

# New Method's Development of Industrial Waste Recycling to Reduce Environmental Stress around Lake Baikal

## Nuevo Método Desarrollo del Reciclaje de Residuos Industriales para Reducir el Estrés Ambiental alrededor del Lago Baikal

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#### ABSTRACT:

The paper discusses some of the environmental issues that exist around the unique Lake Baikal, which is a world's largest fresh water reservoir and has unique flora and fauna. One of the main pollutants of the region is industrial, domestic, and medical waste. The paper presents technical and technological aspects of partial solution of these issues, in particular, the disposal of ash and slag of thermal power plants and thermal boilers. Due to the climatic conditions of the region, the rate of accumulation of ash and slag contaminants will not decrease. Ash and slag are used in construction as additives in to concrete and asphalt, but that is not a complete solution of existing issues. The authors propose as a partial solution of the problem an innovative technology of ash and slag waste recycling to produce cheap and environmentally friendly products in form of fibrous thermal insulation materials that can be applied in various industries. The paper

#### RESUMEN:

El documento analiza algunas de las cuestiones ambientales que existen alrededor del único lago Baikal, que es el mayor embalse de agua dulce del mundo y tiene flora y fauna únicas. Uno de los principales contaminantes de la región son los residuos industriales, domésticos y médicos. Se presentan los aspectos técnicos y tecnológicos de la solución parcial de estas cuestiones, en particular, la eliminación de cenizas y escorias de centrales térmicas y calderas térmicas. Debido a las condiciones climáticas de la región, la tasa de acumulación de cenizas y contaminantes de escoria no disminuirá. La ceniza y la escoria se utilizan en la construcción como aditivos en hormigón y asfalto, pero eso no es una solución completa de problemas existentes. Los autores proponen como solución parcial del problema una innovadora tecnología de reciclaje de cenizas y residuos de escoria para producir productos baratos y

offers the research results on feedstock as well as on processes of getting melts and formation of fibers from melts. Physic-chemical properties of the formed fibers were studied. The developed technology is environmentally friendly and low-cost in terms of energy and materials consumption. **Keywords:** Lake Baikal, ash and slag waste, environmental issues, new technology, mineral fiber.

respetuosos con el medio ambiente en forma de materiales aislantes térmicos fibrosos que pueden aplicarse en diversas industrias. El documento ofrece los resultados de la investigación sobre la materia prima, así como sobre los procesos de obtención de fusión y formación de fibras a partir de fundidos. Se estudiaron las propiedades físico-químicas de las fibras formadas. La tecnología desarrollada es respetuosa con el medio ambiente y de bajo costo en términos de consumo de energía y materiales. **Palabras clave:** Lago Baikal, residuos de cenizas y escorias, temas medioambientales, nueva tecnología, fibra mineral.

## 1. Introduction

Due to the industrial activity of humankind, fresh water is becoming one of the most crucial and difficult to renew natural resources (Nekhoroshkov, 2016, pp. 1761-1771; Ravera, 2013).

Lake Baikal is one of the world's largest lakes that contains about twenty per cent of the world's fresh water (Jakob, et al., 2016). The development of various industries (mining, metallurgy, energy, etc.) and infrastructure (railway and roads construction, pipelines and power lines construction, etc.) changed environmental situation in the region, and not for the better. In this regard, various Russian and international organizations and fund were founded that work hard to establish protected reserves and to attract attention of the world community in order to improve lake's ecology (Hosaka, et al., 2016, pp. 61-67). As a result of their activities following acts were adopted: the UNESCO and the UN decision to assign Lake Baikal the status of World Heritage; the Law of the Russian Federation on Lake Baikal, and the concept of the target program "Protection of Lake Baikal and Socioeconomic Development of the Baikal Natural Territory up to 2020" (Bychkov, Maksimova, & Kuznetsova, 2015, pp. 350-357; Hosaka, et al., 2016, pp. 61-67; Jakob, et al., 2016). These acts laid foundation for the strategy and tactics of solving Lake Baikal environmental issues on state and international levels. Along with that, the issues of systematic monitoring and analysis of Lake Baikal ecology, the search for financial, technical, and innovative technological solutions to further insure the reduction of environmental stress around the lake remain pressing problems. Continuous independent monitoring of the ecological status of Lake Baikal could use the experience of the USA and Canada, which established the International Joint Commission (IJC) for the environmental protection of the Great Lakes (Friedman, et al., 2015, pp. 171-179; Gronewold, & Stow, 2014, pp. 1084-1085; Schoen, 2016, pp. 1800-1813). The IJC is a nongovernmental organization that operates as a collegial agency in the interests of both countries.

One of the main pollutants in the region is waste from power companies (thermal power plants and thermal boilers) that work on low quality solid fuels, and coal mines that produce and supply solid fuel. These enterprises' 'products' that pollute the environment are flue gases containing NOx nitrogen oxides, CO carbon, SO2 sulfur, etc., as well as soot and fine-dyspersated ashes particles. Another type of pollution from power plants are thermal power plants' ash and slag waste as well as coal mines' heaps (Buyantuev, & Sultimova, 2004, pp. 51-53; Chaus, Chistov, & Labzina, 1988; Popova, 1977, pp. 20-37). The problem is further exacerbated by the fact that Lake Baikal is an isolated ecosystem; despite the fact that the lake has 336 tributaries, most of them are insignificant (Batuev, et al., 2015, pp. 5-16). The lake has a single main inlet and a single main outlet for refilling its water (Evangelinos, et al., 2016, pp. 179-182; Kozhov, 2013, p. 11). At the inlet lies the polluted Selenga River (Rozhkova, et al., 2016, pp. 53-64), which flows from Northern Mongolia; at the outlet lies the Angara River.

This study aims to develop a technique for manmade waste processing.

## 2. Materials and Method

## 2.1 Research object

The object of research is ash and slag waste of thermal power plants and thermal boilers working on low-grade brown coal. There are large reserves of such coal in the region.

**Table 1.** Chemical composition of brown coal's ash and slag of the Zabaikalskiyi region

Concentration of components of cinder-slate waste	%
SiO <sub>2</sub>	56.50
Al <sub>2</sub> O <sub>3</sub>	20.87
TiO <sub>2</sub>	0.71
Fe <sub>2</sub> O <sub>3</sub> + FeO	14.38
CaO	3.80
MgO	1.86
Na <sub>2</sub> O	0.57
K <sub>2</sub> O	0.82
P <sub>2</sub> O <sub>5</sub>	0.28
SO <sub>3</sub>	0.21

## 2.2 Research methods

In each case of destroying, recycling and disposing of man-caused, domestic, and medical waste it is needed to know that what its made from, what harmful effects it may cause to the environment, and then choose the most effective method of destruction, recycling, and utilization with useful products production.

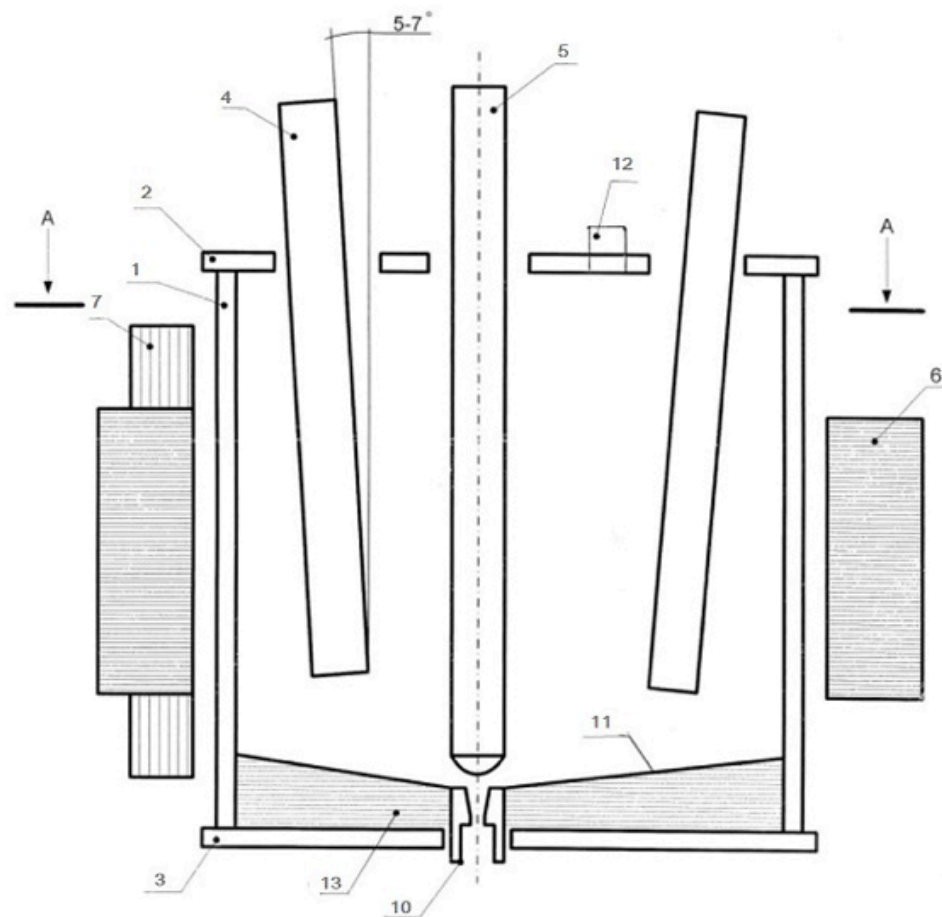
So, the study was carried out based on the following procedure:

- Chemical analysis of experimental waste samples
- The choice of innovative recycling method in order to insure efficient recycling with minimal power consumption and exclusion of harmful emissions into the atmosphere
- The study of physical and chemical properties of waste recycling products during its utilization with not full destruction
- Recommendations development and creation of new technology for the studied waste recycling
- Comparative analysis of the effectiveness of traditional and innovative recycling waste technologies.

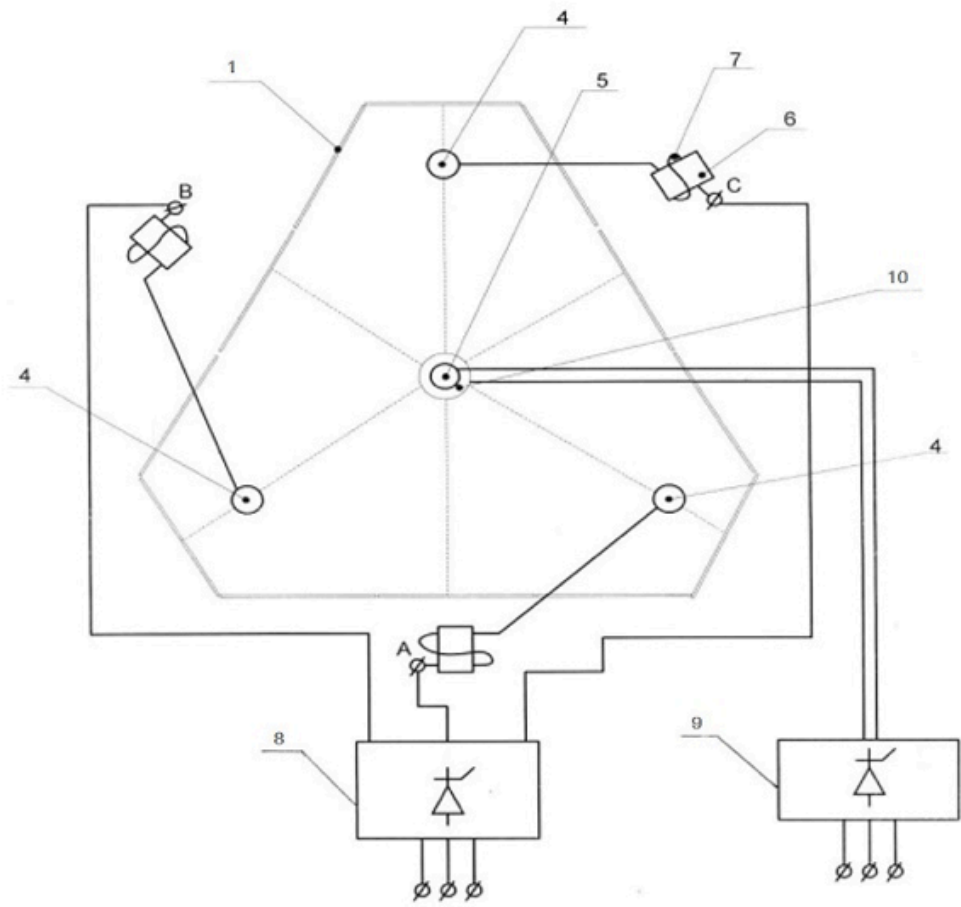
## 3. Data, Analysis, and Results

### 3.1 Plant design and experimental research

Schematic diagram of the smelting unit is shown in Figure 1. Ash and slag feedstock is fed from above into the reaction chamber of the smelting unit where arc burns at the first stage between three core electrodes. Then by the time of the molten bath formation begins the second stage of Joule heating. At these stages, to ensure even melt heating throughout the whole reactor chamber conductive plasma and fluid rotate between three electrodes due to the magnetic field of coils. These coils are connected in series to each of the three electrodes. Upon reaching the required melt fluidity by the temperature of 1750-1800 °C central locking electrode opens, opens the taphole opening, and the melt stream flows further on the fiber forming unit (not shown on the Figure) by any of the known circuits.



**A**



**B**

**Figure 1.** Slit (A) and cross cut (B) of electromagnetic technological reactor.  
 1- reaction chamber, 2- water-cooled cover, 3- water-cooled bottom,  
 4- core electrode (3 pcs.), 5- locking core electrode, 6- polepiece,  
 7- series coil, 8- power source, 9- additional power source for stream heating,  
 10- device for melt removing (taphole), 11- lined chamber bottom,  
 12- nozzle into reaction chamber for raw material supply, 13- lining.

Design features of the reactor allowed receiving clean melt that is free from occluded gases and reduced metals. This melt enables production of higher quality products and low energy consumption in comparison to the known smelting units.

With the new type of smelting unit it was possible to arrange smelting into one single step consisting of the combined heating of raw materials:

- Arc plasma heating and melting of raw material happens at a start. Then, while melt occurs and melt's conducting bowl is formed, raw material is being added and electric current flows through the molten silica-alumina mass. At the same time, this mass is being mixed and homogenized with a help of series-connected series electromagnets. That significantly reduces the time-to-operation and reduces power consumption. Defined in practice expended power that is required to produce melt with a weight up to 150 kg/h is 1.1-1.3 kW/kg (in comparison, expended power of the known induction furnaces is 6 kW/kg) (Buyantuev, et al., 2011).

Mineral fibers obtained by the electromagnetic technological reactor were examined to determine their physical and chemical properties.

Mineral fibers composition was determined by methods of chemical analysis.

Table 2 shows chemical composition of the fiber obtained from ash and slag.

**Table 2.** Chemical composition of fiber

Oxide	Oxide content in fiber, mass %
	Ash and slag
SiO <sub>2</sub>	54,69
Al <sub>2</sub> O <sub>3</sub>	19,73
TiO <sub>2</sub>	1,31
Fe <sub>2</sub> O <sub>3</sub> + FeO	12,47
CaO	3,98
MgO	3,49
Na <sub>2</sub> O	1,37
K <sub>2</sub> O	1,23
MnO	0,21
P <sub>2</sub> O <sub>5</sub>	0,28
Mk	9,96

The Table 2 shows that the content of silicon and aluminum oxides in the ash and slag fiber decreases slightly, with a slight decline of iron oxide. That is because during melting contained in it metal oxides are being restored into a compact metal which is simultaneously drained with melt pouring. These features of the smelting unit allowed to produce clean melt that is free from occluded gases and reduced metals. And that allows to produce the product of higher quality.

It is important to determine mean diameter of the fibers in order to assess suitability of mineral fibers as thermal insulation materials. Because the thinner fibers are, the lower thermal productivity it possesses. Microscopic method of sample analysis was used to determine the fibers mean diameter. The mean diameter was calculated by the following formula:

$$MD = g \cdot P \quad (1)$$

where  $g$ - fiber mean diameter in ocular micrometer division;  $P$ - price of ocular micrometer's dividing,  $\mu\text{m}$ .

It has been determined that ash and slag fibers have a mean diameter  $MD = 4-12 \mu\text{m}$ . Thus, fiber materials represent thin mineral fibers (Spirin, Ustenko, & Volodina, 1968, pp. 24-25).

## 4. Discussion

In aggressive environments fibers are exposed to corrosive action. There are two kinds of corrosive actions of aggressive environment on fibers: chemical (lixiviation) and dissolution in environment's volume. Transition from lixiviation to direct dissolution is possible by interaction of fibers with acids and even water in case if fiber is strongly enriched by alkali and contains little silica (ultra low acidity module  $Ma$ ).

The results of water-, acid-, and alkali resistance are shown in Table 3.

**Table 3.** Fibers chemical resistance

Fiber type	MD, $\mu\text{m}$	Chemical resistance (weight loss up to) $\chi$ , %		
		H <sub>2</sub> O	HCl	KOH
Ash and slag fibers	8	99,4	78,57	90,56

It is evident from the Table 3 that fibers have sufficiently high water resistance. By acid resistance, fibers may be divided in three groups: dissolving, lixiviating, and relatively persistent. From the presented samples of mineral fibers, more persistent are ash and slag fibers that content high level of silica and alumina oxide and low level of calcium and magnesium.

In order to explain the reasons for a high chemical resistance of ash and slag fibers its acidity module  $Ma$  was calculated by the following formula:

$$Ma = \frac{SiO_2 + Al_2O_3}{CaO + MgO} \quad (2)$$

As follows from the calculation, acidity module of ash and slag fibers is  $Ma=9,96$ . Fibers chemical resistance highly increases with  $Ma$  increase, which is observed in ash and slag fibers.

The dependence of strength properties according to diameter was also determined. Fibers mechanical characteristics were determined by breaking experiment. Breaking stress ( $\sigma$ ) of filament was calculated by the following formula:

$$\sigma = (4P * 10^4) / \pi d^2 \quad (3)$$

where  $\sigma$ - breaking stress, MPa,  $P$ - breaking load,  $H$ ,  $d$ - filament diameter,  $\mu\text{m}$ . Data on the dependence of fibers strength according to diameter is shown in Table 4.

**Table 4.** Dependence of strength properties according to diameter

Indicator	Fiber type

Diameter, $\mu\text{m}$	4; 8; 12; 16
Breaking stress, MPa	1927
	1390
	1213
	1130

As follows from the Table 4, fibers specific breaking stress depends on its diameter. The larger the diameter is, the lower is breaking stress (Bobrov, et al., 2003; Zyablitskii, 1979).

By mechanical properties (breaking) presented fibers are not inferior to the fibers obtained at well-known fields, as well as satisfy required state standards.

As we can see, obtained fibers are characterized by high performance and high acidity module. There is also a possibility to produce mineral wool from ash and slag waste. That shows prospects of this material not only in construction industry, but also in the production of fire and thermal insulation materials.

## 5. Conclusion

The discussed above research results lead to the following conclusions. By physical and chemical methods it was determined that during electromagnetic technological method of obtaining of mineral fibers certain processes occur that are different from processes that occur during conventional methods. Namely, at high processing temperature (1600-2500 K) there is deeper decomposition of raw material into elemental constituents in the form of respective oxides ( $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{MgO}$ , etc.). At the same time the reactor's design features allowed to obtain clean melt occluded gases and reduced metals enabling production of high quality products. Based on this research it is possible to see the advantages of using the designed plant and technology for destruction and utilization of various solid domestic, medical, and other toxic waste to produce new types of composite materials. Because, first, these types of waste melting point and evaporation is lower than ash and slag. Second, it is possible to control (with a wide range) melting point on the designed plant. And third, there is possibility to decompose released harmful toxic gases into neutral components.

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