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A comparison of the influence of adsorbed gases on gas stresses leading to coal and gas outburst

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HIGHLIGHTS

- Coal and gas mini-outburst initial conditions were analyzed.
- Coal briquettes and three different gases: CO_2, CH_4 and N_2 were used.
- Briquettes saturated with CH_4 were the least prone to undergoing outbursts.
- All analyzed factors together were responsible for mini-outburst initiation.

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ABSTRACT

The present work analyzes the influence of seepage and desorption processes on the initial conditions of coal and gas mini-outbursts. A series of laboratory experiments incorporating coal briquettes and three different gases, namely carbon dioxide, methane or nitrogen were carried out. Experiments relied on mini-outburst inducing. Space and time pressure distributions along the briquettes were recorded. A comparative analysis of the results revealed that the observed differences in mini-outbursts initial conditions cannot be explained by means of a simple coal or gas property such as sorption capacity, desorption rate, seepage rate, or viscosity of gas. On the contrary, the efficiency of accumulated gas releasing processes – desorption and diffusion inside of the coal grains and seepage through the briquette coupled processes – seems to explain the observed variations.

1. Introduction

In the late 40s of the XXth century, it became obvious that it may be impossible to make further progress in understanding the dangerous phenomena called sudden rock and gas outbursts without having the experimental conditions under control. A few years later – in 1953 – two Russian researchers announced the first (at least according to the bibliographic research done in [1]) rock and gas mini-outburst carried out under laboratory conditions [2]. Shortly after, other researchers started similar experiments incorporating coal briquettes and enhancing the experimental setups and procedures [3–8]. The present work belongs to the same line of research and follows the approach of Bodziony and Topolnicki [9,10]. The results presented here are an extension of the research described in [11].

Based on previous observations, it is assumed that coal and gas mini-outburst (outburst involving a small portion of coal and conducted entirely under laboratory conditions) is a cyclic process that takes place near the coal face. Coal and gas mini-outburst consists of several sub-processes, of which the most important ones are the destruction of the coal face and the transport of products formed after this reaction. The term destruction is used to describe the breaking away of a slice of coal and its recoil from the coal face [12]. After that process, the border of the coal face shifts back and the process repeats itself until the conditions to maintain it are satisfied [10].

Aside from the mechanical properties of coal, a sufficient amount of “free” gas is considered a primary outburst initial condition [26]. While decompressing, the “free” gas can immediately provide the amount of energy needed to begin and maintain this specific chain reaction. The gas that is accumulated in the coal, by means of sorption, cannot be extracted quickly enough to take part in the process of coal-face destruction [13]. This form of gas may help in maintaining the outburst products transportation [14] and thus it may alter the pressure distribution in front of the coal face while outburst takes place. The accumulated gas also influences seepage processes taking place inside the coal

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modifying the pressure distribution there as well. Finally, some researchers state that the presence of the adsorbed gas may weaken the coal samples [15–18], though this observation still requires further research [19].

The present work concentrates on the conditions leading to coal and gas mini-outburst. This sudden process itself is out of the scope of this work. As in paper [11], the aim was to find evidence of the influence of desorption on these conditions. The goal of this investigation is to compare the behaviors of chosen pairs, namely gas and coal.

2. Materials

Coal briquettes were employed since they are considered to be representative of coal samples as they posses similar properties to a physically altered coal such as mylonite [27,28]. This type of coal can be found close to the so-called "outburst zones", which are usually long, narrow and intensely deformed areas of a strike-slip, reverse or normal faults [29].

Briquettes used in the research had a porosity (ε) of 22.5 ± 0.5%. This value was chosen based on the results from *in situ* measurements of the porosity of mylonitic coal in the Polish Upper Silesian mine "Zofiowka" [20]. The coal material was obtained from this mine at a location, which was less than 100 m from the area where a massive outburst occurred, in November 22, 2005. It was a medium-rank bituminous B coal according to UNECE International Classification of In-Seam Coals [21]. Pieces of coal were ground and sieved in order to achieve granulation values, which remained under 0.2 mm. Afterward, the material obtained was averaged by means of the Boerner divider [22]. The proximate analysis of this fine coal was as follows: the moisture content – $W_t = 1.2\%$, the volatile matter content $V^{daf} = 26.1\%$, and the ash content $A_d = 11.2\%$.

Three gases, namely nitrogen (N_2), methane (CH_4), and carbon dioxide (CO_2) were used and their selection was based on the following grounds:

- N_2 is relatively weakly adsorbed on the coal and has been widely used in previous experiments.
- CH_4 nowadays predominates in Polish working mines as well as in many mines around the world and is extremely dangerous if released in large amounts.
- CO_2 used to predominate in closed mines of the Lower Silesian Basin (Poland) and is known to be very well adsorbed on coal.

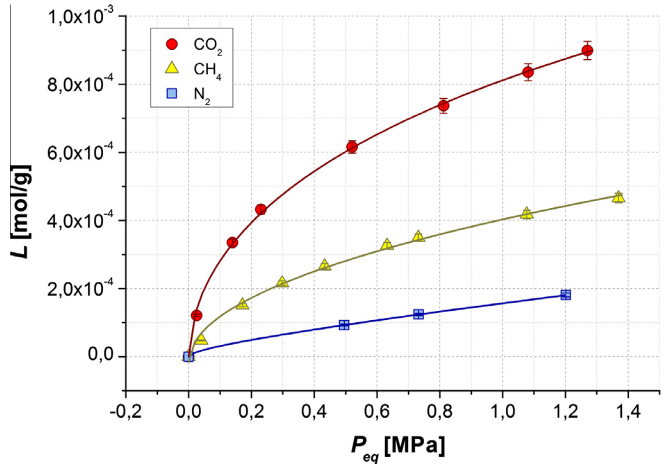

Fig. 1. Isotherms of CO_2, CH_4 and N_2 at 25 °C. L denotes sorption capacity at any given equilibrium pressure P_{eq} (courtesy of B. Dutka, SMRI PAS, Poland).

Methane and carbon dioxide are also involved in most of rock and gas outbursts worldwide [30].

Typically, the adsorption ratio on coal of these gases is around 1, 2.5 and 5 for N_2, CH_4 and CO_2, respectively. The used coal isotherms determined at 298 K by means of the volumetric method [1] are shown in Fig. 1. These gases can also be compared in terms of kinetics of accumulation/releasing processes bearing in mind that adsorption itself is an ultra-fast process [23,31] and transport of gas is the one that creates the delay. While determining isotherms after every application of gas into the chamber holding the coal sample, one had to wait until the rate of pressure drop in this chamber becomes less than 1 Pa/min. Out of the chosen gases, CO_2 showed the shortest time of expectation for the mentioned rate of pressure drop [32]. Much longer times of expectation were observed for N_2 and CH_4.

3. Experimental setup and procedure

The research was carried out employing the typical experimental setup (Scheme 1) used for measuring the dynamic gas seepage through coal briquettes [1,33]. The prepared coal material being in analytic condition (containing mineral substances and moisture that is in balance with atmospheric humidity) was weighed out into 124 g portions from which 15 briquettes were formed directly inside of the so called "outburst pipe" (as described in [34]). This thick-walled pipe (inner diameter $\phi = 48.1$ mm, length $l = 115$ mm) is part of the experimental setup showed in Scheme 1. It is made of special purpose steel and it is sealed with two steel caps whenever another briquette is ready. Six silicon membrane based manometers and two pneumatic sockets are attached to these elements as shown in Scheme 1. The manometers are read by a PC through a fast ADC card. The source of gas (gas cylinder with reducer) and the vacuum pump are connected to one of the two pneumatic sockets, while the valve with an exchangeable diaphragm is connected to the other one.

The outburst pipe was pumped out after each briquette was formed and the experimental set sealed. When the pressure along the pipe dropped below 20 Pa, it was assumed that nearly all gas – free and adsorbed – was taken out of the briquette.

The saturation with one of the selected gases at a chosen pressure level was the next step. Once a steady seepage–adsorption–desorption balance was achieved, the briquette was ready for performing the primary part of the experiment, which consisted of inducing the outburst. The inducing relied on the sudden opening of the valve with diaphragm (Z + D) and releasing the gas from chamber V2 out into the atmosphere [36]. The rapid pressure drop in chamber V2 led to a strong balance perturbation and as a result to a high pressure gradient. Therefore, high tensile stresses were observed, especially in the briquette face neighborhood. The bigger the aperture of the diaphragm the more intensive the inducing. The outburst always happened when certain critical initial conditions were fulfilled.

The dependence of gas pressure in chamber V2 on the time, during inducing, was nearly exponential. Therefore, it was possible to estimate the time constant τ_h of that process. The inverse of this constant may be considered a measure of the strength of inducing.

Usually, there were several unsuccessful induces before the mini-outburst happened. After each inducing event, the briquette was saturated again. Starting from the smallest possible value, the strength of induces was subsequently increased until mini-outburst happened in order to record various space and time pressure distributions $P(x,t)$ including the last one – just before destruction of the briquette. A total of 126 measurements were recorded during each induce, from which 15 were successful (mini-outbursts).