Substantiation of laboratory facilities set to study physico-mechanical properties of coal-gas-moisture composites

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Abstract. Intensive development of coal deposits along with introduction of advanced high-performance machinery leads to higher number of fire- and explosion-hazardous events induced by gas dynamic phenomena at mines. Mass media regularly inform on tragic events concerning the combustible gas explosions and loss of lives at collieries in Russia and abroad. The main subject is development of a composite on the basis of solid coal and rock particles, gasses (methane, hydrogen) and moisture, prone to penetrate into mechanisms, initiating catastrophic dynamic processes in course of mining operations. The present research objective is foundation of a laboratory base to develop coal-gas-moisture composites in the form of coal cores, experimental investigation into their physico-mechanical properties. The special stand for development and investigation into coal-gas-moisture composites was designed. The relationships of variations in physico-mechanical properties of cores versus pressure were obtained experimentally on various materials (coal, limestone, graphite, etc) at the new-designed stand. The long-flame coal of different coarseness were used to establish specific variations in temperature, deformation of briquetted mass, its density under increase in pressure up to 200 MPa. It is demonstrated that temperature of a coal briquette increases by maximum 14 °C under atmosphere pressure and 10 °C in vacuum. The test stand allows physical modeling of coal and rocks with account for their material composition. The scientific novelty involves development of composites simulating mineral coal and rocks under prescribed physical and mechanical conditions.

1. Introduction

Intensive development of coal deposits by introducing innovative high-performance machinery results in higher number of fire- and explosion-hazardous events, induced with gas-dynamic phenomena at collieries. Mass media regularly inform us on tragic events resulted from combustible-gas explosions and loss of lives at coal mines in Russia and world countries.

In this connection, on May 25 1812 in Great Britain the coal-mine explosion carried away 92 human lives. On this subject Society for Prevention of Accidents in Coal Mines was founded with fruitful participation and contribution on the part of great scientists, including Humphry Davy in Anderland (England).

Mineral coal presents a complicated dispersion system, including three mutually interrelated macrocomponents: organic mass, moisture, and mineral components. To characterize properties of a certain coal brand implies consideration of each of three components [1]. It is important to consider a significance of gas phase [2].
Investigation into regularities in variations in physical and mechanical properties of coal and identification of structural-and-chemical parameters to provide their proper description are principal scientific problems. Solving this problem would enable to verify scientifically coal grades by means of a certain set of parameters, to predict coal applicability for a certain process, as well as to utilize physical and structural-and-chemical parameters of coals to manage coal mining and beneficiation processes.

Research activity in this field was initiated by Van Klevelen and his co-workers as early as the 1950s [3]. However, in spite of a lot of available publications on this subject, a satisfactory solution to the present problem lacks so far. Moreover, it is a great pity, but most of these publications deal with solving sub-problems limited by establishment of correlation relations of “black box” type with no application of physical models.

Thus, one of important factors in developing a structural model of mineral coal is foundation of the model base in the form of a coal-gas-moisture composite. Thereto, coal being a solid phase of organic mass and mineral components represents a matrix dressed with such fillers as moisture and gases. The gas-phase base is methane.

Methane, formed in the process of coal substance metamorphism, partially remains inside of the coal matrix. Free methane is present in a gaseous state inside of open and closed pores. Some amount of methane is adsorbed at internal surface of coal pores, as well as in micropores, which dimension is comparable with molecule size. A part of methane dissolves in the solid coal substance. However, laws of adsorption and solubility [4, 5], used to describe gas-content and gas-recovery of a mineral coal fail to explain in full all natural phenomena running with methane in coal beds in underground coal mining processes. The drastic methane decomposition in spontaneous coal and gas outbursts as well as abnormal gas release in degasing boreholes can serve as examples of this phenomenon [4, 6].

The objective of the present research is foundation of the laboratory facilities to produce coal-gas-moisture composites in the form of coal cores and to study experimentally their physical-and-mechanical properties. Thereto, of prime importance is to develop composites imitating natural coal and rocks at study prescribed physical-and-mechanical conditions in view to explain mechanisms initiating catastrophic dynamic phenomena in mining operations. Moreover, as demonstrated in [7-10], the operating mechanism for generation of explosion-hazardous medium does not actually exist, but there are a few theories (hypothesis) differing in estimations of the role and participation of the stress-strain state of a rock mass, physical-and-mechanical and physical-and-chemical properties of a coal mass in simultaneous coal and gas outbursts.

2. Methods and materials
Investigation into the influence of quantitative and qualitative composition of a coal-gas-moisture composite on properties of a coal model is one of research directions practiced at IM SB RAS. For this purpose a special hydraulic stand was designed and manufactured in order to develop different models of composites (Figure 1). The test stand enables to conduct investigations into influence of physical parameters (moisture, fractional and mineral compositions of a solid phase, temperature, pressure, etc) on formation of synthetic composite specimens and to study their mechanical and structural properties.

**Figure 1.** Fragment of the hydraulic stand to study coal-gas-moisture composite: 1—power hydrocylinder, 2—high-pressure chamber, 3—connecting pin, 4—punch, 5—removable flange, 6—composite matrix (briquette).
Figure 2. Working section of the test stand: 1—high-pressure chamber, 2—composite matrix (briquette), 3—pressure shell.

The test stand consists of power hydrocylinder 1 and high-pressure chamber 2, interconnected by pins 3. The high-pressure chamber contains punch 4, actuated by stock of power hydrocylinder. The composite mass is placed into the working cell of high-pressure chamber 2 is closed by removable flange 5. In the working stroke the punch of power hydrocylinder compresses the composite mass and forms a briquetted composite matrix 6. The briquette is pushed out from high-pressure chamber by a working stroke of a punch rod with removed flange.

Of prime value is investigation into the temperature effect in the process of coal matrix (coal briquette) manufacture by static pressure molding method. Measurement of temperature under triaxial compression was performed at the stand equipped with temperature controller (TC) and vacuum pump (VP) (Figure 2).

The initial material of preset coarseness moisture and temperature was loaded into high-pressure chamber where triaxial compression of the material is performed. As compressive pressure increased, the measurements of compressive pressure, deformation of briquette specimen and temperature in its middle section were recorded.

Current temperature was recorded by temperature controller RTC-02. Temperature sensor mounted in pressure shell was designed for 250 MPa pressure. Temperature sensor was connected to temperature controller TC through channel. The prescribed pressure (low vacuum, atmosphere and higher pressure) was supported by vacuum pump (VP) in high-pressure chamber.

Figure 3. General view of the test stand to manufacture and to study the effect of qualitative and quantitative composition of a composite on properties of a rock model.
Figure 3 demonstrates the general view of the test stand designed to manufacture and to study the effect of qualitative and quantitative composition of the composite on properties of a coal and rock model; in the foreground a coal briquette manufactured by static pressing at the test stand is shown.

3. Results
In Figure 4 the experimental relationships of variations in specimen temperature versus pressing pressure are shown for long-flame coal as an example. Specimen temperature was measured under atmosphere pressure and low vacuum. The research results on different materials for briquetting are summarized in table 1.

![Figure 4](image)

**Figure 4.** Relationship of variations in specimen temperature versus variations in pressing pressure for different-coarseness coal specimens: (a) – under vacuum, (b) under atmosphere pressure.

**Table 1.** Research results on the influence of qualitative and quantitative compositions of a composite on briquette properties

| Material                                      | ΔT max, °C under: | Deformation max, mm | Density, g/cm³ | Compression job, kJ |
|-----------------------------------------------|-------------------|---------------------|----------------|---------------------|
|                                               | atmosphere pressure | low vacuum          |                |                     |
| Long-flame coal, fraction ≤ 1.0 mm            | 11                | 7                   | 106            | 1.26                | 25.05               |
| Long-flame coal, fraction ≤ 2.5 mm            | 9                 | 7                   | 112            | 1.14                | 20.29               |
| Long-flame coal, fraction ≤ 5.0 mm            | 9                 | 7                   | 113            | 1.14                | 20.29               |
| Limestone, fraction ≤ 1.0 mm                  | 6                 | 7                   | 106            | 2.41                | 21.2                |
| Limestone, fraction ≤ 2.5 mm                  | 6                 | 4                   | 107            | 2.46                | 21.6                |
| Limestone, fraction ≤ 5.0 mm                  | 11                | 4                   | 114            | 2.51                | 21.4                |
| Graphite, fraction ≤ 1.0 mm                   | 6                 | 6                   | 139            | 1.68                | 31.28               |
| Product of ash removal, fraction ≤ 1.0 mm     | 11                | 12                  | 137            | 1.57                | 25.98               |
| Wood saw-dust                                 | 6                 | 6                   | 183            | 1.73                | 13.34               |

4. Discussion
Relationships of sample temperature variations vs. compressive pressure for long-flame coal of different coarseness (Figure 4) indicate that under higher pressure the briquette temperature rises by maximum 14 °C under atmosphere pressure and by 10 °C in vacuum. In [11] it is experimentally found
that for coal specimens of 40x60 mm under triaxial compression at 5 MPa pressure the temperature rise amounts to $\Delta T \geq 3^\circ C$.

Experimental results reported in Table 1 on influence of qualitative and quantitative compositions of a composite on properties of resultant briquettes indicate a rise of their temperature. Maximum temperature values, namely, 11$^\circ$C under atmosphere conditions and 12 $^\circ$C in vacuum are recorded for briquettes made of ash-removal product of $\leq 1.0$ mm in size.

It is important to outline as it follows from Table 1 of research data on the influence of qualitative and quantitative composition of a composite on properties of the resultant briquettes, the maximum deformation is specific for wood saw-cuttings and the maximum compressive work equal to 31.28 kJ is determined for graphite of $\leq 1.0$ mm in size. Density of different coal brands varies within 1.15–1.80 g/cm$^3$ depending on ash content and occurrence depth. By data reported in [12] density of long-flame coal amounts to 1.2 g/cm$^3$, limestone density varies from 2.37 to 2.51 g/cm$^3$ versus occurrence depth.

5. Conclusions
Thus, the special hydraulic test stand is designed and manufactured to construct models of coal-gas-moisture composites and physical modeling of rocks considering their material composition. The new-made stand was employed to study influence of physical parameters: fraction and mineral compositions of solid phase, temperature, pressure, etc. on formation of synthetic composite specimens based on different rocks and to investigate into properties of new-made briquettes. Thereto, numerical values of physical briquette characteristics: temperature, density, strain, and compressive work comply with those for natural rocks [12-16]. Perspective use of the test stand for coal-gas-moisture composite is intended to establish the mechanism for generation of explosion-hazardous medium, its detonation, and dynamic destruction in zones of metastable state of a coal mass and to construct its physical model.

References
[1] Gyu’maliev AM, Golovin GS, and Gladun TG 2003 Theoretical Fundamentals of Coal Chemistry Moscow: MGGU (in Russian)
[2] Kozlovsky EA, Sharov GN, Kantorovich AE, Gritsko GI, Kuznetsov FA, Kurlyeva MV, Kovalev VA, Rostovtsev VI, Belozerov IM, Cheroenk VA, Minin VA, and Vashlaeva NYu 2018 Gas Explosiveness in Underground Coal Mining in Kuzbass J. Fundament. Appl. Min. Sci. Vol 5 No 1 pp 76-82
[3] Van-Krevelen DV, Shuer Zh 1960 Coal Science Moscow: Gos Nauch-Tech Izd po Gorn Delu (in Russian)
[4] Airuni AT 1987 Prediction and Prevention of Gasdynamic Phenomena at Collieries Moscow: Nauka
[5] Ettinger IL 1966 Gas Capacity of Mineral Coals Moscow: Nedra (in Russian)
[6] Fundamentals of Theory of Sudden Coal Rock and Gas Outbursts Skochinsky AA Mining Institute Moscow: Nedra 1978 (in Russian)
[7] Bychkov SV 2016 Chemical reactions in earthquakes Explosion of rock mass as a source of shocks, sudden outbursts and rock shocks Vestnik Nauchn. Tsentra po Bezop. Rabot v Ugol. Promyshl. No 4 pp 36–47
[8] Petrosyany AE, Ivanov BM, and Krupyna VG 1983 Theory of Sudden Outbursts Moscow: Nauka (in Russian)
[9] Hargraves AJ 1992 Gas and gas-dynamic phenomena in coal and evaporates Proc. Coalbed Methane Symposium November 1992
[10] Kolesnichenko EA and Kolesnichenko IE 2000 Formation of physiochemical structure of coal matter with abnormal properties in focus of sudden coal and gas outbursts GIAB No 5 pp 199–200
[11] Bulat AF and Dyrdy VI 2013 Some Issues of Gasdynamic Phenomena in a Coal Mass in Terms
of Non-linear Nonequilibrium Thermodynamics Kiev: Geotekhnichna Mekhanika (in Russian)

[12] Dortman NB 1984 Physical Properties of Rocks and Minerals (Petrophysics) Geophysician’s Manual Moscow: Nedra (in Russian)

[13] Bayuk EI, Tomashevskaya IS, Dobrynin VM et al 1988 Physical Properties of Minerals and Rocks under High Thermodynamic Parameters Handbook Volarovich MP (Ed) Moscow: Nedra (in Russian)

[14] Shubin VP 1951 On investigation into physical-and-mechanical properties of some Kuzbass coal brands Izvestiya Tomsk Kr Znameni Polytekh Institute im SM Kirova Vol 68 Issue 1 pp 130-170

[15] Ilinskaya EI, Teder RI, Vatolin ES, and Kuntysh MF 1969 Rock Properties and Techniques of Their Assessment Protod’yakov MM (Ed) Moscow: Nedra (in Russian)

[16] Danilovich A Pressure and Its Effect on a Substance www.electrosad.ru/Proekt/Earth.htm