Grzegorz WAŁOWSKI
Institute of Technology and Life Sciences, Renewable Energy Department, Poznań Branch
ul. Biskupińska 67, 60-463 Poznań, Poland
email: g.walowski@itp.edu.pl ; walowski.g@gmail.com
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INTERPRETATION OF GAS PERMEABILITY OF ANISOTROPIC STRUCTURE OF SKELETAL DEPOSIT

Summary

In the paper results of experiments on hydrodynamic assessment of gas flow through backbone (skeletal) porous materials with an anisotropic structure are presented. The research was carried out on materials of different petrographic characteristics and origin of process (char). The study was conducted for a variety of hydrodynamic conditions with the use of air. As the basis for the hydrodynamics of gas flow through porous material we assumed a gas stream as a result of pressure forcing such flow. The results of measurements indicate a clear effect of the type of material on the gas permeability, and additionally – as a result of their anisotropic internal structure – a significant effect of the flow direction on the value of gas stream.
***Key words**: gas permeability, anisotropy, adhesion beds, char, biogas*

INTERPRETACJA GAZOPRZEPUSZCZALNOŚCI ANIZOTROPOWEJ STRUKTURY ZŁOŻA SZKIELETOWEGO

Streszczenie

W pracy przedstawiono wyniki badań doświadczalnych w zakresie oceny hydrodynamiki przepływu gazu przez sztywne (szkieletowe) materiały porowate o anizotropowej strukturze. Badania odniesiono do materiałów o zróżnicowanej charakterystyce petrograficznej, pochodzenia procesu termicznego (karbonizaty). Badania prowadzono dla różnych warunków hydrodynamicznych z wykorzystaniem powietrza. Za podstawę oceny hydrodynamiki przepływu gazu przez złoża i materiały porowate przyjęto strumień gazu, jaki wynika z nadciśnienia wymuszającego ten przepływ. Wyniki pomiarów wskazują na wyraźny wpływ rodzaju materiału na gazoprzepuszczalność, a dodatkowo – co wynika z ich anizotropowej struktury wewnętrznej – na wyraźny wpływ kierunkowości przepływu na wartość strumienia gazu.
***Słowa kluczowe**: gazoprzepuszczalność, anizotropia, złoże adhezyjne, karbonizat, biogaz*

1. Introduction

The gas flow through porous media, both in the aspect of their application in the industrial technology and their presence in the natural environment, is a very complex issue that is not still fully recognised. As for a phenomenological aspect this flow may be subject to various hydrodynamic criteria, which is affected by a medium structure, a kind of fluid (one- and multi-phase) and a flow forcing method (gravitational, pressure). A vast array of publications pertaining to this issue and thoroughly analysed, among others, in studies by Strzelecki [1], Piecuch [2], Orzechowski [3] or Błaszczyk [4] describing this issue on a research and analytical basis *de facto* refer to the phenomenon of filtration and they are generally identified with the phenomenon of laminar fluid flow through granular deposits according to Darcy's law [5]. Obviously, it does not exhaust many other examples of the flow of fluids through porous media. For the turbulent flow of fluids the Forchheimer model [6] and the Ergun model should be distinguished [7]. The more advanced description of the flow for the spatial layout of capillaries in the form of the meandering channels is also found in the Kozeny-Carman model [8].

The reference books frequently discuss other models of hydrodynamics of one- and multi-phase fluids flowing through porous media, considering the impact of fluid features and a kind of porous medium on the flow through granular deposits [2, 3, 4, 9]. However, the vast majority of those models pertain to granular deposits but only a few studies analyse gas permeability through backbone (skeletal) porous materials.

In this context, our own research assesses conditions of hydrodynamics of the gas flow through backbone (skeletal) porous materials with an anisotropic structure. The results of research upon the assessment of gas permeability of solid porous materials have been presented and the assessment of process conditions concerning hydrodynamics of the gas flow through materials with a diversified internal structure has been conducted.

2. Experiments

2.1. Scope and research methodology

To familiarise with hydrodynamic conditions of the gas flow through porous materials, detailed experimental tests were conducted to assess the gas permeability of porous materials with the diversified structure and, at the same time, the diversified process characteristics. The research material comprised of solid skeletal constructions: char *in situ* and polyamide agglomerate of symmetrical spatial structure.

Materials applied in research underwent the assessment of selected parameters describing features characteristic for porous materials resulting from their porosity and physical structure as basic process quantities affecting the hydrodynamics of the gas flow through porous materials. The quantity-based assessment applied to such parameters as the apparent density and porosity of a specific type (sample) of the porous material. In this regard, structural research upon the tested porous materials conducted on the basis of the SEM scanning image [9] was helpful.

The experiments pertained to two different measurement systems thoroughly analysed in other own works [10, 11, 12]. The first system was used to assess the permeability of porous materials in the barbotage conditions. In this case, the shape of samples resulted from naturally obtained parts of the native material with an unspecified sample shape - Fig. 1a. The latter one was applied to analyse the permeability on the basis of the samples configured to the shape of the cubic solid - Fig. 2a. In this system the gas flow might be directed with respect to the arbitrarily selected X, Y and Z axes. This required the development of a special measurement system that is currently being patented by us [13]. In their geometrical form those cubic-shaped samples were parts of volume samples and were compared with them with respect to their internal structure.

In both cases, the tests were conducted with reference to air to the extent of the permeability stream resulting from the reference pressure. The permeability function of the pressure decline in the porous deposit was independently carried out, assuming the so-called multi-directional (fractal) system for the gas flow through samples with unspecified shapes (Fig. 1b) and the directional flow XYZ characteristic for cubic-shaped samples (Fig. 2b).

2.2. Research results and their analysis

The basis for assessing the hydrodynamics of the gas flow through deposits and porous materials is the characteristic of their permeability resulting from the pressure inducing this flow. In each case, this characteristic is determined by calculating the impact of the available overpressure on the obtained gas stream or vice versa - the impact of the gas stream on the value of this overpressure that corresponds to a decline in this stream pressure. In the latter case, this corresponds to the determination of complete resistances of the gas flow through such deposit.

The results shown in Fig. 3 prove that with respect to porous materials in the form of coal char the nature of changes in gas permeability functions is highly diversified. For the same coal char *in situ* (I-1, I-2, I-3) there are obtained highly different permeability characteristics and their common deviation is expressly affected by the structure of the porous material. Moreover, those characteristics are parabolic, which proves their similarity to the hydrodynamics of the flow through the closed channels. On the other hand, the non-linear tendency of those characteristics proves the dominance of the turbulent flow, which is also associated with the deviation from Darcy's law [14].

The analogous characteristics of permeability were made for the cubic-shaped samples (20x20x20 mm) by using the measurement system assessing permeability in the directional flow - Fig. 2. At the same time, the research results shown in Fig. 3 prove that the permeability of the porous material is not affected by the sample shape but by its internal structure. The layout of the experimental points shows that in the same conditions of the reference pressure between the volume coal char sample and the cubic-shaped sample (the Fig. 3 shows averaged air flow values), the permeability characteristics of this material are of a similar nature and within the same scope of values.

In this measurement, example results of measurements for coal char in situ and polyamide agglomerate are illustrated in Fig. 4 which shows characteristics of the air permeability in three independent flow directions (X, Y, Z). The layout of experimental points shows that the permeability of coal char is considerably affected by the direction of the gas flow. This proves the explicit effect of the flow asymmetry with respect to the selected flow direction (axis) and, consequently, the explicit anisotropic structure of this type of material. On the other hand, for the porous polyamide that forms the agglomerate of spherical particles of identical dimensions (diameter of 0.1 mm), the permeability characteristics are not practically affected by the gas flow direction. At the same time, the determined characteristics prove that this porous polyamide, despite the fact its porosity is much smaller compared to coal char (30% [9]), has similar characteristics of the gas flow. This proves the observation that the greater effect of the permeability of various kinds of coal char is rather the result of their porous and gap structure rather than the result of their porosity. It is interesting that the permeability characteristic of the porous polyamide is also of non-linear nature, which - with respect to the measurements - proves the advantage of the turbulent gas flow.

3. Summary

The recognition of hydrodynamics of gas flow through porous media with a skeletal structure has shown that there is very little information in the literature on the subject. In this respect, appropriate experimental studies of porous materials were carried out, and hydrodynamic phenomena resulting from gas flow resistance were evaluated.

a) b)

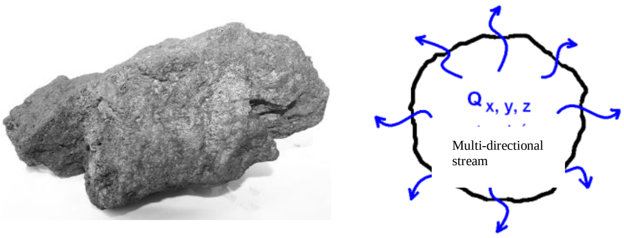

Fig. 1. Sample of unspecified shape [12]: a) research material, b) flow chart (multi-directional - fractal flow)
Rys. 1. Próbka nieokreślonego kształtu [12]: a) materiał badawczy, b) schemat przepływu (przepływ wielokierunkowy-fraktalny)

a) b)

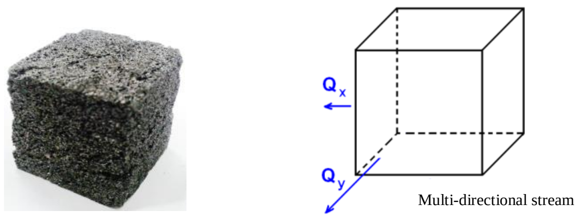

Fig. 2. Cubic-shaped sample [12]: a) research material, b) flow chart (X,Y,Z-direction flow)
Rys. 2. Próbka w kształcie sześcianu [12]: a) materiał badawczy, b) schemat przepływu (przepływ ukierunkowany XYZ)

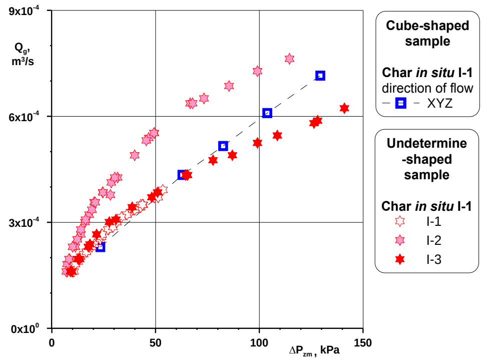

Fig. 3. Gas permeability of coal char for samples of various shapes [12]

Rys. 3. Gazoprzepuszczalność karbonizatu dla próbek różnego kształtu [12]

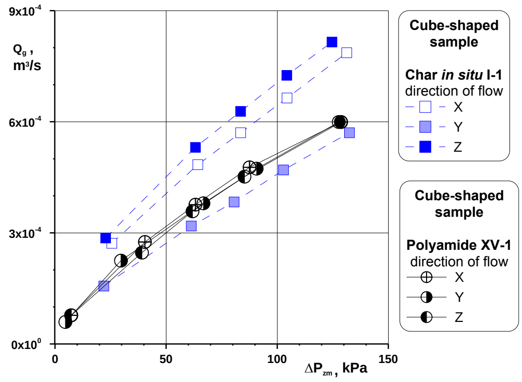

Fig. 4. Layout of experimental points characterising the asymmetry of the air flow in relation to three main axes of the cube (XYZ) for coal char and polyamide agglomerate [12]

Rys. 4. Rozkład punktów doświadczalnych charakteryzujących asymetryczność przepływu powietrza względem trzech głównych osi sześcianu (XYZ), dla karbonizatu i spieku z poliamidu [12]

In literature, in practically all cases, there is no uniform view on the use of hydrodynamic criteria for flow resistance or flow permeability in hydrodynamics. In addition, there are large discrepancies in the approach to experimental evaluation of permeability parameters. This greatly hampers the ability to compare test results, which in turn causes the difficulty of adapting existing computational models. The proper assessment of the nature of the flow and the actual flow parameters resulting from the structure of the porous bed is an additional problem.

The hydrodynamic results of gas flow through porous skeletal structures of the skeleton structure can in many cases be used in the process calculations for biogas technology, especially in the bioconversion process in adhesion beds, in the selection of microbial strains for maximum biogas yield.

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