DOI 10.1007/s10891-019-01929-3

Journal of Engineering Physics and Thermophysics, Vol. 92, No. 1, January, 2019

TECHNOLOGY OF ELECTRIC MELTING OF BASALT FOR OBTAINING MINERAL FIBER

V. G. Luk′yashchenko,[a,b] V. E. Messerle,[a,b,c] A. B. Ustimenko,[a,b] V. N. Shevchenko,[a,b] S. Kh. Aknazarov,[b] Z. A. Mansurov,[b] and K. A. Umbetkaliev[a,b]

UDC 532;539.123.17;621.365.3

The basalt electric melting advantages in application of basalt fiber in industrialized construction and heat power engineering are shown. The results of thermodynamic calculations of the process of Kazakhstan basalt melting are given. The calculations have shown that in gaseous and condensed products of the process there are no harmful substances. Experiments on electric melting of basalt in a reactor with electromagnetic mixing of the melt were carried out. The prospects of electric melting of basalt and obtaining mineral fiber with the use of small-size module installations involving an electromagnetic reactor are shown. The specific energy consumption for obtaining a homogeneous basalt melt does not exceed 1.1 kW·h/kg, which is superior to the widely used SHF-reactors in which the specific energy consumption is several times higher.

Keywords: *basalt, electromagnetic reactor, electric melting, specific energy consumption, gas-dynamical installation, centrifuge, mineral fiber.*

Introduction. In recent years, the abbreviation MMMF (Man-Made Minerals Fiber) — artificial mineral fiber — has become very popular in the world. The world-wide production of MMMF, including slag- and glass wool, amounts to more than 5 million tons per year [1]. About 50% of the world production of MMMF account for glass fiber and glass wool that relate to potentially cancerogenic materials. The production of MMMF in Russia comes to 0.5 million tons per year (10% of the world one). According to forecasts, in recent years, the output of MMMF will increase severalfold in an effort to solve the energy saving problem and to adhere to the requirements of new construction specifications and regulations [1].

The demand for mineral wool increase rapidly in view of its use for heat insulation of buildings, in power engineering and industrial installations, and in pipelines. According to expert assessment, 85% of the entire mineral wool production is used in civil engineering and in residential and public services and 15% in power engineering. According to the information of the European Insulation Manufacturers Association, about 40% of the electric and thermal energy is consumed in the process of the maintenance of buildings, heat pipelines, and constructions in the Common Market countries. Wide application of heat insulation made from MMMF in civil engineering will make it possible to reduce emissions into the atmosphere of the main greenhouse gas — carbon dioxide (CO_2) — which will improve the ecological situation in the world.

The densities of heat insulating materials determine their efficiency: the lower the density of the material, the better its heat insulating properties are. The density of the mineral wool from basalt is 200 times lower than the density of steel, 60 times lower than that of ferroconcrete, and 45 times lower than that of brick. The low density allows mineral wool to compete with foam concretes, whereas the high heat resistance (up to 1273 K) — to compete with synthetic polymer porous fillers. Moreover, articles made from basalt MMMFs may be used for 60–80 years in corrosive media [2].

Blast cupolas and ore-smelting furnaces exhibit high capacities — up to a few tons of melt per hour. The production of mineral wool in the USA and Common Market countries is based on such furnaces. But they are mainly adapted for processing slags, the specific energy expenditures on the melting of which vary within 3–7 kW·h/kg. These furnaces are very cumbersome, require large capital outlays, costly cleaning of escaping gases, and utilization of coke residues.

[a]Scientific-Technical Association "Plasmatechnique," 22 Zverev Str., Almaty, 050010, Republic of Kazakhstan; email: ust@physics.kz; [b]Institute of Combustion Problems, Ministry of Education and Science of the Republic of Kazakhstan, 172 Bogenbai Batyr Str., Almaty, 050012, Republic of Kazakhstan; email: zmansurov@kaznu.kz; [c]S. S. Kutateladze Institute of Thermophysics, Siberian Branch of the Russian Academy of Sciences, 1 Acad. Lavrentiev Ave., Novosibirsk, 630090, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 92, No. 1, pp. 273–280, January–February, 2019. Original article submitted September 15, 2017.

In recent years, in connection with the higher requirements on the protection of the surrounding medium and depletion of the reserves of traditional types of fossil fuels, great attention is paid to the application of ecologically pure electric energy sources for processing different kinds of mineral raw materials (basalt, gabbroic, and diabase rocks, energy slags, and other mineral wastes [3]) in electric furnaces. Electric glassmaking furnaces with daily output of less than 25 t turn out to be economically more profitable than large-capacity gas and coke furnaces [4]. If we take into account the necessity of using costly equipment to reduce pollution of the surrounding medium produced by these furnaces, the advantages of electric furnaces increase. It should be noted here that traditional electric furnaces are cumbersome structures lined by costly ceramics.

In the Russian Federation, increasing use has been made of electric high-frequency installations for melting mineral raw material, including basalt. The main developers and manufacturers of these installations are two firms: the Federal State Unitary Enterprise "Federal Scientific-Production Center Altai" (the city of Biisk) and Limited Liability Corporation "The Firm Ros′" (the city of Barnaul of the Altai region of RF) [5]. The major part of these installations is a water-cooled graphite or ceramic crucible located in a copper inductor whose electric feeding is provided by a high-frequency generator with a frequency from 0.44 to 1.76 MHz. The installations are compact, easily mounted and serviced, and allow one to obtain a well homogenized melt due to its overheating (above 2073 K) with subsequent cooling to the required temperatures (of the order of 1823 K) and discharge of the melt in the upper part of the crucible. The induction heating and overheating of the melt lead to increased energy expenditures from 2 to 4.5 kW·h/kg per kg of melt. Moreover, there are limitations on the output not exceeding 100 kg/h.

Taking into account the foregoing, it seems worthwhile to conduct melting of mineral raw material with subsequent obtaining basalt wool in an electromagnetic reactor (EMR) with higher ecological-economic characteristics as compared to the above-considered fuel and electric furnaces. In this article, we present the results of a thermodynamic analysis and of experimental investigation of the process of melting basalt in a three-phase reactor with bulk electromagnetic mixing of melt [6–8] with its subsequent distention into a basalt fiber.

The most important property of the basalt fiber is that it melts at a temperature of 1423 K, which is much higher than for the glass fiber and is close to the melting point of ceramic fiber. At the same time, basalt fiber is much cheaper than the ceramic one. The temperature of application of basalt fiber varies from 13 to 973 K whereas glass fiber is applied in the temperature range from 223 to 653 K. Basalt fibers have a high chemical resistance to the influence of moisture, solutions of salts, chemical and alkaline media. Basalt-fibrous materials are noncombustible, and at high temperatures they do not emit harmful gases. The thermal conductivity coefficient of basalt wool is of the order of 0.05 $W \cdot m^{-1} \cdot K^{-1}$ [5].

Basalt continuous fiber finds wide application in composite construction materials as an additive to concrete, tile, pedestrian-way tiles and asphalt, and railroad ties. Chemical treatment of the surface makes it possible to provide direct connection of basalt with epoxy regions and other polymeric systems. This is especially efficient in the production of basalt-plastic fittings, various construction profiles, pipes, and nets [9].

Pierced mats from basalt fiber without fillers and binding components have excellent heat- and soundproofing properties, but they do not rot and are noncombustible. Therefore pierced mats are used for raising fire-resistance of metal structures and boxes of the systems of ventilation and removal of flue gases. For example, application of rolled basalt fire-proof material of Public Corporation "Tizol" (the city of Nizhnyaya Tura, Sverdlovsk region, Russia) in Russia and Kazakhstan provides protection from fire for more than 3 mln m^2 of building structures and engineering supply lines per year [10].

Thermodynamic Calculations of Heating and Melting of Basalt. To determine the optimal parameters of the technology of melting mineral substance, thermodynamic calculations of heating and melting in an electromagnetic reactor were carried out. The electromagnetic reactor is a thermally insulated system, the function of the lining in which is played by a natural layer of slag lining deposited in the process of reactor operation from the melt layer that contacts with the water-cooled walls. Thus, the process of melting in such a reactor is close to adiabatic one, and for calculating such a process it is possible to use the methods of numerical analysis for isolated thermodynamic systems.

Calculations of high-temperature processes of melting and processing of mineral raw material were carried out with the aid of a universal program of thermodynamic calculation of multicomponent heterogeneous systems TERRA [11]. Table 1 presents the chemical composition of the main types of Kazakhstan basalts used for calculations. The calculations of heating and melting of basalt were made in the temperature interval 400–2000 K at a pressure of 1 atm. Account was made of the erosion of graphite electrodes by adding 2% of carbon to basalt.