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MIROSŁAW WIERZBICKI*

DYNAMIC SEEPAGE OF NITROGEN THROUGH COAL BRIQUETTES

DYNAMICZNA FILTRACJA AZOTU PRZEZ BRYKIETY WĘGLOWE

This paper concerns the phenomenon of nitrogen seepage through coal briquettes, made from coal dust of grain size smaller than 0.2 mm. The porosity of the briquettes was from 20% to 30%. Seepage took place under average pressures of 0.2–1 MPa. The experiments revealed an existing relationship between the average seepage pressure and the seepage coefficient according to Darcy's Law. To preserve the relationship between the seepage parameters and the seepage conditions, two elements were applied in the form of a non-linear, phenomenological equation. A new equation, with two coefficients, which describe the coal briquette/nitrogen seepage process is presented. The coefficients, in the conditions being studied, are inter-connected and for this reason the equation presented becomes a singled parameter equation.

The paper describes the dynamic seepage of nitrogen through coal briquettes, earlier saturated with gas. Seepage was caused by reducing the gas pressure in the space in front of the briquette face. The pressure fell down from pore pressure to atmospheric pressure. The rate of decrease of nitrogen pressure at the front of the briquettes was not constant over the whole series of experiments. The equation described the course of dynamic seepage related to its form in stationary conditions. Good conformity between the experimental results and the phenomenological solution in both stationary and non stationary conditions was observed.

The values of the parameters of the equation used fitted the process under stationary and dynamic conditions. In both cases very similar values were obtained.

Key words: seepage, coal briquette, gas and coal outburst, Darcy's law

Praca dotyczy opisu zjawiska filtracji azotu w brykietach o porowatościach od 20 do 30%, wykonanych z pyłu węglowego o uziarnieniu przedstawionym na wykresie z rysunku 1. Ciśnienia średnie filtracji wynosiły 0,2–1 MPa. Stwierdzono istnienie zależności między ciśnieniem średnim filtracji a współczynnikiem filtracji, liczonym zgodnie z prawem Darcy'ego (2). Wartości współczynnika filtracji brykietu o porowatości 21,15%, wyznaczone przy ciśnieniach średnich azotu wynoszących od 1,2 do 5 atm, dopasowane do liniowego prawa filtracji (2), przedstawia zależność na rysunku 2. Aby uniknąć zależności pomiędzy parametrami filtracji a warunkami, w jakich ona

* INSTYTUT MECHANIKI GÓROTWORU, POLSKA AKADEMIA NAUK, 30-059 KRAKÓW, UL. REYMONTA 27

zachodzi, zastosowano dwuskładnikowe, nieliniowe równanie (5) podane przez Topolnickiego, Wierzbickiego (2000). Równanie to można zapisać w postaci (6). We wzorze tym występują dwa współczynniki, opisujące własności filtracyjne układu: brykiet węglowy-azot. Współczynniki te w rozpatrywanych warunkach są zależne od porowatości, dzięki czemu podany wzór jest wzorem jednoparametrowym. Zależności $K_G = f(\varepsilon)$ i $K_L = f(\varepsilon)$ w zakresie porowatości 20–30% mają charakter wykładniczy i mogą być opisane równaniem (7).

Przyjmujemy hipotezę roboczą, że wzór (6) opisujący wydatek gazu w warunkach filtracji stacjonarnej stanowi przypadek szczególny wzoru (10) oraz założenia wstępne, że:

- przepływ gazu przez brykiet ma charakter jednowymiarowy,
- brykiet węglowy jest jednorodnym, izotropowym materiałem porowatym,
- odkształcenia szkieletu węglowego pod wpływem zmian ciśnienia porowego są pomijalnie małe,
- proces filtracji gazu jest procesem izotermicznym.

Uwzględniając założenia wstępne i wstawiając (10) do (9) otrzymujemy równanie opisujące zmiany ciśnienia wywołane filtracją (11).

W celu sprawdzenia poprawności opisu zjawiska filtracji niestacjonarnej równaniem (11) i wyznaczenia współczynników K_G i K_L wykonywano eksperymenty na stanowisku pokazanym schematycznie na rysunku 7. Brykiety węglowe umieszczone we wnętrzu rury były pierwotnie równomiernie nasycane gazem. Ciśnienia nasycania wynosiły 0,2–1 MPa. Filtrację wywoływano poprzez obniżanie ciśnienia w przestrzeni graniczącej z brykietem. Stosowano zmienne tempo spadku ciśnienia azotu przed czołem nasyconych azotem brykietów. Równanie (11) rozwiązywano numerycznie metodą różnic skończonych. Aby na podstawie (11) obliczyć rozkład ciśnienia porowego w czasie i przestrzeni $P = P(x,t)$, konieczne jest określenie warunków początkowych i brzegowych. Warunek początkowy ma postać: $P(x,t) = P_0$ dla $t \leq 0$. Warunki brzegowe zadawane są poprzez podanie wartości ciśnień, rejestrowanych przez manometry $P(x_i,t)$, $P(x_j,t)$ umieszczone na końcach (x_i, x_j; $x_i < x_j$) rozpatrywanego odcinka brykietu. Zakładamy, że wyznaczone w warunkach filtracji stacjonarnej zależności (7) obowiązują również w warunkach filtracji niestacjonarnej. Poszukiwana jest wartość porowatości (i związana z nią para współczynników K_G i K_L), dla której suma kwadratów różnic pomiędzy wartościami ciśnień zmierzonych i obliczonych z rozwiązania równania (11) osiąga minimum. Stosujemy metodę gradialną. Uznajemy, że tak wyliczone wartości współczynników K_G i K_L charakteryzują własności filtracyjne badanego materiału.

Wyniki przedstawione w pracy są rozwiązaniami równania (11), w których warunki brzegowe stanowią zapisy zmian ciśnień rejestrowanych przez manometry P_2 i P_5 na rysunku 8. Manometry (P_3 i P_4) służą do odtworzenia profilu ciśnienia wewnątrz rozpatrywanego odcinka. W tablicy 1 przedstawiono wyniki otrzymane dla trzech serii eksperymentów. Podano wartości stałych czasowych spadku ciśnienia gazu przed czołem brykietu (τ_i), wartości średniej rzeczywistej porowatości brykietu, porowatości obliczonej oraz wartości współczynników K_G i K_L, dopasowane do wyników eksperymentów. Podano również wartość odchylenia standardowego pomiędzy wartościami ciśnień zmierzonych i obliczonych.

Średnie wartości ε_p są zbliżone do wartości średnich porowatości rzeczywistych brykietów biorących udział w eksperymencie i wynoszą:

- ε_{p1} = 24,81% — dla brykietu o porowatości rzeczywistej ε_1 = 24,60%,
- ε_{p2} = 22,71% — dla brykietu o porowatości rzeczywistej ε_2 = 22,76%,
- ε_{p3} = 20,90% — dla brykietu o porowatości rzeczywistej ε_3 = 20,40%.

W przedziale stałych czasowych τ od 0,1 do 1,1 s nie zauważa się zmian wyznaczonych wartości współczynników od dynamiki zjawiska filtracji. Ilustracją jakości uzyskiwanych dopasowań są wykresy na rysunkach 6 i 7. Przedstawiają one zmiany ciśnienia gazu w trakcie eksperymentów oznaczonych w tablicy numerami 5 (ε_2 = 22,76%, τ = 0,22 s) i 7 (ε_3 = 20,40%, τ = 0,80 s), w przekrojach wyznaczonych przez zabudowane na pobocznicy manometry. Linie ciągłe na wykresach przedstawiają zmiany zmierzonych wartości ciśnień na manometrach P_2–P_5. Wartości ciśnień, obliczonych z równania (11) dla wartości współczynników K_G i K_L przedstawionych w tablicy 1 obrazują linie przerywane.

Przedstawiony w pracy wzór (6) nadaje się do opisu przebiegu filtracji w brykietach węglowych nasyconych azotem zarówno w warunkach stacjonarnych, jak i niestacjonarnych. Przebieg zjawiska filtracji w obydwu przypadkach może być opisany tymi samymi parametrami. Wartości współczynników K_G i K_L zbliżone są do wartości tych współczynników wyznaczonych w drodze filtracji stacjonarnej.

Słowa kluczowe: filtracja, wyrzuty skalno-gazowe, prawo Darcy'ego

1. Preface

Knowledge of gas seepage through coal briquettes resulting from laboratory research conducted in the Strata Mechanics Research Institute connected with instantenous gas and coal outbursts. The coal briquettes used in laboratory conditions has been used as a model of coal. It has been stated that gas seepage is one of the most important process occurring during the provocation of gas and coal outbursts (Topolnicki 1999; Gawor et al. 2000). To gain knowledge about stresses generated during the process preceeding outbursts, we have to know the time-space distribution of gas pressure during non-stationary gas seepages. It is essential to determine a seepage equation, the parameters of which are independent of seepage conditions, to ascertain this distribution.

2. Material used in the research

Coal briquettes were used as a material for experimental research. They were formed directly inside a steel pipe by bilateral compression. The coal dust, used as a primary material was obtained from crushed coal from seam 768 of the Julia coal mine. This material has been described in a work by (Topolnicki, Wierzbicki 1999). Granulometric analysis shows that the highest percentage of coal dust consists of grains about 0.05 mm in size. The granular structure of the coal dusts is presented in Fig. 1.

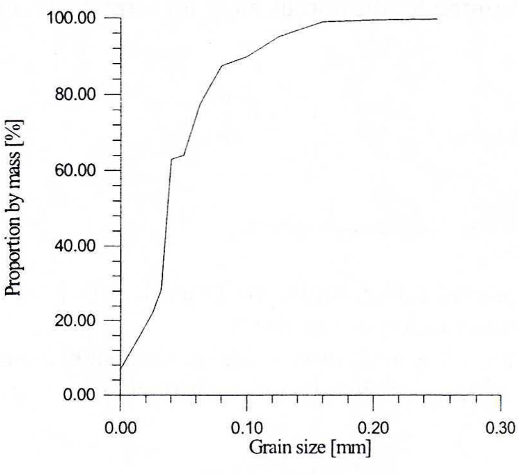

Fig. 1. Granulometric analysis curve

Rys. 1. Krzywa składu ziarnowego pyłu węglowego

In the model, we are using it is assumed that the coal briquette is an homogeneous, isotropic porous material. It is very difficult to make a coal briquette with homogeneous porosity. Because of friction against the walls of the enclosing pipe, with growing depth the values of the applied pressure decrease. According to Drzymała (1988) it is not possible to make coal briquettes with constant porosity through its longitudinal axis when the axial length exceeds its radius. To reduce longitudinal changes of porosity of the briquettes, they were compressed in several stages. The length of each of them did not exceed 5 (pipe diameter — 9.6 cm).

Nitrogen was used as a seepage gas.

3. Stationary nitrogen seepage through coal briquettes

Darcy's Law is commonly used to describe seepage. Its linear nature can be described by the formula (Dake 1978):

$$v = -\frac{k_g}{\mu}\frac{dP}{dx} \tag{1}$$

where:

v — seepage velocity [m/s],
k_g — permeability coefficient [m^2],
P — pressure [Pa],
μ — dynamic viscosity coefficient [P],
x — length [m].

Equation (1) to determine for the porous medium/filtrate pair, can be described by the following:

$$v = -K\frac{dP}{dx} \tag{2}$$

where:

$K\,[\mathrm{m^2/Pa{\cdot}s}] = \frac{k_g}{\mu}$ — seepage coefficient.

The unit of seepage coefficient, traditionally used, is [K] = [darcy/cP] and this unit will be used for the presentation of the results.

In case of isothermal, horizontal, mono-axial gas seepage, the rate of gas discharge in terms mass can be determined by using equation (2) and the Real Gas Equation (Haggort 1988):

$$PV = nzRT \tag{3}$$

from equation:

$$Q = \frac{K}{2}\frac{S}{zRT}\frac{dP^2}{dx} \tag{4}$$

where:

Q — gas discharge in molar terms [mol/s],
z — real gas coefficient,
R — gas constant [Pa·m^3/mol·K]
T — temperature (abs.) [K].

The z coefficient value differs according to the gas being used and its temperature and pressure. For known conditions (temperature and pressure) we can determine it from an empirical depency described by Standing and Katz (1942). In pressures between 0 to 1 MPa and a temperature of about 290 K, for nitrogen we can accept a value $z = 1$. In this condition the behaviour of nitrogen resembles that of an ideal gas.

There is some reservation about using Darcy's Law to describe nitrogen seepage through coal briquettes.

The linear seepage law can only by used for laminar flow (Bear 1972). A commonly used criterion, to permit the type of flow to be distinguished is based on Reynolds's number. In the case of the very complicated internal structure of porous media and the variable time/space dynamics of the phenomenon, to differentiate the laminar and turbulent flows is a very difficult problem. The observed field of velocity, during flow through porous mediums and its models have been described by Dyrga (1986) and Skawiński (1992). These works state that an assumption about a constant stream-line in a flow through porous mediums does not accord with reality.

On the basis of the author's researches with nitrogen seepage through coal briquettes of porosity from 16% to 30%, it can be stated that the seepage coefficient from equation (2) differs from the average seepage pressure. Evaluation of the seepage coefficient for a briquette with porosity 21.15%, applying average seepage pressures from 0.12 MPa to 0.55 MPa, fitted the linear seepage law (2) is presented in Fig. 2. This implies that the seepage coefficient is not a parameter of a porous medium sufficient to describe seepage in the conditions under consideration. Evaluation of a average value of the seepage coefficient K as a function of the coal briquette's porosity is shown in Fig. 3. The method of determining the K coefficient value is described in a work by Topolnicki, Wierzbicki (2000).

From research made in the Laboratory of Micromeritics at the Strata Mechanics Research Institute (Topolnicki, Wierzbicki 2000) would appear to show that the stationary nitrogen seepage phenomenon through coal briquettes is better described by equation (5) than by equation (1):

$$Q = S\left(A\frac{dP^2}{dx} + B\frac{dP}{dx}\right) \tag{5}$$

where:

A [mol/s·m·atm^2], B [mol/s·m·atm] — coefficients.

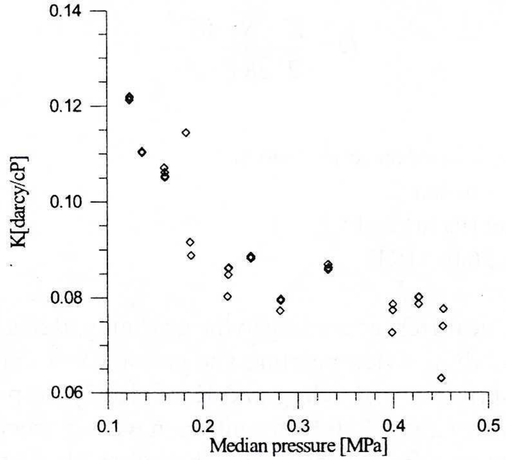

Fig. 2. Dependence of seepage coefficient value *K* on average values of seepage pressure for coal briquettes with porosity 21.15%

Rys. 2. Zależność współczynnika filtracji *K* od średniej wartości ciśnienia dla brykietu o porowatości 21,15%

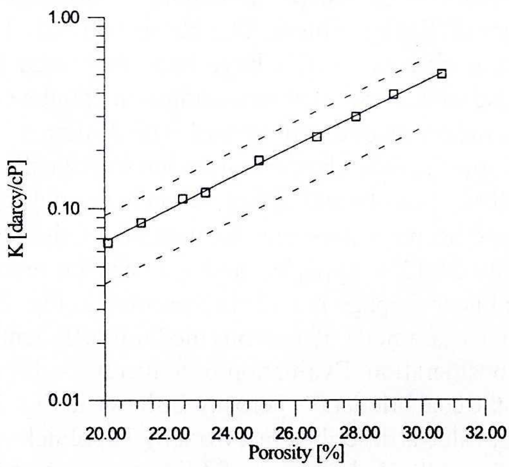

Fig. 3. Dependence of average seepage coefficient value *K* on porosity of coal briquettes

Rys. 3. Zależność średniej wartości współczynnika filtracji *K* w funkcji porowatości brykietów

Equation (5) can be written in the form:

$$Q = \frac{S}{2zRT}\left(K_G \frac{dP^2}{dx} + K_L \frac{dP}{dx} \right) \tag{6}$$

where:

Q — gas discharge in molar terms [mol/s],

R — gas constant [atm·cm³/mol·K],

K_G — seepage coefficient [darcy/cP],

K_L — coefficient [cm²/s].

Let's draw attention to difficult physical sense of coefficients K_G i K_L from equation (6). Can be shown that:

$$K_L = 2KzRT\rho$$

where:

K — seepage coefficient [darcy/cP],

ρ — gas density (mols.) [mol/cm³].

Equation (6) is a phenomenological, macroscopic, non-linear description of flow. The non-linearity of flow in porous media have been known for a long time. In mediums with small pores this can be connected with phenomena and the states on the border of phases and in diffusion layers. (Scheidegger 1974) presents many such descriptions. The latter author refers to Kutilek (1969) and provides 12 graphs characterizing non linear seepage. In the paper of Topolnicki and Wierzbicki (2000), dependencies of the values of coefficients A and B and the porosity of coal briquettes was described. Calculated on this basis, values for K_L and K_G coefficients are presented on graphs in Fig. 4. It can be assumed that the character of dependences $K_G = f(\varepsilon)$ and $K_L = f(\varepsilon)$, in a range of porosity is 20–30% is exponential.

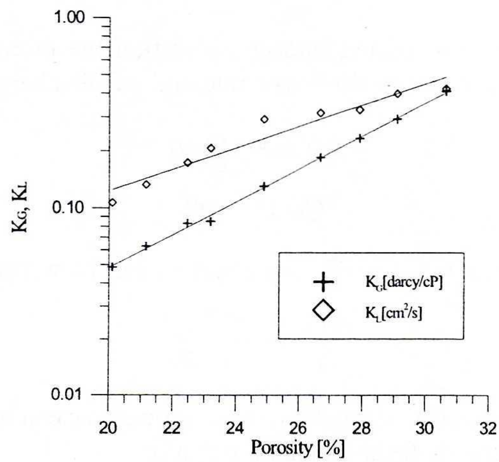

Fig. 4. Dependence of average seepage coefficient values K_G and K_L from equation (6) on porosity of coal briquettes

Rys. 4. Zależność współczynników filtracji stacjonarnej K_G i K_L ze wzoru (6) od porowatości

$$K_G(\varepsilon)=0.0009e^{0.20\varepsilon};\ K_L(\varepsilon)=0.0091e^{0.13\varepsilon} \tag{7}$$

Thus equation (6) lies in the considered range of porosity and average pressures of seepage as per (7), becomes a single-parameter formula.

4. Dynamic seepage of nitrogen through coal briquettes

It is assumed that the:

- gas flow through the briquette is a one dimensional flow,
- coal briquette is an homogeneous, isotropic, porous material,
- deformation of the coal skeleton under gas pressure changes is so small as to be negligible,
- gas seepage is an isotropic process.

Let us take the following symbols to the note:
$P(x,t)$ — pore pressure [Pa],
$q(x,t)$ — gas flow rate [m^3/s],
$Q(x,t)$ — gas discharge in molar terms [mol/s],
$\rho(x,t)$ — molar density of gas [mol/m^3],
$v(x,t)$ — seepage velocity [m/s],
ε — porosity of medium,
T — temperature [K],
The continuity equation take the form (Bear 1972):

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\operatorname{div}(\rho v)=0 \tag{8}$$

For one dimension flow, taking into consideration the premises stated earlier, to express the relationship between discharge rate and gas discharge in molar terms:

$$q(x,t) = vS(x,t)$$

$$Q(x,t) = \rho vS$$

and the real gas equation (3), a continuity equation can be written as follows:

$$\frac{\partial P}{\partial t}=-\frac{zRT}{S\varepsilon}\frac{\partial Q}{\partial x} \tag{9}$$

Let a working hypothesis that equation (6) describes gas discharge in molar terms in stationary conditions results from a general equation:

$$Q(x,t)=\frac{S}{2zRT}\left(K_G\frac{\partial(P^2)(x,t)}{\partial x}+K_L\frac{\partial^2 P(x,t)}{\partial x}\right) \tag{10}$$

To take into consideration the same premises and to put (10) into (9) an equation describing gas pressure changes to caused by seepage results.

$$\frac{\partial P(x,t)}{\partial t}=\frac{1}{2\varepsilon}\left(K_G\frac{\partial^2(P(x,t)^2)}{\partial x^2}+K_L\frac{\partial^2 P(x,t)}{\partial x^2}\right) \tag{11}$$

4.1. Description of experiments made in order to determine non stationary seepage coefficients

Experiments to determine non stationary seepage coefficients K_G and K_L were made using the apparatus depicted schematically in Fig. 5.

After closing the outflow valve, the briquette is uniformly saturated with gas. The saturation process is complete when pore pressure and gas pressure in the space at the ends of the briquette equals the determined level:

$$P_i = P_0;\ dP_i/dt = 0.$$

Let the value of the gas pressure P_0 be called the saturated pressure. Experiments were conducted with saturated pressures between 0.2–1 MPa. After saturation the briquette valve connected to the gas supply was closed, and then the valve in the front part of pipe was opened. Because the gas volume in the vacant space at the front of the briquette contains up to 3000 cm^3 and gas within the porous spaces within the briquette occupies about 100 cm^3, we can ignore the seepage flow rate from the briquette. The analytical solution of the problem of the gas flowing, from the reservoir through the hole to atmosphere pressure, shows that changes of gas pressure in an adiabatic proces, can be described by the exponential formula as follows: (provided that the nitrogen pressures inside the reservoir is higher than 0.2 MPa).

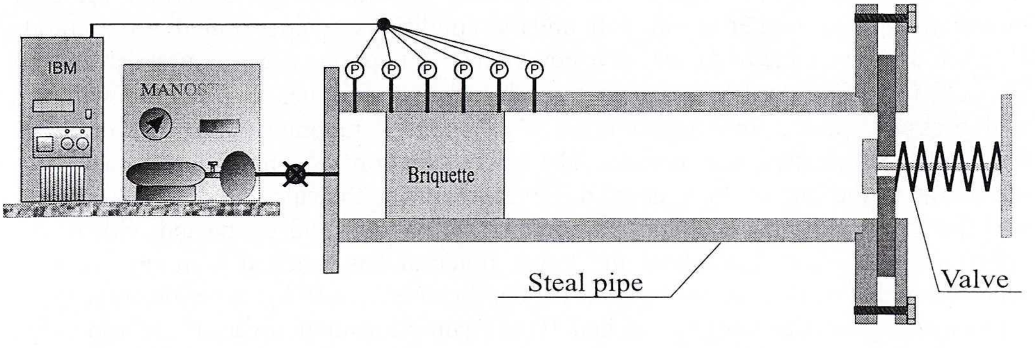

Fig. 5. Scheme of measuring apparatus used for research into dynamic nitrogen seepage through coal briquettes

Rys. 5. Schemat stanowiska pomiarowego do badania przebiegu niestacjonarnej filtracji azotu w brykietach węglowych

$$P(t) = P_0 - (P_0 - P_a)\left[1 - \exp\left(-\frac{t}{\tau}\right)\right] \tag{12}$$

where:

P_0 — initial pressure [Pa],
P_a — atmospheric pressure [Pa],
τ — time constant [s].

The value of the time constant τ approximates the dynamics of the process of falling gas pressure during the experiment is comparable to events preceding an outburst. The pressure fall at the front of the briquette initiates non stationary seepage of gas through the briquette. Changes of seepage dynamics were caused by changing washers with differing diameters behind the valve. A data registration system was started at the moment when the output valve was opening. The experiment yielded records of gas pressure changes in briquette at several places along the pipe.

4.2. Initial and boundary conditions to solve seepage equation (11)

It is necessary to assume the initial and boundary conditions in order to evaluate the gas pressure distribution dependant on time and distance $P = P(x,t)$.

Before seepage starts ($t \leq 0$), the coal briquette is evenly saturated by gas. Thus, the initial condition is as follows: $P(x,t) = P_0$ for $t \leq 0$.

Boundary conditions are given by pressures, recorded by manometers $P(x_i,t)$, $P(x_j,t)$ placed on the ends (x_i, x_j; $x_i < x_j$) of the section of the briquette under consideration.

It is assumed that dependences (7) $K_G = K_G(\varepsilon)$, $K_L = K_L(\varepsilon)$ derived for stationary conditions also work in non stationary conditions. For a certain value of porosity ε_{pi} and higher defined boundary conditions, using numerical methods (limited difference method), we solve equation (11), to obtain the pressure distribution $P(x_i,t,K_G(\varepsilon_{pi}),K_L(\varepsilon_{pi}))$. We then compare the calculated values of pressures with the real pressure values from manometers ($P_{i+1} - P_{j-1}$), mounted along the briquette between the boundary manometers. The target function, depending on porosity ε_{pi}, we define as the sum of the squared difference between the calculated pressure values and the measured values. Values of porosity are sought (and connected with it pair coefficients K_G and K_L) where the target function has reached a minimum. It is recognized that by this means the values of coefficients K_G and K_L, describe the seepage quality of the material being researched. If the assumption about invariable relationships (7) holds true, value of porosity $\varepsilon_p^{\cdot}$, from the solution of equation (11), should be similar to the real porosity of the coal briquette (ε), calculated from helium density and its capacity.

4.3. Results

The results presented in this work are solutions of equation (11) where boundary conditions were given by records of pressure changes registered by manometers P_2 and P_5. The first of them was mounted at a distance of 28mm and the second at a distance of 138 mm from the face of the briquette. A section of briquette 110 mm long was considered. The siting of manometers on the pipe during the experiments is schematically depicted in Fig. 6.

Records from manometer P_1 were used to determine the time-constant of the falling pressure (τ) at the front of the briquette. Pressure values $P_2(t)$ and $P_5(t)$ determined boundary conditions for equation (11). Two manometers were mounted between them (P_3 and P_4). This permitted the pressure profile inside the section of briquette under consideration to be replicated. The results of three experimental series are presented in Table 1. Coal briquettes with average porosity 24.75%, 22.76% and 20.40% were used. Measurements were taken with different values of time constants of pressure drops at the front of the briquettes (τ_i) — equation (12).

There is are average porosities of briquettes (ε), time constants of pressure drops at the front of the briquettes (τ_i), values of calculated porosity (ε_p). The values of seepage coefficients K_G and K_L are compared with the experimental results in columnar form in Table. 1. The last column contains the value of the standard deviation between values of measures and calculated from equation (11) pressures in.

The experiments presented in Table 1 gave 11 values of porosity ε_p and 11 pairs of coefficients K_G and K_L.

The average values ε_p are similar to the average real values of porosity of the coal briquettes used in the experiments and are as follows:

- $\varepsilon_{p1} = 24.26\%$ — for briquette with real porosity $\varepsilon_1 = 24.98\%$,
- $\varepsilon_{p2} = 22.71\%$ — for briquette with real porosity $\varepsilon_2 = 22.76\%$,
- $\varepsilon_{p3} = 20.90\%$ — for briquette with real porosity $\varepsilon_3 = 20.40\%$.

Change in the assigned values of coefficients from the dynamic of seepage phenomena in range of time constant τ from 0.1 s to 1.1 s. were not observed. An acceleration of seepage dynamics can result in outburst phenomena. Research made by the author shows that for a briquette with a porosity of about 20%, when the saturated pressure is P_0 = 0.85 MPa, results in an outburst when time constant τ is about 0.05 s.

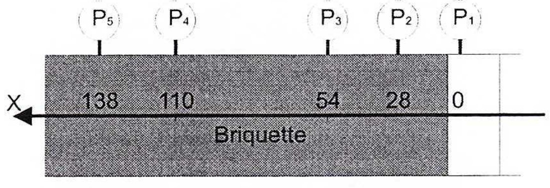

Fig. 6. Schematically depiction of manometer stations on the measurement pipe

Rys. 6. Schemat rozmieszczenia manometrów podczas eksperymentów

TABLE 1

Analysis of non-stationary coefficients for coal briquettes with porosities from 22.76 to 20.40%

TABLICA 1

Wartości współczynników dopasowanych do równania filtracji (11) dla brykietów o porowatościach od 22,76 do 20,40%

No.	ε [%]	τ [s]	ε_p [%]	K_G [darcy/cP]	K_L [cm^2/s]	Standard deviation [kPa]
1	24.26	1.10	24.96	0.133	0.236	6.4
2		0.75	24.85	0.130	0.230	4.3
3		0.48	25.14	0.137	0.239	7.1
4	22.76	0.70	22.73	0.084	0.177	6.8
5		0.22	22.68	0.084	0.175	6.7
6		0.11	22.71	0.084	0.176	5.7
7	20.40	0.80	20.88	0.059	0.139	2.2
8		0.52	20.85	0.058	0.138	2.3
9		0.38	20.90	0.058	0.139	2.5
10		0.26	20.88	0.058	0.139	2.1
11		0.10	21.00	0.060	0.141	2.0

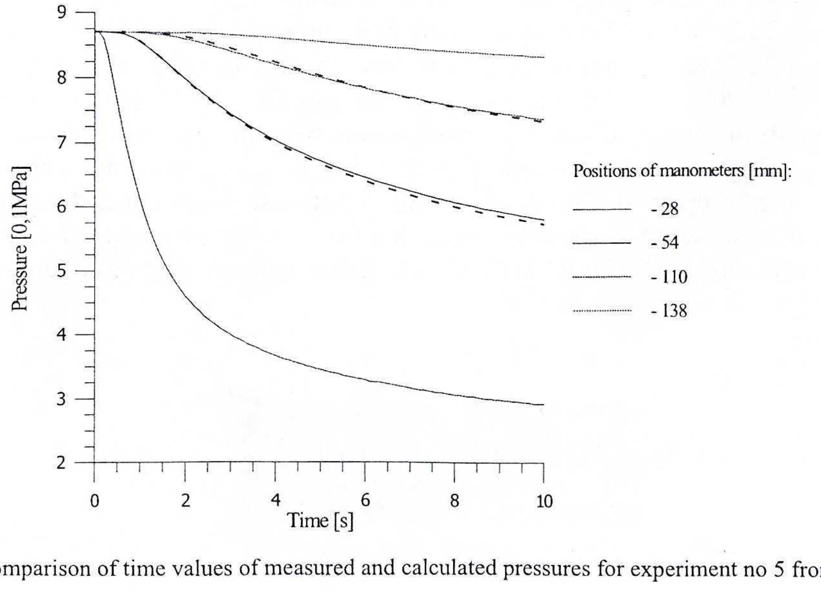

Fig. 7. Comparison of time values of measured and calculated pressures for experiment no 5 from Table 1

Rys. 7. Porównanie wartości zmierzonych i obliczonych ciśnień w trakcie eksperymentu nr 5 z tablicy 1

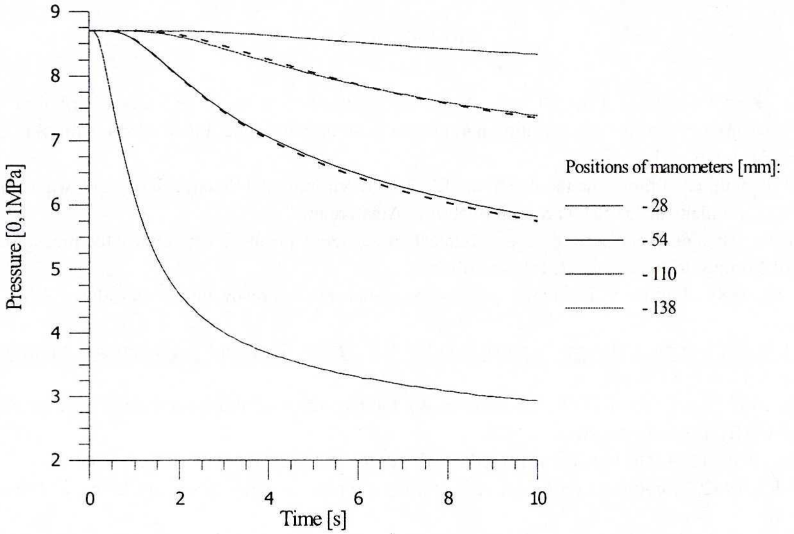

Fig. 8. Comparison of time values of measured and calculated pressures for experiment no 7 from Table 1

Rys. 8. Porównanie wartości zmierzonych i obliczonych ciśnień w trakcie eksperymentu nr 7 z tablicy 1

The graphs on Figs. 7 and 8 show the proximity of the theoretical and actual values. The changes of gas pressures during the experiments marked by number 5 ($\varepsilon_2 = 22.76\%$, $\tau = 0.22$ s) and 7 ($\varepsilon_1 = 20.40\%$, $\tau = 0.80$ s) from Table 1 at the manometer stations, are presented. The continuity lines on the graphs illustrate changes of measured values of pressures from manometers P_2–P_5. Values of pressures calculated from equation (11) for values K_G and K_L, from Table 1, are represented by dotted lines.

Maximum deviation between measured and calculated values of pressures are:

- 8.3 kPa (0.083 atm), for experiment nr 2, after 50 s (0.61% of measured value),
- 6.1 kPa (0.061 atm), experiment nr 8, after 10 s (0.56% of measured value).

4. Conclusions

1. Equation (6) presented non linear description of seepage, based on laboratory research, describes nitrogen seepage phenomena in coal briquettes, both in stationary as dynamic conditions.

2. The process of seepage in each case can be described by similar parameters K_G and K_L.

3. Because of experimental conditions was similar to conditions during the process of gas and coal outburst provocation, the provided coefficients can be used to model this phenomenon.

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