

Thermal insulation of pipelines by foamed glass-ceramic

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Abstract. Based on broken glass, clay and organic additives granular insulating glass crystalline material and technology of its receipt are developed. The regularities of the effect of composition and firing temperature on the properties of the granules are specified. The resulting granular thermally insulating material is produced with a bulk density of 260-280 kg/m³, pellet strength - 1.74 MPa, thermal conductivity - 0.075 W/m °C, water absorption - 2.6 % by weight. The effect of the basic physical characteristics of the components of the charge on the process of pore formation is studied. According to the research results, basic parameters affecting the sustainability of the swelling glass are specified. Rational charge composition, thermal and gas synthesis mode are chosen so that the partial pressure of gases is below the surface tension of the melt. This enables the formation of granules with small closed pores and vitrified surface. The article is the result of studies on the application of materials for pipe insulation of heating mains with foamed glass ceramics.

1. Introduction

One of the main issues of the economy is preservation of fuel and energy resources. Priority role in the solution of this issue is given to energy saving in construction and industry, namely, the effective thermal protection of buildings and structures, heat insulation of industrial installations and pipelines of large diameters. Great attention in the protection of pipelines of large diameters is paid to the quality of the applied heat-insulating materials, which should have low thermal conductivity and corrosion resistance for providing stability to mechanical influence. Now for insulation of pipes mats, semi-cylinders, shells on the basis of staple fiber (URSA, ISOVER, Tisma, KNAUF, and so on), basalt fibers (Teparak, Rockpipe, Rockwool, Paroc, Nobasil), rubber (K-Flex, Armaflex) and blast furnace slag are used [1,2].

The purpose of work is development of technology of glass-ceramic insulation pellets of glass waste, raw clay, organic additives and shells on their basis for insulation of pipes of large diameters.

Object of research are glass-crystalline granules and products for thermal insulation of pipes.

In order to achieve the goal stated tasks were the following: 1. To develop the composition of the charge and to investigate the processes of the pores formation and structure formation of granules of glass-ceramic material. 2. To make calculations and analysis of thermal protection and efficient use of coverings of products on the basis of granulated glass-ceramic material.



2. Materials and methods

When conducting research different wastes of glass, clay, coke and sawdust were used for glass-ceramic pellets.

2.1. Waste glass

For the production of foam glass, glasses of following chemical composition are used: SiO₂ - 60...72,5 %, Fe₂O₃ - 0...2,5 %, CaO - 4...6,0 %, MgO - 1,5...2,5 %, Na₂O - 12,5...15,0 %, Al₂O₃ - 1,2...1,57 % [1]. The most similar to the structure is the window glass, glass bottles and lamp glass (Table 1). During the production of granulated foam glass ceramics it is necessary to carry out the correction of the functional composition of charge taking into account every type of glass used.

Chemical compositions of windowpanes are the closest to this. Their distinctive characteristic is low level of Al₂O₃ compared to other types of glass.

Table 1. Chemical composition of the crushed glass used.

Type of glass	Glass chemical composition, %											
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	R ₂ O	SO ₃	K ₂ O	Na ₂ O	Cr ₂ O ₃	BaO	
Window glass	73.0	0.9	0.12	8.7	3.6	13.6	0.53	-	-	-	-	
Bottle glass	70.7	4.0	0.65	6.5	3.5	-	-	-	14.5	0.15	-	
Lamp glass SL96-1	71.9	1.5	0.1	5.5	3.5	-	-	0.15	16.1	-	2.0	

2.2. Clay raw materials

Clay was introduced in the charge to increase the mechanical strength of interporous partitions, the surface of granules and reduce water absorption. For the studies clay rocks of Tomsk region were used. Clay minerals are presented by kaolinite, hydromica and montmorillonite. In addition, clay contain quartz, feldspars, carbonates, oxides and organic impurities. Kandinsky field meets the requirements for the production of pellets clay to the great extend. The best results were obtained using clay that is classified as pulverous loam, with a domination of SiO₂ – 70.73%; Al₂O₃ – 17.12% and Fe₂O₃ – 5.68% in its chemical composition. Good foaming is ensured by the presence in the clay of hydromica, montmorillonite, compounds of iron and feldspar.

2.3. Coke

Coke is used as the blowing agent. In the justification of the choice of blowing agent the coincidence of temperature intervals when appeared melt of the desired viscosity and formed the greatest partial pressure of gaseous products when burning of organic matter are taken into account.

2.4. Sawdust

Sustainable gassing is introduced to reduce the viscosity of the melt and security together with coke. In the compositions of “glass powder - clay - coke – water”, it is better to use coniferous breeds of wood. Sawdust has been introduced in the charge by joint grinding with broken glass that ensured they were chopping up of particles less than 560 mm with a high value of the coefficient of the form of wood fiber (the ratio of length to thickness equal to 4).

In the course of the study the following charge of composition was used (% by weight): crushed glass 67 – 84; clay 8 – 25; carbonite 5 and sawdust – 3. The charge degree of fineness 0.45 – 0.15 mm.

The granules were made in the following way: crushed glass was crushed in a grinder to 1.5 – 3.0 mm, and then in a ball mill combined with sawdust to the particle specific surface of 300 – 350% m²/kg. In such a way the sawdust was added to the charge during the moment of glass grinding, which enabled their pulverizing to a wood powder together with obtaining of a high shape factor of wood fiber (length-to-thickness ratio) equal to 4 and the size of particles no more than 560 microns. A grinding process of carbonite and clay also occurs in the ball mill. The obtained glass-wool and carbonite-clay powders were dosed and loaded in a rod vibrating mill where they were jointly mechanoactivated to a specific surface of 400 m²/kg. The obtained charge was gaged with water (10-

15% of the charge mass) for gaining the required plasticity, and then was formed into granules of 3-8 mm in size.

The experiments were carried out with a permanent carbonite value of 5% and organic additives (sawdust) of 3%.

Granule burning was carried out at temperature of 830-850 °C within a sintering range of foaming mixtures equal to 4 – 6 minutes.

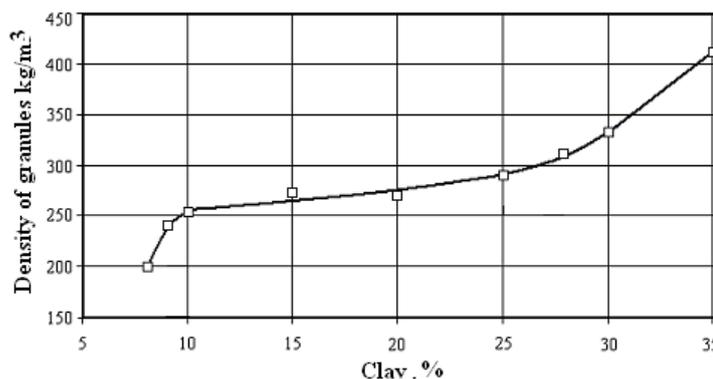


Figure 1. Impact content of clay in the charge on the density of granules.

Pore formation and sustainability of porous structure depend on surface energy on the phase boundary “gas – melt”. In Figure 1, the results of studies of the influence of content of clay on the density of granules are shown. When the clay content is in the charge from 8 to 25 % favorable conditions for the formation of pores and produce pellets with a density of 200 to 300 kg/m³ are created. If you increase the clay content in the charge of more than 25%, pores to unite, the gas will be released into the atmosphere - foam settles.

In order to solve this problem it was decided to use sawdust as an organic additive in the charge. It was experimentally estimated that adding up to 3% of sawdust with a simultaneous increase of the foaming temperature up to 830 °C and the time of pore formation up to 5 minutes the amount of gases and their partial pressure would increase. Furthermore, the viscosity of the hot melt begins to decrease and the particle sintering commences, leading to the formation of glass ceramic mass.

Clay as a fusible additive plays the role of stabilizer in the rational composition of a charge. The stabilizing impact of clay enables the formation of so-called “energy barrier” which increases the mechanical strength of partitions with the narrowest thickness. In the process of foaming, pores are mutually combined under slow speed. The gases in the pores work against the energy caused by the surface tension. The presence of clay in a hot melt significantly increases the energy of the surface tension and the gas pressure in pores decreases as the pores diminish. As the result, there are up to 92% of closed pores of 0.2 – 0.4 mm in size with the thickness of the dividing partition within the bounds of 0.07 – 0.1 micron up to 12 microns. The granule density is 260 kg/m³.

A thermal shock in the zone of high temperatures (830 °C) in a reductive conditions with 3.0% CO containment is characteristic for granular thermal processing. Furthermore, the mechanical strength comes to the maximum while granules are in the high temperature zone for 5-6 minutes. Thermal cycle “foaming→ pore formation→ annealing” provides an optimal time for granules in the foaming zone, regulating the size and the quantity of pores and prevents the process of bubble coalescence (increasing of pore size), for which greater time in the high temperature zone is required. Research resulted in RF patent № 2374191 was received. After completion of the synthesis in a rotary kiln granules size of 8 - 10 mm are able to pyroplastic status. There was a proposal on the possibility of the formation of granules of various geometric shapes of plates, cylinders and other segments of the shells for the insulation of pipes.

Annealing is necessary to fix the porous structure and to relieve temperature stresses in the pores. Thus, technological rules of manufacturing heat-insulating products made of glass-ceramic granules consist of three stages: formation and expansion, manufacture of building products, annealing

products. For the production of heat-insulating materials from granules foamed glass-ceramic can also be used by the technology of gluing of granules. Technical and economic efficiency of heat-insulating coating of pipes of foamed glass ceramic has been defined for pipelines located in the open air at a temperature of 110 °C (Figure 2).

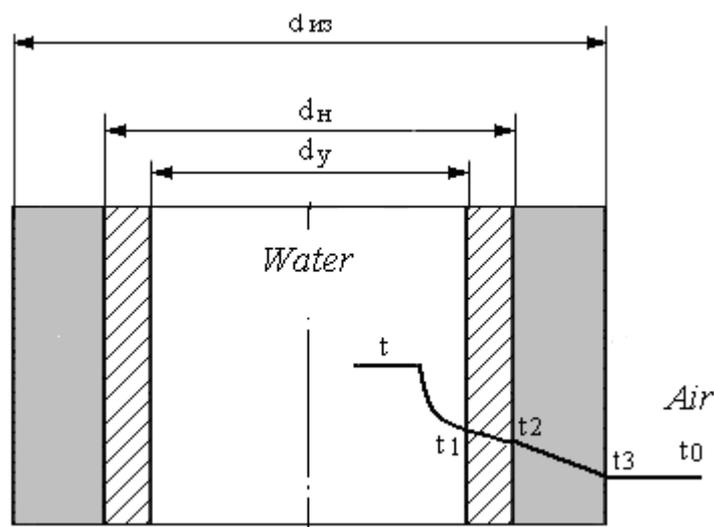


Figure 2. Heat transfer in an insulated pipeline.

Heat losses through the isolated surface with insulation thickness $d_{из}$, m shall be determined according to the formula 1, and the thermal resistance - by the formula 2. The temperature of the inner and outer environments t_b and t_h accept the calculated heat carrier temperature and the ambient air.

Mathematical formulation of the problem takes the following form [3-5]:

$$q_l = \frac{\pi (t - t_0) K}{R_l} \text{ K}, \quad (1)$$

where:

$$R_l = \frac{1}{\alpha_1 d_1} + \frac{1}{2 \lambda_2} \ln \frac{d_n}{d_y} + \frac{1}{2 \lambda_{из1}} \ln \frac{d_{из1}}{d_n} + \frac{1}{2 \lambda_{из2}} \ln \frac{d_{из2}}{d_{из1}} + \frac{1}{\alpha_2 d_{из2}} \quad (2)$$

q_l - the density of a thermal stream flowing through patterns, W/m²;

t - the coolant temperature, °C;

t_0 - the ambient temperature to be considered equal to the average temperature of the heating period ($t_0 = -5,2$ °C);

d_y - conditional diameter of the pipeline, m;

d_n - the outer diameter of the pipe, m;

$d_{из}$ - outer diameter of the heat-insulating shell, m;

α_1 - heat transfer coefficient from the coolant pipe inner surface, W/(m²·°C);

α_2 - coefficient of heat transfer from the outer surface of the insulation W/(m²·°C), taken equal to 29 W/(m²·°C) [4].

λ , $\lambda_{из}$ - thermal conductivity of the pipe material and the heat insulation of the shell, respectively, W/(m·°C).

K - coefficient of additional losses, taking into account the conductive heat loss through the inclusion of thermal insulation structures caused by the presence of fasteners and bearings.

$K = 1.2$ [4].

For comparison, the heat losses through the insulation use articles having an average density close to the maximum design density of foamed glass ceramic [1-5]. Characteristics of pipes and heating medium is shown in Table 2 and comparative thermal characteristics of the products in Table 3.

Table 2. Physical and technical characteristics of the pipe.

Name	Conditional diameter, d_y , m	The outer diameter, d_n , m	Temperature, °C.	Thermal conductivity, W/m °C
Mild steel (plain pipe)	0,3	0,325	110	50.0

Table 3. Thermo-physical characteristics of heat-insulating materials.

№	Heat-insulating materials	Density, kg/m ³	Coefficient of thermal conductivity, W/m °C	Temperature operation, °C
1	Vermiculite shell	230	0,0814+0,000233 t_m	450
2	Mineral wool segments	350-400	0,0814+0,003 t_m	840
3	Sovelite shell grade 500	200	0,107+0,00116 t_m	400
4	Nyuvele shell	350	0,0808 + 0,000097 t_m	375
5	Foamed glass-ceramic	200	0,059+0,00016 t_m	- 50 up to 720

When using a shell made of foamed glass-ceramic heat loss is 1,37 times less than when using vermiculite shell, 1.45 times less than application of segments of mineral wool; 2,47 times less than at application of sovelite shell marks 500 and 1,25 times less than nyuvele shell.

Figure 3 graphically shows dependence of thermo-physical characteristics for mineral wool segments, shell of granular foamed glass-ceramic, and vermiculite shells.

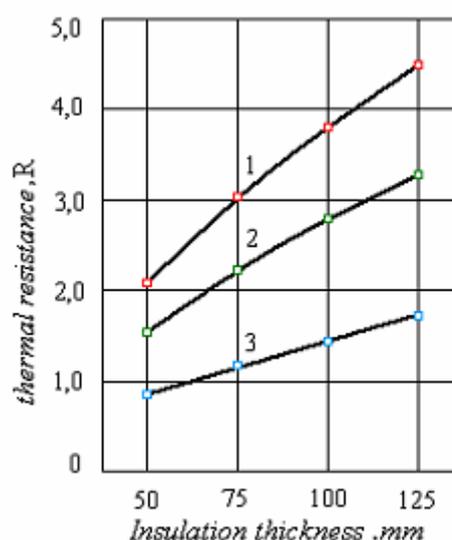


Figure 3. Dependence of the thermal resistance of the insulation materials the thickness of the insulation layer.

1 - shell of granular foamed glass-ceramic, 2 - mineral wool segments, 3 - vermiculite shell

3. Conclusion

Application of granulated foamed glass-ceramic significantly reduces heat loss, and as a consequence saves fuel and energy resources.

Application of granular materials from foamed glass enables to decrease the thickness of the insulating layer of pipelines, as thermal resistance depends on the thickness and heat conductivity of insulation materials. The thickness of the insulating layer is calculated from the conditions of minimal heat loss of the environment, the difference of the temperature and the thermal properties of heat-insulating materials.

Taking into account the dignity of the other insulation materials, as well as taking into account the physical and technical characteristics of materials foamed glass-ceramics, one can say that foamed glass-ceramics has its place in the use of insulation of buildings and energy constructions.

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