded into the lehr processing capacity.

When the unit energy consumption is compared with that of other companies, it is necessary to note how the reference or standard has been determined as well as to clarify whether the energy means the total energy in the plant or only the energy used in the furnace, whether the forehearth is also included in the furnace or not, and whether electric power is included or not.

Table 2 Unit energy consumption of lehrs

Style	Fuel	Operating time	Rising time Holding time	Production	Condition of input	Capacity	Unit energy consumption (monthly average)
Muffle	Gas	8h	4h	Cup	After forming	219 kg/h	448 kcal/kg
Direct	Electrity	8	4	Cup	After forming	219	385
Muffle	Gas	8	4	Cup	After grinding	156	1572
Muffle	Oil	8	'6	Head lens	After forming	250	1861
Direct	Gas	8	2	Head lens	After forming	250	596
Muffle	Gas	24		Bottle	After forming	360	462
Direct Radiation	Gas	8	1	Grove lens	After forming	180	778
Muffle	Oil	24		Bottle	After forming	168	827
Radiant tube	Gas	8	1	Bottle	After forming	238	506

Source : Guidance of Energy Conservation (1983), The Glass Manufacturing Industry

Figure 5 shows the flow sheet of energy conservation. The flow sheet should be modified according to the particular requirements of each plant.

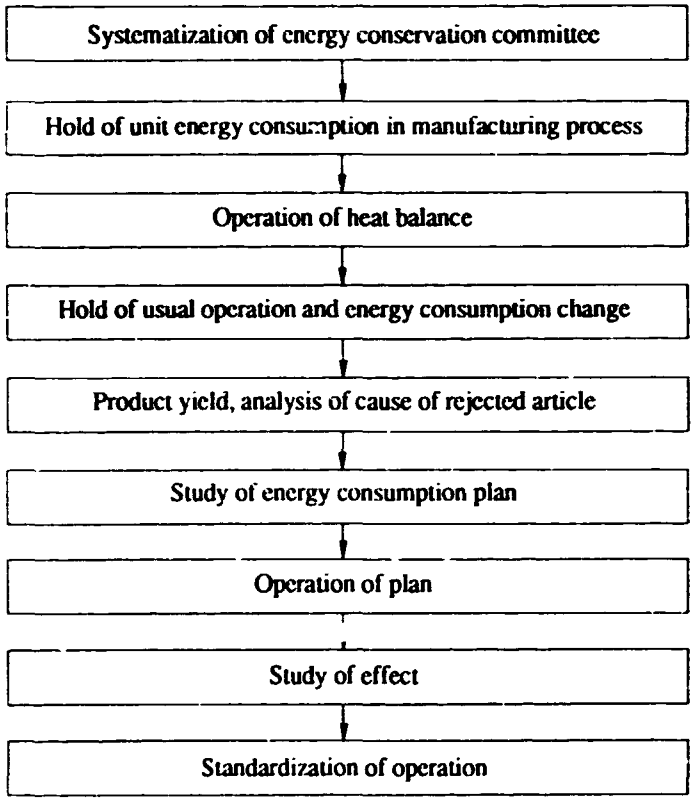


Figure 5 Flow sheet for energy conservation

3. Promotion of energy conservation technology

3.1 Melting furnace

Melting furnaces used in the glass production are available in a great number of types. They can be broadly classified into the types shown in Figures 6 to 10.

Figure 6 shows the side port type. This is a large furnace with a daily capacity of 100 to 150 tons or more. Two or more ports are installed at a right angle to the direction of the glass flow, and temperature distribution within the furnace can be changed to a desired value by controlling the amount of combustion of each port; this permits to produce high-quality glass. This type of furnace is often used as a furnace for production of plate glass or a bottle making large furnace.

Figure 7 shows the end port type furnace. It is a small and medium type furnace with a daily capacity of 100 tons or less. Compared with the side port type furnace, the end port type furnace features a simple structure and less expensive installation cost, but has difficulties in increasing its size. The flame returns along the longitudinal direction of the furnace and is sucked into the port on the side opposite to the rear wall. The temperature distribution inside the furnace varies according to the length of the flame and it is comparatively difficult to change the temperature distribution.

These two types of furnaces in many cases use regenerators. Some of the small type furnaces use the recuperator.

Figures 8 to 10 illustrate the pot furnaces for the small quantity production of multiple product types. Figure 8 illustrates the conventional multiple pot furnace used since early times, where six to ten pots are installed in the circular furnace, and glasses of different kinds are molten in these pots. The batch is loaded into the pot and molten during the night, and forming is performed during the daytime. The efficiency is not so good, and high-quality glass cannot be obtained. Most of the small and medium companies use this type of furnaces.

Figure 9 represents the pot furnace where only one pot is installed. It allows the use not only of the close pot but also the open pot. In spite of its small size, it is designed for high efficiency. Some of this type of furnaces have a unit energy consumption of 4,000 to 5,000 kcal/kg-glass.

Figure 10 shows a multiple pot furnace where the pots are installed in parallel, not in a circular form. The small and medium companies also tend to use robots and conveyers for transportation. Since the use of the circular form will make the layout within the plant rather difficult, this type of furnace has been developed to solve this problem.

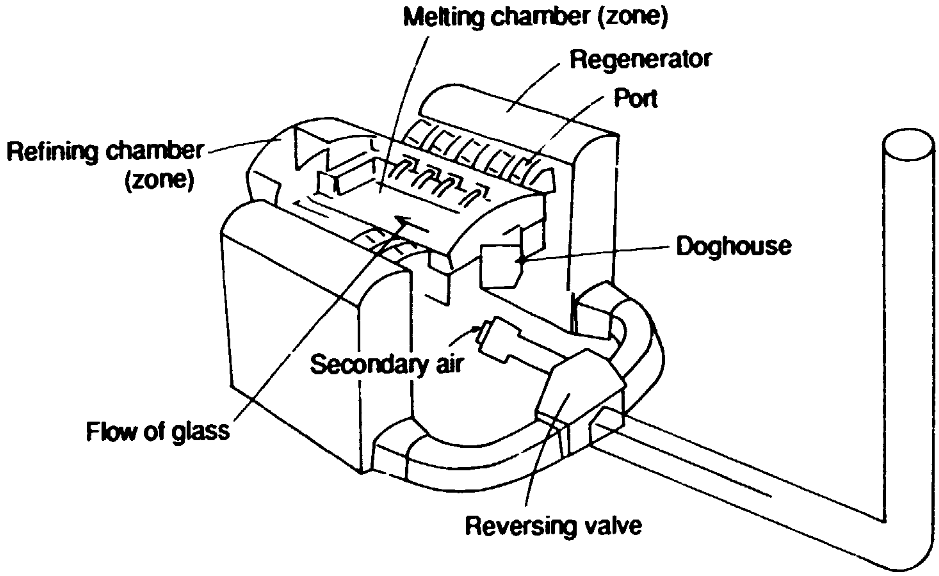


Figure 6 Tank furnace (Side port type)

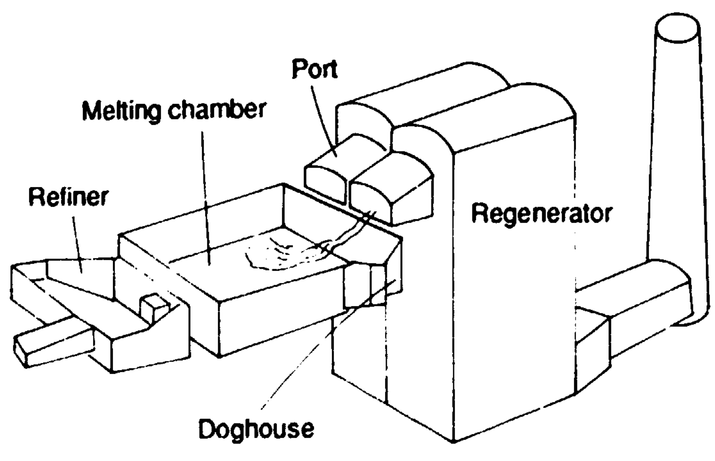


Figure 7 Tank furnace (End port type)

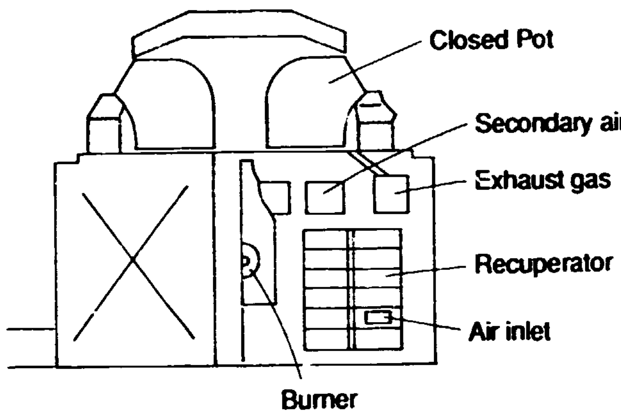


Figure 8 Pot furnace

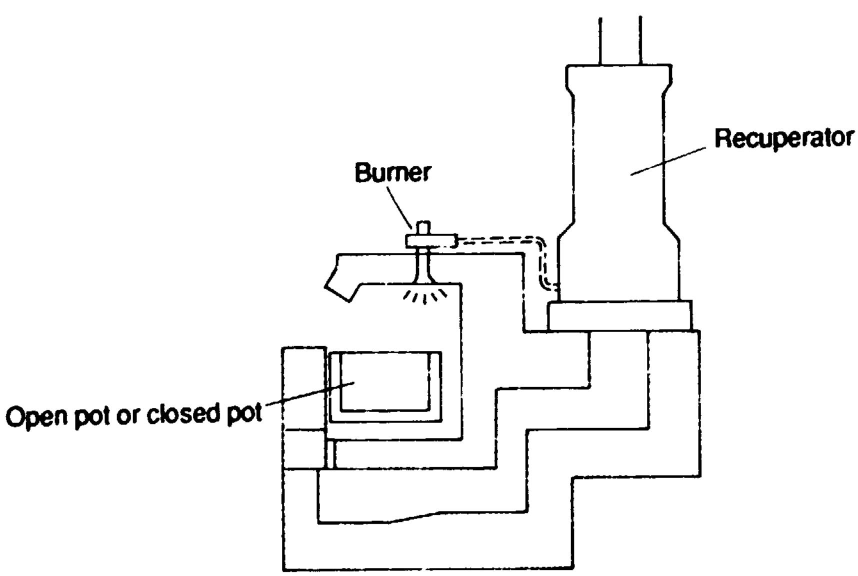


Figure 9 Single pot furnace (New type)

In the pot furnace the recuperator is used exclusively as a heat exchanger.

Since the melting furnace consumes much energy, this design provides a great energy conservation effect, which is represented in the reduced unit energy consumption. The unit consumption varies according to the scale. Figure 11 shows the yearly average value for the bottle making plant in Japan.

For twelve years from 1975 to 1986, unit energy consumption has reduced about 26% from 3,470,000 kcal/ton to 2,560,000 kcal/ton. According to the recent report, some of the furnaces have reduced the unit energy consumption below 2,000,000 kcal/ton. This is not only largely due to the reduced amount of oil used.

The first step toward the energy conservation in the melting furnace is to improve the combustion efficiency, to intensify heat insulation and to make an effective use of the exhaust gas.

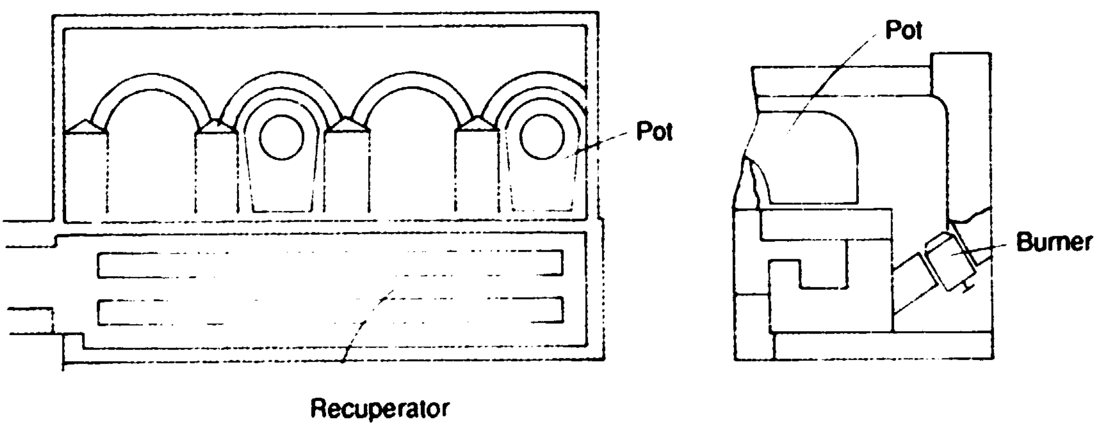


Figure 10 Parallel multi-pot furnace

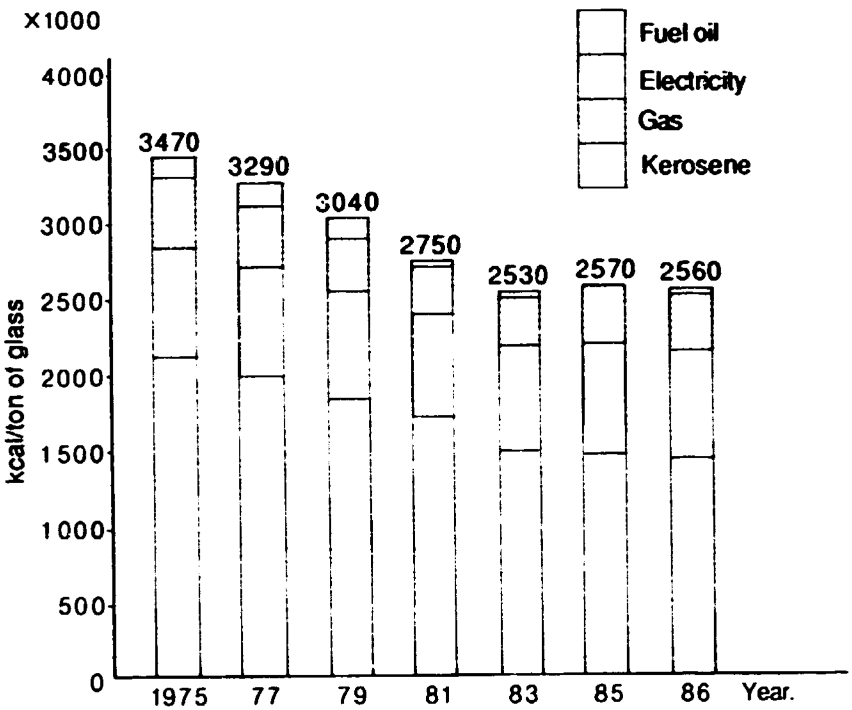


Figure 11 Unit energy consumption for glass bottle manufacturing

3.11 Combustion control

The fuel used in the melting furnace is liquid fuel (heavy oil) or gas fuel (LNG, LPG). Appropriate combustion can be checked by measuring the CO_2, O_2 and CO contained in the exhaust gas.

Glass materials used in the tank furnace are carbonates such as soda ash (Na_2CO_3) and limestone ($CaCO_3$). They are decomposed during the reaction for vitrification to discharge CO_2. Thus, as a result of the gas analysis, the sum of CO_2 generated by combustion and CO_2 generated from the material is produced in the tank furnace, so the amount of CO_2 is greater than that in the case of combustion alone. It is to be noted that, when the combustion control is considered, the value will be inappropriate. It is desirable to make combustion control with oxygen volume in the exhaust gas for the tank furnace.

(1) Influence of cooled air other than preheated secondary air

The secondary air used for combustion is preheated by the heat exchanger. The primary air for spraying and air intruding from the clearance of the burner tiles enter the furnace as they are cold. Reduction in the volume of such cold air will lead to energy conservation. Figure 12 shows the result of calculating the amount of possible energy conservation by reducing the volume of this cool air and replacing it with the preheated air. It gives a graphic representation based on m=1.25 and the volume of cold air accounting for 10% of the entire air. If the cold air is reduced by 1% and the preheated air is increased by 1%, it corresponds to reduction of air ratio by 1%; the fuel is saved about 0.5%.

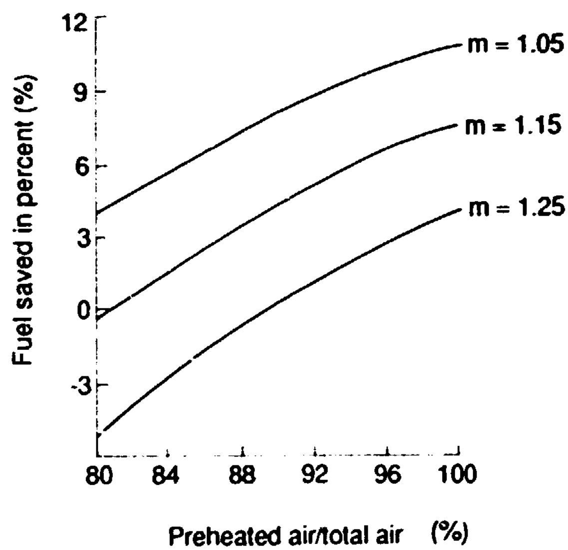


Figure 12 Relationship between preheated air and saving in fuel

Source : Glass Technical School Textbook "Melting" (1989)

(2) Temperature distribution inside the furnace

To ensure stable production of high-quality glass, temperature distribution must be maintained at the optimum level inside the furnace.

As shown in Figure 13, temperature distribution inside the tank furnace is so designed that the hot spot is located at the central position slightly displaced in the direction of the throat. The position of this hot spot moves a little depending on the load conditions.

If the combustion is such that this spot is displaced greatly, the flow of the glass will be disturbed inside the furnace, and striae, blister, seed and similar defects will appear, deteriorating the product quality.

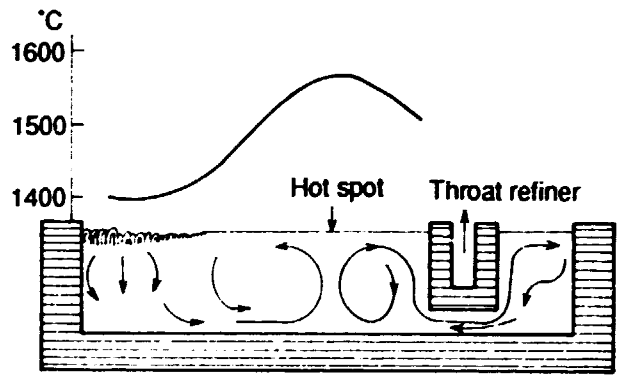


Figure 13 Relationship between temperature distribution and flow of molten glass

If the temperature distribution inside the furnace is maintained at the optimum value, the leading edge of the loaded batch will move in such a way that it is pushed backward. If the temperature distribution inside the furnace is not satisfactory, and the back current of the glass is poor, the batch will go forward.

In the side port furnace, temperature distribution should be optimized with comparative ease by controlling the combustion at each port, but it is actually accompanied by difficulties. That is, adjustment of the fuel for each port can be done by the burner, but the volume of the preheated secondary air cannot be controlled for each port. Figure 14 shows the volume of air supplied to each port. As shown in the figure, more gas flow occurs at the position closer to the flue through which the exhaust gas is discharged, and the checker bricks are also heated to high temperature. On the other hand, more air flows at the position farther from the flue. So great volume of air flows at the port farthest from the flue with large m combustion, whereas combustion with small "m" results at the port closest to the flue. The average value is recorded as a value for "m" in the analysis of gas inside the furnace. This can be said to be satisfactory neither from the viewpoint of obtaining the optimum temperature distribution nor from the viewpoint of energy conservation for combustion.

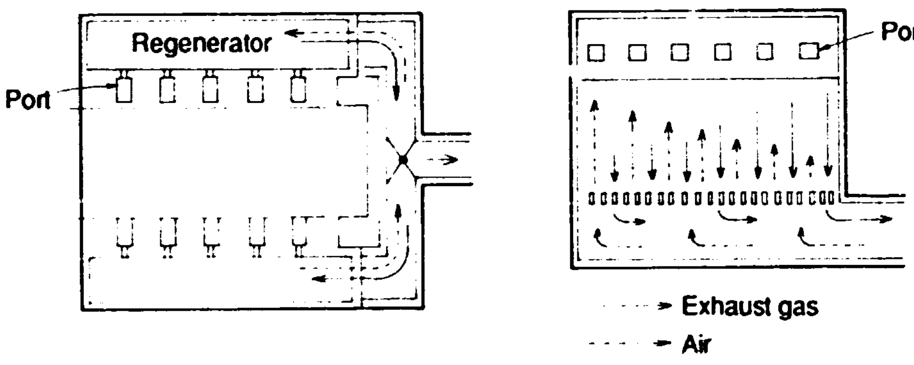


Figure 14 Distribution flow of exhaust gas and air in regenerator

To improve this situation, the separate regenerator chamber has been developed, which enables the volume of air to be controlled for each port. However, this is not much used because of the clogging caused by carry-over and other problems.

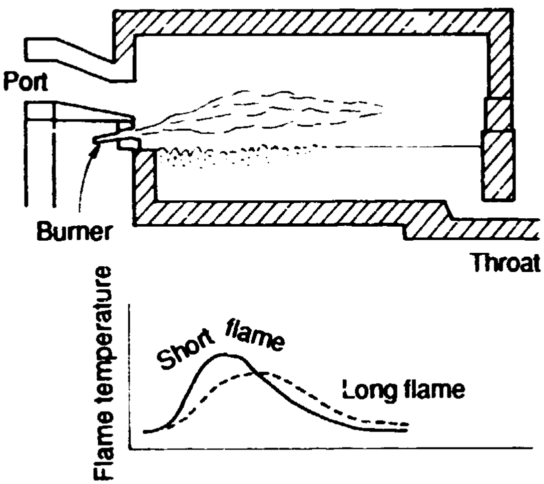


Figure 15 Temperature distribution of combination flame for end port type furnace

The optimum temperature distribution in the end port type furnace is more difficult to create than that of side port type. As shown in Figure 15, the burner of the end port type furnace is installed on one end of the glass flow, and there is no way of creating the temperature distribution except by controlling the flame length.

If the short flame is selected, the hot spot will be positioned closer to the burner; if the longer one is selected, it will move toward the throat side.

The flame length can be adjusted by:

(i) changing the burner capacity (by replacing the nozzle),

(ii) changing the burner type (by changing the volume of primary air and the flame rotary angle),

(iii) changing the burner atomizing pressure (longer flame is obtained by lowering the primary pressure), and

(iv) adjusting the secondary air.

However, these methods are also limited in effects, so the end port type is not often used for the large furnace with daily capacity of 100 to 150 tons or more.

(3) Combustion in forehearth

The forehearth has a function of controlling the glass temperature before its formation, and has a direct influence on the quality of the glass product. Its outline is shown in Figure 16:

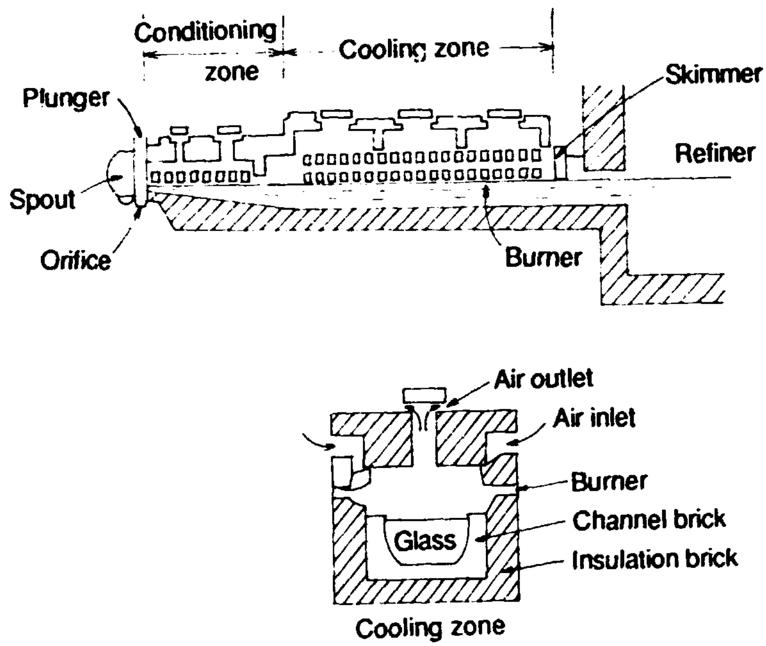


Figure 16 Outline sketch of forehearth

The basics for temperature control are:

(i) optimization of the temperature of the gob to be fed to the forming machine, and

(ii) temperature distribution from the forehearth inlet to the feeder to be adjusted so that the temperature will be lowered gradually along the glass flow, without any high temperature occurring on the way.

For the purpose of temperature control, a great number of small burners are installed in the flow direction. For this control the cooling zone is divided into 3 or 4 zones.

LPG or similar gas is used as fuel because gas features fast combustion, easiness to create short flames, and little or no generation of carbon. When carbon falls on the glass, it will cause foams to be produced, resulting in coloration.

When the colored glass is molten, the color may be changed by the influence of the atmosphere. To ensure the stable coloring, sufficient care should be taken of the atmosphere for oxidation or reduction in the forehearth.

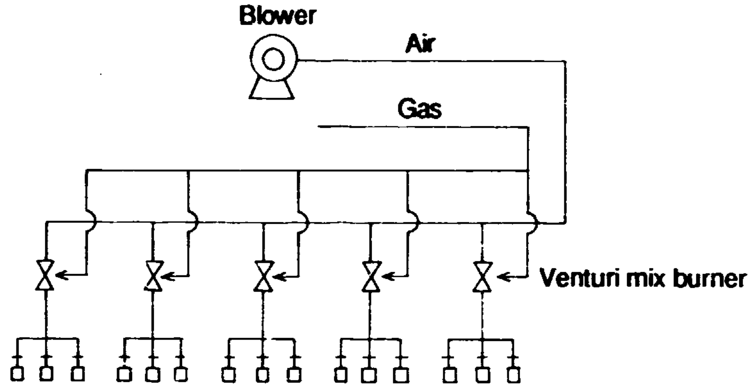
When gas is to be burnt, air is often pre-mixed into the gas. This method is available in three types as shown in Figure 17.

Figure 17 (a) represents a pre-mixing system using the venturi mixer for gas and air. This permits the total air ratio to be optimized, and, if the air ratio is changed in any zone, air ratios in other zones are also affected. So this is not applicable to the combustion control system where many burners are used.

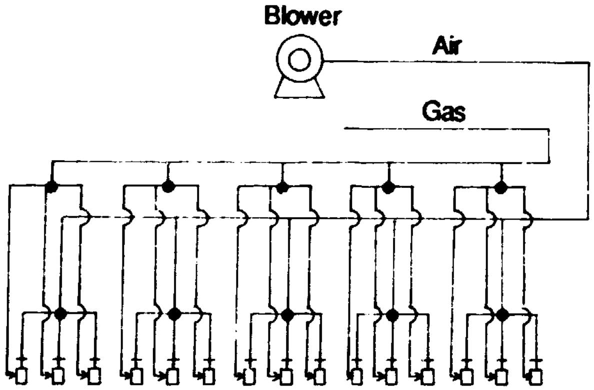
Figure 17 (b) shows the method where gas and air are mixed by the burner tip. This method is designed to ensure safety by preventing back firing, but it fails to eliminate interference between gas and air zones.

Figure 17 (c) illustrates the method where the gas-air pre-mixing valve is installed in front of the blower. According to this method, the gas-air ratio is constant in front of the blower, so the air ratio is constant at all zones, even if the volume to be combusted by the burner is changed for each zone. Therefore, it ensures reliable control of the air ratio, and permits substantial energy conservation, according to a report.

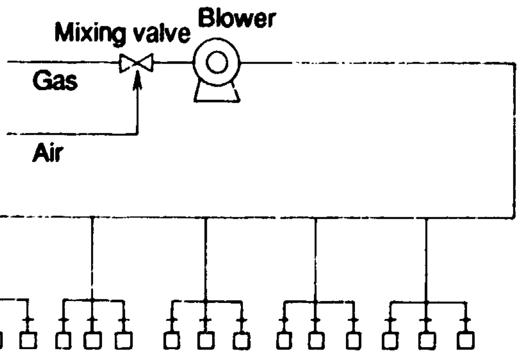
Comparison of oxygen (O_2) in the exhaust gas according to three methods has revealed that 8% of oxygen was contained in the exhaust gas according to method (a), 6% according to method (b), and 1% according to method (c). Substantial reduction of the air ratio has succeeded in reducing the volume of the fuel gas.



(a) Venturi mix burner



(b) Nozzle mix burner



(c) Pre-mix burner

Figure 17 Gas burner system

3.1.2 Insulation

Since the melting furnace has a large surface area, the minimization of loss of heat from the furnace wall is a major concern for energy conservation.

However, the heat insulation of the melting furnace must be carefully studied. Otherwise, it will cause the erosion of the used bricks, reduce the service life of the furnace and deteriorate the glass quality, thereby bringing about many adverse effects.

(1) Insulation for melting chamber bottom

Improved insulation at the bottom will raise the furnace bottom ground temperature. This will improve the melting capacity of the furnace, resulting in better yield. The subsidiary advantage of productivity improvement is secured in addition to the direct advantage of reduction of the heat loss from the bottom. Figure 18 (a) illustrates an example of insulation. Compared with the conventional case without using the insulation brick, the amount of heat loss has reduced by about 43% from 3240 to 1382 kcal/m^{2}h.

The refining chamber is also heat-insulated like the melting chamber. The insulation may be intensified in order to prevent the glass from being cooled.

(2) Crown insulation

As silica brick used for the crown, super-duty silica bricks have been developed; they are high-purity products containing the minimum alkali and alumina, providing improved insulation.

Some furnaces use AZS type electrofused refractory (fused AZS) for the crown. Figure 18 (c) shows the example of insulation. AZS means alumia-zirconia-silica.

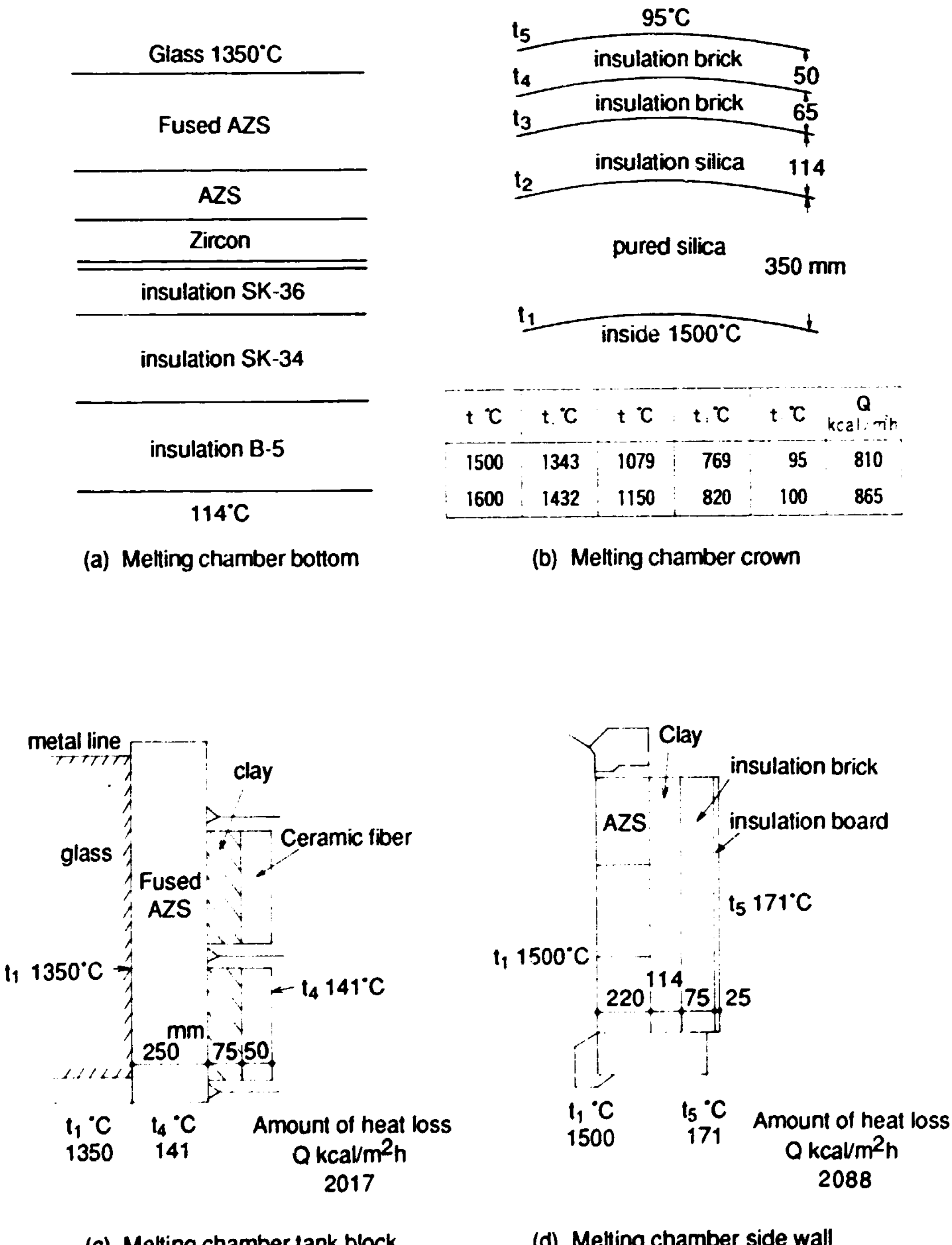
When the temperature inside the furnace is 1500°C, the temperature on the outermost insulation wall is reduced to 95°C, and the amount of heat loss reaches 810 kcal/m^{2}h. When insulation is not provided, the crown external wall temperature reaches 300 to 400°C.

(3) Side wall insulation

It has been an established trend that the fused AZS is used for the tank block, and the insulation is provided, except for the metal line. The brick joints are also insulated but sufficient care is required. Figure 18 (c) shows an example of insulation, where the outermost wall uses the ceramic fiber board. When the average temperature on the inner wall is 1350°C, the outer wall temperature is 141°C, and the amount of heat loss is 2017 kcal/m^2h. The temperature of the outer wall is 232°C, and the amount of heat loss is 6102 kcal/m^2h if insulation is not provided.

The upper side wall not in contact with the molten glass has come to use the fused AZS in place of the silica brick. At the same time, insulation is also improved. Figure 18 (d) shows an example of insulation:

When the average temperature on the inner wall is 1500°C, the outer wall has the temperature of 171°C, and the amount of heat loss of 2088 kcal/m^2h. When insulation is not provided, the temperature on the outer wall reaches 304°C and the amount of heat loss reaches 6152 kcal/m^2h.



t ℃	t ℃	t ℃	t ℃	t ℃	Q kcal/m²h
1500	1343	1079	769	95	810
1600	1432	1150	820	100	865

(a) Melting chamber bottom

(b) Melting chamber crown

(c) Melting chamber tank block

(d) Melting chamber side wall

Figure 18

3.1.3 Exhaust heat recovery

The melting of glass requires a temperature of 1450 to 1550°C, so the exhaust gas contains a great deal of heat. The temperature of the exhaust gas entering the regenerator from the melting chamber reaches as high as 1450°C. In this way, exhaust gas having a high temperature is recovered by the regenerator or recuperator, and is used to preheat the secondary air for combustion.

(1) Exhaust gas recovery by regenerator

The regenerator is designed in a way that high temperature exhaust gas is passed through the checker bricks, and the heat is absorbed by these bricks. After the combustion, gas is fed for some time (15 to 30 minutes), air is fed there by switching, and the brick heat is absorbed, raising the air temperature. The air is used for combustion. This procedure is repeated at intervals of 15 to 30 minutes. Thus, two regenerators are required for each furnace.

The exhaust gas temperature is 1350 to 1450°C at the regenerator inlet, and drops 400 to 500°C at the regenerator outlet. Air enters the regenerator at the room temperature, and is heated to reach 1200 to 1300°C at the outlet. Then, it is used as secondary air for combustion.

(2) Exhaust gas recovery by recuperator

Exhaust gas and air flow through the wall of the recuperator, and the heat is exchanged by the wall. This method is used for the small or medium furnace where the amount of exhaust gas is smaller, and is featured by its capacity of ensuring the stable pre-heating air temperature. However, the maximum temperature of the pre-heated air does not reach that in the case of a regenerator.

The air leakage through the wall into the exhaust gas side occurs in the brickwork type recuperator. To check if leakage has occurred to the recuperator is to analyze the exhaust gas to examine the change in oxygen. If air has entered the exhaust gas due to leakage, the gas temperature will drop and the increased amount of exhaust gas will cause a greater loss of the exhaust gas. If air leaks into the exhaust gas through the secondary air passage, the amount of secondary air will become insufficient in an extreme case, resulting in combustion failure.

Table 3 shows the leakage of the recuperator used in the pot furnace:

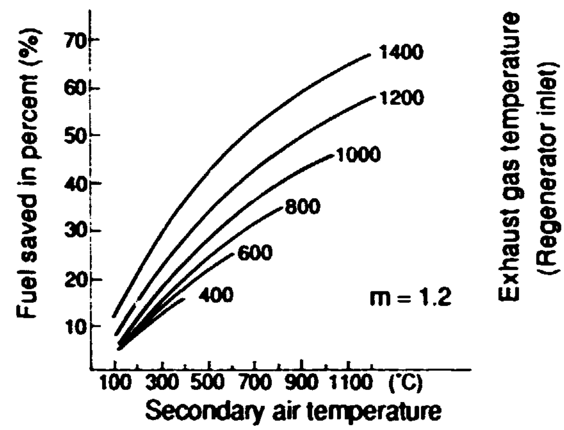
Table 3 Air ratio of exhaust gas for pot furnace and recuperator

	A	B	C	D
Furnace outlet O_2%	0.2	3.3	1.0	0.6
Air ratio (m)	1.01	1.17	1.05	1.02
Recuperator outlet O_2%	6.2	11.8	5.6	8.9
Air ratio (m)	1.4	2.2	1.3	1.7

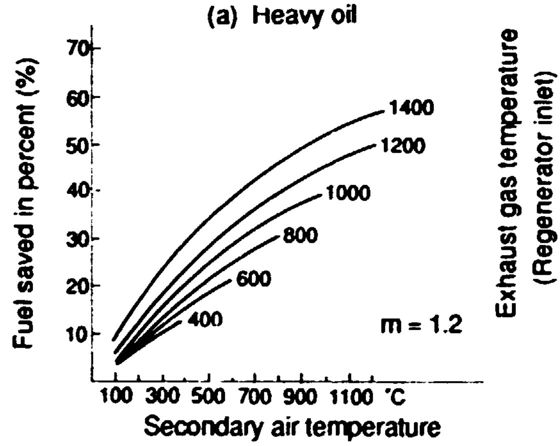
Regarding 4 furnaces, the content of oxygen (O_2) was analyzed in the exhaust gas inside the furnace and at the recuperator outlet, and the air ratio (m) was compared. The value "m" was 1.05 to 1.3 in the furnace C where the difference was the minimum, and 1.17 to 2.2 in the furnace B where the difference was greatest, showing an increase of about 1.8 times. As can be seen, entry of air is unavoidable for the recuperator, and this trend becomes more conspicuous as the furnace becomes older. So daily care is essential.

Figures 19 (a), (b) and (c) show the relation between the percentage of conserving the fuel and the preheated air temperature when the exhaust gas is used to preheat the secondary air. Figure 19 (a) shows an example in the case of heavy oil. When the temperature at the regenerator inlet is 1200°C, fuel of about 50% will be saved if the air temperature is pre-heated to 900°C. If the air temperature is raised to 600°C when the exhaust gas temperature is 800°C, fuel of about 28% can be saved. In this way, the furnace with higher exhaust gas features the better effect of air pre-heating, according to this Figure.

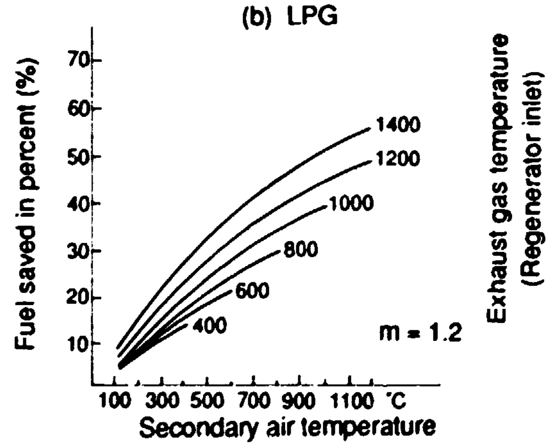
Figure 19 (b) illustrates the situation with LPG, while Figure 19 (c) represents the situation with LNG.



(a) Heavy oil



(b) LPG



(c) LNG

Figure 19 Savings in fuel due to preheated air

3.2 Lehr

Annealing is a process specific to glass manufacturing. If the glass is left as it is after having been formed, strain will occur due to the temperature differences on the surface and interior, and will break when it has exceeded a certain amount. Annealing is performed to minimize the possibility of strains occurring during the cooling process. To rationalize the cooling process, it is essential to get correct information on why stain occurs to the glass.

Lehr is available in two types; a direct fired type where the combustion gas contacts the product directly, and a muffle type where gas and products are separated from each other by the partition. The muffle type permits the use of less expensive heavy oil but the heat efficiency is low.

The directly fired type uses gas and electricity as fuels, and features high heat efficiency and easy temperature control. So the directly fired type is coming to be used in greater numbers.

Figure 20 illustrates an example of the lehr based on the forced circulation convection system. Gas inside the furnace is force-circulated by the fan to ensure a uniform temperature distribution, improving heat transfer efficiency. It permits annealing in a shorter time than the conventional Lehr.

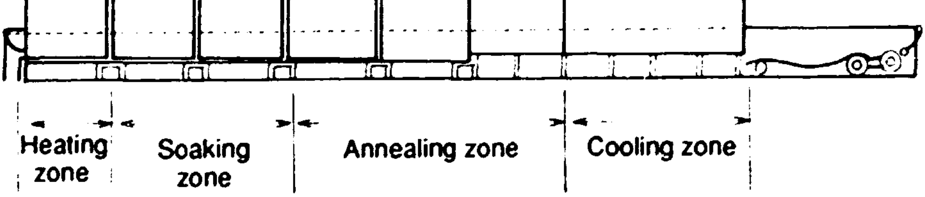


Figure 20 Outline sketch for lehr

Energy conservation of the lehr should be carried out, with consideration given to the following:

(1) Heat insulation of the furnace wall

The conventional wall materials were mainly the refractory bricks and insulating bricks. For the furnace wall, it is effective to directly use the heat insulating materials made of fibers having the minimum thermal capacity, when the temperature is as low as 600°C as in the lehr and the operation may have to be stopped during the night. Since the furnace, having the minimum thermal capacity, is susceptible to temperature variation, sufficient consideration must be given to the control system. As the products with considerably high temperature are charged into the lehr, the amount of fuels for heating can be reduced by providing sufficient insulation.

(2) Preventing cold air from entering through the inlet opening

The lehr has a short distance between the inlet and the heating zone, and soaking zone is quite close to the inlet. Therefore, entry of cold air from the inlet will give a serious influence; for example, it will disturb the temperature distribution inside the furnace. Since the opening serves as an inlet for the products, it is designed to be wide open. It will be necessary to install a damper or insulating curtains, without keeping it open. This opening also serves to discharge the heat of high temperature from the soaking zone.

(3) Preventing the outlet opening from being opened

As the inner part of the lehr outlet has a higher temperature, air flows toward the inner part. Air entering the outlet will disturb the temperature distribution in both the vertical and horizontal directions inside the furnace. It is desirable to provide covers above the belt conveyor as well as below it to enclose the space whenever possible.

(4) Alleviating the mesh belt heating

The mesh belt is made of steel wire or stainless steel. When it enters the furnace and is heated, the caloric will be considerably high. For example, assume the following:

Weight of products to be processed: 630 kg/h

Temperature of the product entering the lehr: 400°C

Soaking temperature: 550°C

Specific heat: 0.252

Then, the calorie required to heat the product is given by:

$Q_1 = 0.252 \times (550 - 440) \times 630 = 23814$ kcal/h

where:

Belt width: 1500 mm

Belt weight: 20 kg/m²

Belt speed: 380 mm/min.

Temperature of product entering the lehr: 15°C

Soaking temperature: 550°C

Specific heat: 0.132

The calorie required for belt heating is given by:

$Q_2 = 0.132 \times (550 - 15) \times 20 \times 0.38 \times 1.5 \times 60 = 48304$ kcal/h

The calorie required to heat the belt is more than twice that required to heat the product. To save this heat, the belt wire diameter is minimized, and the weight is reduced by making the pitch loose. However, this method has a defect in reducing the strength. The returning belt passes outside the furnace. To prevent the temperature from lowering to the room temperature, some plants provide improvements so that the belt will pass through the bottom inside the furnace, and the heated belt will enter the heating zone.

(5) Making the temperature inside the lehr uniform

The Lehr interior is designed so as to have a certain temperature curve with respect to the flow, but the temperature distribution in vertical and horizontal directions with respect to the flow cannot be controlled. If this temperature distribution is not uniform, the strain may be removed differently depending on the position on the belt conveyor. This will give an adverse effect on the production yield. To improve the temperature distribution, the forced circulation convection system is used, as illustrated in Figure 20.

(6) Temperature of the product entering the lehr

After being formed, the product is carried by the conveyor and is charged into the lehr. The product temperature differs depending on the distance to be carried by the conveyor. When energy conservation is considered, the product should enter the lehr after being carried over the minimum possible distance. This is related to the total layout of all the production processes, so modification is not very simple. However, if layout modification is possible in future, the possibility of this improvement should be studied.

3.3 Heat balance (in melting furnace and lehr)

Measuring the furnace temperature or observing the combustion is the routine procedure to ensure a stable furnace operation and high-quality products. Heat balance is an effective means of promoting energy conservation. A heat balance table is made to numerically grasp the present situation of heat loss and efficiency in furnace operation.

For the concrete heat balancing technique and calculation formula, see the related publications. The following shows major points for measurements in heat balancing procedure:

(1) Heat input

Combustion heat of the fuel: lower calorific value of the fuel

Sensible heat of the fuel: This may be omitted when fuel is not preheated.

Sensible heat of air for combustion: Caloric of the air preheated by the regenerator, etc. The flow rate is calculated from the inlet area and air flow rate.

Batch sensible heat: This is omitted except when it is not preheated.

(2) Heat output

Heat carried out by glass: It is a common practice to take heat balance including that of the refiner. The glass temperature in this case is measured at the forehearth inlet. The amount of the glass should be the amount taken out of the forming, machine or the amount of loaded batch. Table 4 illustrates the caloric of the glass:

Table 4 Heat required for production of various kinds of glass at various temperatures (Theoretical value)

Kinds of glass	Temperature °C	Heat required for melting glass kcal/kg glass					
		Cullet addition rate (%)					
		0	20	40	60	80	100
Tableware glass	1400	576	543	510	477	444	411
	1250	530	497	464	431	398	365
Sheet glass	1400	666	615	563	512	460	409
	1150	571	520	468	417	365	314
Borosilicate glass	1400	508	482	455	429	402	376
	1300	477	451	424	398	371	345
Lead crystal glass	1400	496	472	448	424	400	376
	1100	391	367	343	319	295	271

Source : Glass Engineering Handbook (1966)

Heat loss from furnace wall: The heat loss of the crown, side wall, bottom, etc. are measured by the heat flow meter. One or more points for 5 m^2 must be measured. When the heat flow meter is not available, use the surface thermometer to measure the surface temperature, and obtain the answer by calculation. It should be noted that calculation assumes the air flow close to the furnace wall as natural convection.

Latent heat of vaporation for batch moisture: For measurement, sample the batch moisture from the hopper located in front of the furnace.

When the batch charger and throat are cooled, add them to the amount of heat loss. Furthermore, if the electric booster is used for auxiliary heating, it is necessary to add its heat input and heat output.

Example of heat balance chart for glass melting tank is shown in Figure 21.

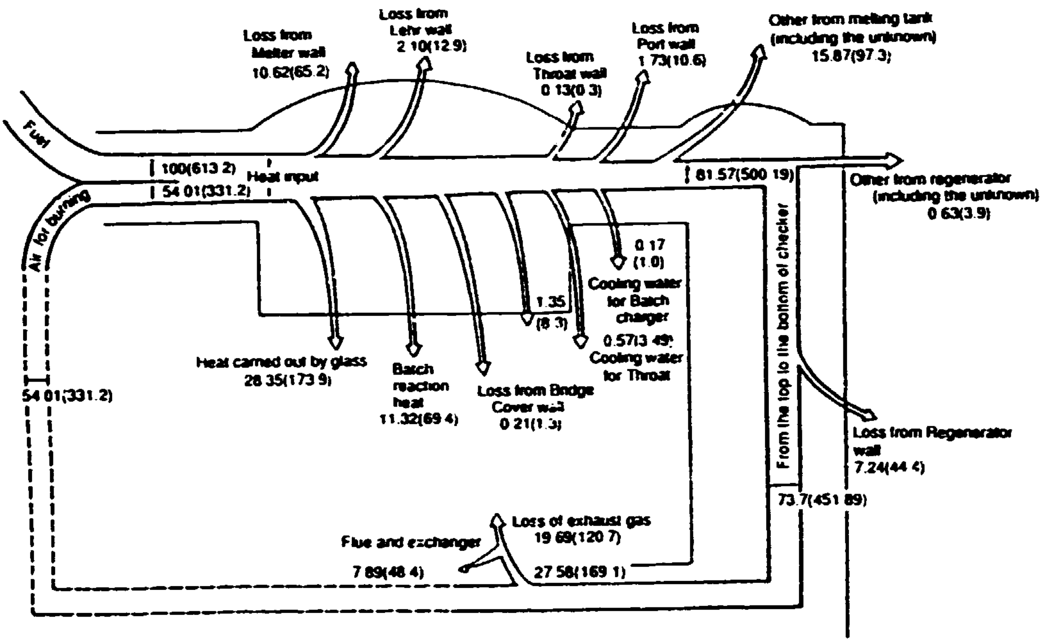


Figure 21 Heat Balance Chart for Glass Melting Tank

Source : Guidance of Energy Conservation (1983),
The Glass Manufacturing Industry

Tables 5 to 8 show the examples of the heat balance of the furnace, forehearth and lehr. Table 5 indicates the heat balance for three furnaces produced at different times. It shows that good results are obtained according to the progress of the energy conservation efforts. Tables 6 and 7 show the heat balance of the forehearth. The positions for measuring the temperature are illustrated in Figure 22.

Table 8 presents an example of the lehr heat balance. The characteristic of this case is that the other heat outputs are greater. Amount of caloric to heat the chain belt appears to be included.

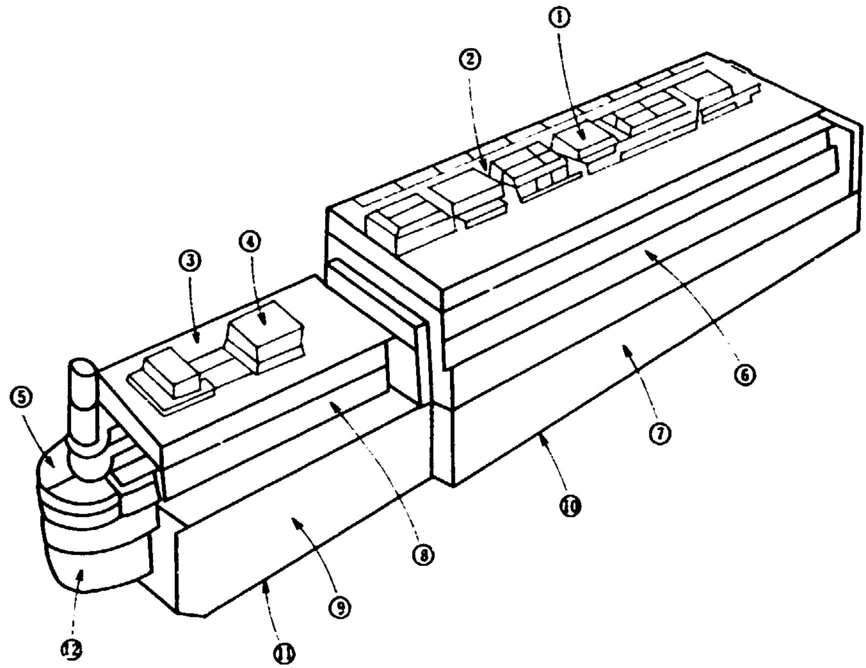


Figure 22 Measured positions for heat loss measurement from forehearth

Table 5 Heat balance of three generation furnaces

		A After 1972	B	C
Pull	(t/day) (fx²/t) (1000 kcal/t)	266 4.25 1323.0	121 5.58 1215.0	264 5.53 1107.0
Heat loss	(kcal/m²h) × 1000 kcal/t.d	1666.1 256.0	1223.2 268.0	677.5 135.0
Heat efficiency %		34.1	39.7	44.0
Heat carried out by glass (%) Reactor heat by batch (%)		27.4 67 (Cullet 38%)	28.4 11.3 (Cullet 23%)	31.4 12.6 (Curret 16%)

		A	B	C
Heat input	Fuel Secondary air	100 50.7	100 54.0	100 56.6
Heat output (%)	Melter wall	12.0	10.82	5.8
	Refiner wall	2.0	2.1	0.8
	Port wall	1.7	1.7	1.4
	Throat wall	0.1	0.13	0.1
	Batch moisture	2.3	1.35	2.50
	Loss by water cooling for throat	0.2	0.57	0.33
	Loss by water cooling for batch charger	0.2	0.17	0
	Others	21.1	15.9	27.0
	Heat carried out by glass	27.4] 34.1	28.4] 40.0	31.4] 44.0
	Reactor heat of batch	6.7	11.3	12.6
	Total	73.7	72.4	81.9
	Regenerator heat loss wall	3.6	7.2	3.7
	other	5.4	0.63	0.5
	Total	9.0	7.9	4.2
	Heat loss by exhaust gas	17.3	19.7	13.9

Source : New Glass Tech Vol. 3(1983), No. 4

Table 6 Heat loss value of forehearth

		A Area m²	B Average heat loss kcal/m²h	A × B kcal/h	Total heat loss kcal/d	Part loss/ total loss %	Heat loss/ area kcal/m²h
Crown	1	0.56	10000	5600	372000	37.3	1526
	2	7.30	519	3788			
	3	1.80	885	1593			
	4	0.11	9000	990			
	5	0.39	9050	3530			
Side wall	6	7.48	1206	9017	411000	41.2	959
	7	7.84	751	5886			
	8	1.0	1290	1290			
	9	1.90	490	931			
Bottom	10	8.43	695	5860	214000	21.4	768
	11	2.05	387	793			
	12	1.11	2030	2253			
Total		39.97		41531			

Source : New Glass Tech Vol. 3 (1983), No. 4

Table 7 Heat balance of forehearth

		× 10⁴ kcal/d	%	as 100% heat bring of glass
Input	Heat bring of glass	2184.5	83.0	100
	Heat of combustion	448.8	17.0	20.5
		2633.3	100	120.5
Output	Heat carried out by glass	2104.6	79.9	96.3
	Heat loss from wall	99.7	3.8	4.6
	Exhaut gas and other	42.9	16.3	19.6
		2633.3	100	120.5

Source : Now Glass Tech Vol. 3 (1983), No. 4

Table 8 Heat balance of lehr

Heat input			Heat output		
	kcal/kg	%		kcal/kg	%
Fuel	450	79.5	Side wall heat loss	27.4	4.8
Heat carried in by glass	116.3	20.5	Open space heat loss	139.1	24.5
			Exhaust gass heat loss	134.0	23.7
			Heat carried out by glass	14.0	2.5
			Other	251.8	44.5
Total	566.3	100		566.3	100

Source : Guidance of Energy Conservation (1983).
The Glass Manufacturing Industry

3.4 Other measures

(1) Use of electric booster

To increase the pull without changing the furnace size, alternating current (AC) is supplied to the melting chamber or heating. This method is often used for the bottle making furnace. Since this electricity is used for glass melting at the efficiency of close to 100%, this method is very effective.

Since the electricity required to increase the pull by 1 ton is said to be 22 to 28 kW. Assuming it to be 28 kW, input of 24080 kcal is sufficient since 1 kW corresponds to 860 kcal. The use of the booster to increase the pull will reduce the specific energy consumption.

(2) Bubbling

Air is put through the bottom of the melting chamber, and glass is agitated by the bubble, thereby speeding up the homogenization and improving the product quality. Bubbling increases the temperature at the bottom of the melting chamber, resulting in increased furnace temperature. Thus, this method directly contributes to energy conservation. Moreover, improved product quality reduces the failure rate, and decreases the specific energy consumption.

The bubbling method

Several nozzles or ten or more nozzles are installed, perpendicular to the flow of the glass, at the bottom close to the hot spot of the melting chamber, and 1 to 10 liters of air per hour are fed into molten glass.

(3) Electric heating of forehearth

It is extensively known that direct heating of the forehearth by electric power will greatly save energy. In the case of borosilicate glass, the entire forehearth is enclosed without contact surface between air and glass; this method ensures high-quality glass. Since this method, however, is not often used, its advantages or disadvantages are not so clear at present.

(4) Use of cullet

Figure 23 illustrates that use of a great number of cullet saves energy. When no cullet is used at all in the furnace with a daily production capacity of 150 tons, fuels of 200 kg/kg-glass are used. On the other hand, when 50% of cullet are used, spent fuels will be reduced to about 180 kg/kg-glass.

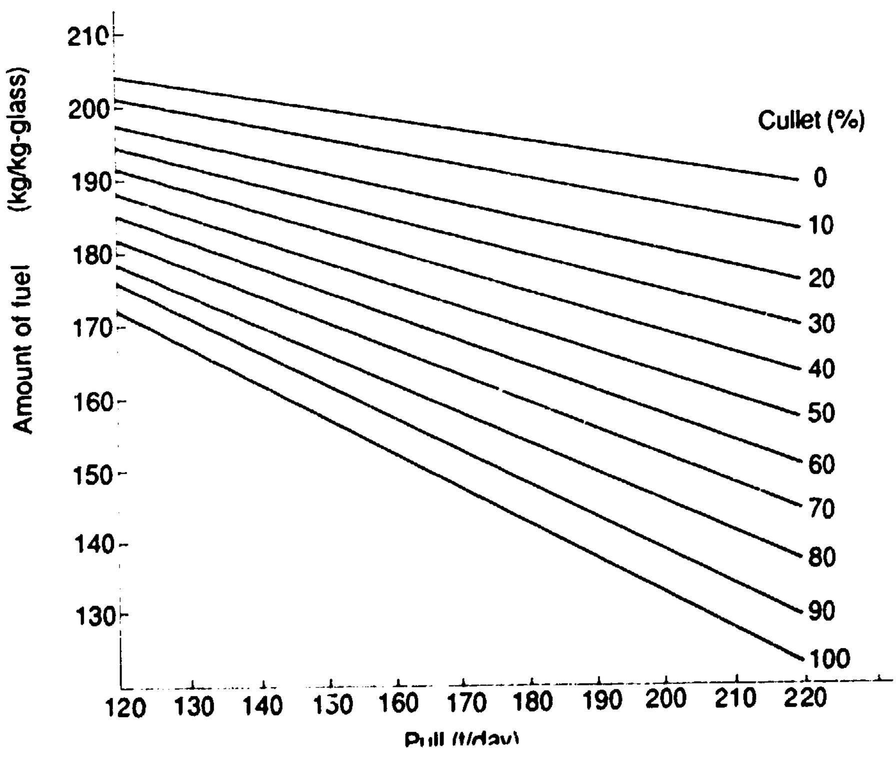


Figure 23 Relationship between pull and fuel amount for various cullet content

The use of only the cullet produced in the plant may be satisfactory. However, the generation of such a great deal of cullet means a high failure rate in production; this is not desirable. Cullet placed on the market are inevitably mixed with foreign substances, and it is expensive to maintain the quality. If high-quality cullet can be ensured in ground amount, the use of many cullet will contribute to energy conservation.

(5) Development of low melting temperature batch

Various studies have been made on the batch for reducing melting temperature without deteriorating the quality of glass. The method considered to be most effective is to add lithium. Lithium carbonate or spodumene (Li_2O, Al_2O_3 $4SiU_2$) are used as lithium materials. The spodumene is composed of 5% of Li_2O, 18.7% of Al_2O_3, 74.7% of SiO_2 and 0.1% of Fe_2O_3. They must be checked for confirmation before use.

The addition of a small amount of lithium reduces the high temperature viscosity of the glass, and reduces the foam breaking temperature. Take an example of the glass (composed of Na_2O-CaO-SiO_2). As illustrated in Figure 24, the temperature showing $\log \eta = 2.0$ was 1400°C when 0% of Li_2O was used. When 0.2% of Li_2O is used, that temperature is reduced by 30°C. When 1.9% of Li_2O is used, that temperature is reduced by 60°C to 1340°C. Thus, the addition of a small amount of lithium reduces the viscosity. This has been demonstrated by the reduced bubble breaking time in the commercial furnace. However, the lithium material is expensive. Therefore, a study will be made according to the trade-off between the energy conservation and material cost.

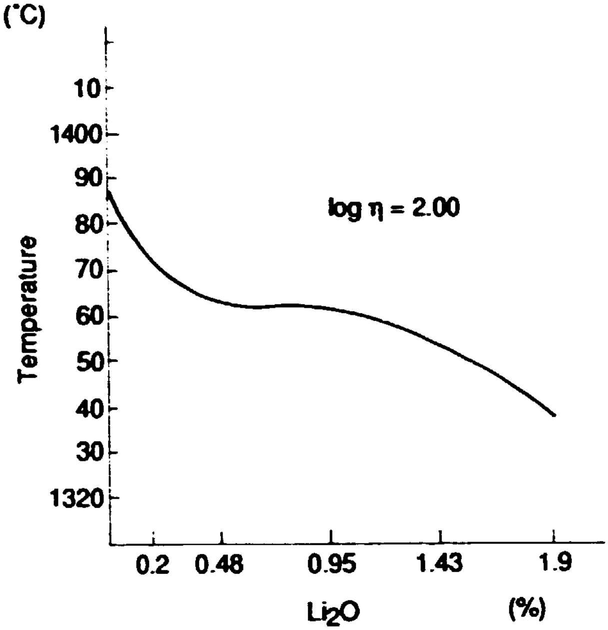


Figure 24 Viscosity vs Li_2O content

(6) Furthermore, for the small furnace with a daily production capacity of 10 tons or less, the conversion to the fully electric furnace, addition of oxygen in the burner combustion and introduction of gas into the primary air atomizer must be studied, but they will not be described in this paper.