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GAS PERMEABILITY OF ZEOLITES – DESCRIPTION OF THE PHENOMENON

GAZOPRZEPUSZCZALNOŚĆ ZEOLITÓW – OPIS ZJAWISKA

Summary: This article presents gas flow through porous beds, indicating the results of gas permeability measurements related to the total pressure drop. A clear difference in gas permeability was observed with respect to a given flow direction – this creates unlimited possibilities for heat storage and utilization of zeolites in the context of unconventional energy generation. An important premise is the low energy input required for gas flow in the zeolite system.

Keywords: zeolites; gas permeability; porous materials, cubic solid

Streszczenie: W niniejszym artykule omówiono przepływ gazu przez złoża porowate, przedstawiając wyniki pomiarów gazoprzepuszczalności w odniesieniu do całkowitego spadku ciśnienia. Zaobserwowano wyraźną różnicę w gazoprzepuszczalności w zależności od kierunku przepływu – stwarza to nieograniczone możliwości w zakresie magazynowania ciepła i wykorzystania zeolitów w kontekście niekonwencjonalnego wytwarzania energii. Ważnym założeniem jest niski nakład energii wymagany do przepływu gazu w układzie zeolitytowym.

Słowa kluczowe: zeolity; gazoprzepuszczalność; materiały porowate; ciało stałe o strukturze sześcienniej

Introduction

Innumerable studies [1, 2] have been published on gas flow through porous beds, focusing primarily on the study and description of gas permeability when flowing through cylindrical samples or in a column filled with porous material, as well as on the characterization of the porous materials themselves. The methods for measuring gas permeability through porous materials were described, depending on their structure:

- granular (sand, gravel, soil),
- skeletal (carbon matrix, char, melted gangue),
- capillary-porous (concrete).

Gas permeability through porous deposits is important in various technological processes [3-6], therefore, research is being undertaken on measurement methods and methods for assessing gas permeability. Samples are generally cylindrical, and gas permeability is assessed along one axis of the sample. Permeability is described as the property enabling gas migration through the system of pores (open, blind, closed) and crevices present in the deposit medium. It is shown that this parameter depends on the pore size, shape, and diameter – all of which determine gas movement within the structure. The gas permeability coefficient describes not only the properties [7, 8] but also the nature of gas flow in the deposit medium [9, 10].

Based on our own research to date [11-17], it can be concluded that in gas flows through porous media with channel dimensions of the order of millimeters or less, hydrodynamic phenomena (gas flow, viscosity) dominate over physicochemical phenomena (shaping the structure and mechanical properties) occurring at the interface. However, the latter are of significant importance in flows through structures with very small pore dimensions of the order of a few tenths of a micrometer. The flow structure of a porous medium depends on the size (diameter) of the channels and their shape – for a given channel length. Consequently, the resistance during flow around tortuous walls will differ from the resistance through structurally closed channels. It is indicated that a measure of this deviation can be the drag coefficient (of a certain equivalent value), resulting from the hydrodynamics of gas flow through such materials with a specific porosity, the equivalent diameter of the channels, their shape, and the given gas flow path length. With the above in mind, it seems that a broader understanding and description of the hydrodynamics of gas flow through porous materials, and linking this phenomenon to the internal structure of the material being tested, is worthwhile both from a research and application perspective. Having a universal method for determining permeability, both in laboratory tests and in the interpretation of technological processes, can improve the efficiency of gas permeability.

Own research.
Results of preliminary studies and their analysis.

Detailed experimental studies were conducted to assess the gas permeability of porous materials: carbonization, polyamide (porous sinter), and zeolite. The tests were conducted on a specially designed stand [18], the key element of which is a flow channel into which a sample of the porous material is introduced (Fig. 1a).

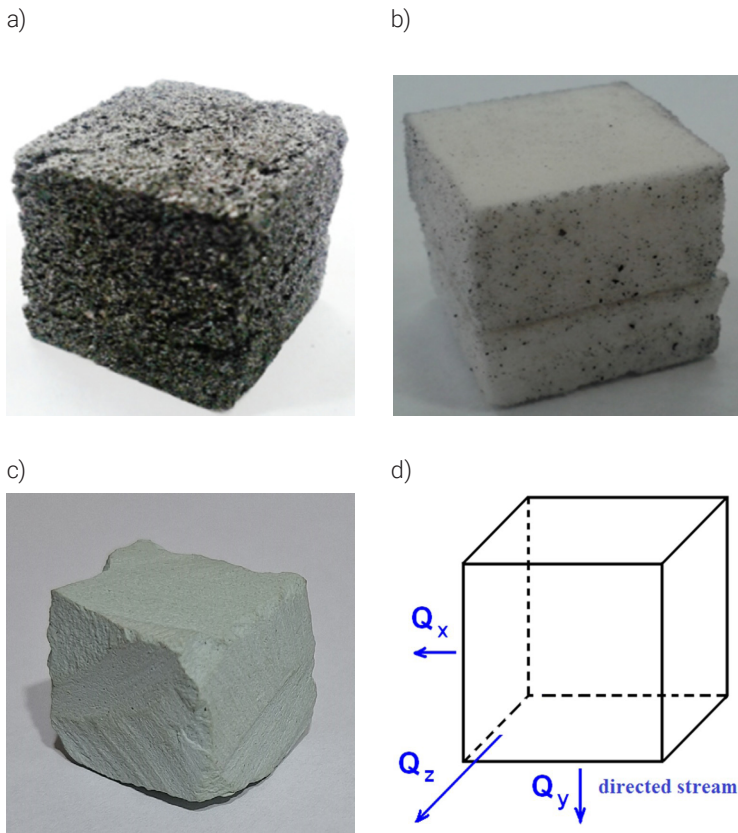


Fig. 1. Sample of the test material (photo by Grzegorz Wałowski) – porous material with dimensions of 20 x 20 x 20 mm: a) carbonization, b) polyamide (porous sinter), c) zeolite, d) gas flow diagram through the sample (own work)

The tested sample had a cubic shape, and the design of the flow channel enabled the measurement of gas permeability for each of the main flow directions (X, Y, Z) (Fig. 1d) by rotating the cubic sample in a selected plane of the measurement cell [19].

Quantitatively, experimental studies assessed parameters such as apparent density ρ_o , porosity ϵ , and gas permeability. This allowed for the definition and determination of the permeability coefficient K , as well as the equivalent flow resistance coefficient ξz . The gas (oxygen) volumetric flow rate V resulting from the pressure difference ΔP forcing this flow was adopted as a measure of gas permeability. Apparent density and porosity of the char were determined based on measurements of the total sample volume and its mass. Figure 1 presents the results of gas permeability measurements related to the total pressure drop ΔP for a cubic solid of char. For comparison, Figure 1 also shows the permeability determined for a dimensionally analogous sample made of porous polyamide. The distribution of experimental points indicates that the polyamide sample exhibits isotropic properties, as evidenced by the lack of discrepancies in gas permeability with respect to the flow direction. In turn, char is characterized by a strong anisotropy of its structure. This is evidenced by the distinct differences in gas permeability with respect to a given flow direction.

It can also be observed that the permeability of char is more or less similar regardless of the type of the sample tested. This suggests that the permeability of a porous material bed can be estimated based on the elementary bed unit, which is a cubic body.

Figure 2 presents the results of gas permeability measurements related to the total pressure drop ΔP for a cubic zeolite solid. The distribution of experimental points indicates that the zeolite sample exhibits isotropic properties, as evidenced by the lack of discrepancies in gas permeability with respect to the flow direction. A peculiar phenomenon of a successive increase in the gas flow rate (oxygen) depending on the flow direction was observed. This is evidenced by the distinct difference in gas permeability with respect to a given flow direction – this creates opportunities for heat storage.

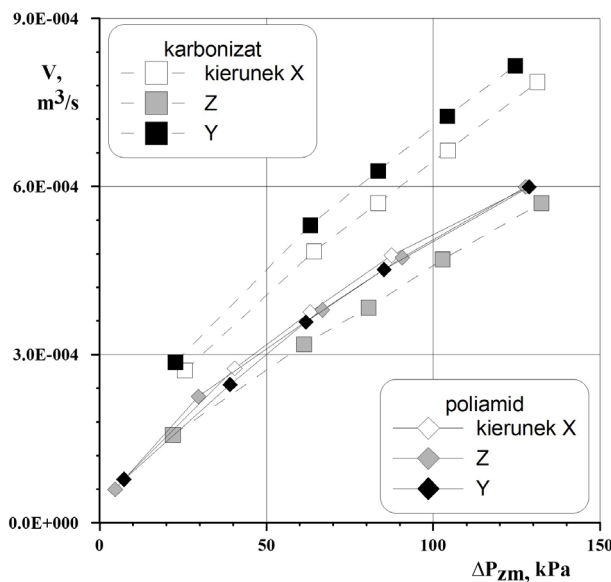


Fig. 2. Permeability of porous material [prepared by G. Wałowski]: carbonization – cubic body: □ direction X, ■ direction Z, ■ direction Y; isotropic cubic solid (polyamide): ◇ direction X, ◆ direction Z, ◆ direction Y

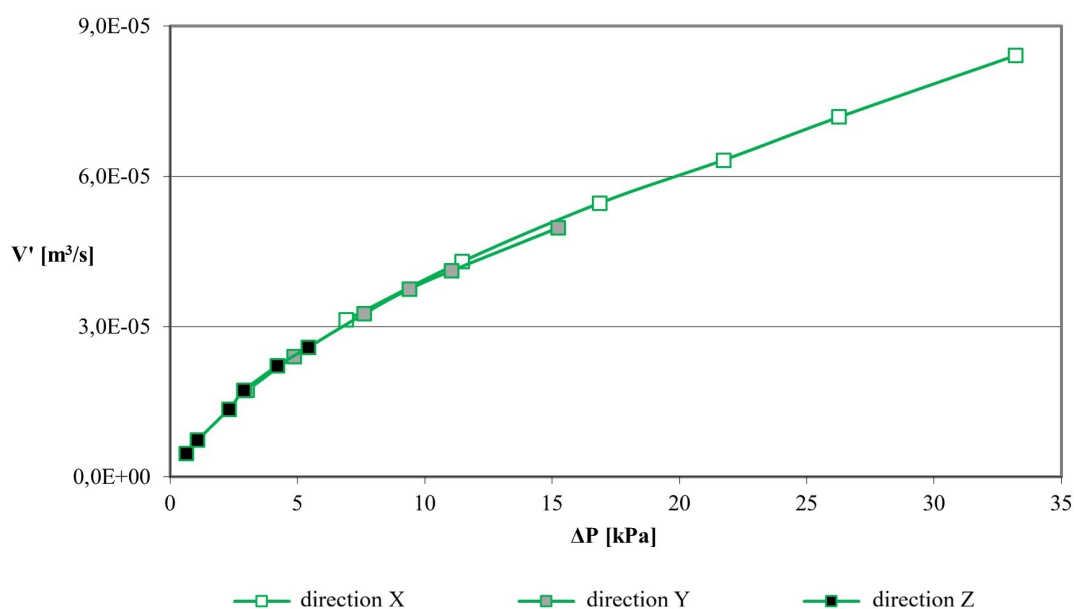


Fig. 3. Permeability of porous material [prepared by G. Wałowski]: zeolite – cubic body: direction X, direction Y, direction Z

Comparing the data in Fig. 2 and Fig. 3, it should be noted that zeolite exhibits the lowest flow rate, taking into account the range (0-35) kPa of flow resistance compared to char and polyamide. An important factor is the low energy input required for gas flow, which translates into an optimal energy storage system.

Assessment of the gas permeability phenomenon

The assessment of gas flow through porous media (i.e., gas permeability) was linked to the pressure drop during flow in a porous bed, assuming (by convention) a single-variant gas flow through the material sample: a directed XYZ flow pattern, characteristic of a cubic sample.

The basis for assessing the hydrodynamics of gas flow through porous beds and materials is the characterization of their permeability. In each case, determining this characterization involves determining the effect of overpressure on the achieved gas flow rate, or conversely, the effect of the gas flow rate on this pressure value.

The main subject of the study is to determine the permeability of porous materials to gas using two independent gas flow circuits – external and internal.

Gas flow through porous media occurs in many process areas. It is most often associated with filtration and the distribution (migration) of process gases in adsorbents. This phenomenon is also encountered in technological processes related to fracturing and thermal processing of coal, as well as in the flow of gases through rock masses and various types of chars, such as coke or activated carbons. In many technological processes, the operation of apparatus and the gas flow occurring within

them depend on the type and construction of distributors, which are often made of porous materials.

In each case, identifying the conditions of gas flow through porous deposits poses significant challenges related to the description of hydrodynamics and the assessment of gas flow mechanisms through such deposits, especially given their diverse structures. Furthermore, knowledge of these mechanisms allows for an assessment of the process conditions accompanying the hydrodynamics of gas flow through such materials, and consequently, a detailed description of the gas flow conditions through porous deposits.

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