ECOLOGICAL QUANTIFICATION METHODOLOGIES FOR GLASS MANUFACTURING AND PROCESSING INDUSTRY

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Environmental impact analysis for domestic and special glass manufacturing processes and techniques is necessary for the analysis of operation of the existing systems, to implement the most effective measures for reducing environmental impact and in order to establish "the right ecologic", in case of implementing new technologies. It completes a complex analysis: economic and energetic of the industrial costs in the glass industry, in order to establish main solutions to increase energy efficiency and implementation of clean technologies in this area.

Keywords: glass, environment, emission, analysis

1. Introduction

The environmental impact analysis of the domestic glass manufacturing and processing technological processes is necessary for:

- Analyzing the operation of the already existing systems in order to apply the most efficient measures to reduce environmental impact;
- Establishing the "ecological optimum", in the case of the new technology implementation.

This comes to complete a complex energy, ecological and economic analysis of the industrial processes from the glass industry in order to establish the priority solutions for increasing energy efficiency and implementing certain clean technologies in this field.

A complete analysis of the environmental impact presupposes the implementation of the following methodological stages:

1. Selection of the most adequate environmental analysis methodologies considering both the data available in the analyzed case and the scope of

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the analysis, the importance of the environmental aspects in the analyzed context;

2. Establishment of the general and individualized hypotheses in order to apply the environmental impact analysis to the analyzed environment;
3. Development of a data base as comprehensive as possible, necessary for the development of the environmental analysis from the point of view of the established hypothesis;
4. Determination of the emissions generated by the analyzed processes;
5. Establishment and calculation of the impact indicators that are considered significant in the case of each analyzed system;
6. Analysis and comparison of the resulting impact indicators on the basis of the ecological analysis that has been carried out by means of the internal and international norms and regulations in force for the typology of the installations taken into consideration.

2. Methodology for calculating the greenhouse gas emissions resulting from the domestic glass manufacturing process

In the glass manufacturing installations the sources of CO_2 emissions are:

a) Decomposition of the alkaline and alkaline earth carbonates during raw material melting;
b) Traditional fossil fuels;
c) Raw materials and alternative fossil fuels;
d) Fuels from biomass (biomass wastes);
e) Other fuels;
f) Carbon additives, including coke and coal dust;
g) Flue gas cleaning

Three methods were devoloped in order to calculate the CO_2 emissions resulting from the domestic glass manufacturing technology, namely:

Method A - determination of CO_2 emissions by carrying out the mass balance;

Method B - determination of CO_2 emissions by means of the analysis of the gases from the glass melting furnace;

Method C - determination of CO_2 emissions by applying certain general emission factors

2.1. Method A - Determination of the CO_2 emissions by means of the mass balance

- Calculation of the process emissions (CO_2 emissions resulting from the melting process)

$$Q_{CO2}^{mp} = FE_{mp} \times Q_{st} \tag{1}$$

Where: FE_{mp} - CO_2 emission factor of the raw material (determined on the basis of the stoichiometric chemical reactions), [kg CO_2/t glass];

Q_{st} – glass output [t]

- Calculation of the combustion emissions (CO_2 emissions resulting from the fuel combustion)

$$Q_{CO2}^{comb.} = FE_{comb} \times P_{comb} \times Q_{comb} \tag{2}$$

Where: FE_{comb} - CO_2 emission factor of the fuel (determined on the basis of the elementary /chromatographic analysis), [t/TJ];

P_{comb} – net calorific power of the fuel, [MJ/Nm^3]

Q_{comb} – fuel consumption, [Nm^3/h]

- The total CO_2 emissions are obtained by summing up the process emissions with the combustion ones

$$Q_{CO2} = Q_{CO2}^{mp} + Q_{CO2}^{comb} \tag{3}$$

2.2. Method B - Determination of the CO2 emissions by analyzing the gases from the glass melting furnace

When measurements for determining the concentrations of the flue gases resulting from the melting furnace, the fuel flow, flue gas flow and temperature and flue gas temperature are made, the CO_2 amount can be calculated on the basis of the obtained results by means of the following relation:

$$Q_{CO2}^{ga} = Q_{ga} \times c_{CO2} \times k_1 \tag{4}$$

Where: Q_{ga} - gas flow in the melting furnace, [m^3/h];

c_{CO2} - CO_2 volume concentration, [%];

k_1 - correction coefficient that depends on the temperature in the melting furnace, gas characteristics [kg/m^3]

The correction of the CO_2 emissions resulting from the incomplete burning of carbon. Thus, the CO emission will be calculated by means of the relation:

$$Q_{CO}^{ga} = Q_{ga} \times c_{CO} \times k_2 \tag{5}$$

Where: c_{CO} - CO volume concentration, [%];
k_2 - correction coefficient that depends on the temperature in the melting furnace, volume and molar mass [kg/m^3]

The CO_2 emissions (from the incomplete burning) will be corrected by means of the relation below:

$$Q_{CO2}^{corectat} = Q_{CO2}^{ga} + Q_{CO2}^{nears} \tag{6}$$

2.3. Method C - Determination of the CO_2 emissions by means of the general emission factors

The emission factors recommended by the BREF-Glass Industry Guide, CORINAIR methodology, Decision 2007/589/EC for establishing the guidelines for the monitoring and reporting of the GHG emissions can be used according to the Directive 2003/87EC of the European Parliament and of the Council)

- *Calculation of the process emissions:*

$$Q_{CO2}^{mp} = \sum FE_{mp} \times M_{mp} \tag{7}$$

Where:

Q_{CO2}^{mp} - CO_2 emissions resulting from the melting of the raw materials,[t CO_2/h];

FE_{mp} - Emission factors specific to each raw material, recommended by the national and international guides in force, [tCO_2/t carbonate];

M_{mp} - Amount of raw material fed into the furnace, [t]

- *Calculation of the combustion emissions*

$$Q_{CO2}^{comb.} = FE_{comb} \times P_{comb} \times Q_{comb} \times t \tag{8}$$

Where:

Q_{CO2}^{comb} - CO_2 emissions resulting from fuel burning, [t CO_2/h];

FE_{comb} - CO_2 fuel emission factor (recommended in the GHG emission monitoring and reporting guides), [t/TJ];

P_{comb} – net calorific power of the fuel, [MJ/Nm^3];

Q_{comb} – fuel consumption, [Nm^3/h];

- *Calculation of the total CO_2 emissions* will be made by means of the following relation:

$$Q_{CO2} = Q_{CO2}^{mp} + Q_{CO2}^{comb} \tag{9}$$

3. Case analysis relating to the application of the methodologies for the determination of the CO_2 emissions from a domestic glass melting furnace

The selected glass melting furnace is of the U-shaped flame tank furnace type for the automatic forming of the domestic glass. CO_2 emissions resulting from the domestic glass manufacturing technology by means of the analyzed furnace were calculated by means of the three aboved methods.

A. Determination of the CO_2 emissions by carrying out a mass balance

The glass produced by means of the selected technology has the following oxide composition (table 1):

Table 1

Oxide composition

Component	%
SiO_2	51.17
Al_2O_3	0.91
CaO	4.55
MgO	2.8
Na_2O	10.08
K_2O	0.35
Sb_2O_3	0.14
Cullet	30

In order to obtain the above mentioned oxidic recipe the following raw material amounts have been used (table 2):

Table 2

Raw materials

Raw material	Amount (kg)	Losses (kg)
Sand	51.17	0
Aluminum Hydroxide - $Al(OH)_3$	1.39	0.48
Dolomite - $CaCO_3.MgCO_3$	12.96	6.19
Lime - $CaCO_3$	1.09	0.48
Sodium carbonate - Na_2CO_3	16.04	6.66
Sodium nitrate - $NaNO_3$	2.3	1.46
Potassium carbonate - K_2CO_3	0.51	0.16
Antimony (stibium) oxide – Sb_2O_3	0.14	0
TOTAL	**85.6**	**15.43**

To the raw materials given above, the following are added: external cullet = 30 kg; water fed with the raw materials, as moisture = 1.28 kg. Thus, the total losses with water and decomposition gases = 16.71 kg/100 kg glass.

On the basis of the chemical reactions and of the amounts of the input raw materials the corresponding gas and water vapor amounts discharged from the melt can be calculated by means of the stoichiometric calculation. The results obtained for the selected domestic glass recipe are given in table 3:

Table 3

Domestic glass composition

Component	Amount (kg)	Volume (Nm^3)
CO_2	13.49	6.9
NO_2	0.62	0.3
NO	0.41	0.3
O_2	0.43	0.3
H_2O	1.28	2.2

The characteristics of the gaseous fuel utilized are presented in table 4:

Table 4

Characteristics of gaseous fuel

No.	Characteristic	M.U.	Value
1.	Composition		
	methane	% volume	96.96
	ethane		0.98
	propane		0.49
	i-butane		0.13
	n-butane		0.22
	i-pentane		0.01
	n-pentane		0.09
	i - hexane		0.16
	n-hexane		0.05
	i- heptane		0.04
	n - heptane		0.02
	C_{7+}		0.01
	Nitrogen		0.30
	CO_2		0.55
2.	Content of C	% mass	74.18
3.	Relative density	-	0.585
4.	Molar mass	kg/kmol	16.907
5.	Inferior calorific power	$kcal/m^3$	8813.72
6.	Emission factor	tCO_2/TJ	55.75

The results of the measurements at the domestic glass melting furnace are synthesized in table 5:

Table 5

Measurement results

No	Measurement	Symbol	M.U.	Value
1.	Duration of a cycle	τ	h	0.80
2.	Number of batches	n	bathces/24 hs	72
5.	Analysis of flue gases in the melting tank			
	- Carbon dioxide	CO_2	%	8
	- oxygen	O_2	%	6
	- carbon monoxide	CO	%	0,55
6.	Extracted glass flow	Gp	kg/h	972
7.	Flue gas flow in the melting tank		m^3/h	28000
8.	Temperature of the flue gas discharged from the melting tank	tgaBT	^0C	1470

- Total CO_2 emissions

$$Q_{CO2} = Q_{CO2}^{mp} + Q_{CO2}^{comb} = 720.9 \text{ kgCO}_2\text{/h} \quad (10)$$

B. Determination of CO_2 emissions by means of the glass melting furnace gas analysis

The corrected CO_2 emissions

$$Q_{CO2}^{corectat} = Q_{CO2}^{ga} + Q_{CO2}^{nears} = 711 \text{ kg CO}_2\text{/h} \quad (11)$$

C. Determination of the CO_2 emissions by means of the general emission factor application (Decision 2007/589/EC establishing the GHG emission monitoring and reporting guidelines according to the Directive 2003/87EC of the European Parliament and of the Council)

- CO_2 emissions resulting from the melting process

Table 6

Emission factor

Raw material	**Amount**		**Emission factor**
	(kg/100 kg glass)	**(t/h)**	**(t CO_2/t carbonate)**
CaCO3	1.09	0.0109	0.440
MgCO3	12.96	0.129	0.522
Na2CO3	16.04	0.160	0.415
K2CO3	0.51	0.005	0.318

Considering that the hourly glass production in the case of the selected application is of 1 t the values of the reported CO_2 emissions to a tonne of produced glass (gross) will be:

Process CO_2 = 140 kg CO_2/t glass
Combustion CO_2 = 590 kg CO_2/t glass
Total CO_2 = 730 kg CO_2/t glass

4. Conclusions of the obtained result analysis and comparison with the international reference values

We will present a comparison between the results obtained by applying the ecological analysis described above for the selected domestic glass recipe and the values recommended or obtained at the international level, taking as reference the norms and guidelines applied in the EU countries.Table 7 presents the values obtained for the CO_2 emissions resulting from the domestic glass manufacturing process with the composition established in the previous application, calculated by means of the developed methodology. At the same time, the values (available) in the international guides are presented.

Table 7

CO_2 emission values

Type of CO_2 emission	Developed methodology			BREF Guide - Glass Industry	CORINAIR Guide	Values obtained different countries[1)]
	Method A	Method B	Method C			
Process emissions	134.9	-	140	-	137	150
Combustion emissions	586	-	590	-	-	265
Total emissions	720.9	691	730	700	-	415

[2)] *Values obtained in different countries (e.g. Netherlands), included in the international guides and presented for comparison.*

We notice that for the total CO_2 emissions, the values obtained by applying the methodology are close to the ones recommended by the BREF-Glass Manufacturing Industry Guide. The lower value obtained by means of the technology from the Netherlands is due to the lower value of the burning emissions obtained by utilizing pollutant reduction/retention measures. Nevertheless, it is to be noted that the values obtained for the CO_2 emissions resulting from melting obtained by means of the above technology are higher (150 kg CO_2/t against 137 CORINAIR and 134.9 and 140, obtained by applying the methodology).

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