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COAL PERMEABILITY IN THE FLOW OF WATER AND ALCOHOLS

PRZEPUSZCZALNOŚĆ WĘGLA W PRZEPŁYWIE WODY I ALKOHOLI

Hard coal is a system of both hydrophilic and hydrophobic character, which is of vital importance in the research concerning its interaction with water as well as various organic liquids. Their contact with the coal substances is followed by sorption and swelling of the coal, which is manifested by a distinct decrease of its permeability in the liquid flow.

The aim of the present study has been a comparison of the interaction of water as well as methyl and ethyl alcohols with coal, by measuring the coal permeability in the flow of those liquids.

Key words: coal, fluid flows, permeability, swelling.

Celem prezentowanych badań było porównanie oddziaływania wody, alkoholu metylowego i etylowego z węglem poprzez pomiary jego przepuszczalności w przepływach tych cieczy.

Do badań użyty był węgiel z kopalni Zofiówka (C = 86,4%, V^{daf} = 23,3%, A = 8,6%, W = 0,9%) w postaci próbek wyciętych z bryły węgla. Przed badaniem przepływów wody i alkoholi dokonywano wstępnej charakterystyki próbek przez wyznaczenie ze wzoru Darcy'ego przepuszczalności standardowej k_s w przepływie azotu. Po kilkugodzinnym odpowietrzaniu próbek nasycano je wodą lub roztworem alkoholu i prowadzono przepływ przy stałym gradiencie ciśnienia. W wyniku wiązania cząsteczek wody lub jonów zawartych w roztworze przez węgiel następuje zmniejszanie się wymiarów porów węgla w miarę zachodzącego procesu, co jest przyczyną zmniejszenia przepuszczalności w przepływie wody lub innych wodnych roztworów. Pęcznienie węgla pod wpływem wody prowadzi często do całkowitego nawet zatrzymania przepływu. Cofania tego pęcznienia próbuje się dokonywać w laboratorium przez stosowanie przepływów odpowiednich roztworów.

Przepuszczalność w przepływach roztworów alkoholi zmniejsza się dużo szybciej niż w przepływie wody. Już 1% roztwór alkoholu metylowego powoduje obniżenie przepuszczalności od 0,01 wartości przepuszczalności standardowej k_s, zaś alkohol etylowy jeszcze znaczniejsze. Jest to wynikiem silniejszej aktywności alkoholi w oddziaływaniu z substancją

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węglową. Sorpcja alkoholu wynikająca z dwoistego charakteru węgla zwiększa bowiem dodatkowo pęcznienie substancji węglowej i zmniejsza jego przepuszczalność. W miarę przepływu coraz bardziej stężonych roztworów alkoholu następuje systematyczne coraz większe pęcznienie węgla i znaczne zmniejszenie przepuszczalności.

Otrzymane wyniki korelują dobrze z badaniami rozszerzalności liniowej węgla pod wpływem wody i alkoholi. Większą rozszerzalność węgla pod wpływem alkoholi wyjaśnia duże powinowactwo grup $-OH$ do połączeń tlenowych występujących w węglu i rodników węglowodorowych alkoholu do hydrofobowych elementów węgla.

Słowa kluczowe: węgiel, przepływy cieczy, przepuszczalność, pęcznienie.

1. Experiments

The experiments were carried out on the coal obtained from the Zofiówka mine ($C = 86.4\%$, $V = 23.3\%$, $A = 8.6\%$, $W = 0.9\%$) in the form of samples cut out of a coal lumps. The placing of the core inside a metal tube prevents any changes in the external dimensions, thus imitating the conditions existing in a coal bed. Consequently, in the processes connected with liquid and gas flow, the internal coal swelling (manifested by the changes in its permeability) will be more significant.

The examination of water and alcohol flows was preceded by a preliminary characteristic of the coal sample by determining (according to Darcy's formula) their standard permeability k_s in nitrogen flow at a definite pressure difference of 0.1 MPa (0.1 MPa at the inlet to the sample and the atmospheric pressure at the outlet).

A precise definition of the conditions for the determination of permeability is necessary. An increase in the flowing gas pressure is accompanied by a corresponding drop in the sample permeability (varying according to the kind and pressure of the flowing gas as well as the permeability of the examined medium) (Żółcińska and Dyrga, 1996; Skawiński, Żółcińska and Dyrga, 1987). Of all the cut-out samples

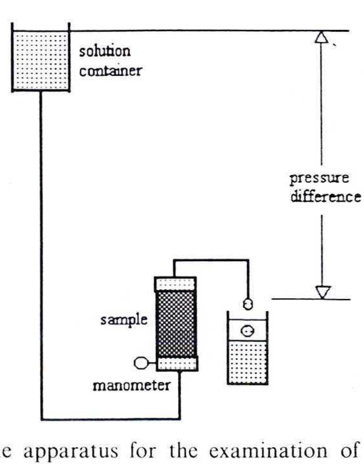

Fig. 1. The apparatus for the examination of liquid flow

prepared for testing liquid flows, those ones were selected whose permeability values in the nitrogen were most approximate (ranging from 13 mD to 39 mD).

After a few hours' degassing of the samples with a rotary pump, they were saturated with either water or alcohol solutions. This was followed by a flow of water or alcohol at a constant pressure gradient (1.3 MPa/m). The discharge of the flow (changing in time) was also measured. This process was continued till a practical stabilisation of that discharge was achieved. The real coal permeability in the examined liquid flow was calculated from Darcy's formula, with the viscosity and density of the applied solutions taken into account.

The scheme of the liquid flow experiments is presented in Fig. 1.

2. Water and alcohol flows in coal

The effect of interaction of coal with the flowing liquid is swelling of the coal substance (mostly internal one as the tested sample is confined within a metal tube). It is especially distinct immediately after the saturation of the sample with water. As a result of bonding water particles or ions contained in the solution with coal, the dimensions of the coal pores diminish with the process. This is a reason for a decrease of permeability in the flow of water or other water solutions (Dyrga, Żółcińska and Skawiński, 1992; Skawiński, Żółcińska and Dyrga, 1991; Dabbous et al., 1974). The diverse porous structure of coal samples, expressed in the standard permeability values k_s, is also reflected in the changes of permeability in water and solution flows. The greater and quicker swelling, expressed in the changes of the

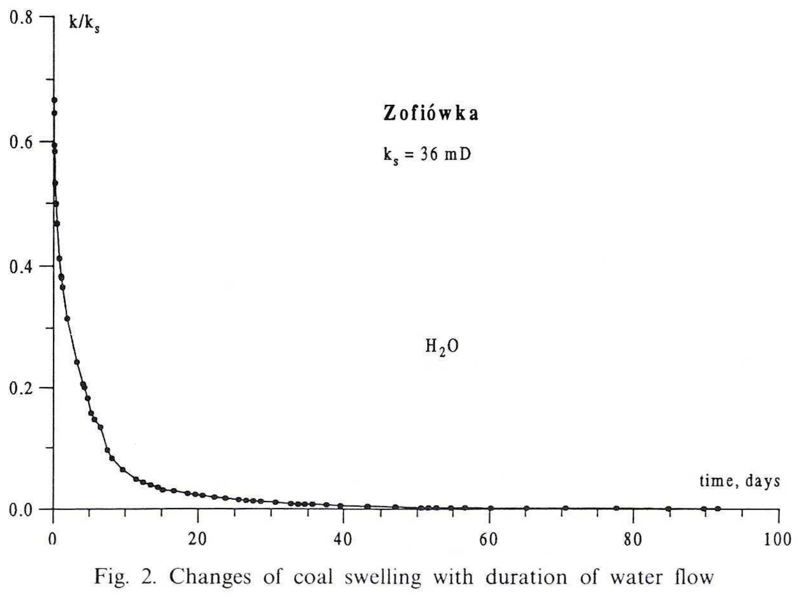

Fig. 2. Changes of coal swelling with duration of water flow

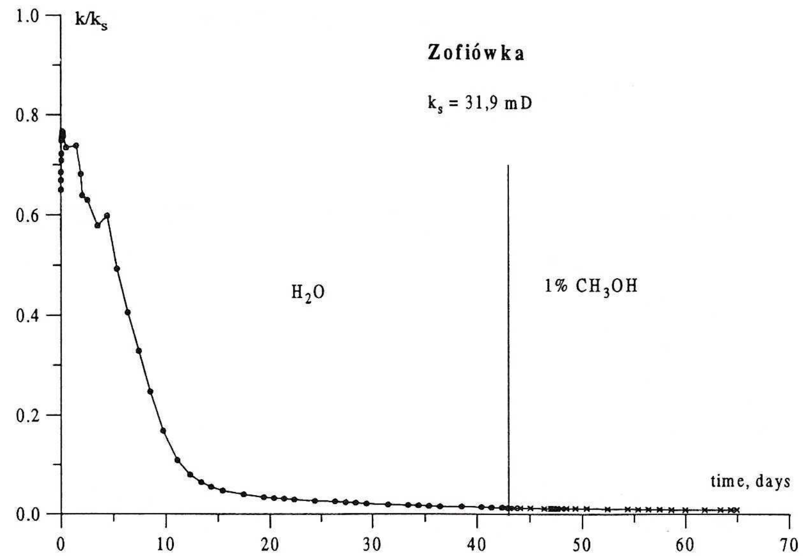

Fig. 3. Changes of coal swelling with duration of water flow and dilute methyl alcohol

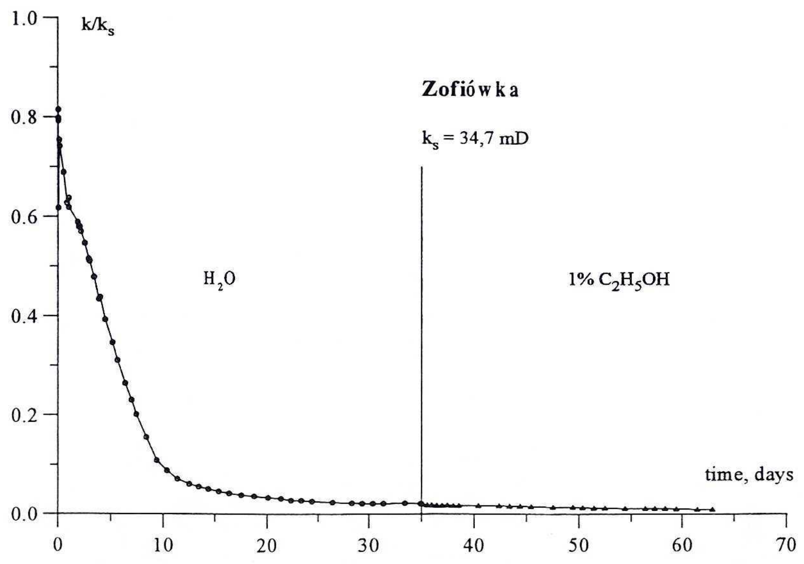

Fig. 4. Changes of coal swelling with duration of water flow and dilute ethyl alcohol

measured permeability, occurs in the samples characterized by higher standard permeability values.

Fig. 2. presents a typical course of permeability changes in the water flow in coal in relation to the flow duration.

A considerable drop in the permeability (up to 2 – 3 orders of magnitude) can be observed immediately after the saturation of a sample with water. The subsequent flow of water also causes a decrease in permeability but it is smaller and slower. The testing of flows in coal conducted to reach the state of equilibrium are long-lasting and may even exceed a period of three months. The swelling of coal due to the water influence can often lead even to a total inhibition of the flow. A recession of this swelling has been attempted in a laboratory with the use of suitable solution flows (Dyrga, Żółcińska and Skawiński, 1992 b).

After the stabilisation of the water flow in the samples, a flow of the dilute, 1% methyl and ethyl alcohol solutions was introduced. The results are presented in Fig. 3 and 4. No significant changes in permeability were observed, so a little addition of alcohol to water does not affect the coal swelling. Alcohol solutions of such low concentration do not practically change the state of the coal swelling caused by a previous water flow.

The further experiments consisted in the flow of water solutions of both methyl and ethyl alcohols of successively growing concentration, i.e. 1%, 10%, 50% and 96% (for ethyl alcohol) or 100% (methyl alcohol) in the coal samples (Fig. 5 and 6).

Even a 1% methyl alcohol solution makes the permeability drop to 0.01 of the standard permeability value k_s; in the case of ethyl alcohol the effect is even greater. This results from a stronger activity of alcohols in their interaction with coal substance. In the case of alcohols it is not only due to the great affinity of the hydroxyl groups $-OH$ of alcohol to the polar centres of coal surface coming from numerous oxygen functional groups, but also to the dispersion effect between the apolar alcohol alkyls and the apolar basic mass of coal substance. This structure of an alcohol particle, i. e. containing an aliphatic chain and a strong polar group,

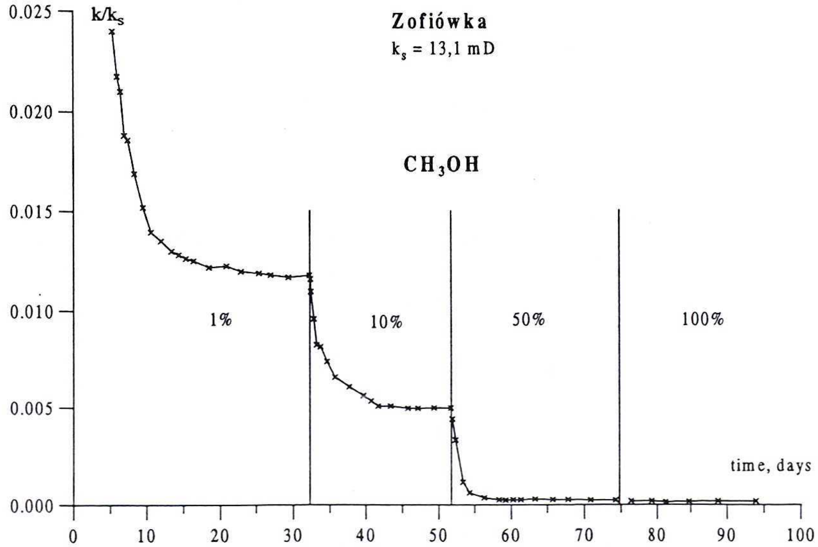

Fig. 5. Changes of coal swelling with duration of methyl alcohol flow of successively growing concentration

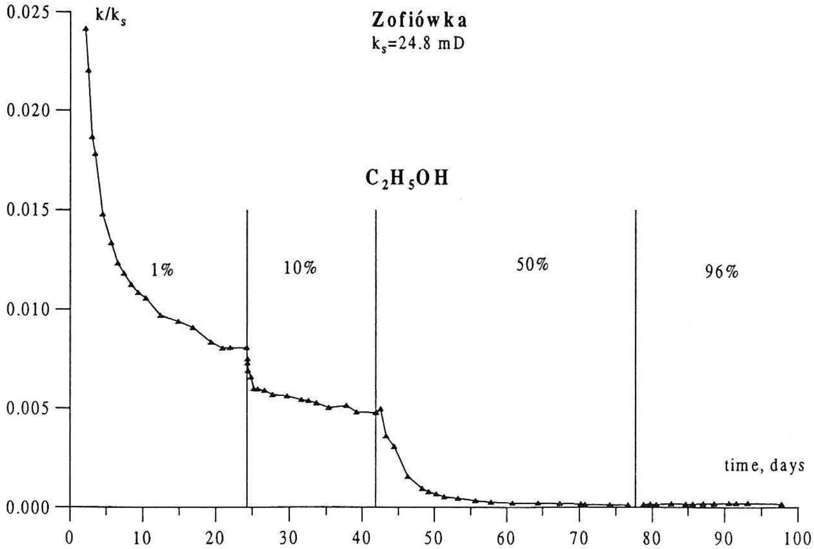

Fig. 6. Changes of coal swelling with duration of ethyl alcohol flow of successively growing concentration

produces its stronger bonding and creates greater possibilities of the sorption of such a particle into the coal substance (Lasoń, Żyła, 1973). This interaction causes strong swelling of the coal with all the effects of the process. The flow of more and more concentrated alcohol solutions corresponds to a systematic growth of the coal swelling as well as a considerable decrease in its permeability.

The sorption of alcohol, resulting from the dual character of coal (i. e. taking place on polar as well as apolar coal centres) additionally increases the coal substance swelling and decreases its permeability. However, after a longer flow, when all the places capable of sorption of water molecules have been already occupied with these molecules, the difference in swelling and its effects in the flow of water and alcohols gradually diminishes.

A comparison of the initial flow of water and alcohols seems especially interesting. It is presented in Fig. 7.

The differences in swelling as an effect of the flowing liquid are the greatest immediately after the saturation of the coal. After 5 days' flow the permeability normalised in water flow is six times as great as the permeability in the methyl alcohol flow and twelve times as big as the ethanol permeability.

The obtained results correlate with the linear expansion tests of coal when exposed to the influence of water and alcohols (Żyła, Kreiner, Bodek, 1991). The greater expansion of coal when treated with alcohols (in comparison with influence of water) can be explained by the great affinity of the $-OH$ groups to the oxygen groups in coal ($-OH$, $-COOH$, $-OCH_3$) as well as of alcohol alkyls to the hydrophobic elements of coal.

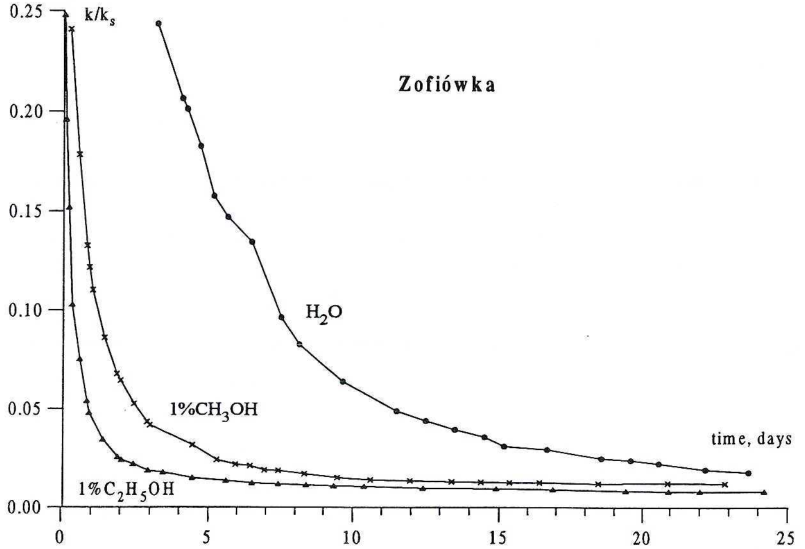

Fig. 7. Comparison of coal swelling caused by initial flow of water and both dilute alcohols

3. Conclusions

1. The investigations were carried out on samples cut of coal lumps coming from the Zofiówka Mine.

2. A preliminary characteristic of the investigated samples was executed by the determination of the permeability in nitrogen flow — k_s (using Darcy's formula). The samples with the most approximate permeability values were selected for the investigation of liquid flows.

3. In the water flow in coal, a typical course od changes in permeability (related to the duration of the flow) can be observed; a considerable drop in the permeability takes place immediately after the saturation of the sample with water; in the further flow the decrease of the permeability is smaller and slower.

4. The permeability in the flow of alcohol solutions changes much quicker than in the case of water flow. Even a 1% solution of methyl alcohol causes a decrease in permeability to 0.01 of the standard permeability value k_s. In the case of ethyl alcohol the decrease is even greater. The growing concentration of the flowing alcohol solutions causes a systematic increase in coal swelling as well as considerable decrease in its permeability.

5. The obtained results correlate very well with the tests of coal linear expansion under the influence of both water and alcohols conducted by M. Żyła.

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