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# Х А Б А Р Л А Р Ы

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## ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК  
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## NEWS

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OF THE REPUBLIC OF KAZAKHSTAN  
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named after K. I. Satpayev

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*Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.*

*НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.*

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**Zh. M. Kasenova<sup>1</sup>, B. T. Ermagambet<sup>1</sup>, G. E. Remnev<sup>2</sup>,  
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<sup>1</sup>LLP "Institute of Coal Chemistry and Technology", Astana, Kazakhstan,

<sup>2</sup>Tomsk polytechnic university, Tomsk, Russia.

E-mail: coaltech@bk.ru, zhanar\_k\_68@mail.ru, remnev@tpu.ru,  
martemyanov@tpu.ru, ater@tpu.ru, nurgaliyev\_nao@mail.ru

## **MODELING OF SUBTERRANEAN HEATING OF COALS OF MAYKUBEN AND EKIBASTUZ BASINS**

**Abstract.** The paper describes experimental studies of the pyrolytic decomposition of coals from the Maikuben and Ekibastuz basins with analysis of the gases. Heating of coal samples was carried out by the industrial frequency current after preliminary breakdown of the interelectrode distance. The samples were heated in conditions that simulate the subterranean reservoir to simulate the process of underground pyrolytic conversion into combustible gases and fluids. Experiments were carried out on the samples of coal weighing about 5 kg with the interelectrode distance 150 mm.

**Keywords:** conversion, coal seam, gas, electric heating, pyrolysis.

**Introduction.** The technologies of intralayer development of solid fossil fuels are currently attracting the attention of many researchers, with the physical and mechanical properties of rocks being one of the main criteria for mining works

[1]. There are significant prerequisites for the creation of various methods of in-situ processing- over the past decade significant advances have been made in drilling technologies, three-dimensional geomodelling methods, methods of chemical, thermal and electrical treatment of a subterranean formation and other breakthrough directions. A number of technologies based on pyrolytic processing are proposed. These include above-ground and underground pyrolytic conversion and gasification. Above-ground gasification of coal has a long history with periods of rapid development and recessions [2, 3], and to date, besides traditional and industrially developed, more promising, such as plasma, catalytic, layer gasification with reversed blast, have been developed [4, 5].

Underground conversion is realized by heating the coal seam in situ and accumulation the pyrolysis products through the wells. This path to the recovery of coal deposits seems to be the most promising and environmentally friendly [6]. Access to the reservoir is through wells, and heating can be realized by incomplete oxidation of the coal itself [7], heat conduction heating [8,9], electric heating [10-12], etc. In our opinion, one of the most effective ways to heat coal is electrophysical heating, based on exposure to high voltage electromagnetic field [13, 14].

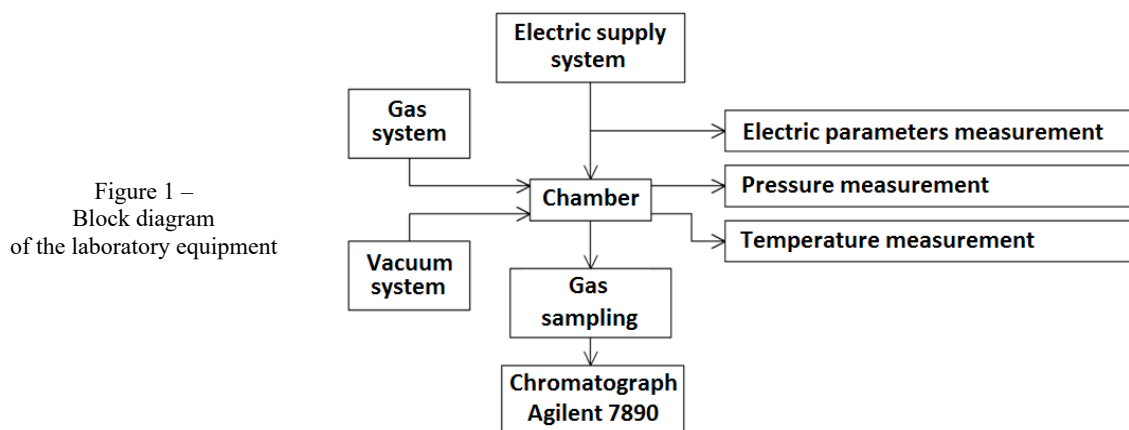
The method consists in the following. Along the edges of the heated part of the reservoir, two wells are drilled, in which electrodes are placed. First, a high voltage is applied to the electrodes, sufficient to initiate electrical discharge processes in the pores of the subterranean formation. Further, the action of partial discharges leads to the formation of a channel of electrothermal breakdown. The breakdown channel has a significantly lower resistance than the original coal. Passing a current through the channel leads to its heating. Thus, the use of the channel as a resistive heater will allow heating of the subterranean formation to the pyrolysis temperature.

The composition and ratio of pyrolysis products – combustible gas and tar – depend on the composition of the original coal and the heating rate. In addition, presumably, the composition of the products can be affected by electrochemical and electrokinetic processes occurring under the action of the current flowing through the coal. The composition of the pyrolysis products in turn affects the areas of their possible use. For example, depending on the ratio of hydrogen and carbon monoxide, pyrolysis gas can be used as follows:

- to produce liquid hydrocarbon fractions by Fischer-Tropsch synthesis [15];
- to separate pure hydrogen as a commercial product or as an intermediate product for the subsequent synthesis [16-18];
- to generate heat or electrical energy by direct gas combustion in gas piston or gas turbine generators [19, 20].

The paper describes the method and results of laboratory heating of coal with an electric current under conditions close to intralayer. The composition of the resulting pyrolysis gas is determined. Coals taken from the Maikuben, Bogatyr and Saryadyr mines were used for study.

**Research methodology.** In-situ conversion of solid fuels involves heating the rock directly in the conditions of occurrence. The laboratory studies were carried out in conditions similar to the underground reservoir for a sample of solid fuel. Such similarity criteria as reservoir pressure and electric field intensity were simulated. The block diagram of the laboratory equipment is shown in figure 1.



The reservoir pressure is the pressure of the fluid phase of the reservoir and, as a rule, for a certain depth is equal to the hydrostatic pressure of the column of the corresponding height. Imitation of reservoir pressure was carried out by increasing the pressure of the buffer gas in the chamber of the laboratory unit (figure 2). Nitrogen was used as a buffer gas. The chamber has a volume of 0.06 m<sup>3</sup> and a maximum pressure of 10 kgf/cm<sup>2</sup>, which makes it possible to simulate reservoir pressure at a depth of 100 m. Gas was supplied to the chamber from cylinders through a reducer. Previously, air was pumped out of the chamber by a backing pump. This eliminates the ignition of pyrolysis gases in the chamber during the experiment. A rotary lamellar foreline vacuum pump LB 60 with a residual pressure of 0.005 mbar was used.

The power supply system of the laboratory equipment is represented by a set of high-current and high-voltage electronic and electrical devices combined into a common circuit and controlled from a single control unit (figure 3).



Figure 2 – Laboratory chamber

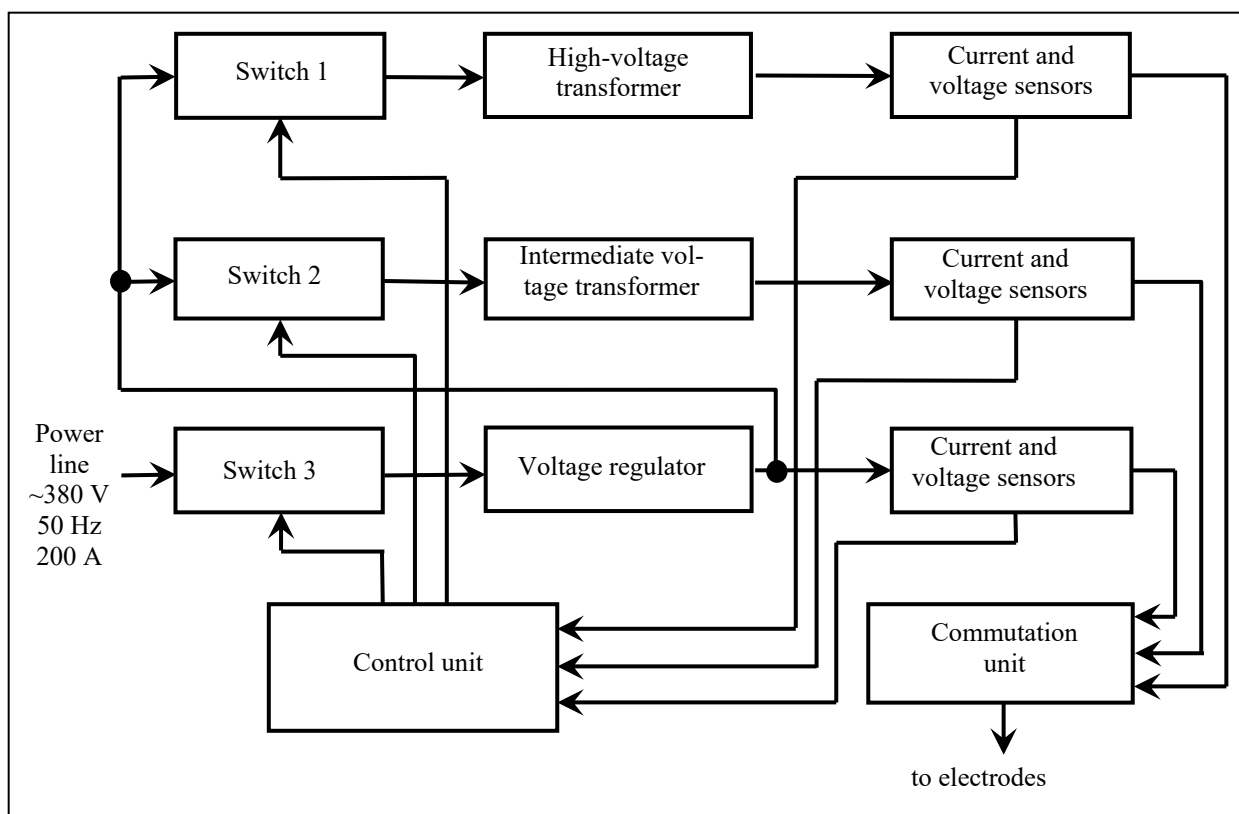


Figure 3 – Blockdiagram of laboratory equipment

The maximum output voltage is 100 kV of industrial frequency, the maximum output current is 240 A of industrial frequency. The output voltage is regulated smoothly in three ranges: 0..220 V, 0..10 kV, 0..100 kV.

During the experiment, the temperature dynamics at certain points of the sample is measured. For this purpose, a multichannel thermoconverter Thermodat 25M5 and a set of chromel-copel thermocouple were used.

During and after the experiment, gas samples were taken from the chamber and analyzed. Gas is sampled directly from the chamber and through the air tubing enters the filter regulator LFR-1/4-D-5M-MINI. This device allows taking a sample of gas, without affecting the pressure in the chamber, and also removes the aerosol phase and dust particles from the gas. After the filter regulator, the gas was fed to an Agilent 7890 chromatograph, which was used to analyze the resulting pyrolysis gas. Pneumatic hoses, valves and gas fittings manufactured by Festo (Germany) were used.

The chromatograph is equipped with a ShinCarbon ST 100/120 capillary column, 2 m long and 1 mm internal diameter. This column is designed to separate the following gases: hydrogen, oxygen, nitrogen, carbon monoxide and carbon dioxide, methane and heavier hydrocarbons. The column uses a thermal conductivity detector.

Samples of coal were in the shape of a parallelepiped 300×200×200 mm in size, cut from a solid coal fragment on a stone-cutting machine with an abrasive-cutting disc with a diamond coating.

Electrode system was presented by two rods of carbon steel 10 mm thick, spaced 150 mm from each other and recessed into the specimen by about 100 mm. The temperature was measured at 3 points. The first point was located in the center of the interelectrode distance. The second and third points were 30 mm and 60 mm from the axis drawn between the electrodes, respectively (figure 4).

The experimental procedure was as follows. A sample with electrodes and thermocouples was placed in the chamber. Electrodes and thermocouples are connected by conductors to the electrical inputs of the chamber, which are isolated from the body of the chamber by ceramic insulating tubes. After sealing and vacuuming, the chamber was filled with nitrogen to the working pressure, which in the experiment was 2 kgf/cm<sup>2</sup> and was kept constant. Outside the electrical inputs of the chamber were



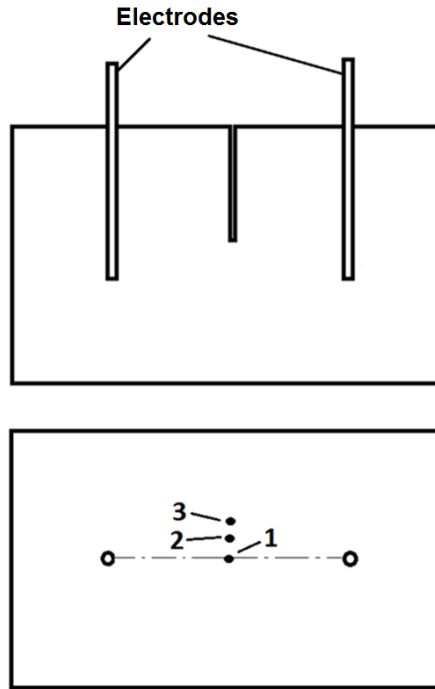


Figure 4 – Layout of thermocouples in the sample:  
1, 2, 3 – thermocouple placement points

connected to the electrical equipment. By applying a high voltage, the sample was first electrically broken. Next, the electric circuit switches from high-voltage to high-current mode of operation and coal sample heats. During the heating produced gas is mixed with nitrogen. For keeping the pressure in the chamber constant, an overpressure is allocated through the gas inlet of the chamber. Thus, the released pyrolysis gas gradually replaces nitrogen. At the end of the experiment, gas was sampled from the chamber for analysis. Sampling was carried out through a straight hose connecting the chamber and the chromatograph.

Figure 5 shows the temperature dependences on time for the Bogatyr coal specimen. Curves of the other coals are identical.

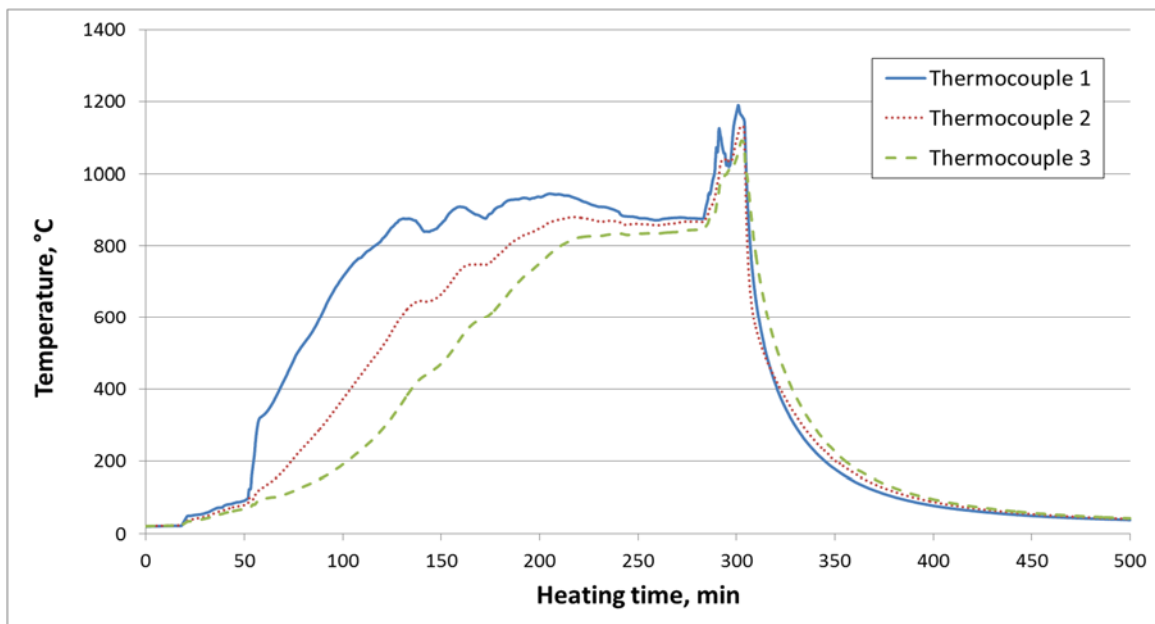


Figure 5 – Temperature versus heating time

**Results and discussion.** The average heating power was 800 W, although a change in the resistance of the sample sometimes caused deviations. As the sample heats up, its resistance decreases, and in order to maintain a given power it is necessary to increase the current. The sample was heated until the current required for heating exceeded 130 A.

Before and after heating, the sample mass was measured to calculate the mass loss. The volume of released gas was determined using a membrane gas meter with automatic thermal compensation. The amount of released liquid products cannot be directly determined, since gummy substances settle on the entire inner surface of the chamber. Thus, the mass of liquid products was determined by subtracting the mass of gas from the total mass loss of the sample. The mass of gas was determined by calculation from a known composition and volume.

Summary of the results of the research are shown in table 1.

Table 1 – Summary data on physical modeling of underground coal heating

Parameter	Sample			
	Bogatyr	Maykuben	Saryadyr (nadezhniy layer)	Saryadyr (pyatimetroviy layer)
Initial sample weight, kg	5,590	5,067	4,199	4,316
Weight after heating, kg	5,022	4,155	3,993	3,842
Weight loss, g	568	912	206	474
Gas volume under normal conditions, m <sup>3</sup>	0,764	1,066	0,175	0,432
The average molar mass of gas, g/mol	7,65	10,85	9,34	9,09
Specific calorific value of gas, MJ/m <sup>3</sup>	13,89	11,93	14,18	19,16
Specific calorific value of gas, kcal/m <sup>3</sup>	3320	2851	3389	4577
Calculated mass of gas, g	261	516	73	175
Calculated mass of liquid products, g	307	396	133	299
Electricity spent on heating, kW·h	4,54	1,94	0,78	3,39

The mass loss of the samples during the heating time was from 5 to 20% of the initial mass. In experiments, a small part of the sample interelectrode space is heated. It is impossible to heat the entire sample with this experimental technique due to the fact that at a certain stage there will be a mechanical destruction of the sample and the heating process will stop.

The ratio of the mass of the gas to the mass of the liquid products in the heating mode used was from 35:65 to 55:45 for the used coal. This ratio is influenced by the composition of the coal and the heating rate. In industrial use, this ratio can be changed by varying the heating power. If it is necessary to obtain more liquid products, heating should be carried out with less power. In this case, the conversion of the same amount of coal will take more time.

The calorific value of the gas produced for the used coal was from 13 to 19 MJ/m<sup>3</sup>, which is a high value in comparison with the gas produced by UCG-gasification with partial oxidation of coal [21, 22].

The calorific value and the calculated mass of the gas were determined on the basis of the known composition. The results of the analysis of the composition of the obtained gas and its calorific value are shown in table 2.

The main component of the gas is hydrogen, the concentration of which exceeds 60% for all the coals under study. It also shows that methane concentration is very high. The high calorific value of the gas is achieved mainly due to the high concentration of methane. There are also hydrocarbons C<sub>2</sub>–C<sub>4</sub>, also having a very high calorific value. Unlike UCG-gasification, which is characterized by a high content of carbon dioxide in a gas, the gas in our experiments contains from 1.7 to 6.41% CO<sub>2</sub>.

Table 2 – Composition and calorific value of pyrolysis gas obtained from coal

Component	Bogatyr	Maikuben	Saryadyr (nadezhniy layer)	Saryadyr (pyatimetroviy layer)
H <sub>2</sub>	73,15	66,99	67,44	63,97
CO	13,29	21,35	16,61	9,89
CH <sub>4</sub>	10,64	4,81	10,80	19,90
CO <sub>2</sub>	2,13	6,41	3,58	1,70
C <sub>2</sub> H <sub>2</sub>	0	0	0,14	0,03
C <sub>2</sub> H <sub>4</sub>	0,26	0,12	0,69	1,15
C <sub>2</sub> H <sub>6</sub>	0,44	0,29	0,55	1,20
C <sub>3</sub> H <sub>6</sub>	0,03	0,01	0,09	0,12
C <sub>3</sub> H <sub>8</sub>	0,01	0,02	0,07	0,14
C <sub>4</sub> H <sub>10</sub>	0,04	0	0	1,88
Calorificvalue, MJ/m <sup>3</sup> (kcal/m <sup>3</sup> )	13,89 (3320)	11,93 (2851)	14,18 (3389)	19,15 (4577)

**Findings.** In-layer pyrolytic conversion of solid fuels by electric heating, in our opinion, is promising. With its help, it is possible to process fuels of unprofitable fields: low-thickness formations, high-ash fuels, formations with complex mining and geological conditions. One of the main positive properties of electric heating is the high quality of the product gas - high calorific value, high content of hydrocarbons, low content of carbon dioxide and absence of nitrogen. Such gas can be used as a raw material for further processing to produce a large number of products.

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Ж. М. Касенова<sup>1</sup>, Б. Т. Ермағамбет<sup>1</sup>, Г. Е. Ремнев<sup>2</sup>,  
С. М. Мартемьянов<sup>2</sup>, А. А. Бухаркин<sup>2</sup>, Н. У. Нурғалиев<sup>1</sup>

<sup>1</sup>«Көмір химиясы және технология институты» ЖШС, Астана, Қазақстан,

<sup>2</sup>Томск политехникалық университеті, Томск, Ресей

#### КОМІР ҚАБАТЫН ҚАБАТІШЛІК ҚЫЗДЫРУДЫ ФИЗИКАЛЫҚ МОДЕЛЬДЕУ

**Аннотация.** Мақалада Майкүбен және Екібастұз бассейндеріндегі көмірдің пиролизтік қыздыруының тәжірибелік зерттеулері және газдардың анализі келтірілген. Көмір сынамаларын қыздыру алдын-ала электродаралық қашықтықта өнеркәсіптік тоқ жиілігінің ағымы арқылы жүзеге асырылды. Көмір қабатының жер асты пиролизтік конверсиясы кезінде жанғыш газ бен шайырдың түзілу процесін модельдеу үшін, сынамалар имитациялаушы қондырғыларда қыздырылды. Салмағы ~ 5 кг көмір үлгілері пайдаланылды, электродаралық қашықтық ~ 150 мм құрады.

**Түйін сөздер:** конверсия, көмір пласт, газ, электр өткізгіштік, пиролиз.

Ж. М. Касенова<sup>1</sup>, Б. Т. Ермағамбет<sup>1</sup>, Г. Е. Ремнев<sup>2</sup>,  
С. М. Мартемьянов<sup>2</sup>, А. А. Бухаркин<sup>2</sup>, Н. У. Нурғалиев<sup>1</sup>

<sup>1</sup>ТОО «Институт химии угля и технологии», Астана, Казахстан,

<sup>2</sup>Томский политехнический университет, Томск, Россия

#### ФИЗИЧЕСКОЕ МОДЕЛИРОВАНИЕ ВНУТРИПЛАСТОВОГО НАГРЕВА УГОЛЬНОГО ПЛАСТА

**Аннотация.** В статье описаны экспериментальные исследования пиролизического разложения углей Майкубинского и Экибастузского бассейнов с анализом получившихся газов. Нагрев образцов углей производился током промышленной частоты после предварительного пробоя межэлектродного расстояния. Образцы подвергались нагреву в условиях, имитирующих условия залегания пласта, для моделирования процесса подземной пиролизической конверсии в горючие газы и смолы. Использовались образцы углей массой ~5 кг, межэлектродное расстояние составляло ~150 мм.

**Ключевые слова:** конверсия, угольный пласт, газ, электронагрев, пиролиз.

**Information about the authors:**

Kassenova Zhanar Muratbekovna, Master of Chemical Sciences and Technology, Deputy Director of LLP "Institute of Coal Chemistry and Technology", Astana, Kazakhstan; zhanar\_k\_68@mail.ru; <https://orcid.org/0000-0002-9497-7319>

Yermagambet Bolat Toleukhanuly, Doctor of Chemical Science, Professor, Director of LLP "Institute of Coal Chemistry and Technology", Astana, Kazakhstan; bake.yer@mail.ru; <https://orcid.org/0000-0003-1556-9526>

Remnev Gennadiy Efimovich, Doctor of Technical Science, Professor, Tomsk polytechnic university, Tomsk, Russia; remnev@tpu.ru; <https://orcid.org/0000-0002-1654-3179>

Martemyanov Sergey Mikhaylovich, Candidate of Technical Science, Associate professor, Tomsk polytechnic university, Tomsk, Russia; martemyanov@tpu.ru; <https://orcid.org/0000-0001-5372-6276>

Bukharkin Andrey Andreevich, Master of Technic and Technology, engineer, Tomsk polytechnic university, Tomsk, Russia; ater@tpu.ru; <https://orcid.org/0000-0002-6877-1595>

Nurgaliyev Nurken Uteuovich, Candidate of Chemical Science, Leading Researcher of LLP "Institute of Coal Chemistry and Technology", Astana, Kazakhstan; nurgaliyev\_ao@mail.ru; <https://orcid.org/0000-0001-9171-2238>

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