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ENERGY SAVINGS BY RECYCLING

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ABSTRACT

Glass containers are 100% recyclable, and can be repeatedly recycled. Collection and use of used glass containers in Yugoslavia are still in the initial phase. The present paper is an identification of quantities of used glass containers per inhabitant, based on a research experiment performed over a long period. The energy consumption data within the system of municipal collection of waste glass, its transportation to the special plant for crushing and preparing into batches, next phase is the transportation of the materials to the very glass container factory. The energy research includes the analysis of energy consumption in the production process per unit weight of the newly manufactured glass containers. Within the manufacturing process various percentages of participation of waste glass are applied, as compared to participation of natural (primary) raw materials - indicating the whole range: from 0 to 100 per cent.

INTRODUCTION

Glass is one of the oldest materials for packaging and keeping food, soft drinks, medications and other daily-consumed staff. Made always of natural materials, it has retained its important place in the production of packaging materials, irrespective of the occurrence of new modern materials. Owing to its origin and stability, it continues to be the best and irreplaceable packaging material in many areas.

Therefore, the per cent share of glass in municipal wastes is considerable. Volumes of crushed glass depend on the policy of managing packaging materials in individual countries, i.e. from their determination in favor of corresponding materials (that are easy for recycling, composting, etc.).

The level of using crushed glass in the production of glass packaging varies from country to country. It exceeds 50% in the EU countries, whereas in Yugoslavia it is 20-25% (Pavlovic, 1995).

USE OF CRUSHED GLASS IN GLASS PRODUCTION

Advantages of Introducing Crushed Glass in Glass Production

Reusing of glass packaging can be conducted in two ways: by reemploying used containers or by recycling the glass.

In addition to the application in glass production, crushed glass can be processed and used as construction material, in the production of façade coatings, for abrasive materials, for drainage materials, etc.

In order to have glass with a high share of crushed glass (up to 100%) melted in furnaces, the recycled material, apart from being separated by color, has to meet a number of quality requirements before melting. Use of crushed glass improves clearing of the molten mass during melting.

If the composition of crushed glass coincides with the composition of the mix, then under such conditions the resulting glass is without remarks on quality. If there are larger deviations in the composition of crushed glass, the melts provide a non-homogenous, low strength and highly brittle glass product.

When the mix of primary raw materials is used, then corresponding material losses occur during melting (81.3 kg of glass is obtained from 100 kg of the primary raw material) (Pavlovic, 1995), depending on the method of conducting the technological procedure of melting and the composition of the mix. The primary mix losses occurring in the process amount to 15-30% (Wolfgang, 1992). These losses are not present when crushed glass is used.

Charge losses (on the mix of primary raw materials and crushed glass at the furnace inlet) can be divided into:

- Losses due to annealing;
- Losses due to evaporation of certain oxides from raw materials;
- Losses due to dust evacuation from the charge.

Using of crushed glass reduces the volume load on city waste disposal areas and extends their utilization life.

Energy Savings Using Crushed Glass

In the production of glass packaging, energy is consumed for:

a) Obtaining, preparation and transport of raw materials;

b) Melting process;

c) Molding and other operations.

With increasing the share of crushed glass in raw materials, under item a) and b) above, it is possible to achieve savings in energy in addition to those gained on raw materials.

Energy savings by using crushed glass are (Wolfgang, 1992):

- For a lower moisture content of material 13%
- For a lower melting temperature 32%
- For a lower value of absorbed energy by CO_2 (SO_2) 12%
- For a lower volume of effluent gases 43%

EXPERIMENT

Determination of Crushed Glass Volume

The structure of municipal waste changes over the year – depending on the season and on the social and economic structure of population. It is necessary therefore to perform an experiment over a longer period on a representative sample.

The experiment was performed on 900 households and 26 commercial facilities, and 3,278 citizens of the City of Zrenjanin (population 100,000) took part in it over a period of 6 months (February-July, 1997).

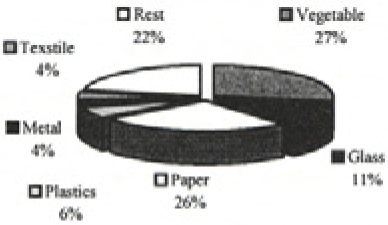

Figure 1 - Per cent composition of waste by weight

A poll research on a sample of 5,300 inhabitants of the City of Zrenjanin was conducted on the population readiness to take part in the municipal recyclable materials collection system. 93% of examined people were prepared to take part in this process.

ENERGY CONSUMPTION

Energy Consumption in Preparing the Basic Raw Material

Basic materials for the production of glass in the SFS Paracin Glass Packaging Production Plant are:

- Silica sand 60%
- Sodium carbonate 18.7%
- Dolomite 10%
- Limestone 8.1%
- Feldspath 3.2%

Specific energy consumption figures are given based on standards in mining, processing, preparation and transport of the corresponding material to SFS Paracin. In their assessing, energy consumption for each operation was determined. Energy consumption in transport was determined according to the distance from the producer to the glass production plant and the optimum transportation means. All the above-indicated materials, except sodium carbonate (Romania), are produced in the territory of the Republic of Serbia.

Table 1 – Specific energy consumption data for primary raw material

Sand	Sodium carbonate	Dolomite
2,619 MJ/kg	10,076 MJ/kg	0.214 MJ/kg
Limestone	**Feldspath**	
0.222 MJ/kg	0.275 MJ/kg	

Specific energy consumption data for obtaining and transport of primary materials to SFS Paracin are given in Table 1.

According to the per cent share in the material mix, specific consumption of energy in this stage is equal to E_p = 0.355 MJ/kg of the mix.

Energy Consumption in Correction, Processing and Transport

Energy consumption in the system of correcting used glass is determined based on the initial data of the experiment. The city recycling material collection vehicle MACK 24 has four flexible bins for materials: glass, paper, plastics, and metal.

In determining the energy required for the collection of one kilo of crushed glass, the following elements have been taken into account:

- Readiness of population to take part in the crushed glass collection process;
- Average distance from the point of collection to the starting position;
- Volume of glass per inhabitant on the vehicle route;
- Distance between the vehicle loading stops;
- Average speed on the collection route;
- Loading time at the stops;
- The quantity of glass per the unit volume of the vehicle of 260 kg/m^3;
- Volume of glass loaded at each stop;
- Fuel consumption of the above-mentioned vehicle.

Based on the analysis of the above-indicated parameters, it was found that energy consumption in collecting the unit volume of crushed glass is e_1 = 0.378 MJ/kg.

The plant for processing, selection and preparation of collected glass to 5-20 mm grain size would be located in Zrenjanin, and this was designed for a capacity covering the material coming from other larger cities within that area of the Province of Vojvodina (population of approx. 1,100,000). In such an organizational system, the plant would be operated at its optimum capacity. The installed power of the plant is 20.9 kW for the maximum capacity of the equipment of 15 t/h of crushed glass.

Specific energy consumption in the above mentioned plant is e_2 = 0.006 MJ/kg of crushed glass.

Transport of prepared crushed glass on the Zrenjanin – SFS Paracin route is carried out by the railways. The specific energy consumption for transport is e_3 = 0.0296 MJ/kg of crushed glass.

The total specific consumption for crushed glass up to the arrival in the glass producing plant is:

$$e_p = e_1 + e_2 + e_3 = 0.4136 \text{ MJ/kg of crushed glass} \qquad (1)$$

Energy Consumption in the SFS Paracin Glass Packaging Producing Plant

Specific Energy Consumption in the Production Preparation. Determination of energy consumption in the preparation of primary raw materials was performed based on standards for electrical units driving the equipment in this stage of processing up to the melting furnace, and according to the volume 554 tons of material prepared on an average basis over 24 hours. This is equal to ε_1'= 0.189 MJ/kg of the primary mix.

Energy consumption for the preparation of used glass up to the melting furnace is ε_2'= 0.013 MJ/kg of crushed glass.

Energy Consumed in the Glass Melting Furnace. Energy consumption in this stage of glass production is obtained by analyzing:

- Theoretical melting heat energy;
- Losses in the furnace;
- Energy consumed by auxiliary units

Table 2 – Mass and energy consumption data in the production of glass packaging

P [%]	Q primary mix [kg]	K crushed glass [kg]	Ms glass [kg]	E_p [MJ]	e_p [MJ]	ε_1' [MJ]	ε_2' [MJ]	ε_1" [MJ]	ε_2" [MJ]	E_u [MJ]	E_u* [MJ/kg of glass]	$\frac{(Eu_0^* - Eu^*)}{Eu_0^*}$	U [%]
0	100	0	81.30	35.50	0.00	18.20	0.00	512.19	0.00	565.89	6.960		0.00
10	90	10	83.17	31.95	4.13	16.38	0.13	460.97	53.47	567.03	6.818	0.02	2.00
20	80	20	85.04	28.40	8.26	14.56	0.26	409.75	106.94	568.17	6.681	0.04	4.00
30	70	30	86.91	24.85	12.39	12.74	0.39	358.53	160.41	569.31	6.551	0.05	5.90
40	60	40	88.78	21.30	16.52	10.92	0.52	307.31	213.88	570.45	6.426	0.07	7.70
50	50	50	90.65	17.75	20.65	9.10	0.65	256.10	267.35	571.59	6.306	0.09	9.40
60	40	60	92.52	14.20	24.78	7.28	0.78	204.88	320.82	572.74	6.190	0.11	11.06
70	30	70	94.39	10.65	28.91	5.46	0.91	153.66	374.29	573.88	6.080	0.12	12.65
80	20	80	96.26	7.10	33.04	3.64	1.04	102.44	427.76	575.02	5.974	0.14	14.18
90	10	90	98.13	3.55	37.17	1.82	1.17	51.22	481.23	576.16	5.871	0.15	15.65
100	0	100	100.00	0.00	41.30	0.00	1.30	0.00	534.70	577.30	5.773	0.17	17.06

P [%] – percentage of crushed glass
Q [kg] – quantity of primary mix (primary raw material)
K [kg] - quantity of crushed glass
Ms [kg] - quantity of produced glass (from volumes Q+K)
E_p [MJ] - energy consumption for preparation of Q primary material to SFS Paracin
e_p [MJ] - energy consumption of K volume crushed glass to SFS Paracin
ε_1' [MJ] - energy consumption of volume Q primary raw material in the preparation and mixing stage before furnace
ε_2' [MJ] - energy consumption of volume K crushed glass in the preparation stage before furnace
ε_1" [MJ] - energetski utrosak primarne sirovine kolicine Q u peci za topljenje
ε_2" [MJ] - energy consumption of volume Q primary raw material in the melting furnace
E_u [MJ] - total energy consumption of (Q+K) mix volume
E_u* [MJ/kg of glass] - energy consumption of produced glass from (Q+K) mix volume
Eu_0* [MJ/kg of glass] - energy consumption of the mix without the crushed glass share
U [%] - energy saving at using volume K crushed glass, in relation to the primary raw material

For the furnace capacity of 211 tons in one batch, the following energy consumption was determined:

Energy consumption per one kilo of glass obtained from the primary raw material is ε_1"= 6.3 MJ/kg of glass, and from crushed glass it amounts to ε_2" = 5.347 MJ/kg of glass.

RESULTS AND DISCUSSION

Assessment of savings at using crushed glass instead of primary raw materials was conducted on a sample of 100 kg of the primary materials mix. The per cent change of the crushed glass share was made in 10 kg or 10% increments (Table 2).

Energy consumed to produce the corresponding volume of glass (depending on the per cent share of crushed glass in the mix) was calculated according to the following expression:

$$e_u = Q(E_p + \varepsilon_1' + \varepsilon_1'') + K(e + \varepsilon_2' + \varepsilon_2'') \text{ [MJ]} \qquad (2)$$

Energy consumption results per expression 2 are shown in Table 2.

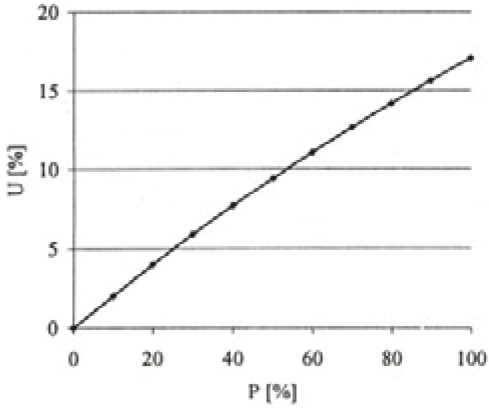

Figure 2 – Energy savings in the production of packaging glass using crushed glass

Functional dependence between the percentage of energy savings and the per cent of the crushed glass share in the mix mass is shown in Fig. 2, based on the data from Table 2.

The analysis of results in Fig. 2 shows linear dependence between the saved energy and the per cent share of crushed glass in the mix up to P=30%. In this interval, the increment in energy saving is 2% on each additional 10% of crushed glass.

$$U = 0.2\,P\,,\quad 0 \le P \le 30\% \tag{3}$$

When the share of crushed glass in the mix is increased over 30%, savings are reduced and dependence between U and P is not linear any more. In this interval, the functional dependence of the saved energy and the per cent of crushed glass is given by the LaGrange interpolation polynomial of the forth order:

$$U = 0.52\,10^{-7}\cdot x^4 - 0833\,10^{-5}\cdot x^3 - 0.208\cdot x^2 - 0.203\cdot x\,,\quad P>30\% \tag{4}$$

Table 2 and Fig. 2 show results that are somewhat lower then those from the pertaining literature, indicating energy savings of 2-4% on each 10% increase in the share of crushed glass in the primary raw material mix. (Tellus Institute Ltd, 1992)

The lower energy saving in relation to other literature data is a direct consequence of the reduced economic power of population due to the economic crisis in Yugoslavia persisting over the last several years. Results from an earlier research project (Pavlovic, 1995) show a higher production of glass per inhabitant of 0.08 kg/day. The reduced volume of obtained crushed glass increases the consumption of energy in the process of its collection and processing.

CONCLUSIONS

Considerable energy savings are achieved by recycling crushed glass in the process of packaging glass production. Results obtained in operation lead to the following conclusions:

- Energy savings achieved by using crushed glass in the production of glass are directly proportional to the economic power of population;
- Higher energy savings are achieved at lower participation of crushed glass of up to P=30%;
- Energy bonus is reduced as the share of crushed glass is increased over P=30%;
- Energy savings of 17% are achieved when 100% of crushed glass is used in the production of glass packaging.

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