Orlov, A.V.; Yu, Q.L.; Rumiantsev B.M.; Brouwers, H.J.H.

Indoor air quality improvement applying novel gypsum based materials

Abstract

This article discusses the possibility of obtaining a multifunctional finishing material, a porous gypsum binder based product with the addition of zeolite. Due to the incorporation of zeolite into the matrix of porous plaster a final product possesses not only decorative, acoustic and fire-protective functions but also can purify the indoor air pollutants due to high sorption and ion exchange capacity of zeolites.

The developed porous gypsum zeolite materials (PGZM) can be used in the production of facial elements of ceilings, dry building mixes as well as in plaster solutions and products based on traditional plaster (walls, gypsum partition blocks, etc.).

Keywords: Gypsum, zeolite, foam, air quality, formaldehyde, adsorption.

Introduction

Improving the health indicators of the indoor air is very important in connection with a high level of chemical pollution. The sources of these pollutants are both external (road transport and combined heat and power) and internal (chemical evaporation of paint, lacquer, furniture glue, plastics, floor coverings, tobacco smoke, organic matter, etc.) factors.

One method to address this problem is reducing the concentration of harmful substances in the indoor air. Systems of natural and forced ventilation with additional filtering elements or without them are currently used as solutions, as well as household cleaning systems and humidification.

In this regard, the creation of multifunctional materials that provide the combination of the maximum number of protective functions is needed. For instance, great attention has been paid to the creation of a material with optional air purification in a room with a long service life. The preferable solution to this problem is the usage of active minerals with high sorption and ion exchange capacity. These minerals are different sorbents widely used in industry [1].

During this study, a scientific idea was formulated, which is: harmful substances reach the surface of the porous gypsum material, where due to its developed surface area and high intergranular pores pass into the depth of the material and come to the surface of the sorbent-filler and then penetrate into its microporous structure due to the gradient-diffusion forces. In the microporous structure of the sorbent pollutant, molecules are adsorbed mainly due to dipole interactions, then some of them experience partial ion exchange. Thus, harmful components and possible products of chemical reactions are retained in the filler and removed from the atmosphere.

In modern chemical, gas and petrochemical industry sorbents are used for deep cleaning and drying process flows, improving the quality of raw materials and processed products. Adsorption method can almost completely remove the impurities from the gas and liquid medium and solve the environmental issues the biosphere from harmful industrial emissions, etc. [2]. In the building industry, the production of materials with high sorption abilities (such as applying zeolites) should be used for effective absorption and reducing concentrations of the most widespread pollutants in the living area.

Experimental

Zeolites have a unique structure with the particular size of 3 to 9 Å and penetrating capacity, which allows the creation the selective sorption sites [3]. It was found that zeolites have flocculent structure with strong intergranular voids up to 3 microns and the input channels are located on the surface of the zeolite grains. In the study of the sorption capacity of zeolites in comparison with another widely used sorbent - silica, it was revealed that the kinetics of saturation of the zeolite is more flat (see Fig. 1). This is because of the smaller diameter of the channels of the zeolite, which are saturated more slowly than the major channels of silica gel [4]. Also, the results show that the sorption capacity of zeolites is higher than that of silica gel. Thus, it is reasonable to use zeolite as an adsorbent for materials which need high sorption capacity in the long term operation.

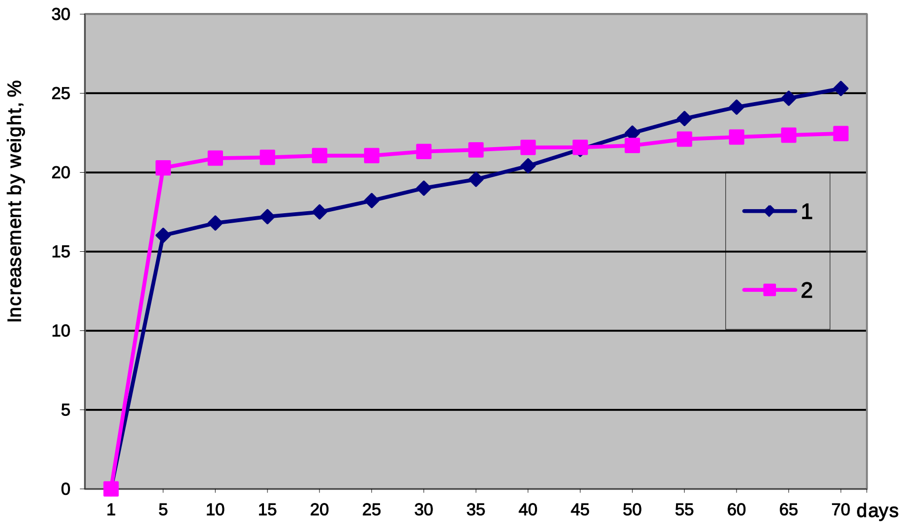

Fig. 1. Sorption capacity of formaldehyde vapors: 1.- Zeolite NaX; 2. - Silica gel.

Experiments on the zeolite sorption capacity of different pollutants were carried out. Results show that the zeolite sorption of ammonia vapors proceeds more efficiently than the sorption of vapors of formaldehyde and phenol in particular. This is due to the size of the adsorbed molecules and the size of the input channels of the zeolite. Also increasing of grinding effects positively on the sorption rate. For example, zeolite with the fraction of 0.14-0.63 mm in 30 days adsorbs 19.4% by weight of ammonia, and zeolite with the fraction of 1.25-2.5 mm adsorbs 16.1%.

It is established that the sizes of intergranular voids in the studied zeolites are sufficient for the passage of sorbed gas molecules into the interior of the zeolite and the further penetration of these molecules into the input channels. The input channels are evenly distributed throughout the volume of grains of zeolite, which allows the absorption of gas molecules effectively by the entire volume of the grain.

X-ray diffraction studies of the zeolite were carried out to determine the nature of the sorption and possible tumors in the interaction with the zeolite sorbate (formaldehyde) (see Fig. 2). When comparing the radiographs of the zeolite before and after saturation of the X-ray, it was revealed that the formation of a saturated sample of at least 4 additional and changes in the intensity of some overlapping in position of the lines that indicate the formation of new compounds. In the process of sorption of harmful substances, zeolite chemical reactions between the zeolite and sorbate were observed, which increases the efficiency of sorption of porous gypsum zeolite materials.

For effective work of the zeolite as a component of the material it is necessary to find a major component of the matrix, which would allow gas molecules freely penetrate into depth of material, and the input channels of the zeolite would be open. A porous plaster material commonly used for acoustic insulation and processing facilities has this structure and thus well suits to the present research [5]. The use of gypsum as a main component in obtaining materials with high sorption capacity is also related to its availability, ease of obtaining with low energy consumption, manufacturability in processing, hygienic and decorative [6].

The β-modification of the hemihydrate binder was selected due to its high water demand than α-modification. This provides a much larger specific surface area of the developed material and, in this way, higher sorption rates.

In analyzing the adhesive properties of the zeolite matrix in relation to porous gypsum, it was found that the contact area is formed by a contact point of needle-like crystals of gypsum to the surface of the zeolite. Gypsum crystals and the surface of the zeolite are located at different angles.

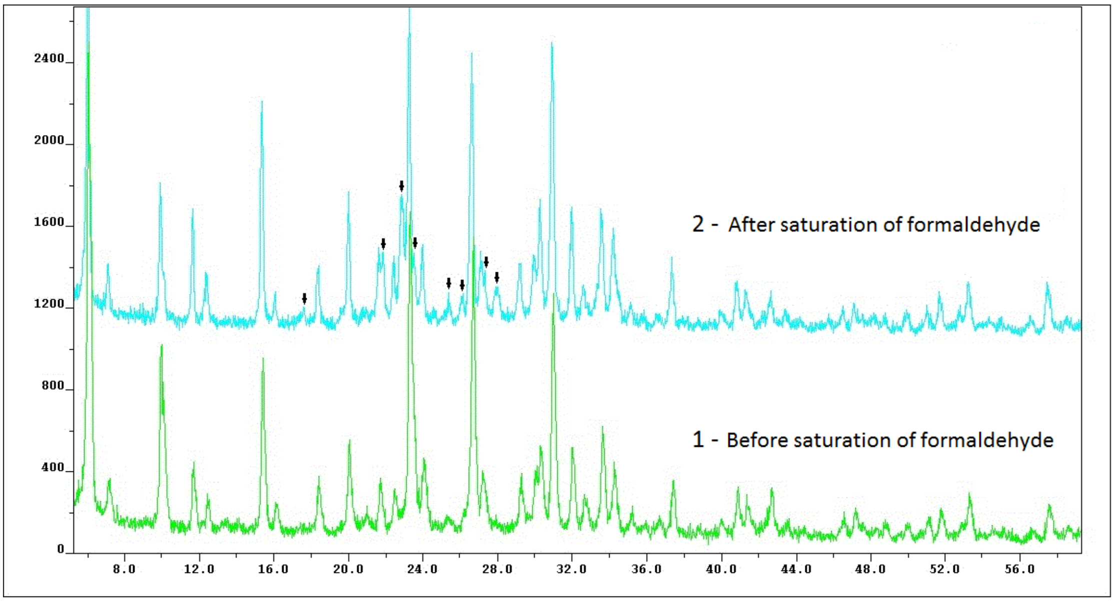

Fig. 2. Radiographs of the zeolite; 1) before saturation of formaldehyde; 2) after saturation of formaldehyde. * Arrows on the radiograph show the formation of new peaks

Studies of the structure of porous gypsum zeolite materials (PGZM) showed (see Fig. 3) that the gypsum crystals have a larger particular size than the zeolite, and the contact area of crystals of gypsum and zeolite is a point. That minimizes the blocking of the input channels of the zeolite. This fact, together with intergranular voiding in a plaster material that can easily allow adsorbed molecule of gas to penetrate through its thickness, can provide high sorption properties of porous gypsum zeolite materials (PGZM), which confirms the scientific idea formulated here.

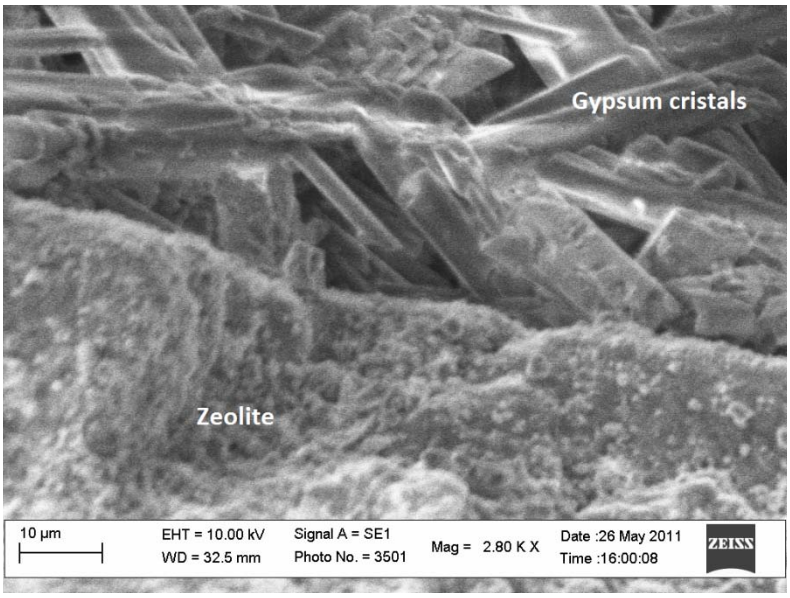

Fig. 3. The structure of PGZM with density 400 kg/m^3 with magnification x2800.

The gypsum material, having a stable crystal lattice, works well with fine fractions of zeolite, which provides advanced surface for ion exchange, and blocking of the input window of the zeolite by a point contact with the gypsum crystals is minimized. The materials themselves, in this case are molecular sieves with the power to control their properties.

Determination of the sorption capacity of the PGZM

To determine the sorption capacity of PGZM in the operation, an experimental set-up which simulates the operation of the material in the real world was developed. In connection with this, a procedure for determining the sorption capacity of materials was proposed, the essence of which lies in the forced pumping contaminated gas through the material with subsequent analysis of the left gas to its purity (see Fig. 4). To do this, the material was placed in the reactor, on one side of the reactor the carrier gas was fed, on the other side through a flexible tube the gas was fed into the flask with the solution-indicator for polluting additive.

Air was selected as the carrier gas, and ammonia was selected as a pollutant gas. Ammonia is a toxic gas, and belongs to a class of harmful substances - 4 [7]. As an indicator, phenolphthalein was chosen due to its high sensitivity to ammonia, which is manifested in the staining of water-alcohol solution of phenolphthalein in the reaction with ammonia in the red-violet color. In the process of filling of the gas into the reactor and through the depth of the test material, part of it is absorbed into the sorbent, and some may pass through the material and into the flask with the solution-indicator. The interaction of the gas (ammonia) with an indicator (phenolphthalein) solution acquires a red-violet color. If the pollutant (ammonia) does not pass through the material, the indicator will remain the same colour.

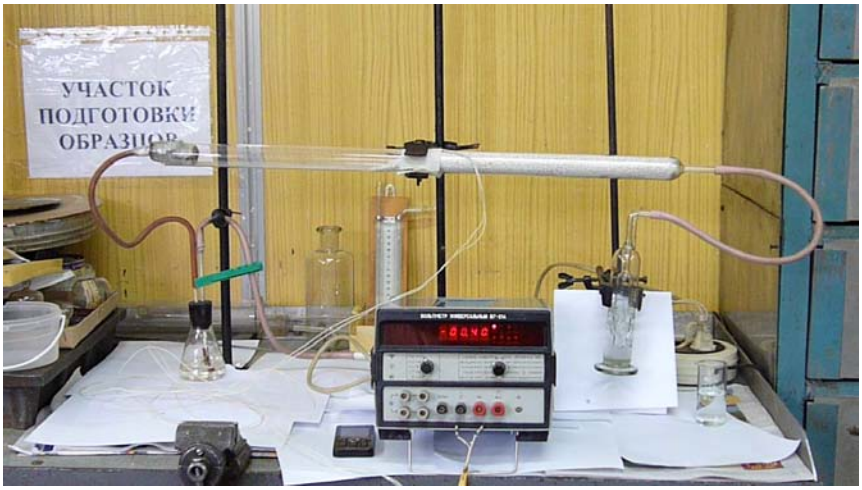

Fig. 4. Installation for evaluation of the sorption capacity of materials

Thus, depending on the time that elapses before the staining indicator solution at a constant discharge of ammonia vapors in the thickness of the material and its subsequent contact with a solution of the indicator, the sorption potential of the materials can be assessed.

For the experiment, the following materials were chosen: a crushed concrete with a size of 0.14-0.63 mm and with an amount of 210 grams, rock wool with an amount of 23.4 grams, PGZM with an amount of 76.3 grams, the zeolite fraction 1.23-2.5 mm with an amount of 130 grams. An exothermic reaction along the reactor was observed for filling of zeolite and PGZM. The reaction began with the entrance of the gas mixture in the backfill. In this zone of the reactor a distinct rise in temperature could be observed. At this time the rest of the tube remained cool. Gradually, the hottest region moved towards to the end of the tube outlet. The heating of the tube at a particular location was fixed by a thermocouple recorded on the surface of the tube.

The temperature change of the sorbent (zeolite) in the reactor indicates that there are chemical reactions between the pollutant and the sorbent. This study found that for different materials the coloring of the indicator occurs at different time, for example for wool dyeing it occurs within 29 seconds after the start of the experiment, for concrete 1 min 27 seconds, for PGZM 12 min 34 seconds, for zeolite 131 minutes, which is consistent with the scientific idea of the work.

The key figures of the developed materials are presented in Table 1.

Table 1. The performance properties of porous gypsum zeolite materials

Name of indicators	The value of indicators		
The average density kg/m^3	350	400	450
Crushing stress, MPa	0.4	0.54	0.63
weight of 1 m^2, кг.	8.75	10	11.25
Group of combustibility	nonflammable	nonflammable	nonflammable
Acoustic absorption class of:			
- low (L) frequencies (63-250 Hz)	2	3	3
- medium (M) frequencies (500 – 1000 Hz)	1	1	2
- high (H) frequencies (>1000 Hz)	1	2	2

Conclusions

- Development of a porous gypsum zeolite product based on the method of dry mineralization gypsum binder by using foam with the addition of fine fractions of the zeolite. Zeolites, which are distributed in the structure of the foamed gypsum, show high cleaning properties and kinetics of harmful substances sorption, which is carried by combined effect of extensive porosity of foamed gypsum and molecular dimensions channels of the zeolite.

- The developed multifunctional product based on the porous gypsum zeolite material has a density of 400 kg/m^3, compressive strength of 0,54 MPa, class of absorption PDR-312, nonflammable.
- The effectiveness of the PGZM is assessed by micro-sized molecular sieve determining sorption properties of the material.
- The expediency of application of gypsum binder in the porous form, as in this case, the sorption capacity and acoustic absorption of the material is considerably increased, and the contact surface of gypsum binder and the zeolite is a point that minimizes the blocking of the input channels of zeolites.
- A method for determining the sorption capacity of materials is developed, which allows to determine the sorption capacity of different porous materials.

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Authors

Dr. A.V. Orlov
Department of Technology of finishing and insulating materials
Moscow State University of Civil Engineering
129337, Yaroslavskoe road 26, Moscow
Russia

Dr. Q.L. Yu
Department of the Built Environment
Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven
The Netherlands

Prof. Dr. Ir. H.J.H. Brouwers
Department of the Built Environment
Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven
The Netherlands

Prof. Dr. B.M. Rumiantsev
Department of Technology of finishing and insulating materials
Moscow State University of Civil Engineering
129337, Yaroslavskoe road 26, Moscow

Russia