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Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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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. Webof 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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CALCULATION OF KINETIC PARAMETERS OF THERMAL DECOMPOSITION OF COALS OF VARIOUS DEPOSITS OF KAZAKHSTAN

Abstract. The article studies the influence of the heating rate and the fractional composition of OMC on the kinetic parameters of the process of thermal destruction, it is revealed that an increase in the heating rate leads to a decrease in the degree of thermochemical destruction of OMC. The coals of the Saryadyr deposit (Pyatimetrovyi, Nadezhnyi), Maykube (Shoptykol), Bogatyr (Ekibastuz) were taken as research samples. The dependence of the kinetic parameters of thermal destruction of coal in the temperature range of the main decomposition of OMC on the rate and temperature of heating and fractional composition, as well as between the kinetic parameters at different stages of the main decomposition of coal, is analyzed. It was found that the heating rate of β samples of coal significantly increases the temperature T_{max} and the destruction rate v_{max}, and also reduces the activation barriers of the process. A study was also conducted of the effect of heating in the temperature range of 30-900 ° C on the degree of thermochemical destruction of coal samples Saryadyr (Pyatimetrovyi, Nadezhnyi), Maykube (Shoptykol), Bogatyr (Ekibastuz). The results showed that the coals of the Maykube deposits are subjected to maximum decomposition (more than 40% by weight). This indicates their lower thermal stability, and hence the lower stage of metamorphism with respect to other coals studied, due to the content of a large amount of oxygen in them in the form of functional, ether groups and other forms. In this case, the process of thermal decomposition occurs at lower temperatures, during which a large number of low molecular weight volatile substances are formed in the form of vapors of resins and gases, and very few non-volatile liquid-phase products are formed, i.e. the stage of transition to the plastic state is absent. These factors are in agreement with the fact that these coals contain a large amount of volatile (51-57%).

The coals of the Bogatyr and Saryadyr deposits, when heated, have the lowest reactivity (decomposition degree less than 30%), which is due to the low amount of oxygen-containing compounds and a high carbon content. Minimal weight loss is also associated with a lower moisture content (2-3%). The higher stage of metamorphism of these coals is due to the fact that their structure has a high degree of crosslinking and a large number of developed polyaromatic formations.

Key words: coal, thermal destruction, decomposition stage, heating rate, kinetic parameters.

Introduction. Most of the kinetics of thermal destruction are based on the results of thermal analyzes (thermogravimetry, differential thermal analysis, derivatography, etc.) [1,2]. Among the methods of thermal analysis of solid fuels, differential thermal and differential thermogravimetric analysis methods are most widely used [3]. The thermogravimetric method allows one to obtain the TG (temperature dependence of the sample mass) and DTG (temperature dependence of the rate of change of sample mass) curves when the temperature of the system changes according to a given linear law [4]. These experimental curves make it possible to judge the thermal stability of the test substance, the composition and thermal stability of substances that are formed at intermediate stages. This method is especially effective if a sample of a substance emits a sufficient amount of volatile substances as a result of various physicochemical processes (evaporation, combustion, etc.) [5].

Depending on the temperature conditions of the process, two research schemes are distinguished: 1) an isothermal scheme, when the sample is placed in a stationary temperature field; 2) non-isothermal circuit, when the sample is heated at a constant speed. One of the main advantages of the isothermal method is that the experimental data lend themselves very easily to rigorous mathematical processing. But there are also disadvantages that are expressed in the long duration of the experience, the complexity of observing the conditions isothermal, the impossibility of determining the activation energy according to the results of one experiment. The non-isothermal method is devoid of all the shortcomings of the isothermal method; therefore, this method has become widespread, allowing for a relatively short time to obtain great information about the nature of the decomposition process with registration of all stages of the transformation in a wide temperature range [6]. The most common differential thermal and thermogravimetric methods of analysis. The application of these methods allows one to calculate the kinetic parameters of the corresponding processes, the thermal effects of the reaction, the onset temperature of decomposition, and other important characteristics [7].

The aim of this work is to determine the kinetic parameters of the process of thermal decomposition of coal from the Saryadyr (Pyatimetrovyi and Nadezhnyi) and Maykube deposits and the Bogatyr mine.

Research methodology. To characterize the process of thermal decomposition of coal, the following indicators were selected: loss of mass of samples in various temperature ranges; temperature T_{max}, speed T_{max}, speed constants k_{max}, corresponding to the highest mass loss rate (i.e., the maxima of the main decomposition on the DTG curves at the inflection points); preexponential factor k0 and activation energy Eact related to the stages of the main thermal decomposition of coal.

The presence of various competing sequentially parallel processes during the thermochemical transformations of coals (according to the molecular and radical-chain mechanism) often leads to fluctuations in the total reaction order in the range 0.5-1.5. It is impossible to describe the whole process of coal decomposition using one first-order equation (monomolecular transformation), since in real conditions the decomposition of the organic mass of coal (OMC) occurs under the mutual influence of substances of different nature constituting OMC [8, 9]. But the process of basic thermal decomposition can be described by the equation of formal kinetics of the first order and calculate the Act. Therefore, due to the variety and complexity of physicochemical transformations, these kinetic parameters describe not certain reactions, but the total processes of thermal decomposition of OMC, therefore they are considered as "effective parameters" of formal kinetics [10].

The kinetic parameters of the basic thermal decomposition of OMC were determined based on the equations of nonisothermal formal kinetics [11]. The mathematical processing of the curves was carried out in accordance with the procedure [12]

Thermogravimetric analysis to study the kinetics of thermal destruction of coal was carried out in an inert nitrogen atmosphere at different heating rates within 3-15 deg / min and coal fractions with granule sizes d = 0.2-5 mm, the DTG curves of Saryadyr coal (Pyatimetrovyi and Nadezhnyi) are presented. Maykube and Bogatyr in a nitrogen environment.

Results and its discussion. It was revealed that the change in the mass of coal occurs in five stages. The temperature range 25 -110 °C corresponds to stage I, which corresponds to the release of pyrogenic water. Stage II corresponds to the interval 110-450 °C, where, under the influence of temperature, gaseous substances, mainly carbon dioxide and hydrogen sulfide, begin to be released from the molecule of organic matter of coal. The jump in the mass change of stage III at a temperature of 450-560 0C is explained by the fact that resin begins to be released in this temperature range, this stage is usually associated with the bituminization process, when the bulk of the coal tar begins to form, but there is not enough heat to evaporate it. With further heating (above 560 ° C) a small amount of gas is released, the resin is almost not released, therefore, at stage IV, the yield of volatile components is not significant. Then, at stage V, another jump in mass loss is observed in the temperature range of 860-900°C, this is due to the fact that in this temperature range there is an active decomposition of the mineral part of coal.

The analysis of the curves revealed three stages of the main decomposition of the OMC of the studied coals on the differential DTG curves, where peaks with maxima of the mass loss rate (inflection points) are observed (figure 1).

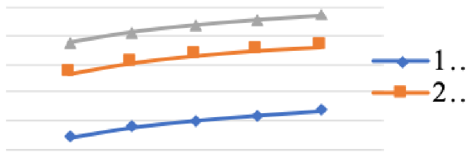

Figure 1 – Dependence of temperature at inflection points on coal heating rate at different decomposition stages

First stage with maximum at T_{max} temperatures in the range 134-226^{0}C is related to evaporation of water, release of oxygen-containing gases due to decomposition of side groups of macromolecules (since carbon-oxygen bonds are least stable in thermal terms). At this stage, it is preferable to break the bonds between the main structural units, cleavage and partial disintegration of the side chains, partially remove O_2, N, S [13]. The volatile yield in this temperature region is low. In the 2nd stage, a peak is observed with a maximum of at 357-453^{0}C, which is responsible for increasing the intensity of the thermosynthesis reaction group due to increased reactivity of the substances of the heated OMC. At the same time reactions of decomposition of oxyaromatic and heterocyclic fragments can take place, as well as thermochemical transformations of humic substances and synthesis of new more heat-resistant compounds based on them, increase in the number of non-organic bonds, the rate of formation of volatile substances increases [14]. In the third stage with peak with maximum at 462-553^{0}C thermal flow reactions of the most thermostable organomineral complexes develop, by the end of this stage the extraction of the main mass of resin and gaseous hydrocarbons is observed, the process is completed with formation of semi-coke.

With a further increase in the temperature, the aromatization and polycyclization reactions intensify (with the removal of gaseous products, mainly H_2, and in a smaller amount - CH_4, CO, N_2), the formation of higher molecular weight polycyclic systems of a mesh structure [15].

At heating rates β from 6 to 15 deg / min at the stage of the decomposition of WMD at temperatures T_{max} in the range of 462–553 °C, peaks with a maximum mass loss rate are weakly expressed with a tendency to decrease with increasing β. This is associated with the imposition of several processes and the impossibility of their separate assessment for the calculation of kinetic parameters.

The results of processing DTG curves at various heating rates in the range of 3-15 deg / min are presented in tables 1-4.

The degree of coal conversion of the Saryadyr deposit (Pyatimetrovyi) during thermolysis decreases with a decrease in the residence time of coal particles in the high temperature zone, as evidenced by a slight decrease in coal mass loss (from 31.6-30.9%) in the range of 3-15 deg / min) at increasing the heating rate (table 1).

Table 1 – Mass losses of samples of coal samples brand Saryadyr (Pyatimetrovyi) in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
				Decomposition stages	
	30-300°C	300-600°C	30-900°C	1	2
3	4.796	26.899	31.641	35.16	681.79
6	3.549.	25.863	29.422	61.53	438.63
9	3.561	25.446	29.183	69.95	450.38
12	3.507	25.642	29.306	71.58	454.06
15	4.457	26.478	30.935	77.32	461.51

For coal of the Saryadyr (Nadezhny) field of the grade, a certain decrease in the loss of coal mass is shown, a decrease in the loss of coal mass from 28.3 liters to 22.1%, with an increase in the heating rate in the range of 3-15 deg / min (table 2).

Table 2 – Mass loss of samples of coal samples brand Saryadyr (Nadezhnyi)
in various temperature ranges and Tmax values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	2.930	25.164	28.269	111.94	450.13
6	2.896	19.768	22.674	60.89	453.33
9	2.506	19.611	22.134	75.24	460.67
12	2.916	19.496	22.535	77.12	465.22
15	2.766	19.341	22.107	78.45	471.87

For brown coal samples of the Maykube deposit of grade B_3 (Shoptykol) in the range of 3-15 deg / min, there is a slight increase in the weight loss of the sample from 19.3 to 38.3%, for samples of coal of the Bogatyr deposit (Ekibastuz) a decrease in weight loss from 21, 3 to 19.4% (tables 3,4).

This is due to the brand of the studied coal samples Saryadyr (Pyatimetrovyi and Nadezhnyi), Bogatyr belong to stone, and Maykube brown B_2 grades, respectively, due to the different structure of the morphological composition, the trend of the weight loss of the samples is different.

Table 3 – Mass losses of samples of samples of coal grade B_3 Maykube (Shoptykol)
in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	1.909	17.579	19.380	71.26	484.6
6	10.800	29.367	40.648	75.90	439.38
9	9.619	29.108	38.849	80.95	442.42
12	9.819	27.658	37.477	87.87	483.43
15	10.108	28.043	38.336	90.20	452.16

Table 4 – Mass loss of samples of coal samples brand Bogatyr (Ekibastuz)
in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	2.009	19.225	21.369	52.67	448.76
6	1.661	17.342	19.080	57.83	462.90
9	2.866	19.814	22.674	62.74	453.33
12	1.866	17.215	19.081	68.35	477.51
15	1.909	17.579	19.380	71.26	484.67

The analysis of the obtained data shows that for all samples of the studied coals in the temperature ranges of 30-300 ° C, the mass loss of the OMC has the smallest values (table 3.3-3.4). In the temperature range 300-600 ° C, where the second and third maxima are observed, higher mass losses of OMC are observed. Apparently, this is due to the release of the bulk of the vapor of the resin and gaseous hydrocarbons with the simultaneous formation of vapor of the so-called pyrogenic water. In the general temperature range of 30–900 °C, the mass loss of OMC is low, due to the high ash content and low volatility.

An increase in the size of coal particles d = 0.2-5 mm leads to a slight increase in the degree of decomposition of OMC (7-8%) and does not significantly affect the kinetics of the studied process.

Table 5 – Kinetic parameters of thermal destruction of OMC of coal

Speed heating ° C / min	Decomposition stages					
	1 stage			2 stage		
	k_{max}, 10^{-3} c^{-1}	k_0, 10^2 c^{-1}	$E_{акт}$, кДж/моль	k_{max}, 10^{-3} c^{-1}	k_0, 10^4 c^{-1}	$E_{акт}$, кДж/моль
3	1,35	2,72±0,13	43,7±0,92	1,23	1,45±0,03	98,2±3,7
6	1,65	7,42±0,64	46,3±2,76	1,19	1,94±0,12	93,3±2,9
9	1,47	1,89±0,11	40,3±2,61	1,34	0,71±0,03	86,8±3,6
12	1,69	2,78±0,18	44,8±2,23	1,52	0,54±0,06	82,6±3,4
15	1,39	1,65±0,06	38,3±1,75	1,32	0,47±0,02	80,1±4,8

As the study showed, when passing from one stage of the main decomposition to another for the coals under study and when the temperature increases at various speeds in the range from 3 to 15 deg / min, with an increase in the heating rate, a significant increase in Eact (approximately twice) is noted. The difference between the activation barriers of the 1st and 2nd stages within the same heating rates is 38-54 kJ / mol. Moreover, the probability of rupture of certain types of bonds during the destruction process increases noticeably, as evidenced by the differences between the values of k_0 at the first and second stages (by 1-2 orders of magnitude, i.e., k_{01} ~10^2 c^{-1}, k_{02} ~10^3-10^4 c^{-1}).

In general, it can be noted that the calculated values of the activation energy are commensurate with the energies of chemical bonds. An increase in the heating rate β from 3 to 15 deg / min at all stages of decomposition for the studied OMC coals leads to a shift in the temperature values Tmax (corresponding to the maximum decomposition) towards large values ($\Delta T_{max} \approx 100^0C$) and an increase in the rate v_{max} of the destruction of the OMC. The value of the velocity v_{max} at the 2nd stage is higher than at the 1st. In this case, the approximation of points by a straight line allows us to obtain approximate dependences between v_{max} and β, shown in figure 2 (R^2 is the reliability of the approximation). At the same time, the difference between the velocities at the inflection points Δv_{max} at the 1st and 2nd stages also increases with increasing heating rate β and the relationship between Δvmax and β is described by a similar function close to linear ($y = 0.011 \cdot x - 0.026$, $R^2 = 0.967$).

Thus, an increase in the heating rate has a more significant effect on the speed of the process with a higher activation barrier, and also contributes to a slight decrease in the E_{act} values at the 2nd stage of decomposition (98.2-80.1 kJ / mol). However, this does not have such a significant effect on the overall degree of decomposition of coal, which is most likely due to the compensation of a higher heating rate with a shorter duration of the thermolysis process (and vice versa).

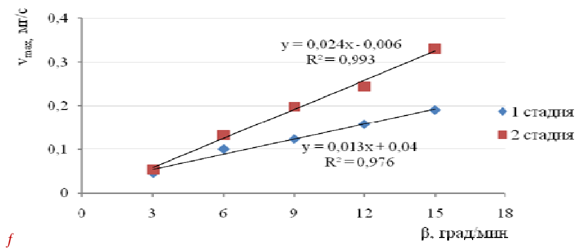

Figure 2 – Dependence of the rate of destruction at the inflection points on the rate of heating of coal at various stages of decomposition

As can be seen from the data in tables (1-4), the coals of the Maykube deposits are subjected to maximum decomposition (more than 40% by weight). This indicates their lower thermal stability, and hence the lower stage of metamorphism with respect to other coals studied, due to the content of a large amount of oxygen in them in the form of functional, ether groups and other forms. In this case, the process of thermal decomposition occurs at lower temperatures, during which a large number of low molecular weight volatile substances are formed in the form of vapors of resins and gases, and very few non-volatile liquid-phase products are formed, i.e. the stage of transition to the plastic state is absent. These factors are in agreement with the fact that these coals contain a large amount of volatile (51-57%).

The coals of the Bogatyr and Saryadyr deposits, when heated, have the lowest reactivity (decomposition degree less than 30%), which is due to the low amount of oxygen-containing compounds and a high carbon content. Minimal weight loss is also associated with a lower moisture content (2-3%). The higher stage of metamorphism of these coals is due to the fact that their structure has a high degree of crosslinking and a large number of developed polyaromatic formations [16,17]. When such fuels are heated, the resin yield is negligible. In this case, mainly reactions of cleavage from macromolecules of relatively small groups and side chains occur, followed by cyclization and ordering of the structure.

Conclusions. Thus, the influence of the heating rate and the fractional composition of OMC on the kinetic parameters of the process of thermal destruction was studied, it was revealed that an increase in the heating rate leads to a decrease in the degree of thermochemical destruction of OMC. The dependence of the kinetic parameters of thermal destruction of coal in the temperature range of the main decomposition of OMC on the rate and temperature of heating and fractional composition, as well as between the kinetic parameters at different stages of the main decomposition of coal, is analyzed. It was found that the heating rate of β samples of coal significantly increases the temperature Tmax and the destruction rate vmax, and also reduces the activation barriers of the process. A study was also conducted of the effect of heating in the temperature range of 30-900 ° C on the degree of thermochemical destruction of coal samples of stone Saryadyr (Nadezhnyi) brand, Saryadyr (Pyatimetrovyy) brand, Bogatyr brand and brown Maykube brand B_3.

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ҚАЗАҚСТАННЫҢ ТҮРЛІ КЕН ОРЫН КӨМІРІ ТЕРМИЯЛЫҚ ЫДЫРАУ КИНЕТИКАСЫНЫҢ ПАРАМЕТРЛЕРІН ЕСЕПТЕУ

Аннотация. Мақалада термиялық деструкция процесінің кинетикалық параметрлеріне КОМ фракциялық құрамы мен қыздыру жылдамдығының әсері зерттелді, қыздыру жылдамдығының артуы КОМ термохимиялық деструкция дәрежесін азайтатыны анықталды. Зерттеу үлгісі ретінде Сарыадыр (Пятиметровый, Надежный), Майкөбе (Шоптыкөл), Богатырь (Екібастұз) кен орнының көмірі алынды. Көмір термодеструкциясы кинетикалық параметрлерінің КОМ негізгі ыдырау температурасының қыздыру жылдамдығы мен температурасына және фракциялық құрамына тәуелділігі, сондай-ақ көмірдің негізгі ыдырау сатысындағы кинетикалық параметрлер арасындағы тәуелділігі талданды. Көмірдің β үлгілерінің қыздыру жылдамдығы T_{max} температурасы мен V_{max} деструкция жылдамдығының мәнін едәуір жоғарылатады, сондай-ақ процестің активациялық кедергілерін азайтады. Сонымен қатар, 30-900°C температуралық интервалдағы қызудың Сарыадыр (Пятиметровый, Надежный), Майкөбе (Шоптыкөл), Богатырь (Екібастұз) көмір үлгілерінің термохимиялық деструкция дәрежесіне әсері зерттелді. Зерттеу нәтижесі көрсеткендей, Майкөбе кен орнының көмірі барынша ыдырауға ұшырайды (массаның 40%-дан астамы). Бұл олардың термиялық тұрақтылығының төмен екендігін көрсетеді, яғни құрамында функционалдық, эфирлік топ және басқа да нысандар түріндегі оттегінің көп мөлшеріне байланысты, метаморфизм басқа зерттелген көмірмен салыстырғанда төменгі сатыны көрсетеді. Бұл ретте термиялық ыдырау процесі төмен температурада басталады, ол кезде шайыр мен газ бу түрінде төмен молекулалы ұшпа зат мөлшері көбейеді, ал ұшпайтын сұйық фазалы өнімдер өте аз, яғни пластикалық күйге өту сатысы жоқ. Көрсетілген факторлар аталған көмірдің ұшқыштығы көп мөлшерді (51-57%) қамтитынын көрсетеді. Богатырь, Сарыадыр кен орны көмірінің күлі көп, қыздыру кезінде ең төмен реакциялық қабілетке ие (ыдырау дәрежесі 30%-дан аз), бұл құрамында оттегі бар қосылыс санының аздығына және көміртегі құрамының жоғарылығына байланысты болып келеді. Аз мөлшерде ылғалға (2-3%) байланысты масса шығыны да аз болады. Көмір метаморфизмінің жоғары сатысы олардың құрылымының жоғары дәрежесіне және дамыған полиароматикалық көпсанды түзілімдерге байланысты. Көмір массасының

өзгеруі бес сатыда жүреді. 25^{0}С-110^{0}С температуралық интервалына пирогенді судың бөлінуі I сатыға сәйкес келеді. II кезең 110-450 ^{0}С аралығына сәйкес, мұнда температура әсерінен көмірдің органикалық затының молекуласынан бірінші кезекте газ тәріздес заттар, негізінен көміртек диоксиді және күкіртті сутегі бөлінеді. III саты 450-560 ^{0}С температурада массаның кенеттен өзгеруі, температураның осы интервалында шайырдың бөлінуі арқылы түсіндіріледі, бұл сатыны әдетте көмір шайырының негізгі массасы пайда болған кезде битуминизация процесімен байланыстырады, бірақ бұл ретте оны буландыру үшін жылу жеткіліксіз. Одан әрі қыздыру кезінде (560 ^{0}С жоғары) аз мөлшерде газ бөлінеді, IV кезеңде ұшатын компоненттердің шығуы айтарлықтай болмағандықтан, шайыр аса бөлінбейді. Одан әрі V сатыда 860-900 ^{0}С температуралық интервалда массаны жоғалтуда тағы бір өзгеріс байқалады, бұл осы температуралық интервалда көмірдің минералды бөлігі белсенді ыдырайды.

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Түйін сөздер: көмір, термиялық деструкция, ыдырау сатысы, қыздыру жылдамдығы, кинетикалық параметрлер.

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РАСЧЕТ КИНЕТИЧЕСКИХ ПАРАМЕТРОВ ТЕРМИЧЕСКОГО РАЗЛОЖЕНИЯ УГЛЕЙ РАЗЛИЧНЫХ МЕСТОРОЖДЕНИЙ КАЗАХСТАНА

Аннотация. В статье проведено изучение влияние скорости нагрева и фракционного состава ОМУ на кинетические параметры процесса термической деструкции, выявлено, что увеличение скорости нагрева приводит к уменьшению степени термохимической деструкции ОМУ. В качестве образцов исследования взяты угли месторождения Сарыадыр (Пятиметровый, Надежный), Майкубе (Шоптыколь), Богатырь (Экибастуз). Проанализирована зависимость кинетических параметров термодеструкции угля в интервале температур основного разложения ОМУ от скорости и температуры нагрева и фракционного состава, а также между кинетическими параметрами на разных стадиях основного разложения угля. Установлено, что скорость нагрева β образцов угля заметно повышает значения температуры T_{max} и скорости v_{max} деструкции, а также снижает активационные барьеры процесса. Также проведено исследование влияния нагрева в температурном интервале 30-900°С на степень термохимической деструкции образцов углей Сарыадыр (Пятиметровый, Надежный), Майкубе (Шоптыколь), Богатырь (Экибастуз). Результаты показали, что максимальному разложению подвергаются угли месторождений Майкубе (более 40% от массы). Это указывает на их меньшую термическую устойчивость, а значит и более низкую стадию метаморфизма относительно других исследованных углей из-за содержания в них большого количества кислорода в виде функциональных, эфирных групп и других формах. При этом процесс термического разложения наступает при более низких температурах, во время которого образуется большое количество низкомолекулярных летучих веществ в виде паров смол и газов, а нелетучих жидкофазных продуктов образуется очень мало, т.е. стадия перехода в пластическое состояние отсутствует. Указанные факторы находятся в согласии с тем, что данные угли содержат большое количество летучих (51-57 %). Угли месторождения Богатырь, Сарыадыр высокозольные при нагревании обладают наименьшей реакционной способностью (степень разложения менее 30%), что обусловлено низким количеством кислородсодержащих соединений и высоким содержанием углерода. Минимальные потери массы связаны также с меньшим содержанием влаги (2-3%). Более высокая стадия метаморфизма данных углей обусловлена тем, что их структура обладает высокой степенью сшитости и большим количеством развитых полиароматических образований. Определено, что изменение массы угля происходит в пять стадий. Температурному интервалу 25^{0}С -110^{0}С соответствует стадия I, что соответствует выделение пирогенной воды. II стадия соответствует интервалу 110-450 ^{0}С, где под действием температуры из молекулы органического вещества угля начинают выделятся, в первую очередь, газообразные вещества, в основном диоксид углерода и сероводород. Скачок в изменении массы стадии III при температуре 450-560 ^{0}С объясняется тем, что в данном интервале температур начинает выделяться смола, эту стадию обычно связывает с процессом битуминизации, когда начинает образовываться основная масса угольной смолы, но при этом недостаточно тепла для ее испарения. При дальнейшем нагревании (выше 560 ^{0}С) выделяется небольшое количество газа, смола почти не выделяется, поэтому на стадии IV выход летучих компонентов незначительный. Далее на стадии V в температурном интервале

860-900 ^{0}С наблюдается еще один скачок в потере массы, это объясняется тем, что в данном температурном интервале происходит активное разложение минеральной части угля. При анализе кривых выявлены три стадии основного разложения ОМУ исследуемых углей на дифференциальных кривых ДТГ, где наблюдаются пики с максимумами скорости потери массы (точки перегиба)

Ключевые слова: уголь, термическая деструкция, стадия разложения, скорость нагрева, кинетические параметры.

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