Lightweight Expanded Clay Aggregate (LECA) as environmentally friendly multifunctional sorbents

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Abstract

The aim of the study was to determine the sorption capacity of Lightweight Expanded Clay Aggregate (LECA), obtained by high-temperature expansion of natural rocks, and to identify possible fields of their targeted application based on their properties. Four common types of rocks found in various regions of Georgia were selected for the study: zeolite, obsidian, pumice, and perlite. Their chemical composition was determined, and the optimal parameters of thermal treatment were selected, which define their high porosity and, consequently, their sorption capacity. The obtained materials were additionally characterized for their performance properties: bulk density, mechanical strength, and water resistance. By comparing the values of the characteristic parameters, it was determined that the following recommendations can be made: porous materials obtained by expanding pumice and perlite at 1100 °C can be used as sorbents for soil and industrial wastewater purification; foam glass produced by expanding obsidian at 1200–1250 °C can be used for the localization of spilled petroleum products as well as for floating covers of petroleum storage tanks; while zeolite can be used as a gas adsorbent, specifically as a CO_2 adsorbent for flue gases from industrial processes, with the possibility of subsequent waste-free utilization.

KEYWORDS: natural rocks, thermal treatment, porous material, properties, sorbent

Introduction

Of the two main types of sorbents (organic and inorganic), considering properties such as high mechanical strength, resistance to aggressive environments, high adsorption capacity, regenerability, and others, inorganic sorbents are distinguished as preferable [1,2].

It is well known that a number of naturally porous rocks are often used as sorbents for solving various environmental problems. In particular, "raw" rocks such as sands, diatomite, clays, limestone rocks, zeolite, and others are widely used in practice for soil detoxification (pesticides, heavy metals, petroleum products, etc.) or for the purification of industrial wastewater. The drawbacks of well-known inorganic sorbents are considered to be their high bulk and true density, which affects their immersion in liquids, as well as their low sorption capacity and difficulties associated with regeneration and disposal [3,4].

We conducted a study aimed at transforming three naturally porous rocks found in Georgia (pumice, perlite, zeolite) and natural glass—obsidian—into highly porous Lightweight Expanded Clay Aggregate (LECA) through thermal treatment, and at evaluating their potential for use as sorbents. For this purpose, the obtained LECA-type materials were characterized by a set of properties: bulk density or apparent density, porosity determined by water absorption or absorbed gas weight, compressive strength, and water resistance, evaluated by the leaching coefficient.

Research Methods

The expansion of all four raw rocks was carried out by thermal treatment of their fragments at 900–1300°C in a carburizing furnace, with a 15–20 minute hold at the corresponding temperature, followed by the preparation of samples or their division into fractions for further study. The bulk density (y) was determined using the formula y= g/v (kg/cm^3), where (g) is the specific gravity of the material placed in a vessel of a certain volume (v), and the specific density (d) was determined by the hydrostatic weighing method. The open porosity of the obtained foamed materials was studied either by absorption (w,%) or by weight gain (Δ,%) due to adsorbed gas, and the compressive strength of 2x2x2 cm cube samples was measured by hydraulic pressure. Water resistance was assessed by determining the softening coefficient (Ɛ); $Ɛ=P_2/P_{1,}$ where P_1 and P_2 are the hardness of the grains of the test material in the initial (dry) and after soaking in water, respectively.

Result

The chemical composition of samples of all four types of raw materials was determined and is presented in Table 1. All of them can be classified as aluminosilicate materials, but contain a small amount (up to 10 wt.%) of R_2O and RO oxides. All the rocks contain iron oxide (up to 2 wt.%) and a negligible amount (less than 0.5%) of manganese or titanium oxide compounds. At the same time, a pronounced difference in the values of **Loss on Ignition** (LOI) was observed. The LOI value is particularly high (greater than 12%) for zeolite, moderate for perlite and pumice (approximately 3.7% and 1.5%, respectively), and very low for glassy obsidian (≈ 0.5%).

Table 1. Chemical composition of acceptable raw materials for LECA-type sorbents made from porous inorganic materials

N	RAW MATERIAL NAME	CHEMICAL COMPOSITION OF RAW MATERIAL, WT.%										
		LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	Na_2O	K_2O	TiO_2	ჯამი
1	Zeolitic Tuff	12,87	62,58	13,24	1,76	2,75	1,06	0,11	3,92	1,31	0,40	100
2	Perlite	3,67	73,07	12,58	1,83	1,38	1,39	0,21	3,41	2,48	-	100
3	Pumice	1,47	71,81	15,1	1,83	1,27	0,92	0,21	3,63	3,76	0,21	100
4	Obsidian	0,47	73,51	14,61	1,25	1,12	1,39	0,10	2,98	4,27	-	100

Based on the objectives of the study, which involved obtaining lightweight inorganic porous materials as potential sorbents, the selected rocks were subjected to thermal treatment over a wide temperature range (200–1250°C). The optimal parameters of thermal treatment (temperature and holding time) for each raw material, which ensured the transition to a porous Lightweight Expanded Clay Aggregate (LECA), are presented in Table 2.

Table 2. Bulk density of LECA, obtained from the raw material under investigation*, and the corresponding optimal thermal treatment parameters

N	Raw material name	Bulk Density, kg/m^3	Heat Treatment Parameters	
			Temperature, °C	Time of material exposure at temperature
1	Zeolitic Tuff	2040	330±20	2 hours
		1130±20	1100±20	30 minutes
2	Perlite	670±20	1100±20	15-20 minutes
3	Pumice	430±10	1100±10	15-20 minutes
4	Obsidian	180±10	1220±20	15-20 minutes

*For 10-15 mm fractional material

According to the obtained results, obsidian exhibits strong expansion at high temperatures (y = 180 ± 10 kg/m^3), which allows it to be practically transformed into foam glass. For pumice and perlite, maximum expansion is achieved at 1100 ± 200°C. The porous material obtained from pumice is lighter (y = 430 ± 10 kg/m^3) than that obtained from perlite (y = 670 ± 20 kg/m^3). Zeolite, compared to the other studied materials, is the least expandable rock, as evidenced by the high density of the material obtained after thermal treatment at 1100 ± 20°C (y = 1130 ± 20 kg/m^3).

The LECA-type materials obtained from raw materials treated under different temperature regimes were characterized for a range of properties: performance properties — compressive strength and water resistance coefficient (for pumice and perlite), and targeted properties — sorption capacity. The main results obtained from the study are presented in Table 3.

Table 3. Characteristic properties of porous materials artificially obtained by heat treatment

N	CHARACTERISTIC PROPERTIES	UNIT OF MEASUREMENT	NAME OF ORIGINAL RAW MATERIAL			
			Perlite	Pumice	Obsidian	Zeolitic Tuff*
1	Bulk density	Y, kg/m^3	670	430	180-200	1130-2040
2	Compression strength	P, MPa	6,8	6,2	0,12-0,14	-
3	Porosity (open)	%	18,2	18,7	0,5-1,0	-
4	Water resistance coefficient	-	0,76	0,75	-	-
5	CO_2 adsorption	Weight gain, (%)	-	-	-	3-10

*Zeolite tuff grains processed at 330±20^{0}C: ε = 3-5 mm, adsorption temperature 35-75^{0}C;

For clarification, the sorption capacity of materials artificially obtained by high-temperature treatment of rocks was determined corresponding to the open porosity (for pumice and perlite), while for zeolite treated at 330 ± 20° C, it was determined by CO_2 adsorption (weight gain of the thermally treated material) within a specific temperature range (35–75° C).

Discasion

Thermal treatment of the four targeted natural rocks — pumice, perlite, obsidian, and zeolite (zeolitic tuff) — yields porous materials with different performance and sorption properties (Table 3). The differences observed can be attributed to their more or less distinct chemical compositions, which likely influenced their structural arrangement. Specifically, obsidian is an amorphous volcanic glass; perlite and pumice can be considered semi-amorphous–crystalline; while zeolitic tuff (a raw material containing clinoptilolite and clay minerals) belongs to the crystalline type. Their structural arrangement must have had a significant influence on the expansion process of the studied rocks, which is determined by the temperature at which the material reaches a pyroplastic state and the behavior of the volatile components of the LOI at that moment [5,6]. In this context, amorphous (monolithic) obsidian (LOI ≈ 0.5%) fully retains its expanding components until reaching the pyroplastic state, whereas pumice, perlite, and zeolitic tuff prematurely lose their volatile components. This is evidenced by the increase in bulk density (y) values (obsidian → pumice → perlite → zeolite), as well as by the degree of sorption capacity, which corresponds to their respective potential fields of application.

The recommended application areas for the expanded lightweight porous materials are as follows: perlite and pumice — as sorbents for polluted soils and industrial wastewater; obsidian — for the localization of spilled petroleum products and as a protective floating cover for petroleum storage tanks; zeolitic tuff — for CO_2 capture from industrial/flue gases with subsequent utilization (waste-free technology).

Conclusion

The targeted study conducted on four types of natural rocks (obsidian, pumice, perlite, and zeolitic tuff) confirmed the possibility of producing Lightweight Expanded Clay Aggregate (LECA) from them. Thermal treatment of the studied materials at different temperatures determined the conditions necessary to achieve high porosity. The determination of key performance properties (compressive strength, bulk/apparent density, water resistance) and sorption capacity/porosity allowed the evaluation of their potential as sorbents and the identification of prospective practical application areas.

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