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Modelling of underground geomechanical characteristics for electrophysical conversion of oil shale

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Abstract. Oil shale energy extraction is an urgent issue for modern science and technique. With the help of electrical discharge phenomena it is possible to create a new efficient technology for underground conversion of oil shale to shale gas and oil. This method is based on Joule heat in the rock volume. During the laboratory experiments the problem has arisen, when the significant part of a shale fragment is being heated, but the further heating is impossible due to specimen cracking. It leads to disruption in current flow and heat exchange. Evidently, in the underground conditions these failure processes will not proceed. Cement, clay and glass fiber/epoxy resin armature have been used for modelling of geomechanical underground conditions. Experiments have shown that the use of a reinforcing jacket makes it possible to convert a full rock fragment. Also, a thermal field extends radially from the centre of a tree-type structure, and it has an elliptic cross section shape. It is explained by the oil shale anisotropy connected with a rock laminar structure. Therefore, heat propagation is faster along the layers than across ones.

1. Introduction

The attention to the development of oil shale energy potential after the «shale revolution» has not decreased until today [1, 2]. However, shale processing *in-situ* remains an urgent task, in connection with unprofitability of conventional development methods for these inferior solid fossil fuels. A great number of underground methods for rock processing has been offered, but neither of them has achieved the stage of industrial application, except formation hydrolytic fracturing (hydrofrac). The issue of hydrofrac application in the world practice is still opened, as this technology is low-efficient and provokes extremely negative ecological effects. According to the data of theoretical calculations as well as preliminary successful experiments it follows that electrophysical phenomena, occurring in oil shale under the electromagnetic field action, are enables to create a high-efficient and environmentally safety technology for underground processing of these fuels. Electrophysical impact on oil shale *in-situ* leads to the formation of an electroconductive channel directly in the rock strata. With the help of this channel it is possible to carry out heating and pyrolytic conversion of a shale organic constituent (called *kerogen*) into flammable gas and synthetic oil. During preliminary experiments it has been established that the adherence to the geomechanical conditions of bedding is very important for obtaining an adequate model of thermochemical, thermo- and elctrophysical processes.

2. Electrophysical conversion

Electrophysical oil shale conversion includes three relative stages. From the point of the required equipment and physics of running processes, ideally, it is necessary to divide them according to the rock conductivity.

2.1. Low conductivity

Initially, oil shale has high electrical resistance ($10^9 \div 10^{12}$ Ohm/cm), consequently, the current, flowing through the rock, is negligibly small, even under the high field stress. However, when voltage exceeds a specified threshold value, partial discharges (PDs) occur in the material volume. Primarily, PDs are the breakdowns of micro- and macrovoids, and they occur because of different dielectric permittivity of the inclusions and enclosing material [3]. Material fracturing and tree discharge structure forming, called dendrites, occur as a result of PDs plasma impact. The quantity of energy, which is required for the thermal destruction of kerogen, is smaller than for the oil shale mineral constituent. Therefore, the organic component is, mainly, subjected to the thermal decomposition under the PDs impact. Material fracturing by PDs plasma leads to treeing, i.e. the growth of dendrites. In some carbonaceous materials, including oil shale, treeing is accompanied by carbonization, i.e. by the increase of carbon local concentration. A conductive carbon layer is formed on tree walls due to carbonization [4,5].

2.2. Medium conductivity

The rock breakdown occurs, when the discharge structure electrodes are connected. The resistance of an interelectrode gap decreases by 3÷5 degrees due to carbonization. The diameter of a formed channel does not exceed 300 μm. The channel resistance remains relatively high because of its small cross-section, so, current can flow through shale only in the case of high voltage application. Also, because of a small channel volume, the concentration of the input energy takes place there. Hence, a significant heat quantity is locally released even at small energy, which is input in the specimen. This process leads to the abundant emission of conversion gases and the formation of a dust-like suspension of solid particles. The educed aerosol is ionized under the external electromagnetic field and high temperature, and a plasma channel is formed. Due to plasma action the interelectrode gap conductivity and carbonization of the peri-discharge area increase.

2.3. High conductivity

The specimen resistance decreases to the value from one to first hundreds Ohm, when a carbonized channel cross-section is extended significantly. As a result, the difference of potentials between electrodes is reduced, and the discharge plasma dies out. The further heating occurs due to Joule heat in the rock volume and leads to the extension of the carbonization area. The subsequent carbonization provokes a greater decrease in resistance and the conversion of a substantial volume of the rock organic constituent.

3. Methods and equipment

3.1. Sample and medium preparation

A rock fragment with the shape of a parallelepiped and dimensions 145x70x85 mm has been prepared for the study of a full conversion cycle of oil shale. The obtained specimen is put in the reinforcing cage. The bars of glass fiber potted by epoxy resin are used as the armature, as far as this material has a high mechanical strength and electrical resistance. The use of the non-conductive armature is determined by the application of high voltage to the specimen at conversion initiation. The use of the conventional metal armature will lead to the significant distortion of the electromagnetic field applied

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to shale, which concentrates on the conducting elements. This process will cause the redistribution of stresses and uncertainty of the obtained data.

The cage with the specimen is infused in concrete. Preliminary, the sample is wrapped with a thin polyethylene film for prevention of water sorbing from concrete. Rock conductivity increases significantly, when it absorbs water, even in small quantities, what influences on the experimental integrity. Two closed holes with the diameter of 12 mm and the depth of 30 mm are drilled at the distance in 100 mm between them in the obtained block for carbon electrodes installation. Carbon is used, because it is resistant to destruction under the high temperature action.

A hermetically sealed chamber with the volume of ~ 60 L and maximum operating pressure up to 3 atm is used to model the fluids pressure in the underground conditions. Nitrogen is used as an inert medium, which simulates fluids and prevents combustion. Before filling the chamber with nitrogen it has been vacuumed, as pyrolysis must progress without any oxidizer.

3.2. Experiment

By the means of the insulators, installed in the wall of the chamber, the electromagnetic field is applied to the electrodes and imposed on the shale fragment. With the help of an adjusting transformer the voltage is increased up to the breakdown value, which is ~ 2 kV. After forming a stable conductive enough channel a high-voltage transformer is switched off, and a high-current adjusting transformer, supplying the variation of the output voltage from 0 to 220 V and the maximum current of 264 A, is directly connected to the specimen. Then, the sample is heated with the constant power of 1500 W during 4 hours. After that the oil shale fragment infused in the concrete cage is sawed up on four parts along longitudinal and cross vertical symmetry axes.

4. Results and discussion

The photographs of longitudinal and cross sections of the oil shale fragment after the conversion by the electrophysical method are shown in Figure 1 b,c,d. Figure 1a shows the heated rock fragment, which is not infused in the concrete cage. During thermochemical reactions the phase transitions of the solid matter into gas occur, it leads to pressure increase within the limits of some volume inside the specimen and occurrence of local mechanical stresses. As a result of a high degree of oil shale heterogeneity and a significant difference in the properties of various fragments, including a thermal linear expansion coefficient, the distribution of mechanical load occurs unevenly. Therefore, due to heating, thermal shocks and excess pressure of conversion gases as well as additional strength reduction during shale carbonization the specimen destruction occurs, primarily, in the form of stratification and splitting. Rock carbonization occurs due to Joule heat at current flowing throw the material. Specimen stratification and separation of rock fragments from the bulk material volume lead to the failure of current flowing paths and, consequently, to the redistribution of heat locations. Also, gas interlayers are formed between partly separated shale fragments, so, heat transfer is disrupted and a thermal field is redistributed. Heat transfer becomes negligibly small at a particular moment, and the further conversion is impossible. Obviously, in the underground conditions the shale strata are surrounded by the enclosing strata, what excludes rock destruction according to the described mechanism. Therefore, for obtaining the adequate data about the thermal field distribution, current flowing paths and conversion of big specimens it is necessary to build the geomechanical conditions of oil shale bedding in the model.

Considering a longitudinal section (Fig. 1 d), it can be noticed that carbonization has occurred from the surface of the shale fragment to the depth slightly bigger than the bottom of electrodes holes. This fact is associated with the contact area expansion. At extension of the carbonized volume the current is distributed evenly by the volume of carbonization, flowing on the path of the least resistance. Therefore, a major part of Joule heat is released directly in the interelectrode area, and carbonization occurs there. After the thermal decomposition of the rock between the electrodes the rest shale part is carbonized, primarily, as a result of heat transfer and only a small current part flows through this volume. Further thermal destruction is possible due to increasing the power input in the specimen and,

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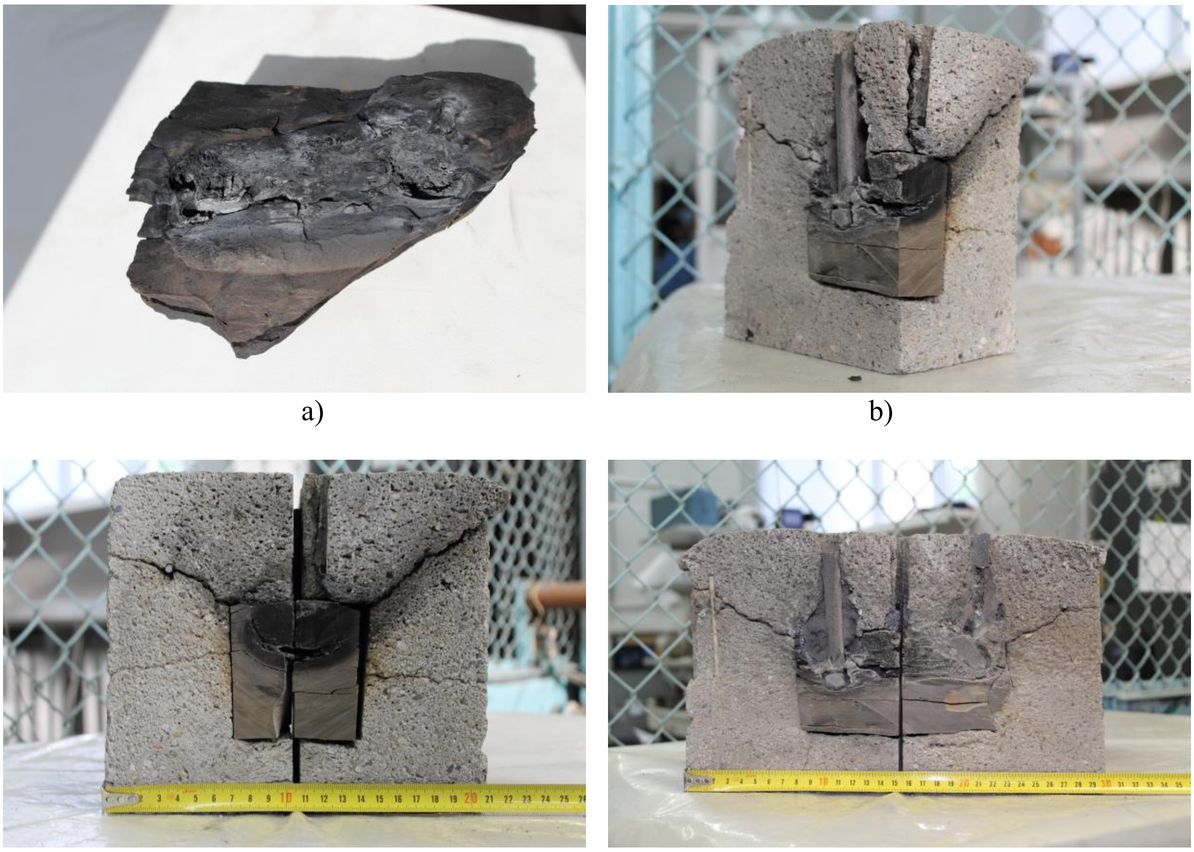
consequently, temperature and/or increasing the time of electromagnetic field impact on rock. However, the increase of hold-up time does not lead to full rock fragment conversion, because with the extension of a carbonized volume the specific energy input will decrease as well as an absolute temperature value. This process will lead to the thermodynamical equilibrium and termination of thermal field distribution.



a) b) c) d)

Figure 1. Photographs of the oil shale fragment infused in concrete after the electrophysical conversion; a) a specimen without a concrete cage, b) a lateral section, c) a longitudinal section, d) the quadrant of the sample.

Figure 1 c demonstrates that the cross section of the carbonized area has an elliptical shape with the position of major semiaxis along the layers and a symmetry center on a half-depth of electrodes penetration. Initially, the conductive channel is a dendrite, connecting electrodes. Due to Joule heat, heating, carbonization and channel extension gradually occur in the newly formed structure. The thermal field tends to equilibrium distribution, but the final form of the carbonized area has the elliptical shape as a result of greater thermal conductivity along the layers of oil shale. Directly after its formation the dendrite, connecting the electrodes, has a stochastically branching structure. Channel flattening occurs, because the system tends to equilibrium.

5. Conclusion

The adherence to the geomechanical conditions in the laboratory model is very important for obtaining adequate data about thermal field distribution, which appears to be the key moment in the underground pyrolytic conversion of solid fuels by the electrophysical method.

If the oil shale fragment is infused in the solid cage, which sustains thermal and mechanical overloads, at modeling underground rock heating, it can be seen that a thermal field front is an ellipsoid. The length and position for one of axes is determined by the depth of electrodes penetration and the distance between them, rest two axes are located along and across the layers, semimajor and semiminor, respectively.
At supplying the constant power, inputting in shale, with regard to the extension of heat emission volume, in the particular moment a thermal equilibrium occurs and the further heating is possible only under the energy increase.

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