Electroplasma installation for producing high-temperature silicate melts

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Abstract. The paper presents the design of an electroplasma installation for producing the high-temperature silicate melts. The optimal operating modes of the screw feeder (from 12.3 kg/h to 25.4 kg/h) were established to ensure the production of a homogeneous high-temperature silicate melt. The design of electroplasma installation with a closed volume to produce highly viscous melts with the viscosity values of more than 10^5 Pa s is proposed.

1. Introduction
Currently, it is not possible to obtain a silicate melt homogeneous in temperature and composition from the raw materials with a melting point of more than 1500 °C [1–3]. The use of energy of low-temperature plasma makes it possible to increase the heating rate of silicate mixtures hundreds of times and to achieve consistently high temperatures of 3000–3500 °C [4–6] producing silicate melts from the raw materials with a melting point of 1500 °C and more. The development of methods for producing silicate melts using the low-temperature plasma energy is of current interest. At the same time, the process of melting silicate mixtures will significantly reduce energy costs and harmful emissions into the atmosphere. A systematic solution of scientific and practical problems related to the production of melts for creating multipurpose silicate materials, the establishment of operating modes of a low-temperature plasma generator ensuring the production of high-temperature silicate melts from raw materials with different contents of silicon oxide as well as the achievement of the necessary homogeneity of the final product turns to be crucial in solving the problem under consideration.

The purpose of the paper is to establish the physical laws for obtaining silicate melts from the raw materials with a silica content of 50÷100% in a low-temperature plasma and the materials based on them.

2. Electroplasma installation
On the basis of theoretical calculations and established modes of heat transfer at melting the silicate raw materials using a low-temperature plasma energy the individual advantages of electroplasma installations were preliminary established in comparison with the installations traditionally used in processing the silicate materials into melts [7, 8]. Based on the analysis of melting furnace designs traditionally used in the preparation of silicate melts and as a result of long experience in optimizing both the parameters and the plasma-chemical reactor design some variants of plasma complexes for producing the chemically homogeneous silicate melts were proposed.
The operating modes of the plasma generator and the thermal parameters of arc discharge were preliminarily established, table 1.

| № of Modes | Power of plasmatron (kW) | Current (A) | Voltage (V) | Specific thermal stream (W.m\(^{-2}\)) |
|-------------|--------------------------|-------------|-------------|-------------------------------------|
| 1           | 24                       | 140         | 170         | 1.0·10\(^6\)                       |
| 2           | 38                       | 230         | 165         | 1.8·10\(^6\)                       |
| 3           | 58                       | 400         | 145         | 2.6·10\(^6\)                       |

It was experimentally found that the operating modes of the electroplasma installation allow us to achieve specific heat fluxes of 1.0÷2.6·10\(^6\) W.m\(^{-2}\) which are sufficient to produce the melt with the required temperature and viscosity.

At the next stage the experimental studies were conducted on the selection of the raw material supply system in the area of plasma arc burning. It was found that the system of air-dispersed raw material supply is not quite effective. Using such system a significant part of raw material is blown out by highly concentrated plasma flows from the plasma arc burning area and melts partially due to the short interaction time with plasma flows. As a result, the quality of silicate melt is reduced. The analysis of operation of the created plasma installations, taking into account their features and disadvantages, allowed us to develop an experimental plasma-chemical reactor (RF Patent 2503628) for producing silicate melts, figure 1.

The body of the melting furnace 3 was made of stainless steel in the form of a water-cooled cylinder with a graphite crucible 4 placed inside it. Drain chute 2 is located in the upper part of the melting furnace. A device for feeding the powder raw material is mounted on the opposite to the drain chute body side surface of the melting furnace and is made in the form of a screw feeder 5.

![Figure 1](image1.png)

**Figure 1.** Diagram of the experimental plasma installation for producing high-temperature silicate melts: 1 – plasmatron; 2 – drain chute; 3 – water-cooled melting furnace; 4 – graphite crucible; 5 – screw feeder; 6 – plasma arc; 7 – silicate melt; 8 – device for collecting melt.

This ensures the introduction of raw materials not from above to the surface of melt but from the side of the melting furnace body and directly into the region of melt excluding the blowing of fine particles by the low-temperature plasma stream. This allows us to maintain uniformity and low melt viscosity throughout the furnace volume. After reaching the level of the drain chute 2 the silicate melt overflows its edge and comes to the melt collection device 8.

The carried out experiments show the advantages of the electroplasma melting method for preparing silicate melts as the temperature increase significantly reducing the overall period of melting process provides a high chemical homogeneity of the melt and, as a result, opens up the
possibility of obtaining such popular building materials as mineral fiber, glass-ceramic materials, quartz glass and others. In addition, an experimental plasma device was developed for melting the fine single-component poly-phase raw material with a closed volume characterized by a fundamentally new scheme for the supply of raw material and the absence of a drain chute, figure 2.

It was established experimentally that on the basis of the studied raw material with a SiO₂ content of more than 62% the possibility of obtaining a product with a high degree of amorphism using the low-temperature plasma is confirmed. This scheme is used for preparing the highly viscous melts with the viscosity values of more than 10⁵ Pa·s for successive fusing of the product without draining it.

Figure 2. Diagram of the experimental plasma installation for producing high-temperature silicate melts: 1 – plasmatron; 2 – water-cooled melting furnace; 3 – graphite crucible; 4 – screw feeder; 5 – plasma arc; 6 – melting product.

Production of silicate melts in the low-temperature plasma conditions proceeds in two stages: simultaneous melting of all charge phases with the formation of heterogeneous melt and homogenization of the melt under reduced viscosity due to overheating the material above the melting temperature unlike the traditional melt production technology consisting of four stages: formation of the eutectic melts, dissolution of refractory components in the eutectic melts, production of the heterogeneous melt and its homogenization.

In determining performance of the above described installation, it is also important to establish the operating parameters of the screw feeder. In a special calibration experiment the raw material feed rate was determined depending on the speed of the screw feeder shaft, figure 3.

Figure 3. The performance of the screw feeder at different speeds of the electric motor shaft. It was found that the capacity of the used screw feeder is adjustable from 12.3 kg·h⁻¹ to 25.4 kg·h⁻¹.
3. Conclusions
Thus, the carried out experiments allowed to conclude that at the temperatures of 3000÷3500 °C realized in the plasma-chemical reactor the melt viscosity with a silicon oxide content of 40÷50% is equal to 2–5 Pa·s, with SiO₂ content of 50÷65% it is equal to 5÷20 Pa·s. The high viscosity of the quartz sand melt (SiO₂≈99%) – 10⁶ Pa·s at a temperature of 2000 °C limits the ways of making of quartz glass. At such values of temperature and viscosity the traditional glass making methods are used – step-by-step glass surfacing and production of glass blocks. In addition, the melting process in the low-temperature plasma conditions is characterized by the melt overheating regarding the silicate raw material melting point over 300 °C that reduces viscosity to less than 10 Pa·s and leads to simultaneous melting of all phases without evaporation of oxides during 2÷3 seconds.

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References
[1] Pillai R, Jariwala C, Kumar K and Kumar S 2017 Surfaces and Interfaces 9 21
[2] Panwar K, Jassal M and Agrawal A K 2017 Particuology 33 50
[3] Hšrika I, Živný O and Hrabovský M 2017 Plasma Chemistry and Plasma Processing 37 947
[4] Myshkin V F, Khan V A, Bespala E V, Tichy M and Izhoykin D A 2016 Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering 327 96
[5] Shinoda K, Kojima Y and Yoshida T 2005 J Therm Spray Tech 14 511
[6] Hofmeister A M, Whittington A G and Pertermann M 2009 Contrib. Mineral. Petrol 158 381
[7] Volokitin O G, Sheremet M A, Shekhovtsov V V, Bondareva N S and Kuzmin V I 2016 Thermophysics and Aeromechanics 23 755
[8] Vlasov V A, Volokitin O G, Volokitin G G, Skripnikova N K and Shekhovtsov V V 2016 Journal of Engineering Physics and Thermophysics 89 152