LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF ENERGY TECHNOLOGY

MASTER'S THESIS

ENERGY EFFICIENCY OF GLASSMAKING PRODUCTION

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ABSTRACT

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Energy efficiency of glassmaking production
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Master's thesis Energy efficiency of glassmaking production gives description of glassmaking production and possible energy saving measures. Due to the high electricity and fuel prices the problem of rational energy utilization rises sharply. In addition the environmental issues also require a great attention. This work represented the feasible increasing of the furnace efficiency as the most productive activity.

Thesis also provides a detail description of utilizing waste heat boiler. Also possible boiler characteristics are calculated and represented at the end of the thesis. As well as brief description of the feasibility of using this method of energy saving.

The solution of this problem has a huge importance. Due to the increasing of energy costs and limits of raw materials, glassmaking industry should overcome on high efficiency operation mode. Especially, if such measures is making a significant contribution in the safety of environment.

Content

Abbreviation and symbols.

% – percent

ºC – temperature

Psi – the unit of pressure

MPa – the unit of pressure

MJ – unit of work, energy and quantity of heat

KJ/mol – the molar internal energy

KJ/m3 – specific energy per cubic meter of fuel

KJ/kg – specific energy per kilogram of fuel

KJ/m3*ºC – specific heat capacity

kg/s – is a derived unit of measurement of mass flow rate

m3/s – is a derived unit of measurement of mass flow rate

m/h – speed

W/m2*K – the heat transfer coefficient

Introduction

Glass is familiar material for everyone, used since ancient times. It is used in many different ways and in everyday life, even in the production of high-tech products. The most prevalent kinds are sheet, containerboard, and the so-called lime-soda glass, which is made from silica sand, soda ash and limestone or dolomite. The oxides from these natural minerals are responsible for major chemical and physical properties of glass, as well as for the smelting process. Glass is 100% recyclable. Processed recovered glass particles play a major role in the glass industry, and natural minerals.

At present time the humanity cannot imagine their lives without glass. Due to its unique qualities, such as transparency, hardness, chemical resistance, cheapness of production, glass is the most widely used material at home, in construction of buildings, transport. Many things that surround us are made from this material. It is impossible to make optical devices, televisions, spaceships without it.

Glass is manufactured in the unit which is called melting furnace. This is the heart of any glass production. Typically, melting furnaces operate with an overall efficiency of 40%, where structural and flue gas losses represent 20-25% and 25-35% of losses, respectively. The biggest value, which can be achieved, is about 65 percent thermal efficiency.

Glass industry is one of the high scaled sectors at present days. That is why it is very important to keep the energy consumption in that sphere in permissible limits. The efficiency of melting furnace is one of the most important issues. Improvements to the traditional furnace technology have indeed resulted in lower energy requirements, improved furnace life, better implementation of pollution control equipment and advanced instrumentation for process control.

1. One of the most important materials in human life.

a. History of glass

Still it is not clearly known how glass was invented. The invention of this material is associated with many legends, but only one of them seems relatively possible. According to this version, the glass is accidentally open material, became a by-product of one of the most ancient crafts - pottery. It is known that many centuries ago, the firing of clay for giving them strength was carried out in sand pits. As a fire in those days usually the dry reeds or straw were used. Due to the influence of high temperatures the sand was interacted with the main products of combustion, the result was the formation of a transparent, quickly solidifying mass. Another common theory about the appearance of the glass is the formation of by-product in the smelting of copper. Some scholars hold the third version. According to them, the glass formed by the impact of high temperatures on the African sand and soda. In obedience to this legend, Phoenician merchants cooked utilizing the hearth of the African soda established on the coastal sand. This version of the glass origin belongs to the ancient historian Pliny the Elder.

There is no doubt that first glassblowers were Egyptians. They have created the glassware in special containers made of clay. In those days, was also invented the ratowania method. Red-hot pieces of glass dipped in cold water, then grounded into dust and melted down again. This technique of glass production has been used for many centuries. Confirmations of this fact are the founded tools of ratowania in the excavations. At that time the production of glass required two furnaces, one of which was used for primary melting, by using the other ratow was melted.

Ancient furnace, in which the glass was produced, was built of clay and stones. Their only drawback was the high consumption of firewood. This is not surprising, because inside the furnace it was needed to maintain consistently high working temperature up to 1200 degrees. Moreover, for penetration the furnace must had heated to 1450 degrees.

As raw material for the glass manufacture soda ash of various plants and sand was used. Many centuries ago, craftsmen learned how to produce not only white, but also colored glass. As the dyes in those days it was customary to use a variety of metallurgical slag, for example, compounds of manganese, copper and cobalt. The ancient oven was like a low arch, under which a clay container for melting glass was placed. The fuel for these furnaces were from the surrounding forest, so when they are completely passed out, furnace had to be moved to another location. In ancient times melting glass was very difficult and required much time. As a result the prices for glass products were extremely high.

The heyday of glass-blowing production began with the Roman Empire. But after a great state collapsed, the glass industry has been developing very slowly. In the future, glass-blowing business was divided into two areas: Western and Eastern.

The superiority in the manufacture of sheet glass needs to be given to the German glassmakers. In the eleventh century they had the idea how to blow a hollow cylinder, then trim its bottom, after that roll the material into a thin sheet to give a rectangular shape to it. Italian craftsmen have begun to use this technique only in the thirteenth century. By the end of the middle ages a center of glass-blowing production becomes Venice. Glassmaking has gained incredible popularity, after a few years in Venice, where worked more than eight thousand glass blowers.

Soon, however, the Venetian glass was forced by the crystal, the production of which was initially only by English glassmakers. According to historical facts, crystal was invented by George Ravenscroft, who first began to utilize more sophisticated source materials. Instead of potash, the inventor used a lead oxide. The result was a beautiful glass with perfect reflective properties.

Industrial production of glass was started relatively recently - only in the nineteenth century. The founder of automatic production of glass products became Otto Schott, the main activity of which was studying the effect of various substances on the physical characteristics of the glass. Schott has done a lot of research work in conjunction with Professor Ernst Abby. Another scientist who made great contributions to the automation of glass manufacturing became Frederick Simmons. He has created a unique oven, allowing increasing volumes of glass production by several times. A few years later, Michael Owens invented the equipment for glass bottles manufacture. This innovation quickly gained popularity. By 1920, the U.S. employed more than 200 machines of this type. One of the most important methods of glass production became extruding the material from the furnace. The author of this invention was the Belgian scientist Foucault. Emil Bishara, his compatriot, decided to improve this technique by proposing to pass the glass between the rollers to obtain a fabric uniform. A revolution in glass production has made the company "Pilkington", which has developed a float-method: from the furnace the melted glass mass is fed into a container with molten tin, then cooled and sent to the annealing. The main advantage of this method is insurance of uniform thickness around the perimeter of the glass sheet. In addition, the glass company "Pilkington" was not needed in the further processing, as it lacked a variety of defects as for products made by any other method. (Roger Kennedy, 1997, 28 p.)

b. Different kinds of glass

The composition of glass defines the physical and chemical properties of the glass. Various applications require particular types of glass and industrial processes. The types differ in each product or application.

Since the composition of the glass can differ indefinitely, there are various kinds of glass. Nevertheless, in commercial glass manufacturing they may be classified into three main groups:

- Soda-lime Silica Glasses
- Borosilicate Glasses
- Phosphate Glasses

The table below illustrates primary components, main properties and typical applications of these types of glass.

Table 1.(data from koppglass.com)

Glass Type	Primary Components	Linear Thermal Expansion	Thermal Shock Resistance	Chemical Resistance	Applications
Borosilicate	SiO_2, B_2O_3	~30-60 x 10^{-7}/°C	Average - High	High	• Industrial equipment • Exterior lighting • Laboratory and kitchen glassware
Soda-lime silicate	SiO_2, Na_2O, CaO	~80-100 x 10^{-7}/°C	Low	Average	• Food and beverage containers • Windows • Lamp envelopes
Phosphates	P_2O_5	~90-110 x 10^{-7}/°C	Low	Low, except high resistance to hydrofluoric acid	• Bone scaffolds • Optical fibers • Heat absorbers

Soda-lime glass is the most common type of glass produced. Almost 90% of glass produced in the world is represented by compositions of soda-lime silica glass. These glasses are utilized in production of food and beverage containers, windows and lamp envelopes. The prevalence of this type of glass can be explained by the following benefits of Soda-lime Silica Glasses:

• Low manufacturing costs;

• The materials needed in glass production are common and widespread;

• The melting process takes place at a low temperature.

However, one of the main shortcomings of Soda-lime glasses is its low durability in comparison with other types of glasses, including borosilicate compositions. Besides they can degrade in chemically corrosive environment and cannot stand a thermal shock.

In comparison with Soda-lime glass, the main feature of borosilicate glasses is their durability. Due to this fact borosilicate glasses are usually used in severe and demanding applications. Borosilicate Glasses have a low coefficient of thermal expansion which makes this type of glass resistant to thermal stresses. Due to this fact Borosilicate Glasses could stand heating and cooling processes without cracking or breaking.

In industry and transport glasses are often subjected to such harsh chemicals as oils, petrol, jet fuel, acids and salt solutions. Even some types of glasses can be damaged by permanent influences of water.

Borosilicate glasses can resist long exposures to water and chemicals. Because of this, they are usually used in laboratory glassware, transformer bushings and exterior aircraft lenses manufacturing. A phosphate glass is a class of optical glasses composed of metaphosphates of various metals.

Instead of SiO2 in silicate glasses, the glass forming substrate is P2O5. The main characteristic of this type of glass is its high resistance to hydrofluoric acid. However, Phosphate glasses can degrade in chemically corrosive environment.

Phosphate glasses are suitable for alloying of various dyes, such as transition metal ions and rare earth oxides. Due to this fact Phosphate glasses are commonly used in different medical, military, and scientific applications. Prior to conducting a research on improving the efficiency of glass making stoves, it is necessary to review the main phases of glass manufacturing process. (Manufacturing Industry Council with the US Department of Energy-Office of Industrial Technologies. Contract #DE-FC36-02D14315. August 2004. p.9)

c. Glass as a foundation of new technologies

At present days glass is utilized as main material in building, car manufacturing, table and kitchen ware and as decorative elements. However, few people know that now research and development sphere has made a huge step in utilizing glass as a material. More and more new technologies are connected with glass using.

One of such ways is unique, innovative building material - liquid glass - consists of a solution of silicate of potassium or sodium with the addition of silica, obtained from quartz sand. This composition combines with molecules of alcohol or water, creates on the treated surface a thin film that protects against bacteria and contamination. Moreover the material of this surface does not matter. Liquid glass is a versatile antiseptic. Using it, you cannot worry about that any microorganism will appear, mildew or any other. This material is non-toxic, fire and explosion resistance.

The effect of adoption is not limited to simple antibacterial protection. The substance prevents the effects of ultraviolet radiation and high temperature; repel moisture, while simultaneously allowing the treated surface to breathe using liquid glass, the properties of which allow solving many of the homeowners' problems. Workers and owners get real economic benefits.

In particular, this innovative material significantly increases the resistance of the plinth and foundation of the house to the adverse effects of the atmosphere (changes in temperature, humidity, precipitation). Liquid glass is the best option to provide the necessary waterproofing in the building. In addition, it can be used even in the construction of wells and pools. Utilizing it as waterproofing will not allow water to seep and leak.

Other building material has different properties from the previous one. However this technology may be considered as innovation. British scientists have developed a new anti-glare, self-cleaning, energy saving smart glass. Innovative material allows not only to reduce the cost of space heating, but also to get rid of the costs associated with cleaning glass, which is especially advantageous for high-altitude objects.

New smart ultra slim glass has a coating of thermochromic vanadium dioxide (5-10 nm). The ability of changing color depending on temperature, it can prevent heat loss from the room in the cool season and to reduce the heating of the air in hot weather. As scholars have noted, compared to similar coatings based on gold and silver, which today are used in the manufacture of energy-saving window designs, vanadium dioxide is less expensive and more sustainable material.

Another advantage of this glass is its ability to self-clean. Due to the conical elements of the unique nanostructure of the coating, the water drops easily roll down with minimal contact with the surface of the material. So, the small drop of the rain takes all of the dust and dirt, when it rolling downs the surface. Washing windows on high buildings is a daunting task. However, the use of the new smart glass, which needs no cleaning, will reduce the costs associated with the washing of glass facades.

And finally glass finds a big range of utilization in the digital technology sphere. The most commonly used optical transmitters are semiconductor devices, light emitting diodes (LEDs) and laser diodes. The difference between LEDs and laser diodes is that LEDs emit non-coherent optical radiation, while the radiation of the laser diodes works in a coherent manner. The size of material in optical communications, semiconductor optical transmitters must be compact, efficient, and reliable to operate in the optimal range of wavelengths, and to be operable at high frequencies. (Roger Kennedy, 1997, 30p.)

Light-emitting diodes LED for the fiber optic equipment is usually made on the basis of gallium arsenide phosphide (GaAsP) or gallium arsenide (GaAs). The emitters are based on LED best suited primarily for use on local networks with information transmission rates of 10-100 Mbit/s and distances up to several kilometers. Modern LEDs can emit at different wavelengths and are currently in use for local area networks built on the technology of WDM (Wavelength Division Multiplexing).

The semiconductor laser generates radiation by means of stimulated emission, and not the immediate issue (as in light-emitting diodes), which helps to receive high output signal power (~100 mW) and has other advantages related to the coherent nature of the radiation. Radiation of a semiconductor laser is relatively directional, allowing obtaining high efficiency in transmission of signal in single-mode optical fibers. The narrow spectral width of the radiation enable to get high speed transmission of information, as it is associated with reduced modal dispersion. In addition, semiconductor lasers can easily be modulated at high frequencies because of short recombination time of charge carriers in P/N junction.

In conclusion one needs to be pointed that glass becoming a high scale material, which may be used in various spheres of production. The modern world cannot be presented without that material. (Keith Jamison April 2002, 31 p.)

2. Glass manufacturing

a. Different technologies in glass production

At present time people use different types of glass materials to meet their needs. The industry of glass can be divided into 5 main sectors: (For instance the information in this article will represents about glass production in European Union)

- Container glass
  It accounts near 70% of total glass manufacturing in EU. The outcome uses in food and store areas. Commonly this type of glass applies as jars, bottles, spots and even high quality containers for pharmaceutical and cosmetics industries. This sector satisfies not only domestics' requirements. However the final consumer can be in another part of the world. This means that EU glass production needs to keep a certain level and quality of their goods. In addition 160 manufacturing plants provide a large amount of job places as a stable chain supply.(SCALET Bianca Maria, 2013, 9 p.)
- Flat glass.
  Another sector, which occupy second place takes 25% of EU glass production. Flat glass is parted on rolled and floats glass. There are some differences in production between these types, mostly in forming section. However float glass takes about 95% of total outcome due to high number of advantages. Main consumers of that glass are building and automotive industries. Windows, doors and mirrors are made from float glass. Another type is used for greenhouses, glass partitions, decorative elements and photovoltaic panels. In other words wired or pattern glass, where light is dispersed. Most part of product is for domestic requirements due to hard transporting conditions for glass. .(SCALET Bianca Maria, 2013, 9 p.)
- Continuous filament glass fibre
  The share of not the biggest one, but still very important sector is 2%. However as the consumer base is large scaling, it could not be mentioned.

This type of glass used in production of composite materials. Wide diversity of sectors uses this raw material: building and transport, electrical and electronics industry, agricultural and machinery sectors. In view of different forms of production and easy transporting, the market of continuous filament glass fibre is international and very wide. .(SCALET Bianca Maria, 2013, 13 p.)

- Domestic glass
  This sector takes the same part as last one type 2%. The products are covers all domestic household needs. Glass tableware, cookware and decorative items are the most common things. As the final consumer product has a big variety in design, color and structure, the methods of manufacturing can include manual as well as automatic techniques. The market is unstable due to wide range of factors like social trends and customer tastes. .(SCALET Bianca Maria, 2013, 21 p.)
- Special glass
  The last sector accounts roughly 1% of total EU glassmaking production. This type of industry manufactures various kinds of glass with different properties. Mainly this sector includes optical and ophthalmic glass, lightning glass, borosilicate glass excluding tubes, glass ceramics, cathode ray tubes and flat panels and glass tubing. Due to the diversity of characteristic, shape and structure every type of glass needs to be done with special equipment and technology. Because of this the investments in this sector are huge. It means that the market of special glass is not as big as for domestic one. .(SCALET Bianca Maria, 2013, 25 p.)

The glassmaking industry is developing sphere, which means that the total production is growing with the demands of people (figure 1).

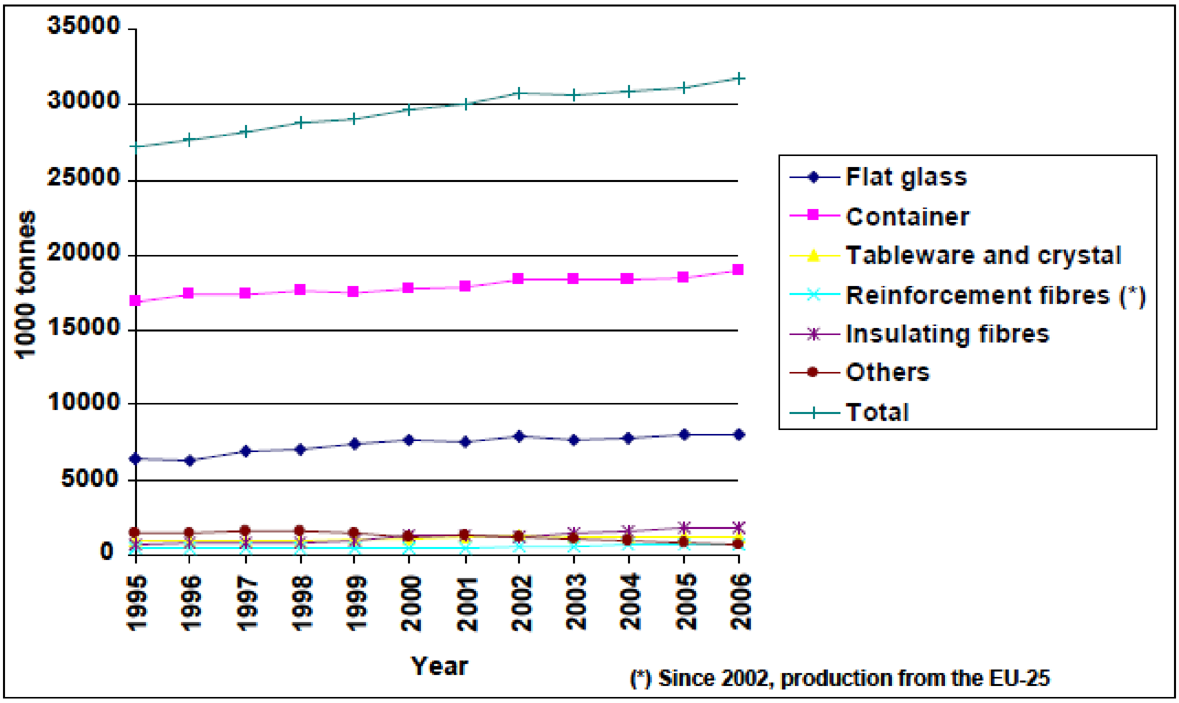


Figure 1. Graph on production development by sector (data from 2004 onwards refer to EU-25)

Due to this factor it is necessary to find the solution on the hardest solving questions, like the consumption of fuel and energy, environmental and social aspects, research and development of new technologies and investments.

b. Types of glassmaking furnaces

To receive the right class of glass, it is necessary to keep a certain technology and use suitable equipment. In every glassmaking production the central part of the manufacture chain is a furnace. Quality of product, fuel and energy consumption, emissions and other aspects are more depend on the chosen furnace. It is very important part of the manufacturing. There are 2 main types of glassmaking furnaces. They are discontinuous and continuous.

The examples of discontinuous one are day tanks and pot furnaces (figure 2). In common the one work load lasts one day. In this type of furnaces at the beginning of operation the raw materials are loaded into the pot. Then this mixture is heated to certain temperature for melting. After the homogenized reaction the content of the pot is cooling till its temperature will be suitable for forming. By the small portions the glass is taken from the pot by craftsman or automatic machines. The main difference from continuous furnaces is that big amount of actions are take part in one section of furnace called a pot or a tank. In one place all operations from load to forming are going in sequence. (Mathieu Hubert, 2015, 6p.)

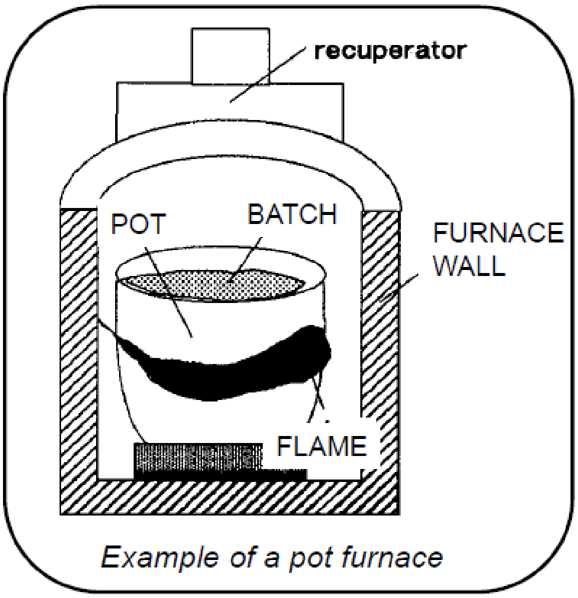


Figure 2. Discontinuous furnace. (. Mathieu Hubert, 2015)

However for industrial production continuous furnaces are usually used. There are 2 main types. One uses a fossil fuel as an energy source and another – the electricity. The first one is called glassmaking tank or tank furnace. The bath of furnace is continuously charged by raw materials. The tank is divided into sections, where the main steps of melting process are taken part. The heat is transferred from combustion of fossil fuels, mainly the nature gas. The duration of one campaign lasts 10-15 years (figure 3).

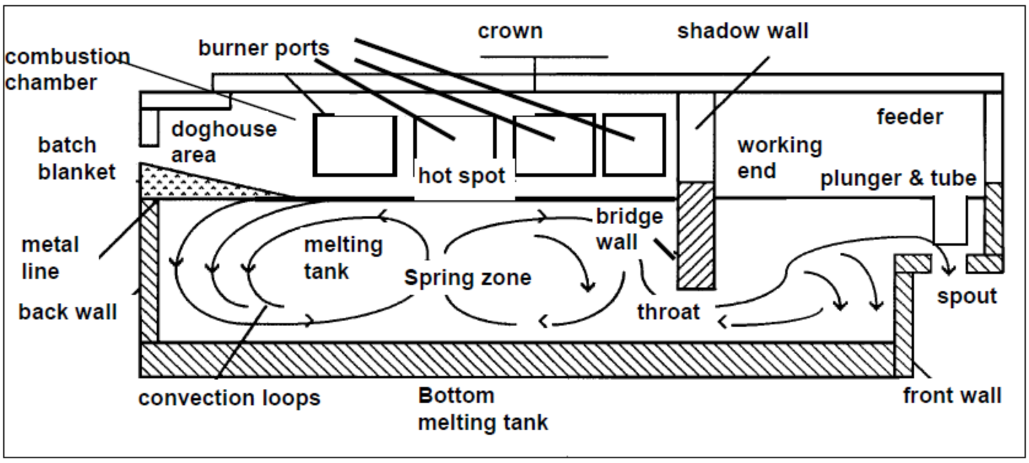


Figure 3. Continuous tank furnace. (Mathieu Hubert, 2015)

This type is the most generally used, due to its high performance, long time work and good thermo technical properties. Also it is the most suitable for mass glass production. Due to various trajectories of movement, different time of distribution and divers temperatures at bath, the quality and outcome parameters can vary from time to time. The one of the main purposes of good manufacturing is to balance the process and make it stable. The furnace consists of 5 main sections:

- Glass melting bath. The basic part, in which the fusion take part.
- Throat. The connection between melting end and the beginning of refiner.
- Neck. On the chance of float process the transition from melting to working end.
- Working chamber. The end of the furnace.
- Combustion chamber. The outcome for exhaust gases of combustion process.

There are many applications and facilities based on continuous tank furnace. The most widely spread type is a regenerative furnace (figure 4). (Mathieu Hubert, 2015, 7-9p.)

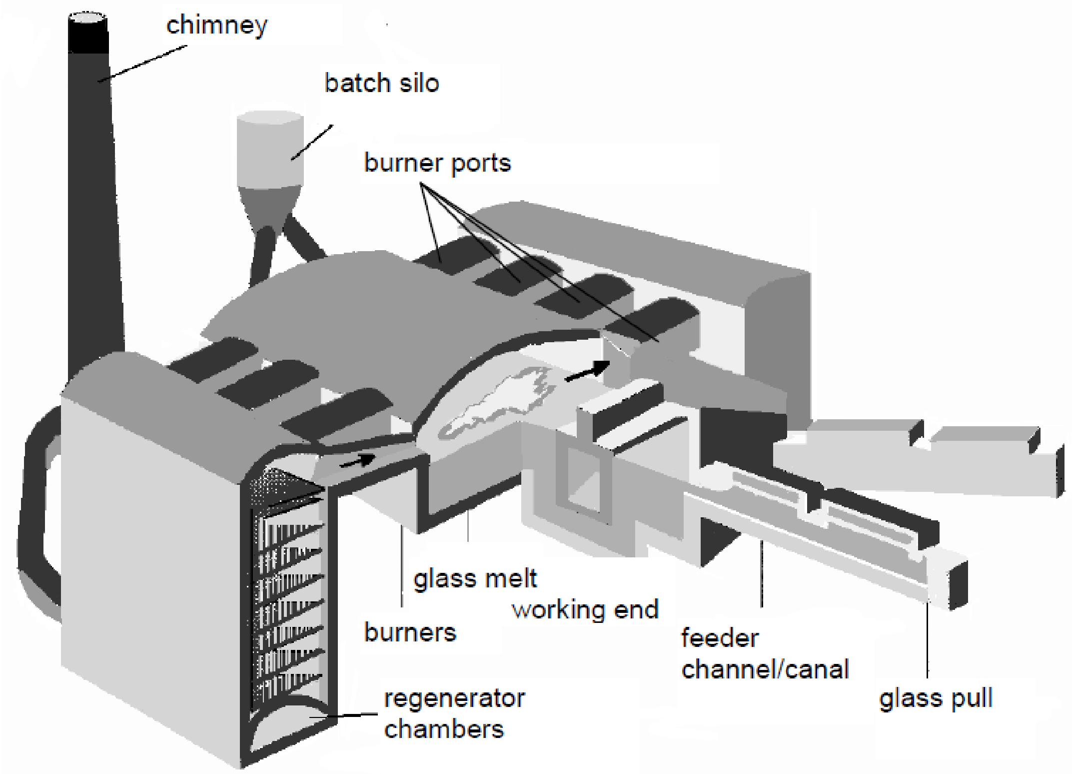


Figure 4. Regenerative tank furnace. (Mathieu Hubert, 2015)

The addition of regenerative preheaters helps to use the heat of flue gases for warming air, which is used in combustion process. From the design point of view, this is an installation with the dimension comparable with the furnace. It is consist of chamber in which a checkers of refractory bricks are ricked. The one cycle of regenerator consist of heating the checker by exhaust gases, and realizing that heat to income air. That means the furnace needs to be provided with 2 air regenerators minimum. When one facility works as accumulator, another one works as a heater. It is called the reversal period (figure 5). Usually the duration of one cycle takes 20-30 minutes. During the shifting between regenerators the burners are changing too. It lasts 30-60 seconds. The reversal period needs to be as short as possible due to the cooling of bath. (Mathieu Hubert, 2015, 13p.)

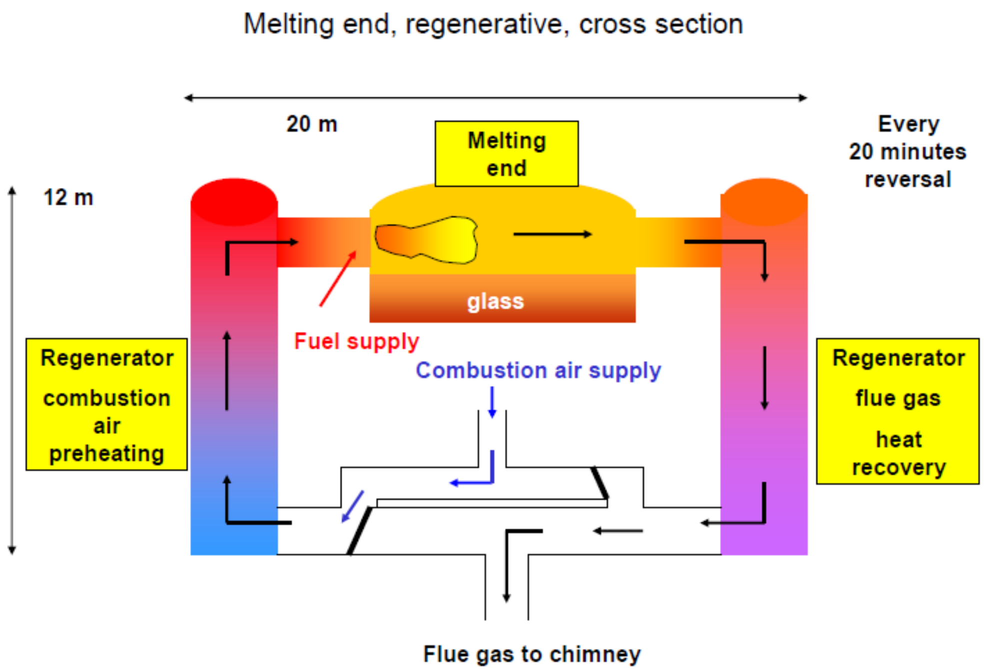
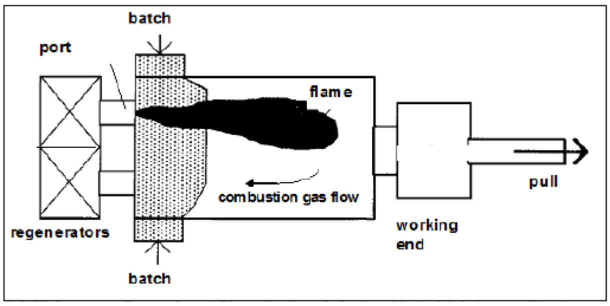


Figure 4. The reversal period of regenerative preheaters. (Mathieu Hubert, 2015)

In its turn regenerative tank furnaces can differ by the burner positioning. In one hand there are cross-fired regenerative furnaces (figure 5). The preheaters are situated on the both sides of the tank. Based on the size of furnace the amount of burner ports can vary from 4 to 8. The flame of burners is directed athwart to the side walls. The privilege of this type is high intensive radiative heat transfer due to huge flame heating plane. On the other hand there are end port-fired (or U-flame) regenerative furnaces (figure 6). The burners are located at the back wall side of combustion chamber. The number of burners changes from 2 to 4. The flame originates at the back side of furnace and spreading over the tank to the end. The advantage of such locating of burners is good convective heat exchange due to long distance to combustion chamber. (Mathieu Hubert, 2015, 15-16p.)



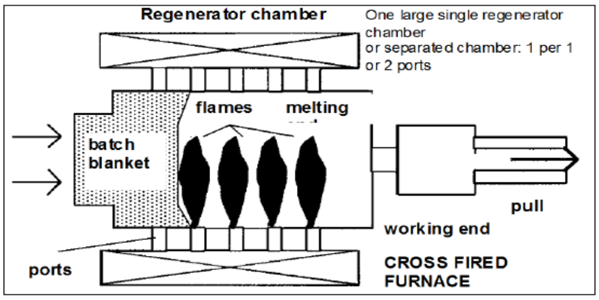


Figure 5. Cross-fired regenerative furnace. Figure 6. End port-fired regenerative furnace.

(Mathieu Hubert, 2015)

Another type of preheater that can be used in glassmaking industry is a recuperator. This facility is also heat the air by the exhaust gases from combustion process. The heat transfers from one media to another through the barrier to prevent the mixing of agents. Generally it is a steel wall. Due to high temperature stress there is a need in high quality of recuperator material. The main advantages compare to regenerative preheater are:

- Investment costs are significantly less
- Continuous process conditions. There is no reversal of burners.
- The temperature of glass surface can be easily controlled, because of stable burner work.
- The construction of combustion chamber is less complicated.

However there is one very important drawback of recuperator preheater. It is the efficiency. It is lower than in regenerative furnaces due to the temperature of heated air. Still the recuperative furnaces (figure 7) are used in manufacturing because of low investment cost. (Mathieu Hubert, 2015, 21-24p.)

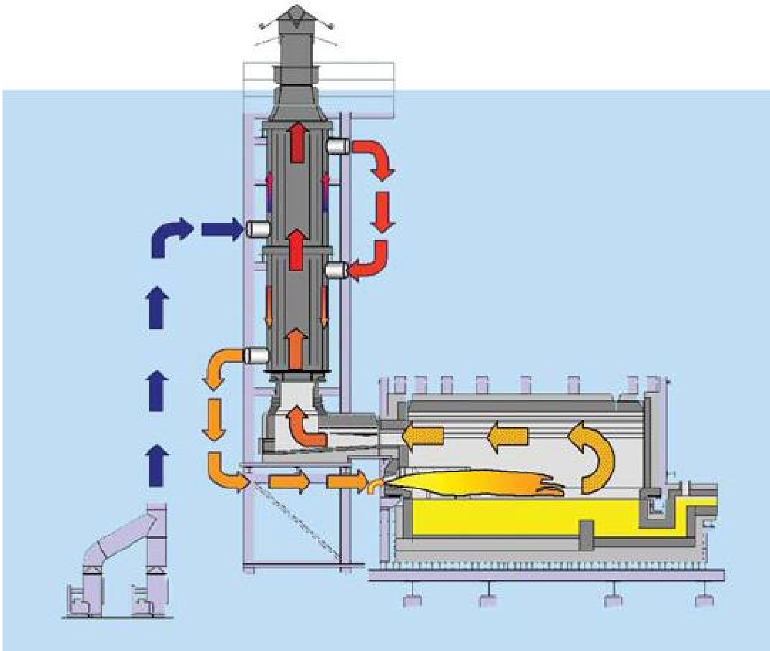


Figure 7. Recuperative furnace. (Mathieu Hubert, 2015)

Last type of furnaces called electric melting (figure 8). The source of heat comes from electricity. The design of furnace is the same as in the typical continuous tank, but there is one distinction. Except of burners there are 2 electrodes: cathode and anode. They plug in the melt bath. When the current flows through raw materials, the temperature of content is raising.

To achieve the desired mode big voltage is required. To divide the area into 2 sections: melting and glass-fining, the optimal length between electrodes needs to be done. In addition cathode and anode make huge contribution in mixing process of bath content. Also electric current releases latent energy that contained in melted media.

Of course the main advantage of electric furnaces is absence of exhaust gases, which means that there is no harmful emissions like greenhouse gases, oxides of nitrogen and carbon, hard metal emissions and so on and so forth. In the conception of green energy system and neutral GHG, this is the best solution that could be offered. Still there are number of unsolved questions like: generation of the necessary amount of power, stable energy supply compliance of energy source with EU policy and high cost of electricity. The manufactories, which use electric tanks, can be located near areas with a large population of people.

Finally the dimensions of the electric furnaces are less than in fossil fuel tank, due to bigger concentration of energy per one cubic meter of the first type. (Mathieu Hubert, 2015, 7-9p.)

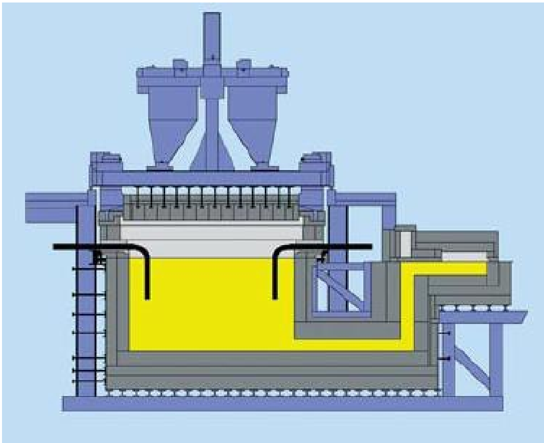


Figure 8. Electric melting furnace. (Mathieu Hubert, 2015)

As the products made from glass can have different properties, forms and appointments, the facilities for manufacturing these types can be various. Obviously, that various types and even sub classes of glass are needed special techniques and equipment. To provide unique conditions in operation mode there are many applications. Every facility has own structure and design, which allow raising the total efficiency of the process. The division of the unite types is indicator of developing sphere. And as others industrial sectors glassmaking manufacturing does not standing outside. To show the difference between installations the most common used are represented below (figure 9-11).

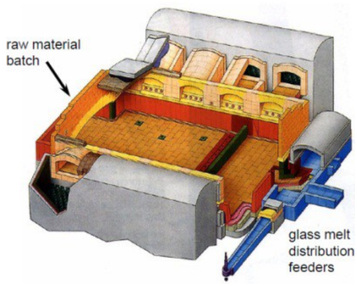


Figure 9. Typical air-fired container furnace.

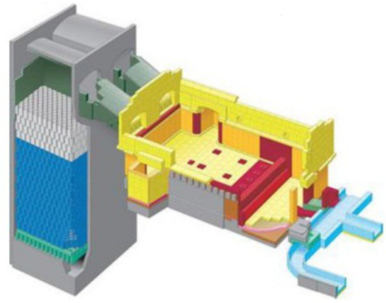


Figure10. End port regenerative furnace.

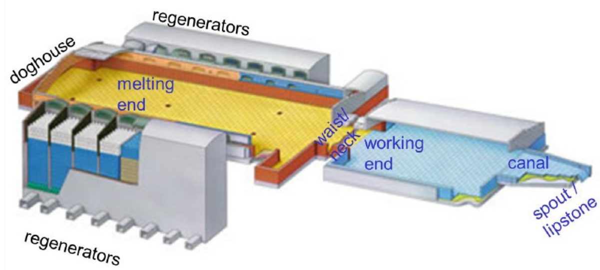


Figure 11. Flat glass furnace. (Mathieu Hubert, 2015)

3. Structure of glassmaking factory

All glassmaking manufacturing consists of some basic steps that could not be neglected. They are batch preparation, melting and refining, conditioning and forming, quality inspection and packaging. The typical scheme of production is represented at figure 12. As it could be seen the process of glassmaking starts from the selection of raw materials, which are the basis of specified type of glass. It is very important to mix the components in right ratio, because the properties and outlook of the glass directly depends on it.

Then all this mixture of components goes to melting tank. This part of production required major share of energy for glass manufacturing. Due to heating to high temperatures, about 1500 °C, the source of energy needs to be stable and give huge amount of caloric. In addition the amounts of heat lose through the furnace walls are the biggest. All this factors indicate that this zone requires great attention. When all crystalline materials are melted, the process may be considered as finished.

The next step is refining. Many reactions take place after the content of the tank goes through the throat of furnace. This is the connection of chemical and physical processes. During them the melted glass is freed of bubbles and homogenized. As in the previous step the amount of heat loses also great. Still they are less, due to quicker flowing of reactions. The temperature of molten glass in this stage can reach 1550 °C.

After the long heating, the melted glass needs to get right form for the further forming and packaging. In the conditioning step the content of tank gets crystallize and cooling to certain temperature, about 1300 °C.

The end of all heat transferring reactions takes place in the forming stage. Glass start to harden, but it is warm enough for changing the form. Different mechanisms help to give an appearance to glass. This is the last action in typical glassmaking manufacturing.

Then there is auxiliary heat treatment for hardening the glass. This stage is called annealing. Basically it is intended for increasing the strength and lifetime of product. This procedure lasts 30-60 minutes with temperature of 500 ºC. After annealing the inspections and quality control take places. At this stage glass is checking for any failure or deviation from normal properties. Sometimes there are test actions, if it is a special glass. Inspection is highly significant step, because the reputation of manufacturing production depends on the quality of their goods.

The glass, which has not passed the control, uses as raw material for batch preparation. It is crushed in the machine and gets suitable form for mixing. In common cullet usually takes about 20 percent of the materials in the origin batch. The last step is packing. As the glass is brittle material it needs to be well protected. It is necessary to prevent the production from direct strike and falling. Also the outlook of the product means a lot. That is why the package must perform not only protective properties but have good and pleasant outlook.

Finally one needs to be mentioned that every step depends on proper work of the system. It is necessary to watch and support all stages of manufacturing. The total outcome and quality are based on correct operation of the system. (Pieter van der Most, 2013, 5 p.)

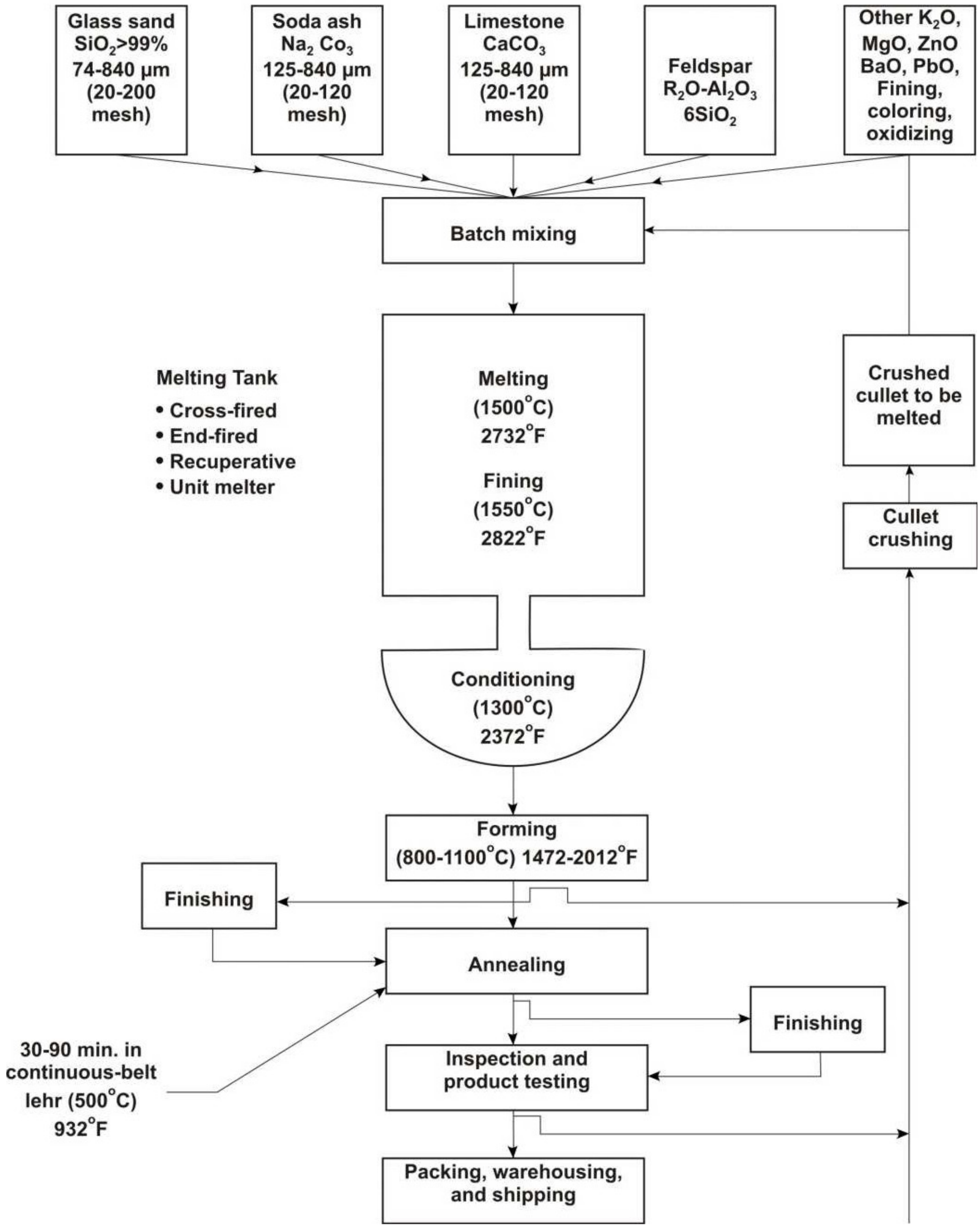


Figure 12. Scheme of glass manufacturing. (Industrial Sectors Market Characterization, January 2012, 81p.)

a. Batch preparation

On the batch preparation stage raw substances for glass are blended so that the final product is completed. The components in glass are not only limited to basic substances such as high-grade sand, soda ash and limestone. Some other materials may be added as well.

Despite the fact that glass products have many differences, all of their production processes start from making a batch from dry materials, which are mixed and weighted, for the melting stove. A multitude of chemical mixtures can be involved in glass production processes. Different formulas make their impact on optical, chemical, thermal, mechanical, electrical and other properties of the glass output.

The main glass components are named formers. Silica (silicon dioxide, or SiO_2), which has the form of high-grade sand, is the base former in all glass types. In order to decrease the batch melting temperature, fluxes are added. Widely used alkali fluxes are soda ash (sodium carbonate, or Na_2CO_3) and potash (potassium carbonate, or K_2O). Stabilizers increase the chemical stability of the output glass and prevent it from dissolving and falling to pieces. Magnesia, limestone, barium carbonate, alumina and are widely used stabilizers. Also borax and boric acid are used as a source of boron for the production of high temperature glass, pyrex, or fiberglass. Aluminum is commonly gets from feldspar. At present time there is a constant growth of using lithium compounds as fluxing matter.

Stock materials, which are stored in spacious silos, are measured and transported to batch mixers in accordance with pre-programmed formulas. There may be additives that allow changing the color of the glass, such as including iron, chromium, cerium, cobalt and nickel. To enhance the properties of optical glass, such as absorption of ultraviolet waves and decreasing x-ray browning impact. For the improving of heat characteristics of melting some anthracite coal or blast furnace slag can be added.

The raw material that was recycled from defected glass of the plant or from used containers, jars and other waste glass goods is called cullet. It can constitute 10-80 percent of the batch. This method helps to reach high efficiency of the process, due to lower cost of cullet compare to raw materials. However it is not always possible to use high ratio of recycled glass, because of final properties of product and stable heat mode of furnace. In addition using the outcome cullet like utilized container can lead to significant impact on glass structure and characteristic. Metal and ceramic contaminant may cause chemical instability. Also other impurities like organic compounds can raise the amount of flue gases, which will increase the emission damage.

Usually glassmaking manufacturing is located near the sources of raw materials, basically in places with large concentrations of sand, which is imperative for glass production. However it is very hard to find right location for plant to satisfy all needs. Therefore a lot of raw materials come from far distances to the storages of the manufactory. All kinds of transport can be used to deliver materials. It depends on such conditions as distance, volume and capability of transport. To unload the materials gravity and vacuum systems and drag shovels are used. Screws and belts are applied for transportation to and from storage. The batch preparation process starts from crushing raw materials and keeping them in the elevated bins till one of the ingredients is needed. Then through the weigher and gravity systems matters go to the mixer. The properties of glass are directly depending on the accuracy of performance of this stage. Efficient blending and well weighing are highly significant for the quality of final product. Sometimes for better mixing small amount of water is added to the dry batch enlarge uniformity and reduce dust, which is extremely bad for furnace and regenerators operation. Glasses with high composition of oxide lead use the agglomeration process for ensuring homogeneity. The atomization of batch preparation stage helps to make this action more accurate and correct. During mixing composes of glass, cullet is added. Total content comes to batch hopper where it stays before to go to furnace. This system, which prepares and mixes materials before glass production, is called batch plant (figure 13). When all raw materials are blended with right ratio, the mixture is conveying to the furnace. As batch enters the melter it is distributed over the glass surface like a blanket.

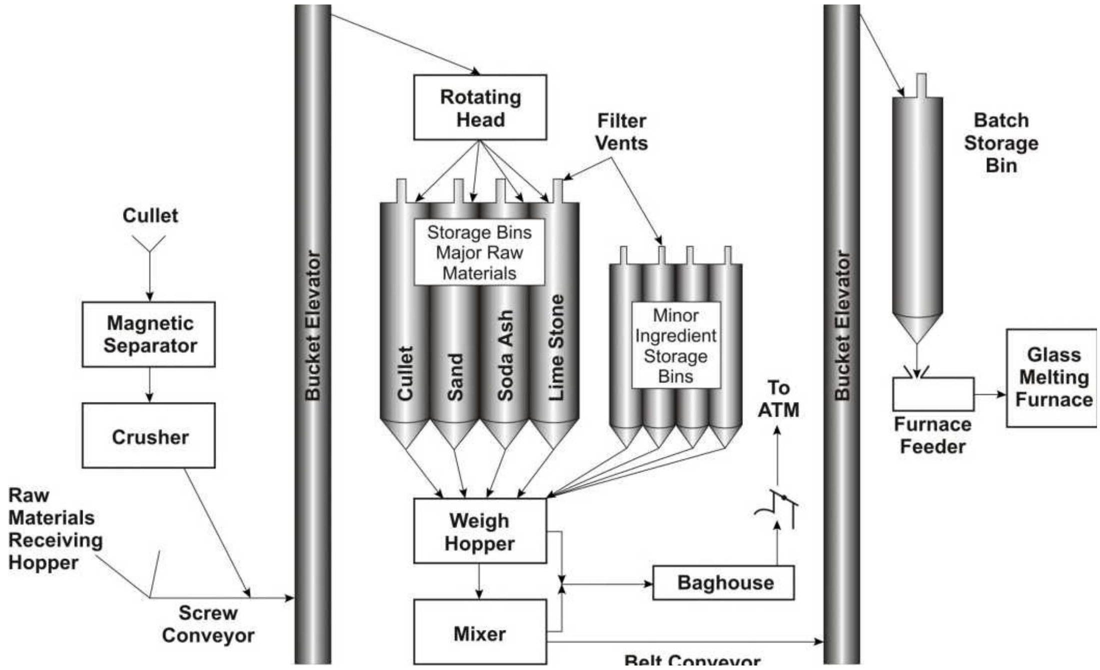


Figure 13. Batch plant. (Michael Greenman, 2002, 99 p.)

For keeping this system in work conditions electricity is needed. Batch mixers, elevators, conveyers and other devices are required power. Generally electricity demands share in batch preparation is about 4% of total consumption. However it is depends on type and form of the glass. Besides there are losses of energy connected with transportation of raw materials to the plant.

In addition batch preparation plant generates dust and particles because of blending process. Treatment systems help to capture such things and use them as a feedback for another production and keep the emission level within acceptable limits. (Michael Greenman, 2002, 35 p.)

b. Melting and refining

Glass is made from solid materials, which are blended and melted together. The process of glassmaking starts from heating the mixture to 1400-1700 °C. When the bath has reached those high temperatures, a number of chemical reactions such as melting, dissolution, volatilization and deoxidization happen in particular order. As the batch warming, the content transforms into homogenous liquid. The process includes many chemical reactions

- Dissolution of Sand with Soda Ash as Flux
  $Na2CO3 + SiO2 > Na2SiO3 + CO2$ (540 °C)
- Further Heating
  $Na2SiO3 + SiO2 > Na2Si2O5$ (700 °C)
- Formation of Liquid Eutectic Mixture
  $3Na2SiO3 \bullet SiO2 + SO2$ (760 °C)
- Carbonates in Limestone Decompose to Form Other Eutectic Glasses
  $CaCO3 + nSiO2 > CaO \bullet n\ SiO2 + CO2$ (760 °C)

When mixed the batch loaded to a melting furnace where it basically passes through the following four phases (figure 14)

- Melting
- Refining
- Homogenizing
- Heat conditioning

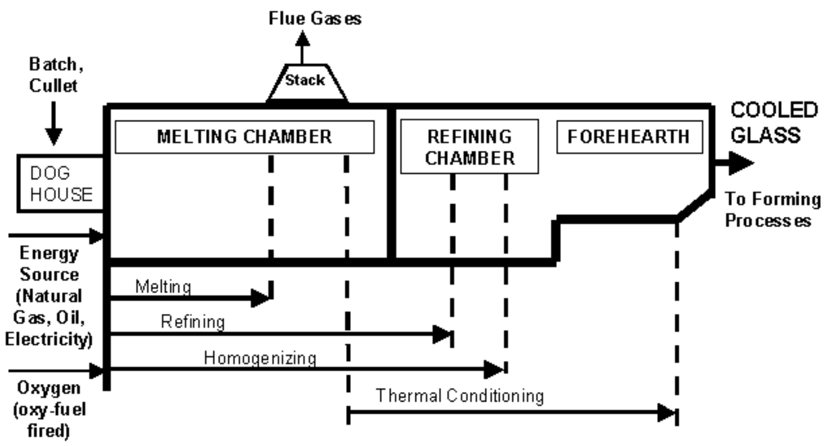


Figure 14. Phases of melting and refining process. (Michael Greenman, 2002, 99 p.)

Melting of the batch can be performed in various kinds and dimensions of furnaces, depending on the desired properties and the type of output glass. At high temperatures crystalline substances are melting forming glasses. When the smelted glass cools down, the atoms fuse into a chaotic state instead of an ideal crystal structure. In industrial processes of glass melting dry components are transformed into a homogenous smelted liquid at the beginning. Initially, the properly mixed batch is loaded to the melting oven and then heated to a temperature from the 1400-1700 °C range. Melting starts when the batch reaches the oven and finishes when the glass has no crystalline substances.

Refining (also known as fining) is a process of physical and chemical nature, which happens in the melting chamber. The process homogenizes the batch and smelted glass and also eliminates bubbles from them. The refining part of the furnace is usually divided from the primary melting section by a bridge wall. The wall aperture that the glass passes through is named the throat. When the glass temperature falls down, the melt reabsorbs some gases. Refining allow to remove gaseous seeds and bubbles. Depending on the glass kind, they may contain oxygen, sulfur dioxide, water, nitrogen, or carbon dioxide in different ratios. Raw substances are heated to a significant melting temperature afterwards in order to form a homogeneous ductile liquid. The duration of the process depends on type and class of the product. Different kinds of glass required various technics in this stage.

Homogenizing takes place in the melting chamber. It is completed when the glass quality satisfies the desired requirements. Homogeneity is ideal when the glass melt has no alterations in the desired qualities. Alterations such as refractive index fickleness and variations of expansion coefficient density impact mechanical and optical qualities of the glass. Glass cannot be homogeneous if it has too many grains and seeds. Homogeneity depends on such factors as temperature, batch content, mixing properties and time. Usually, the extent of homogeneity achieved depends on the desired glass properties and economical costs.

Thermal conditioning makes glass stable and aligns its temperature. The starting point of thermal conditioning depends on the kind of furnace being used and operation mode. Substantially, thermal conditioning is supposed to start instantly after the top mean temperature of the glass melt is achieved in the tank. To achieve stable thermal conditions such ways as stabilization of gases, bubblers and blending in the feeder are used. Then cooling is performed to establish the operating temperature for forming. After this stage hot glass content goes through forehearth. It is an insulated refractory channel with burners and air cooling system. It is obligatory to keep stable temperature of glass for forming process. The system is usually high atomized and the length of the channel based on heat loses and specific of the product.

This part of glassmaking manufacturing consumes about 70% of total energy for production. Main outlays are lie on fuel supply. It takes a lot of energy to melt raw materials and to give necessary heat for diversity chemical reactions. The required amount of fuel or power is calculated from the capacity characteristics of raw materials. However there another factors, like dimensions and form of furnace, which may cause some changes in accounting. From the energy point of view there is high potential in cutting down the demands connected with flue gases, losses through the furnace walls and imperfection of combustion process. In electric furnaces there are no such heat losses as in traditional that used fossil fuel without counting the demands required for electricity production. As it is less expensive to operate furnace, which use fossil fuels, there are different options of chosen the type. The choice definite from kind of glass, characteristics of furnace, required heat power and fuel cost.

This step of manufacture generates the biggest part of all process emissions. It takes about 90%. This happens because in melting and refining processes there is huge number of chemical reactions. Many of these products of reactions are dangerous for human health and environment. The emission rate depends on the amount of produced glass, type of furnace and kind of used fuel. Commonly exhaust gases consist of sulfur dioxide and particles, nitrogen oxides and carbon oxide and dioxide. The last two are having significant impact on environment security and human health. There are few decisions that may reduce the emissions level of NOx. Due to the indispensability of the furnace reactions and high temperature factor this problem is intractable. However modern unites have low nitrogen oxide rate, because of new combustion and construction technologies. At present time much attention is given to the carbon dioxide issue. The global rising of temperature level is becoming more conspicuous from year to year. It is very important to have new clean technologies that can afford reduction of COx emissions. As to carbon oxide problem, it may be solved by choosing optimal combustion conditions. It is highly depends on completion of oxidation reactions.

Certainly this is not full list of all emissions of melting process, but these are the most harmful and high value. Naturally there are such components as arsenic, lead, chromium, cadmium, selenium, phenol, methanol, formaldehyde, fluorides, boron oxides and sodium fluorosilicate. The elements can vary because of different technologies of glassmaking and different properties of the product. However the majority of these emissions can be used as raw materials in different productions. Therefore there are special applications for catching these elements. Commonly baghouses and filters are used. Particles may recycle back to the glass melting process. Another component that generated from this stage is called furnace slag. This is partially glass material. Generally it is settled in the checkers of regenerators. (Michael Greenman, 2002, 41 p.)

c. Forming

Forming phase gives the smelted glass its final shape. When the molten glass is supplied from melting reservoir to the forming apparatus, it looks like a bright red paste. Since the smelted glass becomes solid as its temperature drops, forming has to shape the glass fast. There are many different forming methods. It is possible to form, draw, found, roll or blow smelted glass and even to make fibers out of it. No matter what the process is, forming starts when smelted glass comes out from the front forehearth, where its temperature has been reduced to allow working the glass. Next stages of forming are defined by the shape of the final product.

There is huge number of formation techniques. Basically, the type of process depends on the kind of manufactured glass. Flat glass can be made with method called float glass process. This technique was developed by Pilkington Brothers in 1950s. At present time nearly all flat glass uses this process in production chain. It has supplanted such more energy wasteful technologies as plate and sheet glass forming. Due to the improving of the float glassmaking process the final product can keep high quality characteristics. The technique requires a large area pool of molten tin. When the melted glass flows from forehearth, it rests on tweel where this stream is distributed over the tin surface. Finally it becomes thin, smooth and perfect flatness of glass. Later a PPG process has been invented. The area of the tin pool was reduced by creating special velocity field for better glass forming (figure 15).

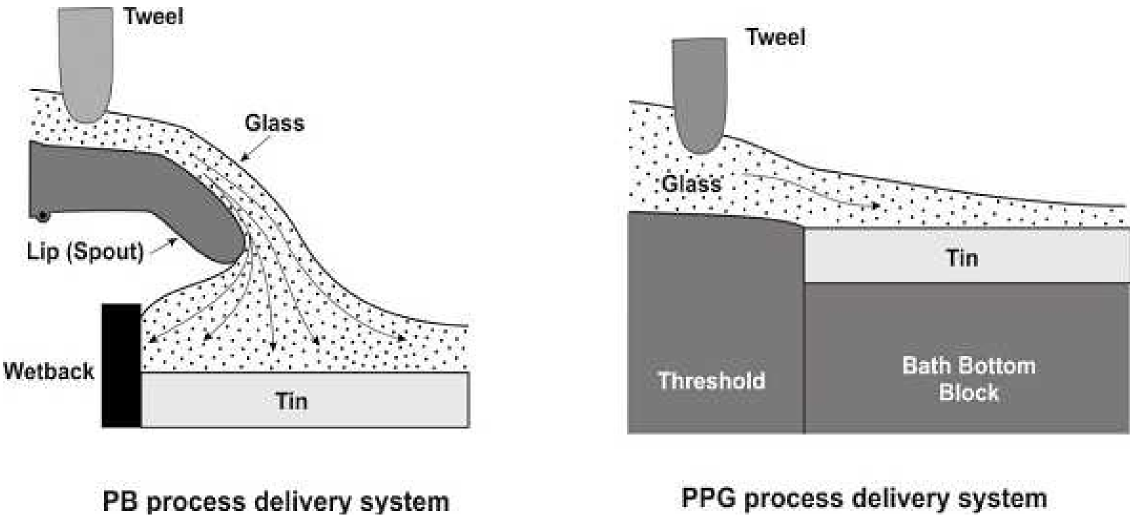


Figure 15. Float glass processes. (Michael Greenman, 2002, 99 p.)

Container glass is formed using molds.

- Gob feeding
  A portion of melted glass with temperature 1800-2250 °C goes through orifice. Under the action of gravity force it stretches down. Then mechanical shears cut the glass to shape the gob form. As mentioned earlier the temperature of glass in forming process needs to be keeping in certain values, because such properties as viscosity and ductility depend from that parameter. At present days more and more factories uses automatic machines and technologies in the forming production to provide sustainable characteristics of outcome glass. As the technical progress is developing, the automation rate and the value of manufactured products are increasing.
- Blow and blow (figure 16)
  This technique includes two steps. First blow takes place when the gob is moved to a blank mold. After a work piece is done the second blow is occurs to give shape for the final product. All these processes require compressed

air for inflation. Advantages of such method are container dimension control and smooth outer surface.

- Press and blow (figure 17)
  Unlike the previous technique to create an origin in the blank mold the plunger is used. Then the work piece is turned to blow mold. There with the force of air pressure or vacuum the parison takes the final shape. This process can provide more comfortable conditions in dimension control of the product.

Figure 15. Blow and blow method. (Michael Greenman, 2002, 99 p.)

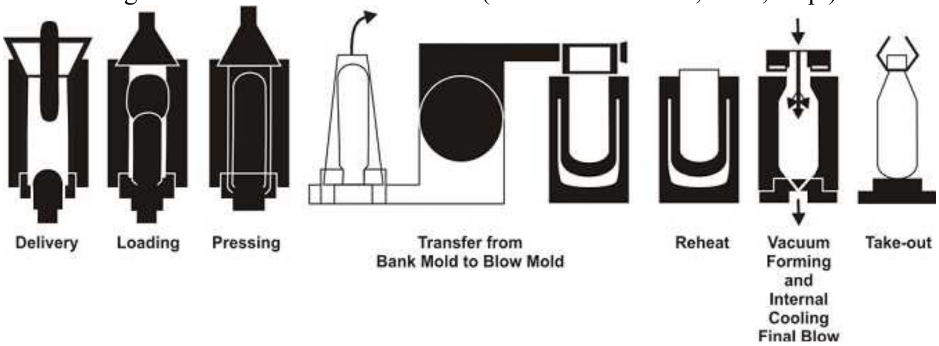


Figure 16. Press and blow method. (Michael Greenman, 2002, 99 p.)

Anyway for every type of glass product there are various technologies for forming operations. Many table, kitchen and art ware manufactories utilize press forming machines. Like in previous processes plunger, molds and the shape ring is used. Products which have simple form are made by press forming. It is a one step process. Plunger can be utilized with several molds. Certainly it is very important to keep defined temperature of gob, because deviations may cause sticking of the product to the mold or bad forming due to low viscosity properties. For that reasons the content from the furnace usually heated to high temperatures, and all forming machines have unites with compressed air for cooling the work pieces. Another kind is spinning facilities. If there is a need of uniform and circle shape, this method may be useful. Under the rotation force of the spinning mold it is simple to get a necessary from as a plate for instance.

For the bulb production a special method called ribbon process was invented by William Woods in 1922 (figure 17). When the glass flows from the tank, it goes through two rollers for the alignment of the stream with heavier sections. Then it moved to the plate with the holes in the same places as the heavier parts of the glass sheet. Under the gravity force this amount of glass make a small bulb. The next step is blowing the air into the bulbs for further expanding. As the product get a definite form, it cracked away from the ribbon.

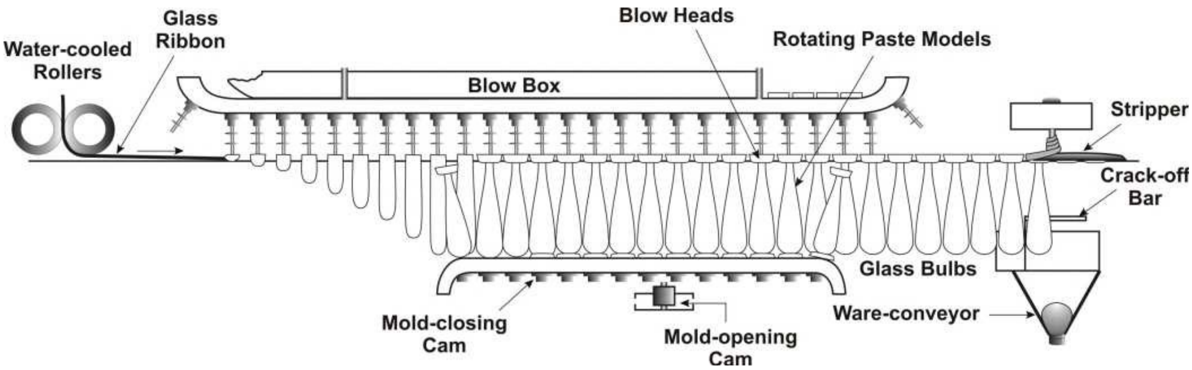


Figure 17. The glass ribbon process. (Michael Greenman, 2002, 99 p.)

For crating tubes and rods Danner and Vello processes may be utilized. During the first technique a certain portion of glass is discharged to the spinning core surface. While this mandrel is rotating and the glass is stretches from the core, air is blowing in the center of mandrel till the form of the tube become right. In this process it is very important to keep the equal shape over the length of the tube. Drawing of the glass in the Vello process is the same as in Danner one. The difference is in that the molten glass goes down between core and refractory ring. Usually application is located at the bottom of the furnace (figure 18).

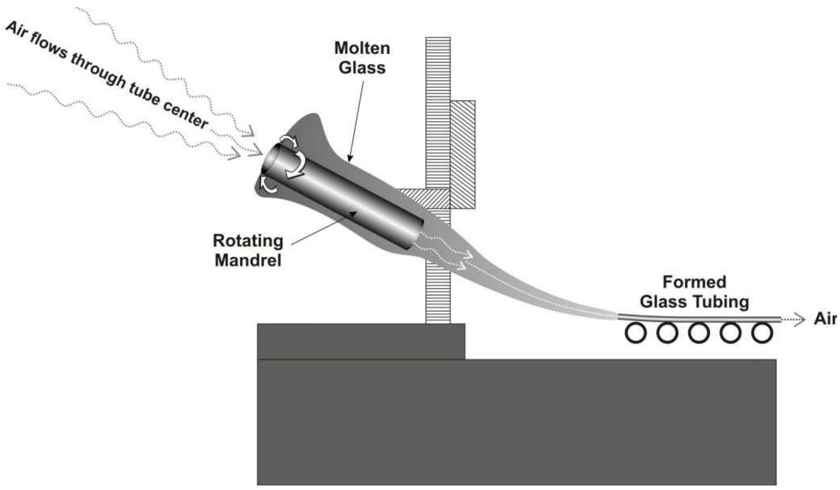


Figure 18. Drawing of tubing process. (Michael Greenman, 2002, 99 p.)

The hand-made glass still based on traditional glass blowing through a hollow blowing pipe. As it is very small part of glass industry, the process of production is depending on masters' taste. However at present time there is technique called gathering. Tumblers or vases may be made by this process.

Last but not least type of glass production is connected with wool fibers, optical fibers, and textile fibers. There are two ways of forming this kind of glass. First one is a rotary spin process which is more popular in industry sphere (figure 19). The installation consists of spinner, bucket, binder spray and conveyor. Molten glass goes from forehearth to the spinner that is located in the bucket. Under the action of centrifugal force and thousands of small holes the stream starts to break up and exude from these orifices. Hot air using in the bucket blows the fiber down to the conveyor for the further formation. Second one is called flame attenuation process (figure 20). In this case glass is flowing from the tank through numerous of small gaps. Then this fiber stretches near to the breaking point with the help of hot air and flame. Last technique can achieve more agglomeration rate and thinner structure than in rotary spin process.

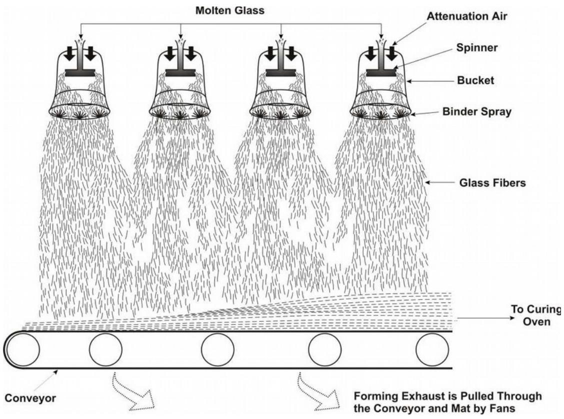


Figure 19. Rotary spin process.

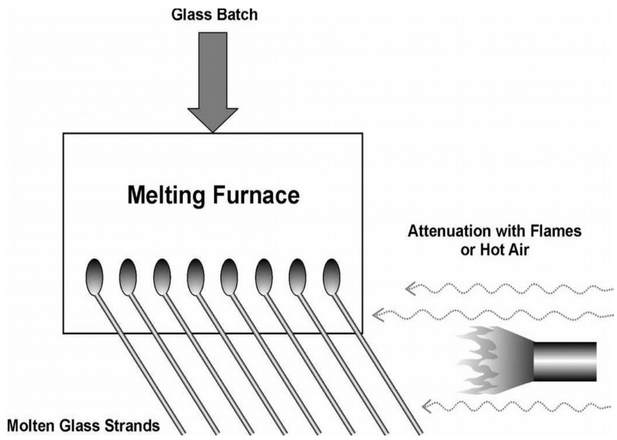


Figure 20. Attenuation process.

(Michael Greenman, 2002, 99 p.)

Forming step takes 12-34% of total energy production. Basically electricity is used for compressing the air. The efficiency of this stage is 90%. It means that forming is high effective part. Some types of glass production can expel wastes. They are particles from fiber glass manufacturing, silicone emulsions and water soluble oils, which eliminate emissions of volatile organics from container one. (Michael Greenman, 2002, 65 p.)

d. Post-forming and finishing operations

Post-forming manipulations are necessary for some products. It may contain procedures that change some features of the glass. There are various post-forming operations

- Annealing
  This is a process of slowly glass cooling to the ambient temperature. Due to the danger of product destruction, it is wrong to put hot glass into low

temperature place. For small and thin objects this effect may not be mentioned, but for big and thick one it is rather essential to have uniform and slowly cooling. Strains that can occur in glass are connected with critical temperature range of the product. Annealing is used for flat, container and most pressed and blown glass. After forming operations the product is usually annealed to provide suitable strain rate and easy cutting. Primarily a sheet of flat glass is heated to 540 °C and maintained at this temperature till reduction the amount of strain. Then the sheet is slowly cooling to the ambient temperature. And finally it is necessary to keep the equal temperature in every part of the product across the lehr (figure 21). Lehrs can be both fired by natural gas or powered by electricity. Generally fossil fuel applications more used due to investment requirements. At present time there are modern decisions that utilized waste heat from the others part of glass making production.

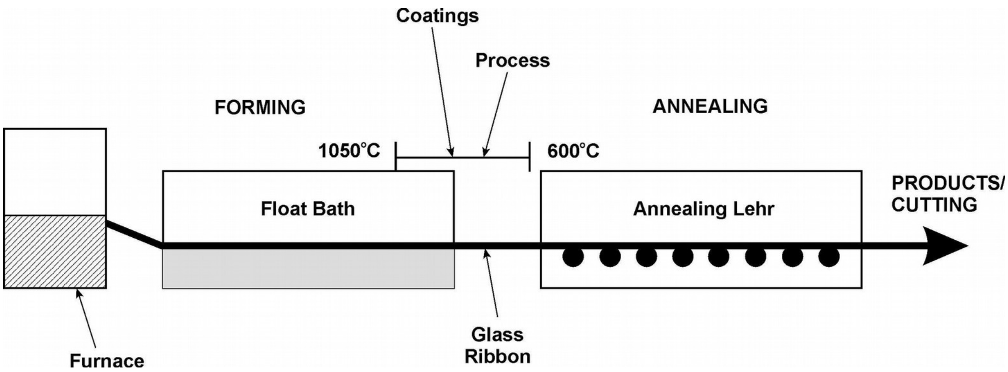


Figure 21. Flat glass annealing. (Michael Greenman, 2002, 99 p.)

The annealing process is used for all container glasses. It is similar to flat type technique. Because of different shapes and thickness of the products there are problems with non-uniform temperatures. At first glass is kept at constant temperature with special annealing window. Then the product slowly cooled to ambient conditions. The last step is checking of the stress and viscous rate. Divers kinds of container glass have various technologies and parameters of annealing process. As to the previous types annealing is done for the optical and special glass.

- Tempering
  To raise the resistance to bending failure tempering process is used. This may be achieved by heating the annealed glass to the temperature of the softening and then cooling the product with the ambient air. This process allows to have uniform temperature gradient over the surface and stress distribution of the glass. This technique can be considered by the example of flat process. After annealing, certain kinds of glasses passes the tempering stage. Basically the heat conduction between glass and application parts is occurring. Tempering process can have different conveyance systems: in-line system, gas/air float, tong-held and roller hearth. Also systems may be divided on batch, batch-loaded and continuous one.
- Laminating
  The technique includes placing plastic microfilm between two or more glass sheets. This procedure protects the product from the total destruction. When glass is broken, small pieces are held in place by the microfilm. In some flat glass manufactories the laminating process goes after annealing. Especially automotive and architectural applications utilized this scheme of production. The operation consists of three steps. At first a plasticized poly vinyl butyral resin is used as glue material. Then trapped air is excluded. Final step is an autoclave operating under the pressure 130 Psi and temperature 150 °C.
- Coating
  This process is connecting with giving special characteristics to the glass. Scratch resistant, heat and light reflection may be included in list of product properties. Most of container glass is coated. This process allows greasing the surface and reducing damage from abrasion. The resistance from scratching damages may be provided by coating a very thin layer of tin or titanium oxide. Then the obtained surface is lubricated by polyethylene. Aqueous spray is utilized for coating the surface of hot container product by the lubricant. There are two types of nozzles. First one is dome-style, which is most commonly used because of their simplicity and reliability of maintenance. Second is a cross-cut nozzle. This kind is more expensive.

However it is still uses in some applications due to the longer life, lower flow rates, high atomization on low pressure and better plug resistance.

- Mechanical impact
  To create the final shape of the product sometimes cutting and drilling operations are needed. A tube of mild steel or other soft metal is used to make gaps in glass. It is spinning while the abrasive material is served under the tube. For cutting there are two options. They are mechanical and thermal ones. In the first case the product is sliced by the glass-cutting steel wheel. Other process utilizes a sharp of flame and a jet of water. The product is heated firstly, and then it cools down quickly by the water. These actions cause the destruction of glass at the desired point.
- Polishing and decorating
  As the previous process this method is used for giving the final outlook of the product. However it could be done not only for enhancing appearance, but for the improvement of the optical properties too.

Post forming stage takes 15% of consumed energy. Very important step before packaging is inspection. Every product is viewed for different dimensions, cracks, cords and other drawbacks. For special types of glass unique inspections may take place. Containers can be tested by pushing them through opposing rubber belts or rollers. After this procedure the product is conveyed to the packaging zone. Generally all types of the glass except fibers are packed into reliable and soft boxes for further transportation. The product, which has not passed the inspection step, comes back as a cullet to the batch preparation stage. (Michael Greenman, 2002, 85 p.)

4. Other aspects of glass manufacturing

a. Industry Performance and Market Trends

At present time glassmaking industry is not only expands the amount of manufactories but introduces new technologies and equipment, cuts the emission level and increase the number of products. However industry sector needs to be characterized by the market factors. It is not enough to operate only with technical aspects. To draw a picture of market trends and performance some information about productivity and must be represented. So to show the competitiveness of this industry sector the data about import and

There are five huge scale producers of glass in EU. They are France, Germany, Italy, Spain, and the UK (figure 22). The information about shares of glass types is in the chapter 2.

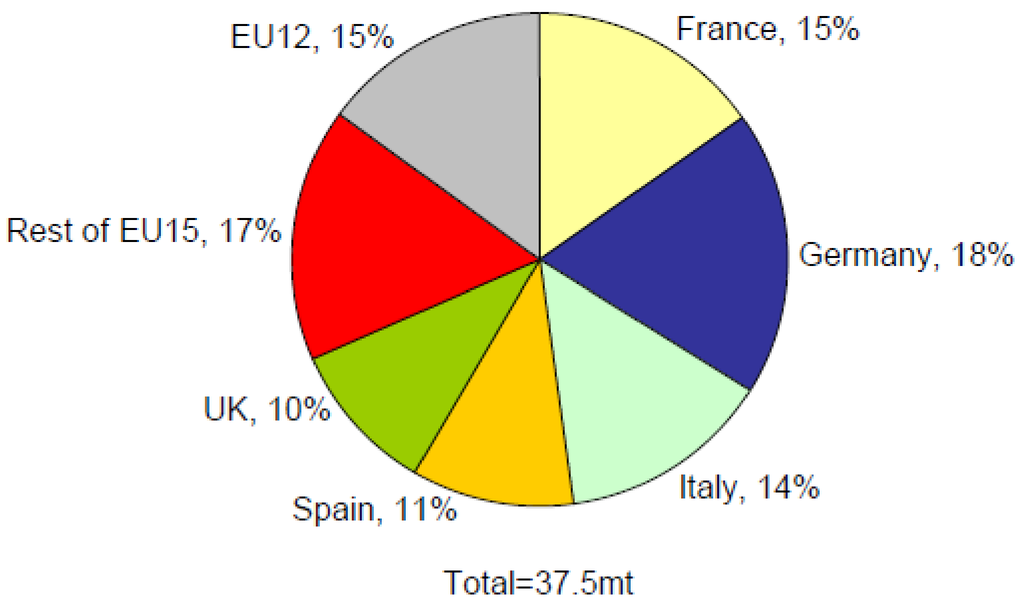


Figure 22. Producers of glass in EU. (FWC Sector Competitiveness Studies - Competitiveness of the Glass Sector, 14 October 2008, 158 p.)

Now one unite of glassmaking industry can achieve about 1000 ton of finished product per day. The leader of the outcome may be considered the flat glass type, due to the novelty of float process and high efficiency of equipment. The rest sectors, as container and fibre, have not so huge productivity due to the complexity of the process and less consumption. Generally there is a significant grow in these kinds of glass manufacturing. Container, flat and fibre productions have increased their outcome by 22%, 35% and 49% respectively for the last 15 years.

Other factor is connected with working places. The amount of employees rises from 150 thousands to 234 by the 10 years. However it has happened because of the expansion of capacity and entering of new member states. Unfortunately all modern application use automatic equipment and lines and industry alliance and eventually new low-cost rivalry. The structure of employment by the states is represented on figure 23.

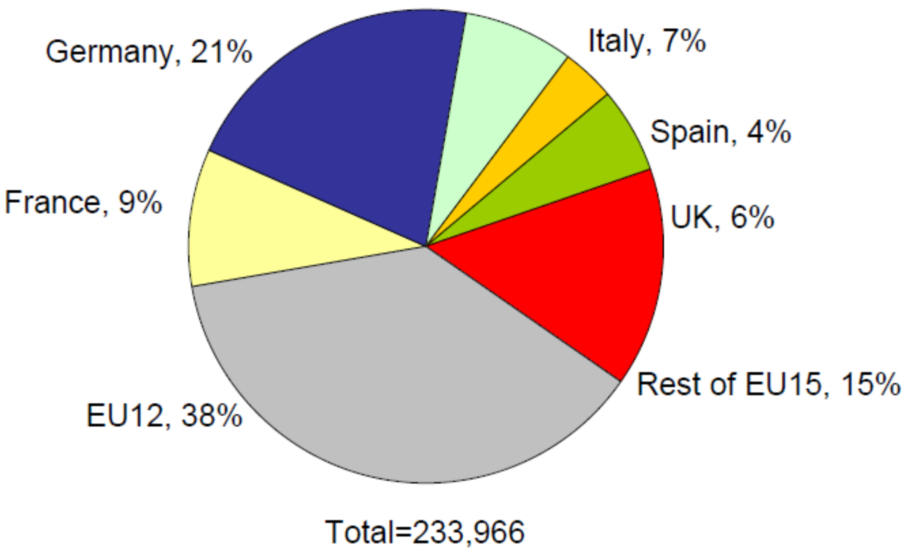


Figure 23. The structure of employment. (FWC Sector Competitiveness Studies - Competitiveness of the Glass Sector, 14 October 2008, 158 p.)

As it could be mentioned Germany can be considered as the greatest producer of glass goods and employer. It is a primary midpoint of glassmaking manufacturing. However France, Italy, Poland and Czech Republic could be considered as key industries clusters in glassmaking production. The biggest manufactories are located near huge springs of raw materials as sand, forest and water.

To describe the amount and speed of production and the level of atomization some information about outcome of EU countries need to be represented (figure 24). (FWC Sector Competitiveness Studies - Competitiveness of the Glass Sector, 14 October 2008, 21 p.)

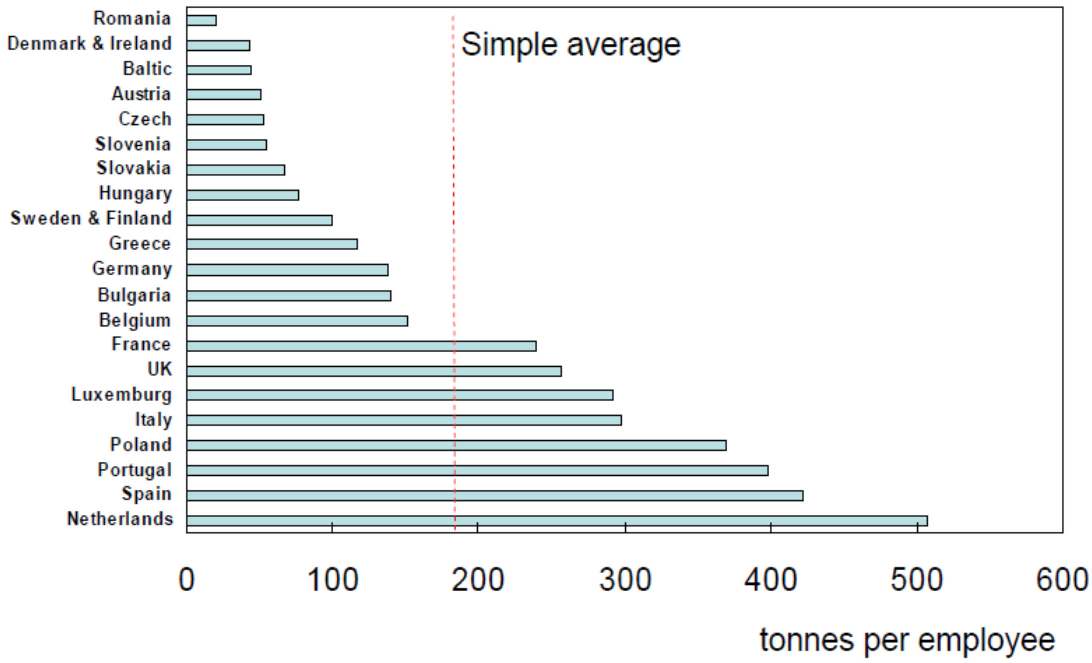


Figure 24. EU glass productivity. (FWC Sector Competitiveness Studies - Competitiveness of the Glass Sector, 14 October 2008, 158 p.)

Other factor like profitability may be reviewed as a characteristic of manufacturing. Significant rises in costs of raw material, fuel and energy prices cause huge impact on shifting the margin. All these aspects influenced on maintenance of factories. Due to big outlay enterprises have to take certain measures. The most important drawback of such consequences is reduction of the working stuff. In addition the falling of net profit margins about 10% in last years has led to the unattractiveness of investments in glassmaking production. As for taxes, there is an obscurely situation. From one hand the increasing of environmental laws, the tax connecting with costs for emission may cause huge trouble in competitive question. From the other hand there is no any change in profit paid in tax in last period. Summarizing all information one needs to be mentioned that final cost of the EU product may be 15% higher than of non EU one. It can occur due to huge labor costs, fuel prices and small sources of raw materials.

Because of high cost of the glass it is utilized in domestic regions or in member states of EU. Also high quality of European glass fibre keeps that product as competitive and even very popular all over the world. If the import and export can be compared, the result would be increasing by 64% and 6% respectively. However the latest statistic shows that the cost of import products per ton has rose more than cost of export products per ton. These aspects indicate the increasing of the quality. Nevertheless the costs of the glass manufacturing in EU regions are also growing. So the result of such conditions may cause the enlargement of price flexibility and market share of non EU companies.

Last serious question is energy and fuel prices. Because of various tax policy, opportunities and location it costs different to keep manufacturing in EU regions. For instance the tax rates in Slovakia and Italy are 25% and 0% in Germany and Czech Republic. It is quite clear that this may be deciding factor in choosing the place of factory set up. From the other hand one should not be forgetting, the labor costs are varying over the EU. Of course the most competitive question concerns the prices of energy and fuel. Probably it is the decisive aspect of glassmaking manufacturing. As the result it is easy to review information about prices of energy sources in countries, which may be considered as main producers of glass goods (figure 25, 26). It is simple to identify that EU fuel prices are in the middle between USA and Japan and does not have big deviations in values. However if the industrial energy price is discussed there would be opposite effect. EU energy prices rises rapidly. It means that unlike the rest of the world Europe needs to cut their energy losses and utilized new technologies in the glassmaking process. (Industrial Sectors Market Characterization, January 2012, 42-50p.)

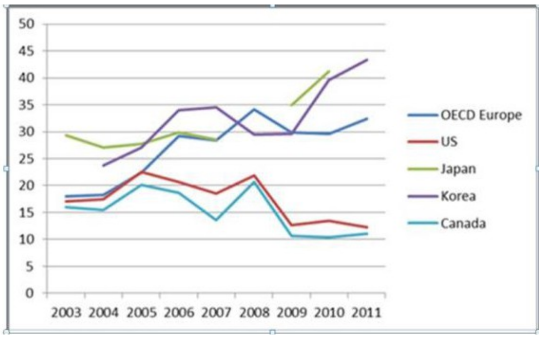


Figure 25. Annual industrial energy prices

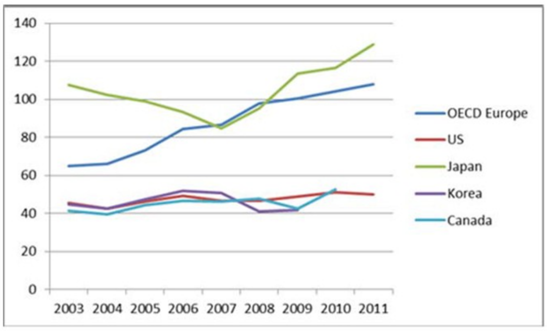


Figure 26. Annual industrial gas price.

(Glass Alliance Europe input to the Public Consultation on the Green Paper “A 2030 framework for climate and energy policies”, June 2013, 14p.)

b. Environmental overview

Generally glassmaking industry face with three extensive problems connected with environmental protection.

- Emissions to the air

  Certainly glass is not the only product that is generated. The result of the combustion process, which occurs in the furnace, is harmful exhaust gases: carbon dioxide, sulfur dioxide and nitrogen oxides. Another significant problem is high temperature oxidation of nitrogen from air for combustion process. And finally dust and small particles complete the list of the most harmful emissions of glassmaking manufacturing. Basically the melting step takes about 90% of total environmental emissions and wastes.

- Nitrogen oxides (NOx)

  The volume of generated gas can be regulated. Basic sources for NOx production are the oxidation of nitrogen in combustion air or in the bath and further reactions that produce NO2 gases. The concentration of nitrogen oxides highly depends on the temperature of combustion process and air and on the ratio of oxygen and nitrogen in the gas. The reaction needs high amounts of energy and flows when the air required for burners contacts with them. Under high temperature the NOx is generated. And the main drawback is that this gas is hardly decomposes into elements when it cools down. Because of that the concentration of nitrogen oxides in flue gases is high. There are various techniques of reduction nitrogen oxide level. It could be changing of fuel to air ratio, fuel type, staged combustion and special burners. However each method has drawbacks. For instance cutting the amount of combustion air can lead to the rising of carbon oxide level due to low accomplishment of oxidation reactions.

- Sulfur oxides (SOx)

  This gas as the nitrogen oxides generated from the oxidation of sulfur elements in fuel and in the batch. Except from nitrogen, sulfur and oxygen need less energy to interface with each other. Basically the fuel type is making significant contribution in sulfur oxide level. As it is hard to change the structure of glass, the option of fuel is the easiest way of cutting the SOx emissions. Another technique requires special facilities called scrubbers. It can be dry or semi wet kinds, which may provide high level of flue gas treatment from sulfur oxides.

- Carbon oxides and monoxides (COx)

In combustion of fuel with carbon in its content the oxide and monoxide of carbon is obligatory component of exhaust gases. The concentration of CO can show the completeness of the oxidation reaction. Generally carbon monoxides emissions also bases on this factor. They can cause soot layer on the inner surface of the unit. For one kilogram of produced glass approximately 0.6 kilogram of CO2 is generated. The concentration of carbon oxides depends on various aspects. One of the most important is the choice of fuel and combustion mode. Other significant factor is effectiveness of the glass manufacturing process. The utilization of waste heat, cullet and techniques for improving furnace efficiency may low the carbon oxide level in flue gases. As at present time there is a goal of reducing GHG emissions, this problem must be solved at primary order. It is highly necessary for all humanity to cut down the emission level on the earth.

- Particles

As the batch consists of various small solid elements, which can leave the melting zone, there is a big chance that flue gases will have high concentration of particles. The main drawback is the pollution of the environment, chimney and reflective surfaces. To reduce the value of this kind of emissions different treatment applications are used. Electro static precipitators and bag filters are used to prevent the release of more than 95% small particles and dust emissions. Particles released from the tank are sodium sulfur in the majority. Other source of pollution is lying on batch preparation stage. As this process includes operation connected with mixing, conveying and storage of raw materials. Some particle loses may occur. Measures for preventing dust emissions containing splitting of the storage and operational areas, correct loading and transportation of raw materials and utilization of enclose facilities for storing and convoying parts of preparation plant.

- Chlorides and Fluorides

These pollutants come from the first stages of glass manufacturing process. The main type of HF emissions is fibre glass production. To reduce them dry and semi-dry scrubbers are used. Basically HCL and HF emissions are related with each other and are the result of addition sodium or calcium chloride to the batch. The pollutant level may be controlled as with the techniques described for SO2 emissions.

- Metals

For the lead crystal and frits production metal emissions may be serious issue. However this problems stay at less degree of importance as others. The minor part of all pollutant is metal emissions. It can be heavy metals, lead or cadmium. Some special glass production contains antimony, selenium and arsenic in flue gases. Techniques for capturing these emissions are the same as for dust and particles ones

- Wastewater

Generally water is used for cullet cleaning and cooling operations. Liquid effluents may contain small particles and harmful elements. However the water pollutant negligible compare to other sectors of industry. The water treatment unit must have oil separators, flow and load equalization with pH adjustment, filtration for certain solids and technical pretreatment facilities and controls of the elements concentration (figure 27).

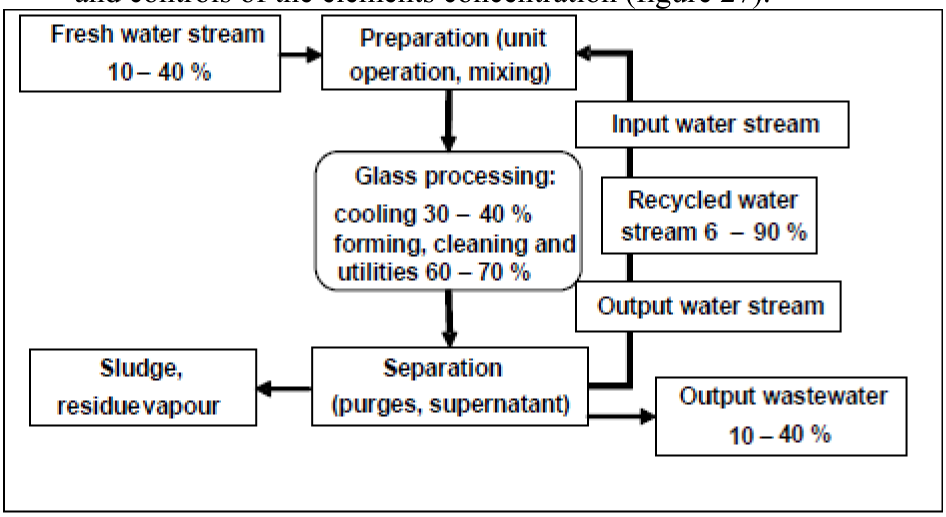


Figure 27. The scheme of water distribution at glassmaking plant. (SCALET Bianca Maria, 2013, 485 p.)

- Solid wastes
  Main sources of solid wastes are the defective product and failed parts of furnace or equipment. Loses may occur in shipping areas. Therefore it is very important to have coordinated maintenance for identifying, cleaning and recycling of the potential cullet material. The scraps from refractory and chimney elements making significant contribution of particles rate in flue gases. Also repair and decommissioning processes accompanied with major solid wastes. The measures for reducing the level of solid emissions are various: enlargement of the cullet use, replacing refractory surface more often than capital repairing and reutilizing collected dust in the batch. (Environmental, Health, and Safety Guidelines, 2007, 2-10 p.)

The emission level of glass production stays at critical zone. To prevent the consequences of the pollution modern plants should have new unites and applications. In addition recent technologies of glass manufacturing helps in achieving this goal. The biggest attention must be given for energy saving measures. As these actions cause the influence for every parameter of glass manufacturing: fuel and raw material consumption, heat and wastes lose, performance and quality of the product. At present days the amount of environmental pollution is staying on a very high level. The examples of air emissions level and elements concentration are represented at table 1 and 2.

Table 2. Air emission level for glass manufacturing. (Environmental, Health, and Safety Guidelines, 2007, 16p.)

Table 1. Air emission levels for glass mnfg.		
Pollutants	Units	Guideline Value
Particulates Natural gas Other fuels	mg/Nm3	100[a] 50[a]
SO_2	mg/Nm3	700–1.500[b]
NO_X	mg/Nm3	1.000
HCl	mg/Nm3	30
Fluorides	mg/Nm3	5
Lead	mg/Nm3	5

Cadmium	mg/Nm3	0.2
Arsenic	mg/Nm3	1
Other heavy metals (total)	mg/Nm3	5[c]
[a] Where toxic metals are present, not to exceed 20 mg/Nm3. To achieve dust emissions of 50 mg/Nm3 installation of secondary treatments (bag filters or electrostatic precipitators) is necessary. Good operating conditions of the furnace and adoption of primary measures can achieve emission levels of 100 mg/Nm3. [b] 700 mg/Nm3 for natural gas firing. 1500 mg/Nm3 for oil firing. [c] 1 mg/Nm3 for selenium.		

Table 3. Effluent level for glass manufacturing. . (Environmental, Health, and Safety Guidelines, 2007, 16p.)

Table 2. Effluent levels for glass mnfg.		
Pollutants	Units	Guideline Value
pH	S.U.	6-9
Total suspended solids	mg/L	30
COD	mg/L	130
Oil and grease	mg/L	10
Lead	mg/L	0.1
Antimony	mg/L	0.3
Arsenic	mg/L	0.1
Fluorides	mg/L	5
Boric acid	mg/L	2
Temperature increase	°C	<3[a]
[a] At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity		

c. Energy overview

The energy consumption divides on two sources. Fuel and electricity are the origins for current glass manufacturing. More than 7.8 GJ of energy is required to keep actual performance of the EU glass sector. Costs of fuel and electricity compose 15% of total investments (figure 28). As the prices for energy are rising rapidly every year, it is essential to make the process of glass making more effective to reduce demands of power. The further research and development, forecast for energy prices are the necessary conditions for right and effective glass making maintenance.

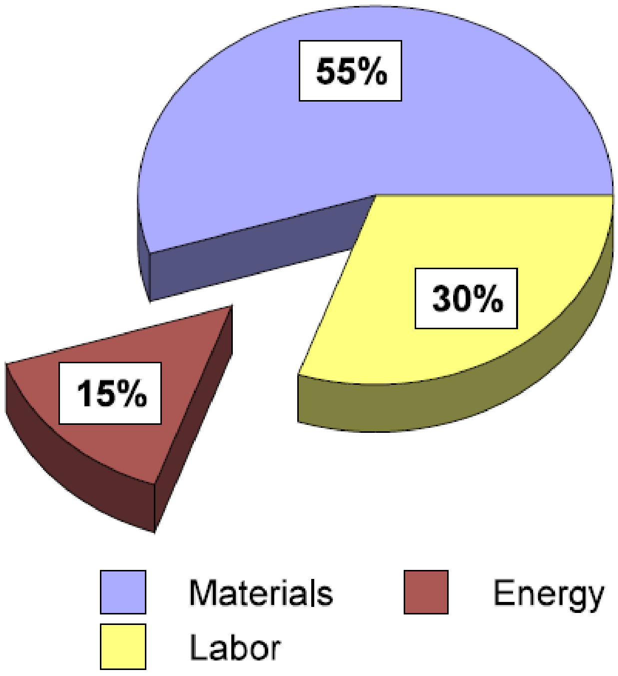


Figure 28. Glass manufacturing costs. (Michael Greenman, 2002, 99 p.)

Market and human needs dictates the trend on annual energy consumption. The requirements for flat and fibre products remain stable for the last years. There are minor changes in container and special glass manufacturing. Due to the competitiveness of alternative materials for package applications the demand for container type has been dropped. As for special glass manufacturing the amounts of performance and requiring energy are rising due to the introduction of new products in electronics, optic and other markets.

The main consumer of the fuel is melting stage. The heat, which is necessary for homogeneous reactions, can be received from the combustion of fuel or electricity.

Generally the first option takes place due to the storage, efficiency and practicality of the method. Major problem of such technique is overusing of energy source because of heat demands. There are four types of heat loses. They are demands connected with heat of flue gases, losses through the walls of the furnace, the incompleteness of the combustion reaction and losses in the operating zone inside furnace. Obviously the efficiency of modern unites has risen significantly compare to past models. However the 60% of energy is accounted for losses, while only 40% others goes for melting of the glass.

The biggest part of all glassmaking furnaces use natural gas as a fuel. There are many positive factors in utilizing this kind of energy

- Natural gas is the most convenient type of fuel. It is easier to operate with gas grid than with oil one.
- The temperature occurring with the combustion of natural gas is higher than from other sources
- Gas is simple to store
- The emission level from natural gas combustion is the lowest between fossil fuels
- Burners, which works on gas are more convenient in operation

Nowadays natural gas becomes an industrial principle source of energy for glass manufacturing (figure 29). Modern unites are convert to utilize this kind of fuel. Thought oil is still used as standby source. Forehearth and lehr are mostly heated by the natural gas and electricity term from resistive heaters, electrodes and radiant heaters. Gas also used to control the air emissions level. Some of the glass types have very harmful and toxic wastes, which need to be controlled through incineration. To reduce capital investments on treatment facility low emission fuel is used.

Generally half of electricity used in glassmaking process goes on electric boosters in furnace. There are a few units, which has full electric melter. Basically power utilized for all machinery that helps in operation of glassmaking factory. Ventilation, lightning, conveyors, pumps, compressors and various forming equipment works on electricity .There is no doubt electrical melting has much more advantages in environmental and technical issue. However at the present time the effectiveness from natural gas combustion is the highest between all known low cost methods. (Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, March 2015, 32 p.)

Table 4. Typical specific energy consumption values achieved by applying available techniques/measures for □inimizing the use of energy. (SCALET Bianca Maria, 2013, 485 p.)

Sector	**Furnace type/capacity**	**GJ/tonne melted glass (1)**	**GJ/tonne finished product (2)**
Container glass			
Bottles and jars	<100 t/d	5.5 – 7	<7.7
	>100 t/d	3.3 – 4.6	
	Electric furnaces	2.9 – 3.6	
Flacconage	<100 t/d	7 – 9	<16
	>100 t/d	4.8 – 6	
Flat glass			
	All capacities	5 – 7	<8
Continuous filament glass fibre			
	All capacities	7 – 14	<20
Domestic glass			
	Conventional furnaces		<24 for capacities<100 t/d(3) <18 for capacities>100 t/d
	<100 t/d	6.7 – 9.5	
	>100 t/d	5 – 6	
	Electric furnaces (4)	3.4 – 4.3	
Special glass			
All products	Electric furnaces (4)	3.9 – 4.5	<20
Soda-lime glass 5-10	Conventional furnaces	5 – 10	
Borosilicate glass		10 – 15	
Mineral wool			
Glass wool	All capacities	2.7 – 5.5	<14
Stone wool	All capacities	4.2 – 10	<12
High Temperature Insulation Wool			
	All capacities	6.5 – 16.5	<20
Frits			
	Oxy-fired furnaces	≤9	
	Air/fuel and enriched air/fuel fired furnaces	≤13	
(1) Data refer to the furnace energy consumption. (2) Data refer to the overall energy consumption of the installation. (3) Values do not include installations equipped with pot furnaces or day tanks which energy consumption for the melting process may be in the range of 10 – 30 GJ/tonne melted glass.			

(4) Data reported refer to energy at the point of use and are not corrected to primary energy.

Huge progress has been achieved in improving the efficiency of the glassmaking production. Especially at melting stage, because this step requires the biggest part of energy and emits high level of emissions. Big attention should be given to new control opportunities and computerization of the processes. The development of new refractory materials also makes a significant contribution in improving of melting zone. There are a number of applications, which will be represented in next chapter dedicated with improving the energy efficiency of the glass melting furnace.

5. Ways of improving the energy efficiency of the glass melting furnace

At present times energy costs and environmental protection laws forces glassmaking manufactories to search new methods of raising the efficiency of energy used and reducing the emission level. It is not possible to challenge with this policy. However this is right and logical way to have non harmful and environmentally friendly glassmaking industry. Due to the global challenges connected with limits of fuel and raw materials the production of glass must improve technology of manufacturing and reduce total energy consumption per one ton of produced glass. Prices for electricity and natural gas have a great impact on probability and margins. Research and development and applying new technologies will bring glass manufacturing to new level. The energy saving measures will provide high competitiveness of the product and guarantee the sector industry, which is totally safety for the environment. In today's complex climate situation, the improving of the energy efficiency of glass making furnace may be the most powerful action.

The greatest goal of the glassmaking sector is reaching of the melting efficiency to 50%. As the process is required much more energy than is needed because of huge heat losses. There are a lot of various technologies for betterment of the tank operation. However some of them are surreal in utilization due to high costs or shortage of power equipment. There is a list of five sectors, which requires great attention.

- Furnace Modeling
  The limits of a specified volume make some restrictions in furnace operation. The received knowledge can facilitate optimizing of glassmaking process and increase the output from the same furnace volume.
- New Glassmaking Technologies
  This is dangerous and protracted problem. As the business sphere is rather conservative. Until revenues exceed expenses, a very few companies pay great attention on development of new technologies of glass receipt. Although searching of new techniques is an open theme. There is no limit of technology perfection.
- Refractory material

If the furnace mentioned as a heart of glass manufacturing, it is impossible to miss characteristics of the refractory material. These properties effects on many operate conditions. First of all it is heat losses through the furnace walls, which may be reduced by changing the structure of refractory surface. And finally such thing as lifetime and one working furnace campaign are also depends from characteristics of that material.

- Glass Melting Research Facility
  Glassmaking production as others spheres of industry has got its own research base. The optimal work modes and furnace efficiency are tested of every unit. Since capital costs for building a plant are extremely high, companies must have such testing centers. Of course new applications may be reviewed and modified.
- Improve Thermal Efficiency
  At present days glassmaking units have very high efficiency compare to last decade. However it still has small value in contrast with theoretically possible. The rate of the income energy should be lower. As about 60% of heat just goes on warming the work surface and walls, throws to the atmosphere or losses because of wrong combustion mode. It turns out that production takes much more energy than is required. This overspending of fuel causes significant impact on other aspects. The emission level is much higher than it could be due to the great fuel consumption. Also right operation mode may extend the lifetime of the unit. The improvement of the efficiency is the best option to raise the characteristics of any glassmaking production in all directions.

The description of all stages of the glass manufactory gives a complete picture of the most energy weak places. And analyzing all information that has been represented previously, the furnace is selected as platform for improving the glassmaking production efficiency. There are many ways of archiving this goal. The most effective and famous will be discussed and described. The furnaces with recuperative and regenerative preheater will not be mentioned as nowadays there are few units, which have no any application for heating the combustion air. This type of furnaces was described at chapter 3. (Keith Jamison April 2002, 17 p.)

a. Oxy-fuel Furnaces

This method is based on replacing combustion air with oxygen (purity more 90%). Removal of the nitrogen from the combustion oxidant reduces the volume of flue gases by 75-80% depending on the purity of oxygen used. The result is saving energy because there is no necessary to heat the atmospheric nitrogen to the temperature of the flame. The scale of the achieved results relies on compare furnaces. Also there is significant decreasing Nox formation. Due to high temperature flame lighter residual nitrogen is converted to Nox. And even relatively low concentrations of N2 may become huge emissions of nitrogen oxides.

Flue gases have a relatively high temperature about 1200-1300 °C and typically require cooling. Due to the high water content and concentration of substances that may cause corrosion, cooling is usually produces using air. Burner for forced oxygen blast should have a special design, which is different from conventional air-gas systems. The burners have had got significant modification since they start to operate. Now only highly specialized burners are used with low Nox formation, which are specifically designed for glass manufacturing. These are the main characteristics of commercial systems:

- A long and wide flame having a large luminosity and giving deeper and more uniform heat transfer
- More flat flames with wide area coverage
- Delayed mixing of fuel and oxygen to reduce peak flame temperatures in the zone of high concentrations of O2
- There is no requirement in cooling water
- The flame can be adjusted for capacity and shape.
- Different types of fuel may be used

Energy savings can exceed 50% for small units that has little efficient from the thermal point of view furnaces. For medium sized recuperative furnace, without utilizing of special measures for energy savings, the standard level of insulation and using only internal cullet, switching to forced oxygen blast will reduce energy consumption by 50%. However, for large regenerative furnaces with optimal thermal performance the savings will be much smaller and potentially tending to zero. In this case the cost of oxygen will be much higher than profit gained from it.

Forced oxygen blasts give higher flame temperature and in some cases can provide higher performance of the glass. This is especially important when there is a need to increase production volumes. The lack of heated air also contributes in the total efficiency of the method. In some cases, forced oxygen blast also facilitates the management process and raises the quality of the glass. This is especially important for a range of special glasses, which requires high temperature of melting. However, the high content of oxygen and water vapor in the atmosphere of flame can affect on the chemistry of glass. This may cause changes in the composition of the batch.

An important component, which determines the economic efficiency of the method, is the lack of need for heated air and corresponding reduction in capital costs compared to traditional regenerative and recuperative furnaces. This may be an important argument in the construction of new furnaces, when you can completely avoid the cost of air heating. Most modern burners for forced oxygen blast are usually more expensive than similar burners for traditional ovens, and the cost of the oxygen system can be quite large. However, for most furnaces the additional costs of provision of oxygen is much lower than savings connected with the absence of heated air. Due to the potential impact of high temperatures on the lifetime of the refractory, it may require the utilization of more expensive refractory material of the furnace, which will significantly increase capital costs. The regenerators of furnaces can be reconstructed only partially from the moment of stove installation in this place. Although the savings will be less than the construction of a new furnace due to the lack of need for regenerators will be significant. Overall, the reduction in capital costs of the furnace using forced oxygen blast is 30-40% compared to new regenerative furnaces and about 20% compared to recuperative furnaces. If the company itself sets up and operates oxygen plant, the capital cost may be up to 10% of the furnace cost.

Method of staged combustion can be applied together with the use of oxygen as combustion air to reduce Nox formation. This technique consists of changing the conditions under which Nox is formed. If the fuel and air or oxygen are introduced into the burner at one point, the resulting flame has a hot oxidant primary zone close to the flaming windows and a cooler secondary zone further away. A large part of the Nox is formed in the hot zone. Therefore, it is possible to reduce the maximum flame temperature and Nox formation by decreasing the fraction of air or fuel in the burner. Missing fuel or air is added to the combustion zone.

Assessing the environmental effectiveness of forced oxygen injection one should be taken into account – the negative impact of the obtaining oxygen process. Basically it is determined by the impact of the electricity production. The electricity consumption of the vacuum absorption method is about 1.44 MJ per 1 Nm3 of oxygen. Overall, the impact is quite difficult to measure without specific data of the electricity production efficiency. Thus, it could be stated that for small and medium furnaces environmental effects from energy savings through the use of forced oxygen injection significantly exceed the impacts associated with the oxygen production.

One of the important issues is the disposal of excess heat of flue gases. This effect may have huge potential in the efficiency improvement of glass melting with forced oxygen blast. High gas temperature increases the potential for possible recycling, but has a number of difficulties. In order to ensure the right operation of pollution control equipment, it is obligatory to organize cooling of the incoming flue gases. The composition of the flue gases also limits the use of direct heat exchange due to concentration of the condensed particles and corrosion. These problems are amplified because of forced oxygen blast. Potentially the most effective way of disposing of excess heat is the utilization of a heating system, which warms cullet and batch. (Energy Efficiency Opportunities in the Glass Manufacturing Industry, 34 p.)

b. Utilizing of cullet. Preheating the glass virgin batch materials and cullet.

The use of external cullet in the manufacture of glass can significantly reduce energy consumption and can be applied on all types of furnaces — fossil fuel, forced oxygen blast or electric heating. Most sub sectors in normal mode recycle all internal cullet. The proportion of cullet in the feed volume is typically in the range from 10 to 25%.

Cullet has lower requirements for the energy required for melting than raw materials of the batch. As cullet already exposed by endothermic reaction associated with the formation of the glass and the weight of cullet already less than an equivalent amount of the batch by approximately 20%. Thus increasing the proportion of cullet in the feed materials potentially allows saving energy. Generally it could be assumed that every additional 10% of cullet can decrease energy consumption in the furnace by 2.5-3.0%. Also the use of cullet usually leads to a significant cost reduction by cutting the consumption of energy and raw materials.

It is very important to distinguish internal and technological cullet (glass, obtained from production lines) and outcome cullet (recycled glass is received from consumers or other industrial sources). Composition of an external cullet is less inaccurately determined and this limits its utilization. High product quality may restrict share of outcome cullet that can be used in production. However, the container glass sub sector has a unique opportunity to use significant amounts of outcome cullet received under different schemes of recycling glass bottles. Sub sectors with higher requirements to the quality of the glass or the insufficient number of available outcome cullet (for example, production of flat glass) may try to contract with large producers of waste glass.

The use of cullet in container glass production varies from less than 20% to over 90%, the average value for the EU is around 48%. The share of recycled glass varies substantially across EU countries, depending on almost existing schemes of collecting used glass from consumers. For the production of container glass of high quality the lower share of outcome cullet is used compare to standard products.

To improve the effect of cullet use, application connected with preheating of batch and cullet may be utilized. Normally batch and cullet are introduced into the furnace in a cold condition. However, there is a possibility of heating the batch and cullet through the use of excess flue gases heat. Of course, the method applies only for fuel glass melting furnaces. Heaters of batch and cullet are developed and established in the EU by the GEA/Interprojekt (direct preheating), Zippe (indirect preheating) and Sorg (direct heating). Recently, the Edmeston has developed install heater — combination of cullet and electrostatic precipitator.

- Direct heating
  This method uses direct contact between flue gases and the raw material (cullet and batch) with opposite motion. The flue gases are fed from the channel behind the regenerator. They passed through a recess in the heater, thus coming into direct contact with raw materials. Meanwhile the glass temperature is achieved by 400 °C. System also includes a bypass channel that allows you to continue working in cases where the heater is inefficient or impossible.
- Indirect heating
  Indirect heater, in principle, is a counter flow heat exchanger with term transfer through the plate, which heats raw materials. It is designed in the form of separate modules and is composed as individual heat exchangers placed one above each other. The modules are divided into horizontal ducts for flue gases and vertical — for raw materials. In the ducts of the raw materials they move downwards under the action of gravity. Depending on the throughput conditions the speed of the incoming raw materials can reach 1-3 m/h. However, they usually are heated to approximately 300 °C. Flue gases are routed to the bottom of the heat exchanger. Then they are directed up through special channels. In separate modules flue gases are moving horizontally. Typically they are cooled to about 270 °C – 300 °C (figure 29).

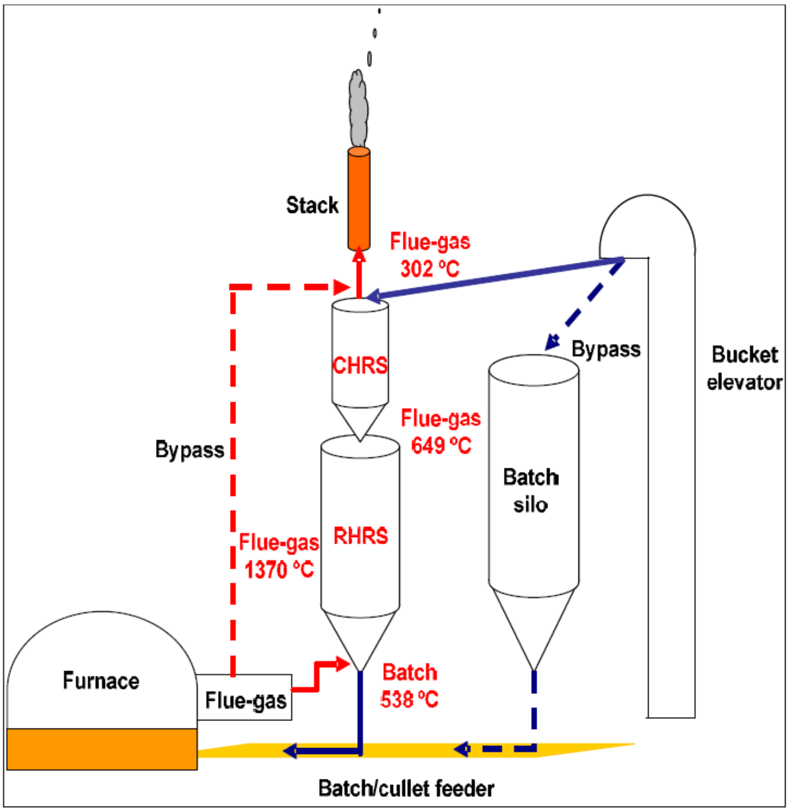


Figure 29. The example of indirect cullet and batch preheater. (SCALET Bianca Maria, 2013, 485 p.)

- Filter with a layer of granulate Edmeston

  The electrostatic precipitator with a granulate Edmeston layer (electrified granulate bed, EGB) is a combination of an electrostatic precipitator for dust removal and a direct cullet preheater. Hot flue gases are fed to the upper part of the system and passed through ionization for charging the dust particles. The gases then go through a bed of granular cullet, which has been polarized by high voltage electrode. Charged dust particles are attracted by the broken glass. They are settled on it. The cullet is constantly loaded in the facility with the temperature up to 400 °C with deposited particles on it. This mixture unloaded into the device for batch and cullet feeding into the furnace. The described techniques bring significant positive results. Usually achieved savings may reach from 10 to 20% of energy. Also there are beneficial effects like decreasing the emission of Nox and using a direct cullet heater the level of acid gases: SO2, HF and HCl at 60%, 50% and 90%, respectively. The method allows increasing productivity of the furnace by 10-15% without reducing the duration of the campaign. As already mentioned, the technique helps to reduce the need for electric heating. Heating of cullet/batch can be installed on any glass furnace with the share of cullet above 50 %. (SCALET Bianca Maria, 2013, 394 p.)

c. Thermochemical regeneration of waste heat

The essence of thermochemical regeneration of waste heat means that flue gases are use their physical heat for the endothermic processing of the original fuel. This gas receives a greater supply of chemically bound heat. In addition it is heated to high temperature. This extra chemical and physical heat of fuel and heat of the combustion air are released in the working volume of the furnace. This provides a corresponding increase of its temperature level and lower specific fuel consumption.

In principle, endothermic chemical processing is possible for any fuel, but using hydrocarbon gases is the most obvious and feasibility. Commonly it is natural gas, consisting 90-95% of the methane. One of the methods of thermochemical regeneration is the application of natural gas steam reforming. The mechanism of steam reforming includes a number of reactions proceeding with the absorption and release of heat. As it is known about the study of chemical kinetics, the most probable are the following reactions:

$$CH4 + H2O \longrightarrow CO + 3H2 – 206.1 \text{ KJ/mol}$$

$$CH4 + 2H2O \longrightarrow CO + 4H2 – 165.1 \text{ KJ/mol}$$

$$CO + H2O \longrightarrow CO2 + H2 + 41.1 \text{ KJ/mol}$$

The reaction is usually conducted at ratio of steam to methane close to 2:1. For the implementation of steam methane reforming external supply of heat with a temperature of at least 750 °C is required. Different catalysts are activated for the fullest extent of methane conversion in the reactors of steam conversion.

It should be noticed that the catalytic steam reforming of hydrocarbons by the thermal effect and the quantity of hydrogen in several times exceeds the endothermic non catalytic reduction processes such as pyrolysis, cracking and depolymerization of hydrocarbons. The difficulty lies on the creation of advanced catalytic surface and on maintaining of its properties by the product entire operating time. One of the options for the utilization of thermochemical recuperation is the waste heat of the flue gases after the furnace (figure 30).

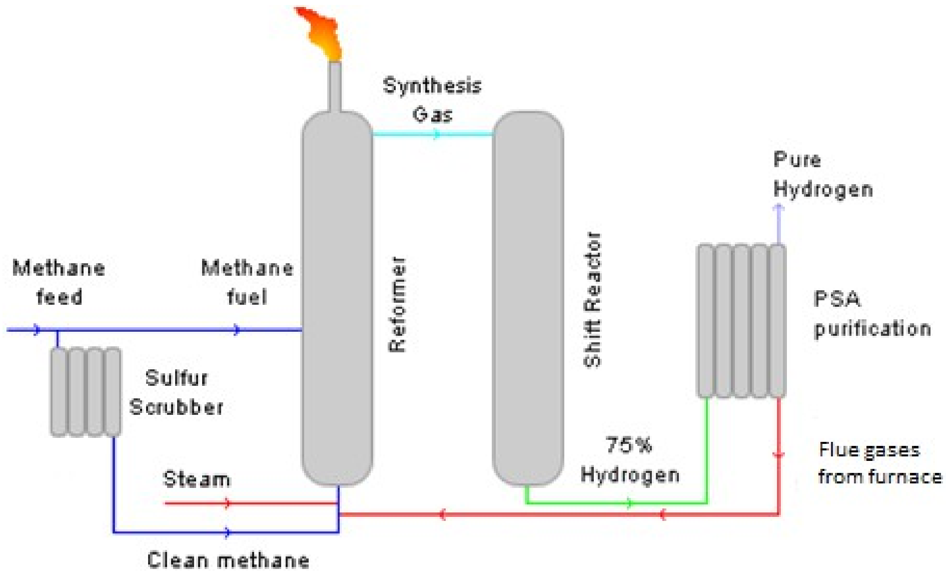


Figure 30. Thermochemical regeneration of flue gases by steam conversion of natural gas.(data from glassefficiency.com)

Natural gas consumption during the recycling of thermal and regeneration of the heat of the exhaust flue gases reduces the fuel consumption for the furnace by 50% in comparison with the scheme, which uses only thermal regeneration of the heat. One of the major disadvantages of thermochemical heat recovery by steam conversion of hydrocarbon is increased specific steam consumption. It may reach two times higher compare to stoichiometric.

The solution of the additional steam generation problem is using gas products of its complete combustion as oxidizing agent of natural gas. The basis of the process is endothermic processes, which combine steam and carbon dioxide conversion of methane, the main component of natural gas. The reactions are described by the following equations.

$$CH_4 + H_2O \longrightarrow CO + 3H_2 - 206.1 \text{ KJ/mol}$$

$$CH_4 + CO_2 \longrightarrow 2CO + 2H_2O - 247.3 \text{ KJ/mol}$$

$$CO + H_2O \longrightarrow CO_2 + H_2 + 41.1 \text{ KJ/mol}$$

The reactions are deeply endothermic and for their occurrence heat is required. If the unit has the necessary thermal capacity, thermochemical regeneration could have all necessary facilities: water vapor, carbon dioxide and high temperature for the implementation of the methane conversion reaction. The result is the transformation of sensible heat of flue gases into chemical energy of the reformed gas. In this case, water vapor and carbon dioxide contained in the flue gas play a role of an oxidizing agent of natural gas. (SCALET Bianca Maria, 2013, 415 p.)

One of the best options of utilizing such technology may be considered thermochemical regeneration of heat by the conversion of natural gas combustion products in the warmed catalyst. The main advantage of this method is the possibility of achieving a high degree of methane conversion due to the fact that catalytic nozzles with different adsorption properties are situated in the direction of reaction mixture movement. So at the bottom of the reactor catalysts are located, mainly carbon dioxide methane conversion, because the reaction requires greater thermal capacity. The upper part of the reaction space filled with catalyst of steam conversion. This is associated with the fact that the reactions of conversion of natural gas require different temperature.

Publications on the use of thermochemical regeneration of heat by the conversion of natural gas products of its complete combustion are of great scientific interest, so the study of this method of heat regeneration seems very promising.

d. Submerged combustion melting technology

In search of solution of many various problems connected with traditional glass melting, sometimes radical measures are applied. The new vision of the fusion technique has been represented. It is called submerged combustion melting technology. This method covers all of the topical issues like homogenization, heat recovery, melting optimization and refining (figure 31).

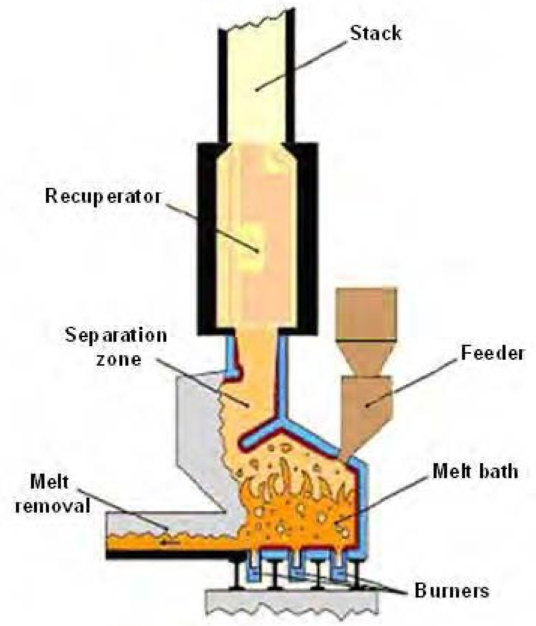


Figure 31. Submerged combustion melting tank. (SCALET Bianca Maria, 2013, 485 p.)

The key achievement of such application may be considered the reducing of the melting time by 80%. The unit consists of small tank where burners are faced to the melted bath. Thus, flue gases passes through the mixture and gives more of potential energy to the melting process. This is happen due to turbulent mixing and high heat-transfer rate. This mode generates special blending conditions, the result of which is more homogenization structure of the bath and rapid dissolution of raw materials. The melted glass, which is ready for forming step, is exhausted from a gap near the bottom of the bath. One of the main advantages is flexible charging and handling compare to standard melter. Due to greater mixing and melting properties, the size of raw materials in batch may achieve big values. That means that there is no more need in careful preparation and high quality of batch materials. This has some consequence in the form of decreasing of labour and capital costs. (Glass Melting Technology:A Technical and Economic Assessment, October 2004, 56 p.)

e. The glassmaking with combined use fossil fuel and electricity

There are two basic approaches to the combined utilization of glass made by fossil fuels and electricity.

- The use of the fuel energy for melting and heating with the electricity.
- Electrical melting with the assistant of fossil fuel heaters.

Equipment for electric heating installed in many furnaces and can provide from 2 to 20% of the total energy for melting. In container sub industry, as well as in the manufacture of sheet glass, the use of electric heating is usually limited by the cost of electricity and it is less than 5%. The high prices of power associated with electric heating, typically means that this method can only be used for keeping necessary parameters of technological process. Of course the economic efficiency imposes restrictions to the use of the power. In particular, the electric heating may be used to improve the convective flow in the volume of batch that leads to the intensification of heat transfer and contributes to the clarification of the glass. Furnaces, which use electric heating as a main source of glass melting, are less used in common. There is a level of feasibility redistribution of using electric furnaces, closely associated with the higher cost of electricity. Based on today's practice, it is possible to give a general assessment of the electric furnaces appropriateness. Although, in all cases local conditions depends on possible exceptions

- The use of electric furnaces with a capacity less than 75 tonnes can usually be justified.
- The use of electric furnaces with a capacity range from 75 to 150 tons of glass per day may be justified in certain conditions.

- The use of electric furnaces with a capacity of over 150 tons of glass per day commonly cannot be justified.

Usually a flame is utilized for heating the charge material and acceleration of melting. This method is usually applied in order to overcome some difficulties associated with the functioning of the all-electric furnaces. (Glass Melting Technology:A Technical and Economic Assessment, October 2004, 112 p.)

6. Utilization of flue gases heat in a waste heat boiler.

This method is based on passing the flue gases directly through an appropriate tube boiler for steam generation. Steam can be used for heating the room or the tanks and piping of fuel oil. However the most common option is turbine utilization for electricity production for further propulsion of equipment, like compressors or ventilators machines.

The flue gases coming from the regenerators or respirators are usually in the temperature range from 600 °C to 300 °C. The temperature at the boiler outlet after the heat exchanger determines by the possibilities for the utilization of heat and is limited to approximately 200 °C. Other aspect is the condensation risk and boiler insurance from functioning of the chimney. Boiler tubes exposed by the furnace flue gases and they can be formed of deposits of various materials and should be cleaned periodically to maintain the efficiency of utilization of heat. However, this becomes less important if the waste heat boilers installed after dust removal equipment.

The applicability and economic feasibility of applying this method is determined by the overall efficiency that can be achieved by using this application. Also the performance of produced steam needs to be taking into account. In practice, waste heat boilers are used only in conjunction with recuperative and regenerative glass melting furnaces. There are two cases of this technique utilization in the furnaces with forced oxygen blast. In many situations, the recyclable amount of heat is insufficient for effective production of steam and is typically possible only for regenerative furnaces, for large installations or in cases when it is possible to combine multiple flue gases of few units. Most of the application of waste-heat boilers relates to the production of flat glass. Although they are used in some manufactures of container glass.

Capital costs can exceed about 1 million euros with different payback periods. Total price depends on the effectiveness and cost of energy used. Sometimes, the payback period may be much longer. In addition, the constant energy efficiency improvement of the main processes also reduces the meaning of utilizing recovery heat boilers.

a. Boiler calculation

Table 5

№	Parameter	Formula	Calculation
1	Heat capacity of gases at the inlet to the boiler	cp = ∑ cp,i ·ri	2.04·0.09+1.34·0.72+1.3× ×0.01+1.6·0.18+1.35·0.02 = 1.48 KJ/(m^3 ºC)
2	Set the temperature of the gas outlet from the boiler	Accepted value	200 ºC
3	The heat capacity of the gas outlet from the boiler	cp = ∑ cp,i ·ri	1.8·0.09+1.3·0.72+1.26× ×0.01+1.52·0.18+1.3·0.06 = 1.46 KJ/(m^3 ºC)
4	Enthalpy of gases at the inlet to the boiler	$I'_g = c_p t'_g$	1.48·600= 888 KJ/ m^3
5	Enthalpy of the gas outlet from the boiler	$I''_g = c_p t''_g$	1.46·200= 292 KJ/ m^3
6	Enthalpy of superheated steam	By i-S diagram	3290 KJ/ kg
7	The steam pressure in the drum	$P_d = P_{ss} + \Delta P$	4+0.4=4.4 MPa
8	The steam temperature in the drum	t_s by i-S diagram of water conditions	255 ºC
9	Enthalpy of steam in the drum	i'' by i-S diagram of water conditions	2840 KJ/ kg
10	The enthalpy of boiling the water in the drum	i' by i-S diagram of water conditions	1117 KJ/ kg
11	Enthalpy of feed water	From water properties	4.19·100=419 KJ/ kg
12	Rate of flue gases	G_0	14.9 m^3/s
HEAT BALANCE AND STEAM OUTPUT OF THE BOILER			
13	Coefficient of	φ	0.98

	heat preservation		
14	The heat given by the flue gases	$Q_g = \varphi G_0 (I'_g - I''_g)$	0.98·14.9·(888-292)= =8718 kW
15	Steam rate	$D_{ss} = Q_g /[(i_{ss} - i_{fw}) + 0,05(i' - i_{fw})]$	8718/[(3290-419)=0.05× ×(1117-419)]=3 kg/s
CALCULATION OF SUPERHEATER			
16	Heat, going for steam superheating	$Q_{ss} = D_{ss}(i_{ss} - i'')$	3·(3290-2840)=1350 kW
17	Enthalpy of gases over the superheater	$I''_{ss}\ I'_g - Q_{ss} / G_o \cdot \varphi$	888-[1350/(0.98·14.9]= =796
18	The temperature of the gases over the superheater	t''_{gs} i-S diagram of flue gases conditions	540 KJ/ m^3
19	Large temperature difference	$\Delta t_l = (t'_s - t_s)$	600-255=345 ºC
20	Small temperature difference	$\Delta t_s = (t''_{gs} - t_{ss})$	540-430=110 ºC
21	Temperature pressure	$\Delta t = (\Delta t_l - \Delta t_s) / \ln(\Delta t_l / \Delta t_s)$	(345-110)/ln(345/110)=205.6 ºC
22	The average temperature of flue gases	$t_g = (t'_g + t''_{gs}) / 2$	(600+540)/2=570 ºC
23	The living section for the passage of gases	By the constructive characteristics, f_r	9.13 m^2
24	The speed of movement of flue gases	$\varpi_g = G_o (t_g + 273)/(3600 f_g \cdot 273)$	14.9·(570+273)/ (9.13·273)= =5.04 m^3/s
25	The average temperature of steam	$t_{av} = (t_s + t_{ss}) / 2$	(255+430)/2=342.5 °C
26	The living section for the passage of steam	By the constructive characteristics	3.14·(0.026)^2·50/4=0.0265 m^2
	The average		

27	speed of superheated steam	$\varpi S=(vSSDSS)/(3600fS)$	$0.06{\cdot}3/0.0265=6.8\ m^3/s$
28	The heat transfer coefficient from the heating media to the wall	α_1 by appendix 1	$0.9{\cdot}1{\cdot}1{\cdot}53=47.7\ W/\ m^2K$
29	The heat transfer coefficient	α_2 Accepted from common values	$900\ W/\ m^2K$
30	The coefficient of thermal efficiency	Accepted from common values	0.9
31	The heat transfer coefficient	$\alpha=\Psi\alpha_1/(1+\alpha_1/\alpha_2)$	$0.8{\cdot}47.7/(1+47.7/900)=$ $=40.8\ W/\ m^2K$
32	The surface area of the superheater	F_{SS}	$159\ m^2$
33	he heat transferred to the superheater	$Q_h = kF_{ss}\Delta t$	$159{\cdot}40.8{\cdot}205.6*10^{-3}=$ $=1337\ kW$
34	The discrepancy of heat	$Q_{ss} - Qh/QSS\ 100$	(1350- 1337)/1350·100=1%
THE CALCULATION OF THE EVAPORATOR			
35	The temperature of the gases after the evaporator	Accepted value	300 °C
36	Enthalpy gases for the evaporator	By flue gases entalthy diagram	$433.8\ KJ/\ m^3$
37	The amount of heat given to the steam-water mixture gases	$Q_{ev} = G_o(I''SS - I''ev)J$	14.9·0.98(796-433.8)= =5229 kW
38	The average temperature difference	$\Delta t_l = (t_g' - t_{st})$	[(680-255)-(300-255)]/ln[(680-255)/(330--255)]=201.8 ºC
39	The average temperature of the gases	$\Delta t_s = (t''_{ss} - t_{ss})$	(300+680)/2=490 ºC

40	The living section for the passage of gases	By the constractive properties $f_s = ab - zld$	3.25·3.73-60·3.25·0.025= =7.2475 m^2
41	The heat transfer coefficient	α_1 by appendix 1	0.9·1·1·43.4=39.1 W/ m^2K
42	The heat transfer coefficient	With amendments	0.9·39.1=35.2 W/ m^2K
43	The heat transferred to the evaporator	$Q_h = kF\Delta t$	35.2·7.25·201.8*10^{-3}=5149 kW
44	The discrepancy of heat	$\Delta Q = (Q_{ev}+Q_h)/Q_{ev}100$	(5229-5149)/5229× ×100=1.5%
CALCULATION OF ECONOMIZER			
45	The amount of heat given to the water economizer	$Q_{ec} = \varphi G_0 (I''ev - I''g)$	0.98·14.9*(433.8-292)= =2070.5 kW
46	Enthalpy of water at exit of economiser	$i'W = i_{fw} + Q_{ec} /D$	419+2070.5/3=1109 KJ/ kg
47	The temperature of the water mixture at the outlet of the economizer	Accepted by diagram of water conditions	255 ºC
48	The living section for the passage of gases	$f_s = ab - zld$	3.25·3.69-56·3.25·0.025= =7.4425 m^2
49	Average temperature	$t_{av}=(t_{ev}+ t'_g{}')/2$	(300+200)/2=250 ºC
50	The speed of flue gases movement	$\varpi g=(t_{av}+273)/(3600fS)$	[14,9(250+273)]/ / (7.4425·273)=3.84 m^3/s
51	The average temperature difference	$t_d=(t_l-t_s)/\ln(t_l/t_s)$	[(200-100)(300-255)]/ [ln(200-110)/(300--255)]=84 ºC
52	The heat transfer coefficient	α_1 by appendix 1	36.5 W/ m^2K
53	The heat transfer coefficient	With amendments	0.9·36.5=32.9 W/ m^2K

54	The heat transferred to the economiser	$Q_h = kF\Delta t$	$7.44 \cdot 32.9 \cdot 84 \cdot 10^{-3}$=2043 kW
55	The discrepancy of heat	$\Delta Q = (Q_{ec}+Q_h)/Q_{ec}100$	(2070-2043)/2070·100= =1.3%
THE CALCULATION IS OVER			

(calculations made on the basis of the "boiler" course)

After the calculations the boiler parameters were obtained.

1) Steam output: D=3 kg/s
2) Properties of the steam: P=4 MPa T=430 ºC
3) Flue gases rate: G_0=14.9 m^3/s (value was taken from heat balance of furnace calculations)
4) Temperature of flue gases before the boiler: T_{in}=600 ºC
5) Temperature of flue gases after the boiler: T_{out}=200 ºC
6)

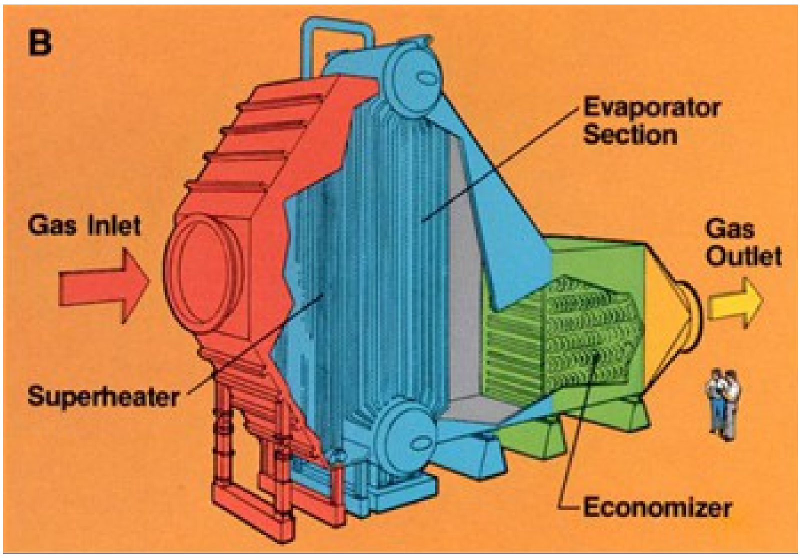


Figure 32. Waste heat boiler oulook.(data from HRSG_Package_Drawing)

b. The feasibility of energy saving measure

After the boiler calculations, working parameters of the boiler were represented. As it could be easily mentioned it is possible to generate a stable flow of steam with required characteristics for utilizing it at the turbine. However there are some drawbacks. First of all the value of steam output is not so big. That means that the gained electricity will be enough only for internal use. Of course it is a controversial issue. For small facility there is no doubt that the amount of generated electricity will be enough. So the rate of flue gases is too high for small application. That means that there are two options.

- One big unit with stable and huge volume of flue gases.
  This variant will have calculated amount of steam, but there is no expectations that this internal electricity will cover all of the plant needs. Still, considering the prices for power, it is rather useful to cover a share in electricity consumption.
- A few units which may operate at different times.
  This option required several small applications, which may work at the same time or separately. In this case the total flue gases rate from all unites will provide stable and specified volume of exhaust gases. The amount of gained electricity will be enough for keeping one unit in the work conditions.

If the economical part will be taken into account, one needs to be mentioned, the capital investments will meet the expectations in the situation of long time operation and payback period. The price for installation such facility is extremely expensive. That means that this solution is necessary to approach seriously. In addition this application may be established only when there is other energy saving measures, like recuperative or regenerative preheater. The possible scheme of glassmaking regenerative furnace with waste heat boiler is represented at figure 33. Due to the income parameters of flue gases, they should not be high temperature valued.

From the environmental point of view the waste heat boiler utilization has many advantages. The recovered energy reduces the total energy consumption, which is beneficial to the human and nature. The first steps on the way to green and pure industry is cutting the potential losses of heat and directing them back to the process. In addition using waste heat boiler can replace the needs in power at the plant. This aspect in large scale can achieve big power generation decreasing. And finally the boiler facilities usually required the installation of additional treatment equipment. Extra filtering of flue gases can bring the emission level to very low values.

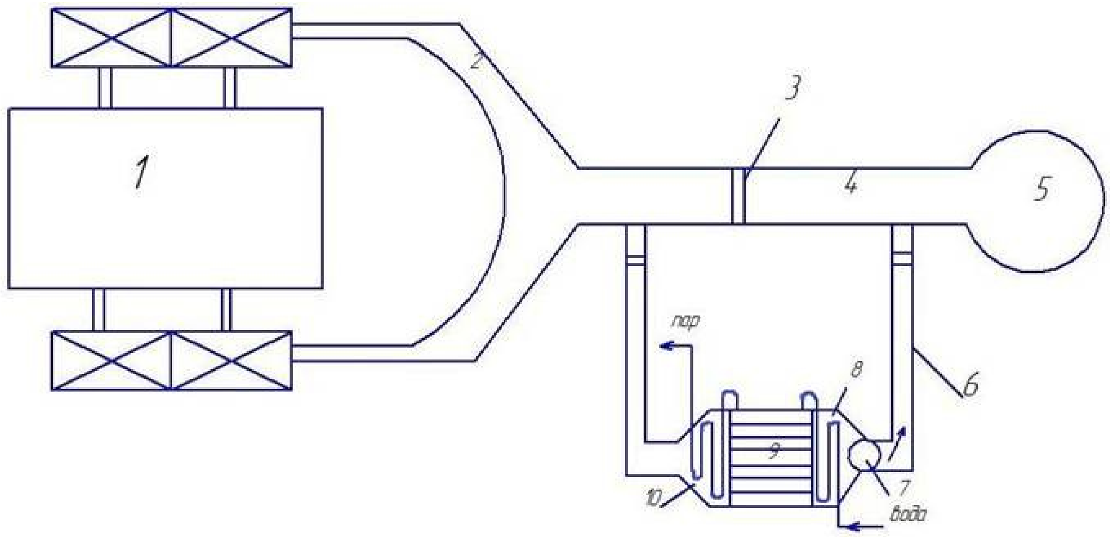


Figure 32. Scheme of glassmaking regenerative furnace with waste heat boiler.(data from glassmaking.org)

Summarizing all information one should be pointed that there are many various aspects of utilizing the waste heat boiler. In each case the decision may as positive as negative. The main argument in this choice may be considered the price and availability of electricity. Other aspect is the setting unit. The operation parameters and furnace characteristics can make a big change in the final decision.

Conclusion

Glass manufacturing is a complicated and resource-intensive process, which takes large amounts of energy and raw materials. However, the humanity has used glass to make goods and in many applications such as transportation, construction, decoration, alimentary and medical industries. For those reasons there is no replacement for glass production.

As every industry sector glassmaking manufacturing has own problems. The solution of actual questions will take many years. However it is very important to have a direct goal and to achieve it. As the prices for fuel and electricity go up, there is only way of improving the process of glass receipt together with the development of new technologies.

Glass production requires much energy at present days because of huge heat demands connected with the furnace operation. Many of possible options for raising the melting effectiveness were represented in this work. Also one of the methods called utilizing of waste heat was discussed. The analysis identifies conditions for using that technology.

In this article technological processes of glass making were described. It is obvious that the total consumption of fuel and raw material is much higher than the production output. Thus, optimal solutions include the major energy saving efficiency techniques, such as improved process control, increased cullet use, increased furnace size, use of waste heat in batch and cullet preheating or in steam generation, use of oxy-fuel technologies, and reduction of rejects.

All the options were taken into account when the values of total fuel consumption and glass output were presented. It is clear that with the implementation of best available technologies the energy efficiency of glass production can be improved. This is also very important for industrial and economic development of the country and decreases the impact on the environment.

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