Impact of Glass Cullet on the Consumption of Energy and Environment in the Production of Glass Packaging Material

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Abstract: - Glass is a very widespread packaging material that is used every day (e.g. bottles for water, for children's food, juices, beer, wine, glass jars for food preservation, etc.). The production of glass containers requires large amounts of raw materials, such as: silica sand, soda, dolomite, etc., and substantial quantities of energy since the production cycle is extremely energy-demanding. The aim of this paper is to present how the usage of waste glass in the production of glass packaging saves the raw materials for the production of glass, reduces energy necessary for the exploitation and melting of raw materials, thus preserving also the unrenewable sources of energy such as natural gas, fuel oil or electricity, which are mostly used as energy sources in the production of glass packaging. Besides, since fewer energy sources are used, the emission of harmful gases (CO_2, NO_X, particulates, etc.) into the environment is lower. By using glass cullet, which is obtained by waste glass recycling, the quantity of municipal waste is reduced, and in this way the environment is preserved as well.

Key-Words: - cullet, energy savings, glass packaging, glass recycling, waste management

1 Introduction

Glass containers represent permanent and high-quality packaging material which we use every day. It is used to produce containers for cooling drinks, mineral water, wine, beer, spirits, children's food, jars for food preservation, etc. The containers can be of different colours: green, amber, flint-transparent, blue, etc.

The advantages of using glass as a packaging materials are [1]:

- chemical inertness,
- ability to be recycled,
- non-polluting nature on ultimate disposal,
- ability to be manufactured from abundant raw materials,
- UV filtration (amber and green glass), optical and transparency qualities,
- low gas permeability and
- high intrinsic strength.

The production of glass packaging material is a very demanding and complex production procedure which requires the investment of large amounts of energy which includes heating, melting and cooling of glass [2]. This energy can be reduced by using glass cullet in the mixture [3, 4].

Glass cullet in the glass mixture can be used theoretically 100 %, since glass can be 100 % recycled, i.e. from 100 kg of glass cullet 100 kg of glass containers can be produced. In practice these values of glass cullet are somewhat lower depending on the colour of the glass in which the glass containers are produced, and the requirements that each glass container has to satisfy.

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For easier understanding of the impact of glass cullet on the energy and the environment in the production of glass packaging, further in the text the raw materials will be described that are used in the production of glass, and the requirements they have to satisfy. The description will also include the very procedure of obtaining glass (batching, melting, fining, forming), and eventually the advantages will be given for the usage of glass cullet (recycled glass) in the production of glass packaging, and the requirements it has to fulfil in order to be used as high-quality raw material, and the resulting impact on the environment.

2 Raw materials for glass production

The raw materials used for the production of glass have constant chemical composition, optimal granulation, minimal humidity percentage, and minimal content of harmful additions [5].

The raw materials are silica sand, soda, calcite, dolomite (raw material of calcium carbonate and magnesium carbonate), and feldspars (raw materials in form of fine sand). Aluminium trihydrate, sodium sulphate, chromite, coal, etc. are used as auxiliary raw materials which are used as dyes and clarifiers of the melt (Fig. 1).

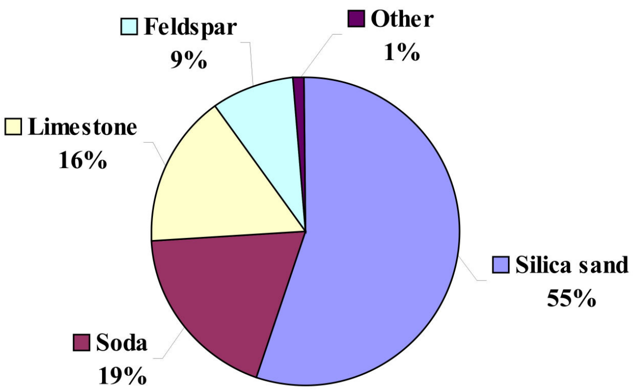

Fig. 1. Raw materials for container glass production

Silicon dioxide (SiO_2) is the main ingredient in the production of glass, the most of it being in silica sand, which is at the same time also the main raw material for the production of glass. To obtain glass its ingredients (raw materials) need to be heated to a very high temperature of ca. 1600 °C. Since the melting temperature of silicon dioxide is very high, oxidants are added that reduce the melting temperature, thus making the procedure of obtaining glass melt easier and commercially time-acceptable. The oxidants used are sodium oxide (Na_2O), aluminium oxide (Al_2O_3), potassium oxide (K_2O), boron oxide (B_2O_3), calcium oxide (CaO). The addition of one or several of these oxides reduces the melt viscosity, thus making the production of glass containers easier [6].

It is necessary to match the particle size of the raw materials (Table 1) as much as possible to allow trouble-free melting.

Table 1. Typical raw materials specifications for container glass production [7]

Ingredient	Chemical composition (weight %)	Tolerance (weight %)	Grain size distribution
Quartz sand (for flint glass)	$SiO_2 > 99.0$	± 0.2	> 0.84 mm – 0 %
	$Fe_2O_3 < 0.030$	± 0.01	> 0.6 mm – 1 %
	$Cr_2O_3 < 0.0002$		< 0.125 mm – 1 %
	$Al_2O_3 < 0.3$	± 0.05	
Nepheline syenite	$Al_2O_3 > 22.0$	± 0.5	> 0.84 mm – 0 %
	$SiO_2 < 62.0$		> 0.5 mm – 3.5 %
	Alkali > 0.13	± 0.5	< 0.1 mm – 20 %
	$Fe_2O_3 < 0.10$	± 0.05	
Limestone and dolomite	$CaO+MgO > 54.0$		> 3.15 mm – 0 %
	$Al_2O_3 < 0.3$	± 0.1	> 2.0 mm – 10 %
	$Fe_2O_3 < 0.10$	± 0.005	< 0.1 mm – 20 %
Soda ash	$Na_2CO_3 > 99.0$		> 1.19 mm – 0 %
	$NaCl < 0.15$		> 0.59 mm – 3 %
	$Fe_2O_3 < 0.001$		< 0.074 mm – 3 %

Glass cullet is classified also as raw material for the production of glass, and it can be represented by high share in the glass mixture. The share of glass cullet in the mixture depends on the colour of glass that is produced, the quality of glass cullet available, the design of glass furnace, etc. The usage of glass cullet saves raw materials and the environment, at the same time reducing the energy necessary for mixture melting.

3 Operations for glass manufacturing

Four primary operations for glass manufacturing are: batching, melting, fining and forming [1]. Batching, melting and fining operations are common to all glass manufacturing processes with some variations according to the glass furnace type.

3.1 Batching

The preparation of the mixture is a process in which the raw materials are mixed in certain shares depending on the type of glass that is produced. This process includes the transport of raw materials, including also glass cullet. Every raw material is weighed according to a precisely defined specification and delivered to compound mixers where all these raw materials are well mixed together and wetted, in order to achieve maximal homogeneity of the mixture. The melting and the glass quality depend largely on the homogeneity and humidity of the mixture. Using belt conveyors the mixture is delivered to the glass furnace storage silos [5].

3.2 Melting
Using a dosing feeder compound is fed into the glass furnace, with temperatures capable of exceeding 1700 °C. The compound floats on the surface of the glass already in the glass furnace and gradually melts into the desired glass composition.

Melting consists of complex chemical and physical phenomena. The glass melting process is an energy intensive process which means that the manufacture of 1 kg of container glass requires 3.5 - 5 MJ/kg of energy, mainly in the form of natural gas, fuel oil or electricity [1].

The production of glass containers from raw materials requires about 0.65 t of silica sand, 0.22 t of soda, 0.19 t of limestone, 0.11 t of feldspar per ton of glass. These input raw materials account for a total of 1.17 t per ton of glass. These 0.17 t are released to the highest extent as gas CO_2 in the phase of melting the raw materials [3]. These large volumes of gas help in the fining of the glass.

Sand and sodium carbonate grains react as follows [1]:

$$SiO_2 + Na_2CO_3 \rightarrow Na_2SiO_3 + CO_2$$

While calcium carbonate transform as

$$CaCO_3 \rightarrow CaO + CO_2$$

Glass furnace can be divided into those heated electrically and those heated primarily by combustion. Often electrical heating is used in combination with fuel firing (so-called electric boost) to improve heating uniformity and melt efficiency and to reduce gas consumption and emissions that is a matter of prime importance in the context of global climate changes [1].

Typical container tanks have melting areas of 60 - 180 m^2, deliver 100 - 500 tons/day, and exhibit economies of scale with regard to their energy consumption/ton of product.

Most furnaces are combustion heated which can be further divided according to the method used to recover exhaust waste heat and the way fuel is burnt (with air or oxygen). Oxygen fuel technology offers several advantages even though requiring pure oxygen. Regenerators can be avoided, eliminating furnace superstructures. Heat recovery is of utmost importance since only 10 % is used for the melt while 70 % is lost through exhaust. Exhaust waste heat recovery is performed using regenerators that alternately store and recover heat, the shift being about every 20 minutes.

The melting and refining stage accounts for 55 - 65 % of the energy used in glass production and has become the focus of industry conservation efforts. Technologies such as electric boosting, better refractories, oxygen enriched combustion air, and chemical boosting could reduce the energy use in this stage by 8 - 37 % [3].

3.3 Fining
Glass fining produces a molten glass that is uniform in terms of composition and temperature, and bubble free.

Fortunately, large volumes of gas are rejected from the raw materials before transformation in a glass melt and this helps homogenize the melt considerably. Before glass delivery, bubbles have to be eliminated. Bubbles contain trapped air (oxygen, nitrogen) and decomposition products of the raw materials, mainly carbon dioxide. Large bubbles rise to the top of the melt and participate in melt homogenization. In contrast, small bubbles would not eliminate because of increasing required time as their size diminishes [1].

$$2Na_2SO_4 \rightarrow 2Na_2O + O_2 + 2SO_2$$

These operations are accelerated by fining agents that are introduced in small quantities in the batch and hence in the glass melt. Fining agents like arsenic and antimony increase dissolution rates. Sodium or calcium sulphate fix on small bubbles that are favourable nucleation sites for fining agents and release gas, increasing the related bubble size and this hence facilitates their elimination.

The temperature of the glass delivered from the melting furnace, and its composition, has to be regulated with extreme care [1].

3.4 Forming of glass containers
When glass moves from the melting tank to the forming machine, the glass has the appearance of a thick and redorange syrup.

Thus formed glass flow is cut into single gobs using the shears which act in accordance with the plunger of the feeder mechanism and glass container producing machine. These glass gobs are distributed via the gob distributor and grooves to certain sections of the blank mould side of the glass container producing machine. In the blank mould side of the glass container producing machine a parison is formed, which is then transferred to the mould side of the glass container producing machine in which this parison is blown in the mould thus acquiring its final form [5].

From the mould side of the glass container producing machine the finished glass containers, after the first visual control, are transported to the hot refining unit and further to the tempering furnace. Coating technology is routinely used to protect the external surface of the containers. Firstly, coatings are deposited at elevated temperatures (so-called hot-end coatings (HECs) ~ 500 °C). HECs are usually 10 nm of a hard ceramic material. These materials are fabricated immediately after forming when the container surface is still at an elevated temperature. Hence, these coatings offer good adhesion and strength. These reduce further contact damage [5].

Then containers are sent through a controlled cooling process, known as annealing, which allows containers to cool down to room temperature in a stress-free condition.

What follows is the optical, mechanical, and electronic testing of the produced glass containers automatically removing those with cracks, inserts, deformations and other defects (Fig. 2).

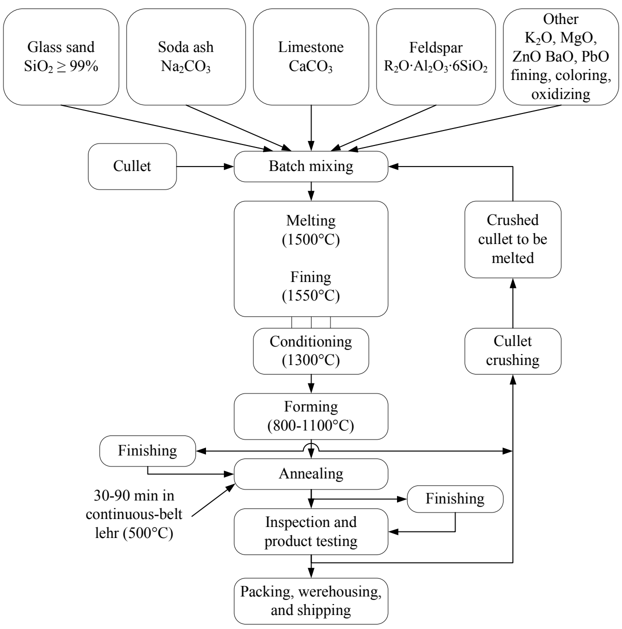

Fig. 2. Glass manufacture [6]

4 Glass cullet

In the production of glass packaging not all of the produced containers are of satisfactory quality (inclusions in the bottle, defects on the bottlenecks, poor distribution of glass, etc.), and cannot be delivered to the customer. All these rejected glass containers (about 5 – 8 % out of the total produced) are collected and crushed, and reused as raw material for the production of glass called glass cullet.

Another method of collecting glass cullet is to collect the glass packaging from the market. The main objective is to collect waste glass packaging as much as possible in order to recycle it and to obtain the glass cullet. Glass cullet is a high-value raw material since its usage results in:

- reduction of consumption of raw materials (silica sand, soda, dolomite, etc.),
- reduction of CO_2 emission that is generated while melting the raw materials,
- prolongation of the service-life of the glass furnace even up to 30 %, because of the lower melting temperature of glass cullet than of the raw materials,
- reduction in the consumption of energy sources (usually: land gas, petroleum) for melting the raw materials, which means also emissions of NO_x, SO_2 and particulates into the environment.
- 100 % recyclable, out of 100 kg of glass cullet 100 kg of glass containers can be produced.

The quantity of glass cullet that is used in the production process varies from glass plant to glass plant. It primarily depends on the quantities of available cullet, purity and quality of cullet, whether it has been sorted regarding colours or mixed.

All the collected waste glass packaging from the customers passes through the recycling plant in order to obtain useful raw materials for the production of new glass containers – glass cullet. In the recycling plant the impurities have to be removed from the collected glass, such as: ceramics, stones, china, iron and non-ferrous metals (aluminium, lead), quartz, glass ceramics, opal, and organic waste (paper, plastic, food rests).

The impact of these impurities in the recycled glass is the following [7]:

- ceramic materials like stones and chinaware (should be < 10 - 50 g/ton in recycled cullet from collection banks), being hardly fusible or which hardly dissolve in the molten glass, and non-ferro metals (Al, Pb, should be < 1 - 5 g/ton in recycled cullet from collection banks). Alumina particles (Al_2O_3) larger than 1 to 1.5 mm might not completely dissolve in the glass melt in the glass melting furnance.
- metalic aluminum in the glass melt reduces SiO_2 into Si – globules (Si – spherically shaped

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due to high interface tension) which have a different expansion coefficient.
- other glass types like vitreous silica and glass ceramics, generally occur less often as impurity, but if present will also create stress-concentrations within the glass product.
- the organic components in the recycling glass can only be separated to a certain extent. These impurities have a strong reducing effect on the glass melt. Consequently the redo state of the melt is decreased which may cause fining problems and color variations in the glass.

After having removed these impurities the glass cullet needs to be sorted according to colours, which is done by a device for colour separation (colour separator) at the end of the recycling procedure. It is important to separate glass cullet per colours, since the main colours for the production of glass packaging are green, amber and flint. For the production of flint glass packaging only flint glass cullet can be used, whereas for the production in green or amber mixed cullet can be used. The higher the purity of the cullet (same colour) the greater share of it can be used in the production. The share of glass cullet in the glass mixture can be even more than 90 %, the usual values for green glass are more than 80 %, for amber around 60 %, whereas for flint about 45 – 50 % [7]. For flint glass the glass cullet is used to a lesser extent in relation to coloured glass since the Fe and Cr content in flint glass should be very low, since it influences greatly the colour of the glass (Table 2).

Table 2. Typical Fe- and Cr- contents of different types of container glass [7]

Glass color	Fe-content as wt % Fe_2O_3	Cr-content as wt % Cr_2O_3
white	0.05	< 0.001
green	0.3 – 0.5	0.25
amber	0.2 – 0.4	< 0.04

4.1 Energy savings by glass recycling

The total energy consumption for the production of container glass can be divided in the energy requirement for [7]:

1. extraction, mining or synthesis, processing and transportation of raw materials;
2. melting and fining process;
3. forming, cooling and post-treatment (applying coatings, inspection, packaging)

By increasing the amount of foreign (external recycling) cullet in the raw materials, energy can be saved in the first two indicated areas: the raw material processing and the melting proces.

The production of glass by using glass cullet saves energy, since remelting of cullet requires no energy for endothermic fusion reactions, shortening also the time duration of melting, thus increasing the furnace capacity (Table 3) [7].

Table 3. Example of energy savings (in kJ/kg glass) due to recycled cullet for container glass production [7]

Theoretical energy consumption for melting soda-lime silica glass from normal batch	2550
Energy-contents of the batch decomposition gases	176
Thermal wall (conduction of heat and leakage´s) and flue gas losses	2074
Total energy consumption of a container glass furnace per kg glass (no cullet)	4800
Theoretical energy consumption for melting soda-lime silica glass from 100 % cullet	1750
Thermal wall (conduction of heat and leakage´s) and flue gas losses	1850
Total energy consumption of a container glass furnace per kg glass from cullet	3600
Energy savings for melting 100 % cullet instead of 100 % normal batch	1200

Replacement of 10 % of regular batch by cullet results nearly always in an energy savings of 2.5 % to 3.3 % (Fig. 3).

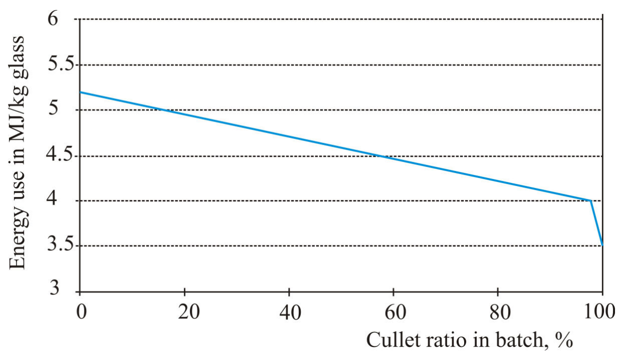

Fig. 3. Theoretical relation for specific melting energy as a function of cullet % in the batch [7]

Effects of recycling on flue gas emissions:
- reduction of NO_x: less energy, lower temperatures
- reduction of CO_2: less fuel and less carbonates in batch

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- reduction of fluorides and chlorides: lower temperatures
- effect on SO_x – and dust emissions depends on specific situation, for green glass and cullet with organic compounds it may lead to increased emissions of SO_2. Cullet should not be too fine (preferably between 10 mm - 40 mm) [7].

5 Conclusion

Glass recycling reduces the need for raw materials (silica sand, soda, dolomite, feldspar) [4, 5], and they need not be exploited from the environment. Each ton of recycled glass preserves 1.17 tons of raw materials and a large amount of energy which is necessary to heat the raw materials to the temperature higher than 1600 °C in order to obtain glass melt from which glass containers are made.

The recycling of waste glass packaging is thus claimed to preserve the environment, since the raw materials are not exploited, energy is saved, the emission of CO_2, NO_x, SO_2 particles is reduced because less heat energy which is usually obtained from land gas and electrical energy is needed for the melting of glass cullet than for obtaining of glass melt from raw materials.

In the future more work should be done in the education of the public in order to increase even more the rate of recycling glass packaging, i.e. to follow the examples of Sweden, Switzerland, Austria, Belgium and the Netherlands, the leading countries in the recycling of glass packaging with return rates greater than 90 % [8]. It is also necessary to work on the development of new technologies such as electric boosting, better refractories, oxygen enriched by combustion air, chemical boosting, etc.

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