GLASS, GLASS TECHNOLOGY AND MANUFACTURING PROCESS

Summary of the material for the GLASSBLOWER educational programme

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1 GLASS

Glass is a hard synthetic material, which is produced by cooling melt and is in an amorphous (non-crystalline) solid state (Bek 2008, 20).

Glass is a product of melting silicon dioxide with other oxide alloys and is hard and fragile at room temperature.

1.1 Materials

Usually raw materials for glass production come in shape of salts/have salt structures which disintegrate at melting temperature. We divide them in two large groups:

- base materials (glass makers, melts, stabilizers) and
- Auxiliary materials (fining agents, dyes, discoloration agents, opal glass and melting accelerators).

The basic materials for glass production are:

- quartz sand (silicon oxide ($SiO2$)),
- soda (sodium carbonate ($Na2CO3$)),
- limestone (calcium carbonate ($CaCO3$)),
- potash (potassium carbonate ($K2CO3$)),
- dolomite (calcium magnesium carbonate ($MgCa(CO3)2$)),
- crushed glass forms 25-30% of the whole mixture and has to be of the right size; the crushed glass pieces must not be too large and also not too small, since the latter make the clarification process more difficult

Auxiliary materials are added to basic materials:

- *Materials for glass discoloring and clarification of glass mixture (manganese dioxide),*
- *Materials for coloring* are metal oxides,
- *Materials for opaque glass texture* (titanium and zirconium oxide).

To be considered as an ingredient for a specific technological process, material needs to meet the following conditions (Bek 2008, 22):

- it has to contain a high percentage of compounds, which serve as part of a new matter being produced,
- it has to have a constant chemical composition,
- it has to contain the lowest possible amount of impurities, which could harm the quality of the product or make the production procedure more difficult,
- the supplies need to be large enough to allow an undisturbed production for a long period of time,
- the price must ensure profitable production.

Materials for glass must be of suitable grain size of 0,1 – 0,3 mm.

1.2 Glass types

We know sodium, quartz, lead, borosilicate and potassium glass types.

Sodium glass is common glass and is mostly used for glasses, bottles and window glass. It melts easily and softens at temperatures of 500 to 600°C.

Quartz glass is used for halogen lightbulbs and ultraviolet microscopes. It is made without any additives. It has a very low elasticity coefficient, which means it does not break at high temperature changes.

Lead glass is used for optical objects. It is difficult to melt.

Borosilicate glass is used in laboratories and households due to its resistance to temperature changes and chemicals.

Potassium glass is used for test tubes as “Bohemian crystal glass” and “crown glass” for optical devices. It’s hard to melt, since the melting temperature needs to be 700-800°C.

1.3 Chemical and physical properties of glass

Amorphous (non-crystalline) materials like glass lack any long-range translational periodicity and possess a high degree of short-range order ("super cooled liquid"). Therfore, the melting point is not fixed, with softening occurring in wider temperature ranges. The glass melting point is between 500°C and 1650°C, depending on its structure.

Glass can be shaped with different techniques like blowing, rolling, stretching and casting.

It is hygienic since it does not assume any flavor the taste of its content. It also has no odor; its surface is smooth and easy to clean. Glass also does not let any gas through its surface.

Under low loads it reacts in elastically, while it crushes under heavy loads. Glass also acts as an isolator and conducts heat poorly. It is resistant to almost all chemical impacts.

1.4 Glass production and processing

1.4.1 Chemical production and processing of glass

The main ingredient of glass is quartz, also known as silicon dioxide (SiO2). Sand acts as glass foundation, by creating a glass web, with the help of color oxides. Due to coloring factors of color oxides, sand can only contain 0.01 – 0,03% of iron oxide. Quartz is the main ingredient of almost all types of glass and it sets the basic properties and structure of glass.

To make glass production cheaper, sand is mixed with additives like soda (Na3CO3). This lowers the high melting point of the quartz.

Limestone (CaCO3) is added to sand and soda to increase structural integrity and chemical resistance.

1.4.2 Technical production and processing of glass

Waste glass is added to finely grinded materials in quantities ranging from 20-50%. This mixture is then melted in the furnace by generator gas. The melting procedure is vital for the later purity of the glass.

After sintering – i.e. the compacting and forming of the material, hich causes the formation of gases, the mixture becomes a non-homogenous mixture full of bubbles. Bubbles disappear during the purification process. In the end, the melt is cooled down to approximately 1100°C, which increase strength and enables further processing.

2 BATCH PROCESSING SYSTEM (BATCH HOUSE)

2.1 BATCH HOUSE DESCRIPTION

A batch house is a plant made for storing and preparation of the glass mixture. It contains large (15 or 24 $m^{3)}$ or small (7 m^3) siloes. Siloes are cone-shaped, with a pipe attached on the bottom. The pipe contains a snail or vibrator for the transport of the mixture towards the scale. Under the siloes there are three scales (the smallest has a capacity of 24kg, the largest of 500 kg) and five dispensers (with an ability to dispense from the same scale to different dispensers to ensure accuracy). Dispensers are emptied into the mixer, which is then emptied into iron containers with a capacity of 500kg. Iron containers are used to deliver the mixture to the furnaces. The procedure is fully automated, but can be operated manually in case of a malfunction.

2.2 Materials and shards

Table 1: Raw Material names

Symbol	Name	Old name
SiO_2	Silicon dioxide	Quartz sand
PbO	Lead oxide	Litharge
K_2CO_3	Potassium carbonate	Potash
Na_2CO_3	Sodium carbonate	Soda
KNO_3	Potassium nitrate	Saltpeter
Sb_2O_3	Antimony trioxide	

$BaCO_3$	Barium carbonate	
ZnO	Zinc oxide	
$Na_2B_4O_7 * 5H_2O$	Sodium tetra borate pentahydrate	Borax
$CaCO_3$	Calcium carbonate	calcite
Na_2SO_4	Sodium sulfate	

The raw materials can be divided in different ways. One possible division is:

1. **Basic materials**; include substances that form glass (sand), and materials that enable melting at lower temperatures and provide stability to glass.
2. **Materials for glass fining**; their task is to remove all gas bubbles from the glass melt and to make glass melt homogenous (even) with help of mixing procedure.
3. **Glass decolorizers**; materials used to remove colors from glass caused by iron alloys, which create blue or green shade in glass. They can be processed in a chemical or physical procedure. Physical decolorization provides complementary colors. Green color provided by iron oxide, is neutralized by adding oxides that produce red, blue and purple colors. This provides glass with colorlessness. The main source of iron is crushed glass, since it gets contaminated with iron during the transport from the batch house to the furnace, and during the crushing procedure in mills. Chrome presents the biggest problem with colorization, since even the smallest quantities produce strong glass colorization. It also can’t be removed with magnets, used for removal of iron from shattered glass. The source of chrome can be glass molds.

3 GLASS MELTING FURNACE

3.1 Chemical procedure of melting

The melting process can be divided in different phases:

1. Silicon shaping; temperatures from 00 - 400°C, water evaporation (moisture from mixture, crystal bound water), disintegration of carbonates and sulfates, chemical

reaction of alkali with quartz sand. The powder mixture becomes an opaque sintered mass which looks of hard foam,

2. Glass forming: temperatures from 1100 - 1200°C, silicates melt completely; remains of sand that have not reacted disintegrate. This procedure takes 60 -70% of the whole melting time; each raise in temperature shortens the process; materials for melting acceleration disintegrate into gas, which mixes the melt.
3. Glass fining; the process of removing gas bubbles takes place at temperatures of 1400 - 1500°C; the bubbles result from the air present in the melt, carbon dioxide, sulfur dioxide, oxygen, nitrogen and water vapors; the bigger the bubbles and the more fluent the glass, easier it is to fine the glass; other factors that are important at this stage are the temperature, time, mixing and additives;
4. Glass forming; occurs at same time as glass fining; important factors for this process are the temperature and elimination of bubbles.
5. Molten glass needs to be cooled down to a temperature acceptable for further processing; it has to be cooled down gradually to prevent gas disintegration. Melt needs to be thoroughly mixed to ensure adequate homogeneity (without vind).

3.2 Physical processes in the furnace

In addition to chemical reactions, there is a series of physical processes needed to form glass.

Batch charger feeds furnaces with constant flow of mixture, after the process melt is removed at withdraw stations. Between these two procedures there is a constant flow of the melt, due to differences in the melt weight and temperature differences in different parts of the furnace.

The highest temperature position (dew point) and the movement of flows depend on the temperature curve in the furnace. Gas bath furnaces are heated with natural gas through burners. The highest heat intensity is in the area of the flame. For this reason, it is desired to have the shortest flame possible to ensure short combustion time, higher temperature and a better heat transfer. If the flame is too long, the furnace walls can be damaged. To prevent contact between different flames, opposite burners are shifted. Flame must not be pointed towards glass melt.

The powder mixture conducts heat poorly, its surface is covered with a layer of melt, while heating of core is slowed down. With prolonged exposure to heat, the melt becomes more heat-conductive and increases in size. A movement of melt occurs on the surface due to higher temperatures. Foam forms on the surface of the melt, towards the end of the process, but disintegrates at higher temperatures and the melting process is completed. A glass fining process follows, with the highest temperatures in the whole process. Simultaneously, a homogenization process is active to ensure even melt.

At worksites melt needs to be cooled down properly. This is ensured with the use of agitators, to prevent the forming of new flows for temperature transfers.

3.3 Silo and feeder

A constant level of mixture needs to be maintained in the silo to prevent stratification. It should be thermally insolated, to remove temperature influence from the furnace, which could cause a mixture reaction in the silo. A vibrator is located underneath the silo to feed the conical sink of the feeder. The sink has a mixture level measuring device to signal the vibrator to feed more mixture into sink. A hydraulic cylinder is located underneath the sink to push the mixture onto a spoon (fireproof plate that connects the feeder with the furnace). With the regulation of hydraulic cylinder speed and amplitude fluctuations, the amount of mixture feed to the furnace can be changed. The hydraulic cylinder is connected with the glass melt level gage, which provides a signal according to the melt level fluctuation. If the level is to low, the hydraulic cylinder pushes the mixture with a set speed and stops when the desired level is achieved. The feeding device spoon is cooled with soft water; in case of power shortage it can be cooled with tap water. The feeding device sink can get stuck due to wet mixture or to large glass shards. Feeding can be operated manually.

3.4 Melting space

A carpet mixture layer is a non-melted mixture at the entrance of the furnace (next to the feeding device). To provide good melting conditions, the carpet needs to be thin and wide along the whole length of the furnace. It is created by adding cold mixture to the procedure, which causes slower melting of the mixture and ensures better quality of the glass. The carpet mixture does not exist, if the temperature is set too high or if there is no output from the furnace. If the carpet is too long or too short, this indicates that there are irregularities in the furnace operation.

3.5 Temperature regime- burner settings

The glass mixture needs to be heated to the melting and fining (highest) temperature, then slowly cooled down to the work/working temperature. The temperature layout in the furnace is regulated with settings of burners. Fuel used to power burners is natural gas due to its low ecological imprint.

3.6 Workstation

The glass melt proceeds towards workstations. Flow physically separates the melting room from workstations and enables the cooling of the melt and at the same time enables flows to travel in both ways. Furnaces are distinguished according to the number of workstations and their size.

3.7 Recuperator

Next to the furnace there are two recuperators. They act as an intake for smoke gas from the melting room and travel from the top towards the bottom. This transmits heat, which flows in the same direction (counter flow would heat the top of the recuperator too much, which would demand for higher quality construction material of the recuperator and that would increase investment costs, it would, however, lead to higher efficiency). The temperature of intake gases is around 1400°C.

3.8 Cooling

There are a water-cooling system and an air cooling system installed.

The water cooling system operates in a closed circuit and uses soft water. It is used for cooling the feeder device spoon, drainage opening, agitators and level measuring system.

Air is used to cool the wall next to the feeder and to cool down the bottom and sides of melting room.

3.9 KP1, KP2 and KP3

All information listed above is generally used for gas furnaces. All three furnaces are continuous tub furnaces. They use natural gas for heating. The melt is moving around due to currents caused by heat differences.

3.10 Ceramic kilns

In ceramic kilns the process is led batch wise. The melting process is also different from the process in continuous furnaces, mixing is done mechanically.

3.11 Electric furnace

In this type of furnace the chemical reactions to produce glass are the same as in gas furnaces, the only difference in comparison with gas furnaces is in the process of melting. Here, melting is done in a vertical direction, instead of a horizontal process of a gas furnace. The vaporing process is much slower than in gas furnaces. Electrically heated furnaces and canals are using released heat, based on a Joul effect reaction. This is achieved by submerging electrodes directly into the melt. Glass acts as user and electrical current causes temperature to rise; this result in the melting and fining of the mixture.

4 DESIGNING GLASS PRODUCTS

4.1 Manual production

Blowpipe: purity (no glass residue on the pipe), if it cracks, pieces may fall in the worksite, and bubbles appear in the product. Purity of the pipe: if a piece of rust falls into the glass, bubbles and dots appear in the glass; making the final part of the pipe. Pipe must be properly prepared (which includes weekly heating and bruising); usually, there are no problems with the regular use of the pipe.

Working fireclay nozzle (slo: kuhlc) at the working aperture: it must be placed correctly and properly timed, in order to prevent the shattering of fireclay, where the pipe, coated with the glass mass, rotates.

An angle of the glass gathering: an incorrect angle of the glass gathering can cause accumulation of elongated bubbles in the product; often with pot furnaces, because the level of the glass tends to fluctuate during the shift (the solution is a graduated fireclay nozzle). In tank furnaces, this improper gathering of the glass should be prevented due to the structural implementation of the work aperture. If the worksite is too big, and the mixer too small, this generates a bigger passive belt of the glass melt, which is solved by raising the level (glass flows through the pockets and thus cleans the surface), or with the fireclay nozzle (which is a specialty of CF2: incorrect angle of the glass gathering is physically disabled).

Beads manufacture: the emergence of bubbles due to improper gathering; dirty tiles, or dirty air for cooling.

Creating stemware: correctly heated talc, so that its foot does not smear; the same with wood and aluminium shears.

Burners for additional heating and gas drum (slo: drumla) for bags and bottles: flame with too little oxygen causes a protrusion of elemental lead in crystal glass; flame with too much oxygen makes gives temperature, which leads to local overheating of the glass and hence gives the right conditions for crystallization, which manifests itself as the dots in the glass. If the temperature is too high, it causes contamination; correct temperature regime, combustion and cleanliness of the space are significant.

4.2 Vacuum gatherer

Accumulation of a yellow powder in bowl of the pipe results in visible dots in the product after the polishing.

Leakage in the area of the cutting mechanism and the lid; mechanical or thermal deformation; and wear - all cause little bubbles.

Too small or too big of a vacuum; air infiltration between the pot and scissors (bad sealing); absorption of cooling water; insufficient vacuuming time; improper operation of the vacuum valve – result in large bubbles.

Submerging the vacuum gatherer at the place where previously cut glass has fallen.

The end of the glass tongue between the vacuum head and the melt falls onto the surface of the melt after the cutting, which causes small bubbles. Parts of the knife with undersized diameter cause a chain of small bubbles. Excessive lubrication of the cutting mechanism (excessive use of WD 40). Oil in the compressed air for cooling and cleaning.

4.3 Automated production

The following are descriptions of three ways of the automatic formation of glass: blowing machine, stem press and automatic glass gatherer.

4.3.1 Blowing machine

A drop of the glass melt comes from the withdrawal point ("feeder") and is shaped into a tablet (plate) by means of a preform and pressing core. Selection of the tool depends on the weight of the product (300 - 1000 g); the thickness of the walls and the bottom of the product; the number of cuts, and the connection between the machine and the withdrawal from the furnace. Resilient station moves the glass tablet from preform on the workbench. Work ring is attached to the upper part of the working position, and after a certain time, it presses the tablet against the bottom ring, thus starting the preforming. The machine rotates and production takes place according to the following positions: preblowing, cooling, closing the models, venting, blow moulding, sticking, blowing out, opening the models, cooling, removal and transportation in cold storage room.

Preblowing forms glass cylinder out of the tablet; by de-airing, the air in the cylinder is removed, thereby narrowing the inside of the cylinder. By blowing, the glass is slowly formed, and blowing out is stronger for the corresponding blowing of glass.

Models for designing glassware are made from the glass cast (grey cast with added carbon and coatings). Before use, models are heated in soft water to a temperature of 80°C, in order to quickly facilitate an adequate quality of the products. Durability of coating is a one to two hours, depending on the product. Before they close, models are cooled with soft water with added detergent.

Water is used to cool preforms and core with soft water from the closed cooling system. In the case of increased hardness of the water, limescale begins to form, which acts as an insulator of heat, which affects the quality of the product.

The gas heats the bottom of the product for sticking with legs (from the stem press). Coordination of all positions in a blowing machine is experiential according to the glass melt, the type of product and withdrawal from the oven.

4.3.2 Stem press

80 mm below the surface of the melt in the chamber is a platinum tube, after which the glass flows to the nozzle, the dimensions of which depend on the weight of the product (80 - 300 g) and the speed of the machine. Through the nozzle, the melt flows to the carrier of the plate, and the weight control is automatic. Pouring is followed by cutting of the glass; the machine shifts for one position under the compression core and a work ring. The model closes, supports the workbench, and the pedestal gets pushed in the model. A pressing core and a work ring, with certain pressure (set according to glass and product), press the carrier of the plate and model, and eject the product. After the set time, the compression is retained in order to prevent deformation of the product. Models are heated using gas at operating temperature of 320-480°C.

The next position is a post-compression with the help of compressed air, which in turn depends on the glass, the product and the speed of the machine. The air of the pressure of 6 bars travels between the product and the model, so that the glass is cooled down and the shape of the product is maintained.

Next, firing with a mixture of hydrogen and oxygen welds the edge of the plate and the cut of the scissors. Then, the models open, and the products cool at three positions with compressed air or a fan, and are withdrawed from the machine.

The last position is reheating and closure of models before pouring of glass. Models are made from stainless steel so they do not get stained. They are preheated to a working temperature of 400°C.

4.3.3 Glass gatherer – ROB 3

Glass gatherer ROB-3 is used for the collection of 300-4000 g glass melt mass, Melt accumulates on the ceramic gathering balls with a diameter of 70 -180 mm; gathering metal ball, coated with fireclay, can also be used for gathering. A gathering ball is attached to the cradle, via which turns and tilts, needed for accumulation of the melt, are transferred.

Melt gatherer has three motors to move the cradle and balls in the required positions: the main stand, additional stand, and angle stand. If the angle is set close to 0°, an additional stand moves in the same plane as the primary and their values are added together. If the angle is bigger (90°), an additional stand moves in a vertical plane and is called “the rise”.

Apart from the three motors for moving, the robot also has a motor for the control of the rotational speed of the gathering ball.

Proper weight and shape of the drop is achieved by optimal gathering ball, the temperature of the glass melt and with the correct setting of motions and rotations in separate positions.

ROB-3 has the following programmable operating positions:

● on the worksite: the basic position, sinking of the ball, lift of the ball, separation from the melt;
● outside the worksite: the angular point, turn and stop, shift towards the model, moving forward, descend, move towards the shears (cutting above the model), a special feature, move towards to the shears (above the sink), a corner point.

It is necessary to determine the coordinates with the programming for each position: for the main stand, additional stand, spaces, angle, rotations and various security updates. Glass gatherer supplies the hydraulic press with the glass melt (automatically or manually), or it can fill centrifuge or "Italian" (filled hydraulic press).

When the robot brings the drop of the melt into the mould, scissors cut the melt and after a set time, the press turns in the position for compression. With this process, we can set the duration of time and the pressure of pressing or containment. After the pressing is completed the press turns to the next position, where the product is cooled, if necessary. At the same time, the next model in the press is placed in the position of pouring the glass melt. In addition to these positions, there is the position of abstraction. With the help of vacuum abstraction device the product is withdrawn from the mould.

When the product is put outside the model, it is transported by the abstraction belt to the device for firing, from where it goes into the cold store.
In addition to gatherer ROB-3, gatherer ROB-4 is also used; the difference between them lies in the fact that ROB-4 can supply two machines at the same time, which allows greater mass of the product, and the movement in the direction of all three axes. Additionally, ROG-4 has extra programs for substitution of the gathering ball, dropping the melt into the cellar, and other improvements.

5 FURNACES FOR COOLING OF GLASS – KILNS

5.1. KILNS

When a glass product is complete and begins to cool, its surface develops temperature differences because the entire product's surface does not cool down equally At first, the surface quickly cools and contracts, yet the warmer interior is preventing it. Later when the product's interior begins to cool, its desire to contract is prevented by its already chilled exterior. Therefore, tensions appear throughout the product which may cause sudden breakage of the product as early as in the annealing/cooling furnace/kiln or after grinding or polishing. The occurrence that appears during the cooling of glassware can be explained as follows: When the glass is hot, its particles are sufficiently flexible and can thus be moved between each other. If the glass if warm for a sufficient amount of time, the particles also obtain sufficient time to arrange in positions that are most favourable to the strength of the glass (itself).

The particles are not given the option of arriving to their designated places if the glass product is rapidly cooled. Thus, the structure of the glass becomes frozen. Tensions appear due to the structure's disorderliness. During the annealing process we must heat the glass product to reach a high enough temperature to enable flexibility and provide the product with enough time for its particles to reach their designated places.

The problem of tension is solved by appropriate annealing (controlled cooling). The latter should be conducted in as slow a manner as possible for the temperature to equalize throughout the product. Of course, the aforementioned process is connected to economic efficiency, which forces us into a compromise between slower cooling for alleviating tensions that could cause the product to break, and a faster cooling process to increase production.

The products can be cooled in (tunnel band furnaces) used for annealing, where they travel on a tape, or in (cold stores) (such as tempirka, which is used to cool the products that need greater amount of time for proper cooling). In both cases, appropriate temperature regimes must be set. They depend on the composition of the glass, thickness of walls, and in different thickness of the individual parts of the product. The composition of the glass gives the information about the temperatures for slowly cooling the glass; and its thickness is used to calculate its cooling rate (that's the speed of the belt in cold storage rooms with belts, and time for stationary ones). The product must first be heated to the annealing temperature, and then held at that temperature for approx. 15 minutes; then slowly cool it in a suitable temperature range, the product can be cooled down faster below the tension's temperature and with no fear of the input of tension. The most important parts of the cooling curve are the interval at a maximum temperature and interval of slow cooling. The usual practice is that the temperature at the cold storage does not vary depending on the type of product; the only thing that changes is the time of annealing o the speed of the belt. Too high temperatures can cause deformation of the product, but if they are too low, the product does not anneal and the risk of fracturing occurs. Where the different parts of the product heavily vary in thickness, we must always adjust to the thickest part. If there is a situation that various products are inserted on the belt, we adjust the speed of the belt to products that take the longest to cool down. It does not make sense to cool down very thick products in cold storages with belts. The openness or closeness of the product is also important (full bowl without caps, narrow vases with a cap ...). The more the product is open, the easier it is to transfer the heat, which makes annealing faster, and vice versa. When we want to accelerate the speed of the belt, we must always ensure that the products are held at the annealing i.e. the highest temperature long enough, despite the speed; moreover, the first stage of cooling has to be long enough. The manager, who is adjusting the speed of the belt according to the speed of production and type of the product, is responsible for setting of the temperature regime in the cold storages. When there is a change of glass' recipe, the instructions for a new regime come from technologist, who determines the suitable temperature on the basis of the composition of the glass.

5.2. Control of cooling process

The tension's content in the glass product can be checked by using polarized light with s polariscope. The product that is properly annealed and does not contain any tension shows no colouring (sometimes warm colours are present – brown and red in the thicker parts of the product, but don't cause breakage). A product that contains tension is coloured with cool colours (blue, green) under the polarized light.

● a good indicator of the tension can also be the location of the breaking in the product. If most of the products break at their thickest part, or in transition areas of different thicknesses, that is the cause for improper cooling.

● if products break only in thin sections, and the whole products have no visible tensions on polariscope, we need to find the reason for the fracture before the entry into the cold storage. Often, a fracture can be caused due to the chilling of the product before it enters the cold storage, or because of repeated temperature changes in the design phase. *An example: with products, manufactured in a vacuum gatherer, fracture often occurs on the top of the product. This is due to the blowing pipes, which after they are made, get spilled with water in order to facilitate reflection; this leads to of micro-cracks on the top of the glass, which later cause the fracture. In the case of taps with thread of such a fracture usually it is not. Pipes with screw threads usually do not have such fractures. An example: jugs and products with an additional coating (pripikanje) on the glass base are also problematic. Where cool and warn surfaces come in contact, the tensions, which cause fractures, are created. All these products are even more sensitive to the cooling rate.*

If there are fractures in the majority of products, we have to check the cold storage's temperature setting and cold storage immediately. In case of breaking of small quantity of products, it is necessary to assess where an improper input of tension came from.

6. QUALITY CONTROL

6.1. Definition of quality

Different sources define the concept of quality in different ways. One of more practical definitions of quality is: ˝**in accordance with requirements**˝.

Due to the fact that glass products are mostly of manual production, it is difficult to determine exact and precise requirements. Therefore, when we talk about the quality of the product, we always define the ″maximum allowed″.

According to ISO 9001 standard:

Quality is the degree on which a set of unique characteristics fulfils some requirements.

A requirement is the demand or expectation of the final customer. Requirements can be expressed generally and are self-granted (e.g. It goes without saying that products for storing liquids must not be porous) or mandatorily. Mandatory requirements must be unambiguously set (dimensions, designs on the products, etc.) and must be communicated in understandable terms to operators (production). They must be checked through the process (mid-phase control) and at the end (final control). All products that do not meet the requirements have to be eliminated.

A characteristic is a feature that defines each product and can be examined.

6.2.Characteristics

The quality of our products is determined by the following characteristics:

1. **Quality of the glass:** we define it by the colour of the glass, the quantity and size of bubbles and pebbles, "vind"
2. **The shape and dimensions of the product**
3. **The pattern on the product** (in structure, sanded, sandblasted, painted): layout, the pattern dimensions (width, height, angle of sharpening), the composition of the pattern
4. **Functionality of the product**
5. **Surface of the product**
6. **Furnishings of the product**

The requirements must be unambiguously set for each characteristic. Anything that deviates from the set requirements is considered as an error and indicates that the product is not suitable for the customer – and is eliminated. Below, typical characteristics and consequently, the errors occurring in the glass industry, such as ours, are listed and described.

6.2.1. Quality of the glass

In the process of melting and forming of glass (compound preparation, transportation, melting, hot shaping) various flaws may occur in the glass. Quality of the glass is defined by the maximum permitted number and size of flaws. Flaws that may occur include: pebbles, bubbles and vind.

Pebbles

They are solid bright dots in the product, and they usually appear due to irregularities in the preparation of the mixture (white dots), crystallization in the process of melting (dots with glassy look), the collapse of fireproof materials from which the furnace is built (white, brown and red dots), or a drop of the axle of a mixer in the worksite (dark dots). These errors occur locally in some products, but when it comes to non-melted mixture of glass, the stones appear as tiny dots at all worksites and in all products, usually accompanied by tiny bubbles and vind.

A pebble or an inclusion in the glass can also occur as a result of improper work. These are dark or black in colour, and are the result of metal fragments, the source of which may include:

- rust from the blow pipe,
- inadequate material for the blow pipe,
- rusting of the pipe's cup for vacuum gatherers (they may occur only after the polishing)
- bright pebbles may be a result of sticking of a fragment of the glass with the product

Bubbles

Bubbles, usually small and dispersed throughout the product, which are regarded as flaws in the glass are; a possible result of improper melting of the glass melt, in which case bubbles appear at the same time and on all products, and inaccurate work; a reaction if the mixers at the worksites are either too old or too fast; or a consequence of so called reboil process. Bubbles are considered as a flaw if they are bigger that 1mm, dispersed locally or in a group in a certain area of the product.

Vind

It appears as lines or areas in glass with different refraction of light as the surrounding glass.

It is considered a flaw on the glass because of:

- new furnace – influence of glass' reaction and fireproof material, also with old ovens
- errors with the preparation of the mixture,
- improper temperature regime of melting,
- a sudden increase of withdrawal,
- variations in withdrawal.

Vind may occur as a result of work error because of:

- gathering on old cooled glass,
- gathering at the edge of the worksite,
- incorrect position of a fireclay ring in a pot, or
- dirty surface of the glass in the pot.

The latter differs from the one that is considered as a flaw by the fact that it occurs only at some working stations and not across the whole furnace or at one worksite in all conditions.

Vind is always present in a pot and at worksite, but can be avoided with the correct gathering.

Colour

The colour is compared with the measurement standards. Glass may be coloured due to the presence of metal oxides that are present in the raw materials, shards, or they enter the furnace subsequently (a drop of various metal particles into the furnace - from level indicator, etc.). Glass usually it turns green or blue.

Errors in cooling

In the process of hot moulding, tensions appear throughout the product. They may trigger damage of the product that is already in the kiln; failure later in the process of sharpening and polishing; or even when the product is used. Therefore, it is very important that the products are properly cooled down and that cooling process is monitored daily.

Annealing of the tension can be measured with the help of polarized light on polariscope. This is measured daily by taking one sample out of every cold storage and checking it on polariscope. For an extra testing and testing of colour products, specific shock test is run in a laboratory.

6.2.2. Shape and dimensions of the product

The shape and dimensions of the product are very important characteristics, and are the basis for the production of the product. They must be precisely defined. In glassmaking, the dimensions are determined in the drawing of the product.

Dimensions must be clearly marked in the drawing. Depending on the type of product, of course, they vary: height, upper diameter, bottom diameter, diameter of the plate, thickness of the stem, edge thickness, wall thickness, etc. Meaning, the product is in accordance with the requirements when it is within the tolerance space. An example: The height of product in the drawing is 187 ± 2 mm. The product may be 185 to 189 mm high. Everything that is below or above this level is not in line with the requirements and must be ejected. In the glass industry, one important dimension is also weight of the product. Specified tolerance of weight for manual production is ± 15% of the median weight; and for mechanical production ± 10% of the median weight.

In order to avoid large amounts of ejection, it is extremely important that dimensions are checked at the hot part of the production.