Mathematical simulation of all-electric furnace with tin oxide electrodes

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Introduction

Technological development in electric melting of tableware glass concentrates on reaching three basic tasks which can be defined as:

a) increase of economy of melting furnace performance

b) decrease of emissions from melting furnaces

c) reaching of desired quality of produced glass

All these three tasks are very closely connected and to reach them, a wide range of technological measures can be applied. The first group are general measures that do not depend on the construction of all-electric melting furnaces, while the second group includes the technological measures related to particular construction of the melting furnace. The general technological measures involve:

a) application of suitable refractory materials for building furnaces

b) application of perfect measuring and controlling systems on furnaces

c) substitution of molybdenum electrodes by SnO_2 ones on furnaces melting lead crystal glass with the PbO content higher than 20%

All-electric melting furnaces have gone through a long-time development, as well as the furnaces melting lead crystals. It was found very early that in all-electric furnaces with molybdenum electrodes there is not possible to melt perfect glass, due to excessive corrosion of molybdenum electrodes, as corrosion products made the glass quality worse. This problem was solved in two ways. The first way was aimed to the protection of molybdenum electrodes from corrosion caused by lead crystal. It was developed quite successfully. There are three methods of molybdenum electrode corrosion protection which have been tested in operation:

a) anodic passivation

b) melting by low-frequency current

c) cathodic passivation

The second way concentrated on looking for new electrode material that would substitute molybdenum in melting lead crystals. Several metal materials have been tested (Pt, W etc.) which appeared to be suitable from the aspect of corrosion, but completely unusable because of their high price. The only one material which corresponds both to the require of its effects and that of the price is SnO_2.

In some countries, lead crystals are melted in furnaces with molybdenum electrodes which are protected from corrosion by passivation methods or by the low-frequency current melting method [1,2,3]. Even if in all-electric furnaces applying these protective methods the glass of a high quality was melted, certain corrosion of molybdenum electrodes always appeared. These very small concentrations of corrosion products made the quality of glass worse from the point of view of its colour, and therefore it was necessary to add various decolourants. This method has produced crystal glass with a certain colour tone which can be seen especially in case of thick-walled products. These problems do not appear in all-electric furnaces using SnO_2 electrodes for introducing electrical energy into glass melt.

On the basis of literature [4,5,6], personal contacts and experiences, there was carried out a survey of used all-electric glass melting furnaces with SnO_2 electrodes, and this survey was used to design an all-electric furnace which was then investigated by means of mathematical modelling. This contribution presents the results of one phase of the research that has dealt with the influence of positioning and the number of SnO_2 electrodes on operation characteristics of the furnace. This characteristics was represented by electric parameters, temperatures, shape, and flow velocities of glass melt current in the furnace.

The influence of the number and position of SnO_2 electrodes on operation characteristics of the furnace has been evaluated both on the basis of the following six criteria:

1) Size of electric input criterion

$$KP = \frac{P_i}{P_{ref}} = \frac{U_i . I_i}{U_{ref} . I_{ref}} \qquad [1] \qquad (1)$$

2) Current load of electrode criterion

$$i = \frac{1}{n} . \sum_{1}^{n} \frac{I_i}{A} \qquad \left[A / cm^2 \right] \qquad (2)$$

3) Uniform load of electrode criterion

$$N = \frac{n . \left| \Delta I_{max} \right|}{\sum_{1}^{n} I_i} .100 \qquad [\%] \qquad (3)$$

4) Electrode position criterion

$$PE = \frac{V_{TP}}{V_{UP}} \qquad [1] \qquad (4)$$

5) Ohmic resistance criterion

$$R_i = \frac{U_i}{I_i} \qquad [\Omega] \qquad (5)$$

6) Temperature distribution along electrode criterion

$$KT = \frac{1}{n} . \sum_{1}^{n} \frac{\Delta T_i}{l_{el}} \qquad \left[^{o}C / m \right] \qquad (6)$$

where n… number of electrodes

I… current passing through electrode [A]

A… electrode surface [m^2]

P… power input into furnace [W]

T… temperature [°C]

R… electric resistance [Ω]

Δ_{I}^{max}…maximum difference between current passing through electrode and mean current passing through all electrodes [A]

U… voltage between electrodes [V]

V… volume of melting and conditioning zones of furnace [m^3]

and on the basis of distribution of temperature and velocity fields in selected spots and cross sections of the melting tank.

Mathematical model of all-electric furnace

Mathematical model has been carried out for a T-shape all-electric melting furnace with the following selected parameters:

• pull	15 t/day
• number of SnO_2 electrodes	12 - 24 pcs
• diameter of electrodes	150 mm
• length of electrodes	300 mm
• orientation of electrode position	vertical, horizontal - see Fig.1

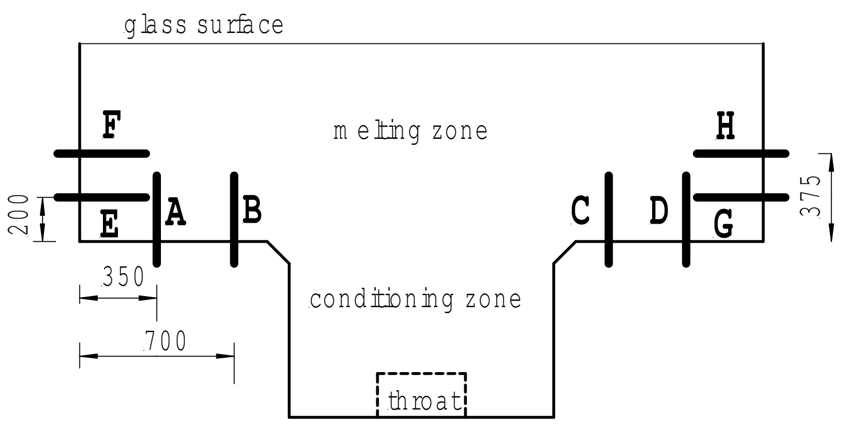

Fig.1 Orientation and position of electrodes in furnace tank
(in each position A -H there are 6 electrodes)

Results

The method of mathematical modelling has been used to investigate 4 variants differing in the number and position of the electrodes in the melting tank of the furnace. The survey of the investigated variants is given in Table 1.

Table 1 Survey of the investigated variants

Variant	Number of electrodes	Position of electrodes*)
1	12	A,D
2	24	A,B,C,D
3	12	E,G
4	24	A,D,F,H

*) see Fig. 1

For individual variants, there were calculated values of criteria (1) - (6), they are introduced in Table 2.

To investigate the influence of position and number of SnO_2 electrodes on operation characteristics of the furnace, also the distribution of temperatures and glass currents in the tank of the furnace have been used - in a vertical cross section (section X) at the distance of 1.2 m from the back wall of the furnace, and in 2 vertical gradients in a horizontal axis of the furnace: a) in the middle of the tank (gradient GM), b) at the distance of 0.1 m from the head wall of the tank (gradient G0.1).

Table 2 Values of criteria (1) - (6)

Variant No	Criterion KP [1]	Criterion i [A/cm^2]	Criterion N [%]	Criterion PE [1]	Criterion R [Ω]	Criterion KT [°C/m]
1	1.00	0.089	13.0	4.22	0.881	101.1
2	1.53	0.068	30.1	5.27	0.377	108.9
3	1.02	0.091	9.3	3.82	0.840	51.7
4	1.21	0.054	13.2	4.20	0.605	97.8

Evaluation of results

By evaluation of criteria (1 - 6) the model criteria can be divided into two groups. The first one includes variants 1 and 2, i.e. variants with vertical electrodes, and in the second group there are variants 3 and 4, i.e. variants with horizontal or combined positions of electrodes, respectively. From the aspect of criteria, better parameters are reached by variants 3 and 4. If the stress is put on the uniformity of current load of electrodes and on the distribution of temperature along electrode surface, then the best values of the criteria are shown by the variant 4. As far as the temperature fields in the tank of the furnace are concerned, the change of electrode configuration causes a shift of the areas with the hottest glass melt, as they always occur above the electrodes. In the middle of the furnace above the thermal barrier there occur no changes of glass temperature, as the found temperature differences between individual variants are smaller than 10 °C. Another situation is in the area under the thermal barrier, where cooler glass melt comes into a throat in variants 3 and 4.

The change of the number and position of electrodes influences more considerably the glass current above the thermal barrier than the temperature fields in the furnace. In case of vertical electrodes, the glass melt flows across the tank in four cycles, from which the cycles by the walls show lower velocities than the middle ones, in case of variant 3 the glass flows only in two cycles. That means that, in comparison with the other variants, in variant 3 the glass melt by the walls flows more intensively. On adding vertical electrodes to the horizontal ones (variant 4) again four cycles of the current with low velocities near the tank walls are formed. Also the extent of individual current cycles in the tank is very important.

Electrode positioning also considerably influences current velocity in the middle of the tank, because in variants with horizontal electrodes threefold (variant 4) or fourfold (variant 3) decrease of glass current velocity.

The glass melt current under the thermal barrier is in all variants equal to very small absolute values of velocity.

Conclusion

The model research of the all-electric melting furnace with SnO_2 electrodes results in the fact that the influence of position and number of electrodes on its operation characteristics has its importance. It is especially important in case of electric parameters (current load of electrodes and its uniformity, distribution of temperatures along electrode surface) and in case of glass melt current in the tank where the shape of the current and also the absolute values of glass melt velocity are influenced by it.

Total evaluation of the four investigated variants shows that the best results have been reached in variant 4, i.e. the variant with combined vertical and horizontal electrodes.

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