

UDC 662.743

Thermal Decomposition of Coal from the Tuva Deposit

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(Received May 31, 2012; revised November 13, 2012)

Abstract

The results of research work are reported concerning the thermal decomposition of coal species from the Ulugh and Chadan beds of the Kaa-Khem site of the Tuva deposit as well as an effect of coal activation on the decomposition process. Potentiality is demonstrated for briquetting the coal after removing gaseous and light liquid fractions from the material.

Key words: coal, thermal analysis, mechanical activation, thermal decomposition, briquetting, condensable sublimates

INTRODUCTION

The coal species from the Tuva coal basin and the products of processing thereof represent a real and reliable energy source for the industrial development of the Republic of Tyva. In general, only concerning the coking coal the resource of the Republic of Tyva is estimated as 14.2 billion tons. According to the grade composition, 88 % of the resources are presented by GZh grade coal, 12 % being presented by G grade coal (according to the State Standard GOST 25543–88) [1], so they could be used not only as a raw material for fuel energy, but also in the coke chemistry and chemical industry.

With a view to the practical use, there was a great scope of work performed concerning the determination of the reserves prospected, geological characteristics and classification of coal from the mentioned deposit, the composition, characteristic properties, quality and coking behaviour [2–17 *etc.*]. For example, the authors of [16] investigated a number of samples taken from the 2-Ulugh bed of the Kaa-Khem coal basin in different times. It was demonstrated that these coal species are character-

ized by stable properties, whereas the carbonization thereof results in producing the gas with an increased content of hydrocarbons and hydrogen. Liquid hydrogenation products contain a relatively small amount of asphaltenes and heteroatomic compounds.

According to the authors of [16], these coal species could serve as a valuable raw material for chemical products. The authors of [17] carried out the pyrolysis of the Kaa-Khem coal and reference samples (B, G, Zh grade coal species). They revealed the features of the Kaa-Khem coal species, distinguishing the latter from the gas coal of Kuzbass coals close to them in the level of metamorphism. The features of the thermochemical transformations of the Kaa-Khem coal cause a high sintering ability thereof and the prospects of its use as a raw material for coking.

However, despite a rather great volume and wide range of the data obtained, the coal mined at the Tuva coal basin continues to be used only as an energy source, without any preliminary treatment.

A high content of volatile components (non-condensable gases, coal resins), and caking in the course of coal combustion in the kiln fur-

naces and boilers prevent complete carbon burn-out, resulting in a systemic release of environmentally hazardous products to the atmosphere. In addition, the specific geographical location of the Tuva region (location of cities and towns in the confined spaces of mountain valleys in a wind "shadow") and its harsh climatic conditions (continental climate, abrupt seasonal variations in temperature and dropping the temperature in winter with profound anomalies below zero) exacerbate to a great extent the mentioned environmentally unfavourable situation. The absence of an adequate circulation of atmospheric air above ground contributes to smog formation, and, as a result, to air pollution with the products of incomplete coal combustion, which leads to a significant environmental contamination with carcinogens [9].

These factors determine the relevance of further research with the purpose to find environmentally sound technologies for processing the coal from the mentioned deposit and rational use thereof.

In order to use coal not only as fuel for power generation, but also as a raw material for coke chemistry and chemical industry, it is necessary to provide them a high reactivity, for example, *via* activation.

In the Tyva Institute of Complex Exploration of Natural Resources, SB RAS (Kyzyl, Tyva, Russia) there were experiments conducted concerning the chemical activation of coal taken from the Elegest open-cast mine of the Tuva coal basin [18–20]. It was demonstrated that the preliminary treatment of coal solutions of inorganic acids and alkalis exert a significant effect on the structure and properties of coal. It was established that the chemical activation of coal causes decreasing the bond strength in the structure of coal with increasing the coal porosity. In this case, chemical activation by alkaline solution appeared more efficient. In addition, the chemical activation of coal promotes increasing the rate and conversion level of coal organic matter (COM) into liquid and gaseous products, as well as increasing the yield of the latter.

However, this method of activation implies the use of chemicals, solutions and, therefore, requires for corresponding instrumental network scheme for the preparation and subsequent pu-

rification of solutions. In this regard, one could consider a method of mechanical activation to be more promising for the activation of coal.

For the rational use of the Tuva coal species, of interest is to study their thermal decomposition with the evolution of gases and low-boiling components to apply as intermediates for chemical industry and with obtaining a solid dry fuel and energy product (briquettes).

Preliminary experiments [21] concerning the thermolysis of coal from the Kaa-Khem deposit demonstrated that in the course of heating in a neutral reducing atmosphere at a temperature above 350 °C there occurs mild sintering the sample material. Subsequent heating was followed by distillation of low-boiling coal components to the gaseous environment, and then the material exhibited a weakly sintering with becoming porous at first, to become loose when the temperature amounted to about 700 °C and higher. In this case, the mass loss (under heat exposure) could reach 60–70 % of the initial value.

The mechanical activation of original coal samples during 10 min in an atmosphere of its own gas medium results in occurring the phase transformations with the decomposition and the formation of active centres, which, to all appearance, causes the oxygen saturation of the material *via* sorption process. Under heating further slow oxidation thereof is observed to form carbonates decomposing with the release of CO₂.

In order to study the possibility of briquetting the coal species under investigation, there were experiments carried out to determine the character and temperature of sintering and subsequent distillation of low-boiling components with use of coal samples taken from different parts of the Ulugh and Chadan beds of the Kaa-Khem coal basin [22].

EXPERIMENTAL

The characteristics of the coal species under investigation taken from the Ulugh and Chadan beds of the Kaa-Khem deposit are presented in Table 1. Alongside with the thermal analysis, we conducted experiments on determining the temperature limits for the isolation individual fractions resulting from thermolysis.

TABLE 1

Technical and chemical characteristics of the coal samples

Sites	Sampling place	Sample index	Technical analysis, %				Elemental analysis, % with respect to the organic matter of coal sample					Coal grade
			W^a	A^d	V^{daf}	S_t^d	C	H	N	O	S	
Chadan open-cast mine	Northern flank	05-03	0.6	10.8	39.8	0.52	87.22	5.61	1.04	5.53	0.60	Zh
Chadan coal bed	« «	06-03	0.4	9.2	40.8	0.21	88.46	5.58	0.99	4.73	0.24	Zh
	Southern flank	07-03	0.8	5.2	35.2	0.20	87.66	5.20	0.95	5.97	0.22	Zh
Kaa-Khem open-cast mine	Northern flank	08-03	1.2	6.4	47.6	0.17	83.90	5.73	1.11	9.09	0.17	G
2-Ulugh coal bed	Southern flank	09-03	1.2	5.9	48.9	0.19	84.00	5.52	1.08	9.19	0.21	G-GZh
	« «	10-03	1.2	9.0	48.6	0.17	83.63	5.70	1.19	9.29	0.19	G-GZh
	Central part	11-03	1.2	6.0	47.6	0.14	83.02	5.97	1.27	9.59	0.15	G

The experiments on thermal investigation were carried out using a MOM-1000 derivatograph (MOM, Hungary). The heating rate was maintained at a level of 10 °C/min. The heating was carried out under the conditions of the own gas environment and of the free diffusion of the resulting gas phase throughout the sample material. To prevent the ignition of the sample and the creation of conditions for the free removal of low-boiling coal components the crucible was closed by a carburized lid made of foamed corundum that impeded free of air access from the furnace and at the same time

permitted the gaseous products of thermolysis formed in the bulk of the sample. The mass of the weighed sample portion amounted to 600 mg. The experiments were repeated for reproducibility. In order activate the original material we used an AGO-2 planetary-type mill with water cooling, at the timing modes of 1, 3 and 10 min. The experiments on obtaining the fractions extracted were performed using a setup comprising a muffle furnace, a quartz tubular ampoule with a system for suction and trapping of condensable sublimates. Vacuum in the ampoule was equal to 0.1–0.2 atm.

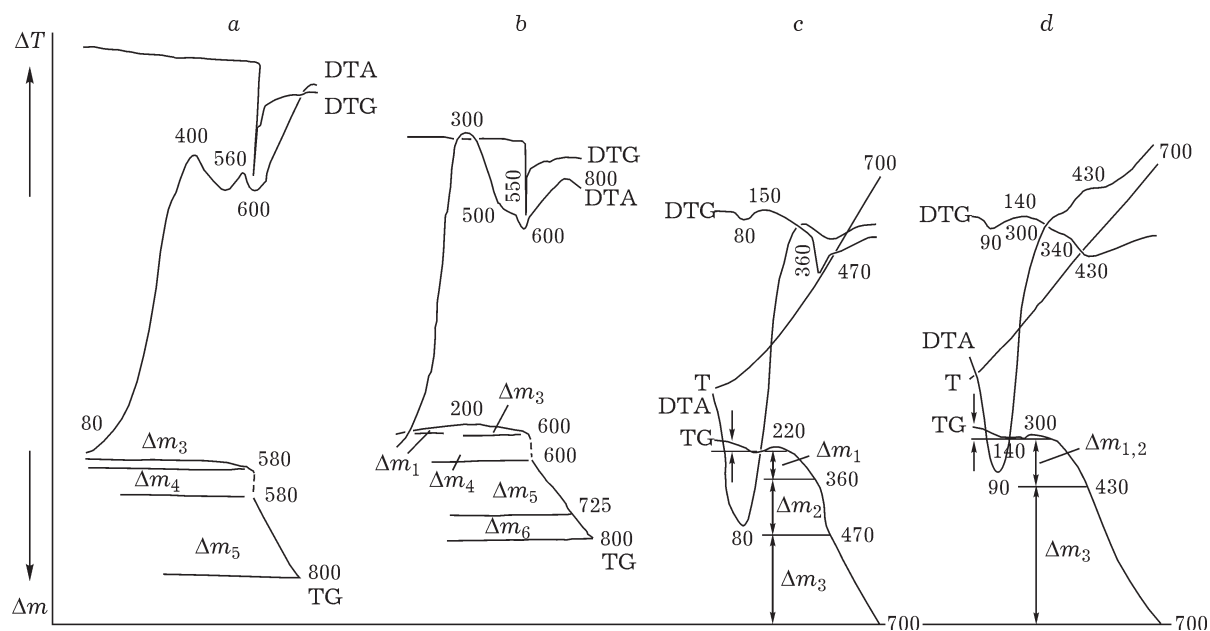


Fig. 1. DTGA data for the sample 05-03 of coal from the Chadan open-cast mine (the Chadan bed): a – original sample; b–d – samples after preliminary mechanical activation for 1, 3 and 10 min, respectively.

TABLE 2

Results of thermal coal decomposition under roasting (DTGA data, see Figs. 1-3)

Original sample index	Activation time, min	Sample mass change on heating												
		Endoeffects												
		1	2		3		4		5		6		$\Sigma \Delta P$,	
$T, ^\circ\text{C}$	$\Delta m_1, \%$	$T, ^\circ\text{C}$	$\Delta m_2, \%$	$T, ^\circ\text{C}$	$\Delta m_3, \%$	$T, ^\circ\text{C}$	$\Delta m_4, \%$	$T, ^\circ\text{C}$	$\Delta m_5, \%$	$T, ^\circ\text{C}$	$\Delta m_6, \%$	$\Delta m_6, \%$		
05-03	-	-	-	-	-	397-560	1.1	560	4.2	560-800	13.1	-	-	18.4
06-03	-	-	-	-	-	410-580	1.2	580	4.0	580-800	13.5	-	-	18.7
07-03	-	-	-	-	-	380-510	1.6	510	2.9	510-800	14.0	-	-	18.5
08-03	-	-	-	-	-	390-500	1.7	500	8.9	500-800	25.0	-	-	35.6
09-03	-	-	-	-	-	400-495	1.5	495	9.1	495-800	25.5	-	-	36.1
10-03	-	-	-	-	-	380-480	1.3	480	6.0	470-800	21.0	-	-	28.3
11-03	-	-	-	-	-	220-390	0.7	390	5.0	400-620	10.5	620-800	12.0	28.2
05-03	1	25-85	1.8	85-200	1.4	200-600	2.0	600	3.5	600-730	10.0	730-800	3.0	18.9
05-03	3	25-100	2.0	100-200	1.2	200-360	1.0			360-470*	7.6	470-700	8.2	17.6
05-03	10	25-140	1.5	140-300	0.5	300-340	0.5			340-430*	6.5	430-700	9.1	17.1
06-03	3	25-120	1.1	120-210	0.4	210-280	0.3	280-400	4.2	400-450	3.2	450-700	8.4	15.8
06-03	10	25-120	0.8	120-240	0.2	240-260	0.1			260-440*	5.7	440-700	10.1	16.5
07-03	3	25-120	1.0	120-220	0.2	220-240	0.1	240-430	2.0	340-440	5.9	440-700	7.9	16.7
07-03	10	25-130	1.5	130-240	0.1	240-270	0.1			270-450*	4.9	450-700	9.5	15.9
08-03	1	-	-	100-240	0.8	240-525	1.6	525	3.7	525-585	12.2	585-800	15.3	35.1
08-03	3	25-130	2.0	-	-	-	-	300-410	4.5	410-450	8.2	450-700	13.2	27.9
08-03	10	25-130	1.4	-	-	-	-	220-380	3.8	380-420	6.1	420-700	14.3	25.6
09-03	10	25-130	2.0	-	-	-	-	210-400	2.8	400-440	6.9	440-700	13.9	25.6
10-03	10	25-150	0.9	-	-	-	-	230-370	2.0	370-450	5.8	450-700	15.5	23.2
11-03	1	25-300	0.6	-	-	300-480	0.9			480-580*	12.5	580-800	14.4	27.1
11-03	10	25-140	1.6	-	-	-	-			200-420*	5.8	420-700	17.9	25.3

Note. Dash means that there are no thermal effects.

* Temperature range for endoeffects 4 and 5.

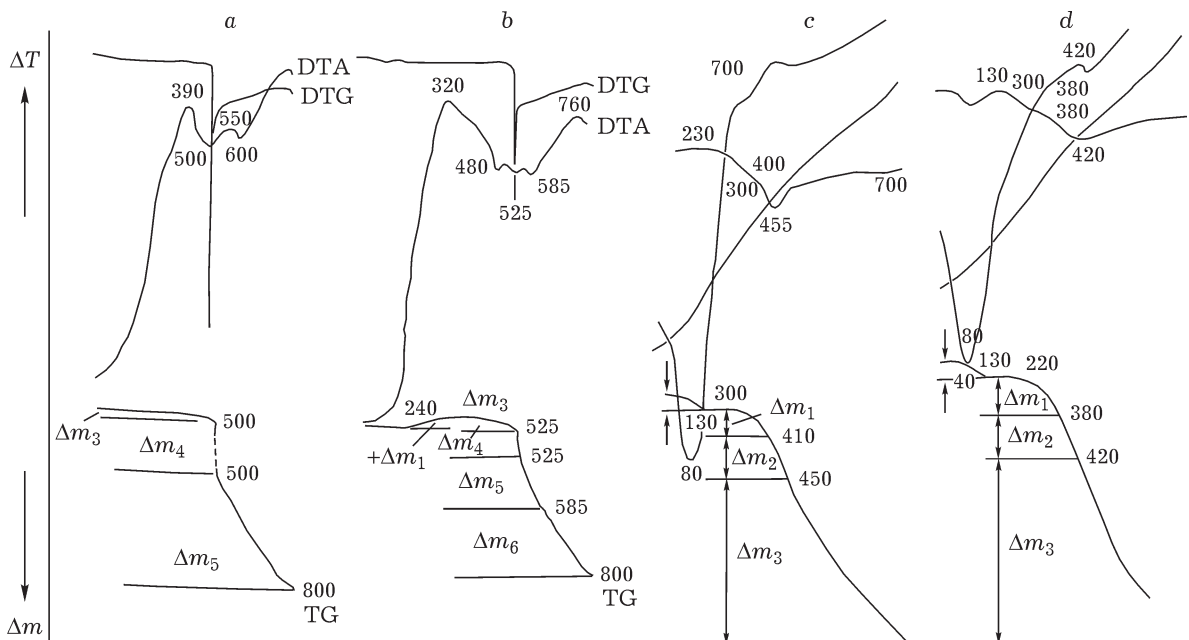


Fig. 2. DTGA data for the sample 08-03 of coal from the Kaa-Khem open-cast mine (the Ulugh bed): a - original sample; b-d - samples after preliminary mechanical activation for 1, 3 and 10 min, respectively.

RESULTS AND DISCUSSION

The dynamics of thermal decomposition obtained in performing the thermal analysis of original coal samples is demonstrated in Table 2 and in Figs. 1–3. The general behaviour character for all the coal samples under investigation on heating is identical, but according to the dynamics of DTGA curves the samples could be distinctly divided into two groups. The first one includes coal species taken from the Chadan bed, whereas the second group includes the coal of Ulugh bed.

An intensive decomposition of all the samples begins at the temperature above 300 °C. The thermolysis process develops in a mode of possible forming the liquid phase and distilling the gas phase. The DTA curve indicated a smooth endothermic effect of evolving the liquid component and a superimposed thereon endothermic effect of the subsequent stage of removing the gas phase.

The initial stage of the process for the samples taken from the Chadan coal bed (for example, sample 05-03, see Fig. 1 and Table 2) is characterized by the melting of low-melting components in the coal conglomerate. The temperature of the softening and the liquid phase formation ranges within 380–400 °C, whereas the decomposition stage is completed at 510–580 °C. The mass of the sample in this case remains almost unchanged, the mass loss being on the average equal to 1.1–1.6 %.

The further stage of thermolysis that consists in boiling the volatile fraction of coal is distinctly exhibited in the thermographic curves for the samples of coal taken from this open-cast mine: the starting temperature being equal to 510–580 °C, the end temperature amounting to 580 °C. The beginning of this thermolysis stage is accompanied by an abrupt dropping break on the integral mass change curve (TG) and an abrupt needle-like peak on the differential mass change curve (DTG). After the completion of the boiling stage and distillation of low-boiling thermolysis products, the gas phase formation and its removal from the sample material continues with an almost constant rate of the process, up to the maximum temperature of heating. This is evidenced by a flattened monotone course of the DTG curve and

a steady decline of the TG curve. The total mass loss in this case amounts to 18.5 %.

The thermolysis process for the coal samples from the Kaa-Khem open cast mine of the Ulugh coal bed (*e. g.* samples 08-03, see Fig. 2, Table 2) as a whole is identical to the thermolysis process for the samples from the Chadan open cast mine (see Fig. 1, *a–c*). Some difference consists in a greater activity at the stage of effervescence and distillation of the volatile fractions formed.

So, the formation of the melt of low-melting coal fractions of takes place at the temperature ranging from 380–400 to 480–500 °C. The mass loss in this case is small, averaging less than 1.5 %. On the DTA curve, the endothermic effect of the first stage is followed by the main effect of the stage characterized by forming and boiling a light fraction with onset temperature of about 500 °C and the completion temperature of 590–600 °C.

The analysis of the differential mass change curve (DTG) demonstrates that the onset of the boiling stage is shifted to the temperature region of melting the fusible coal fractions. In this case the process has a more pronounced explosion-like character, as indicated by an abrupt drop on the TG curve and a more profound peak on the DTG curve already within the temperature range corresponding to completing the first stage (melting). This is especially exhibited by sample 08-03. After completing the second stage of the thermolysis (boiling) the monotonic character of the mass loss is not interrupted and smoothly passes to the stage of high-temperature dry gas distillation. The total mass loss for these samples is much higher than the mass loss of the samples from the Chadan open-cast mine amounting to 28.3–36.1 %.

The behaviour of a sample taken in the central part of the formation Ulugh while heating should be especially noted (sample 11-03, see Table 2 and Fig. 3, *a*). On the DTA curve there are three small endothermic effects observed at the temperature values of 380–400, 450–480 and 510–600 °C. Starting the mass loss on the TG and DTG curves is exhibited by an abrupt break in the course of the integrated mass loss curve (TG) and a needle-like peak on the differential mass loss curve (DTG). Further, the DTG curve exhibits a series of bends those

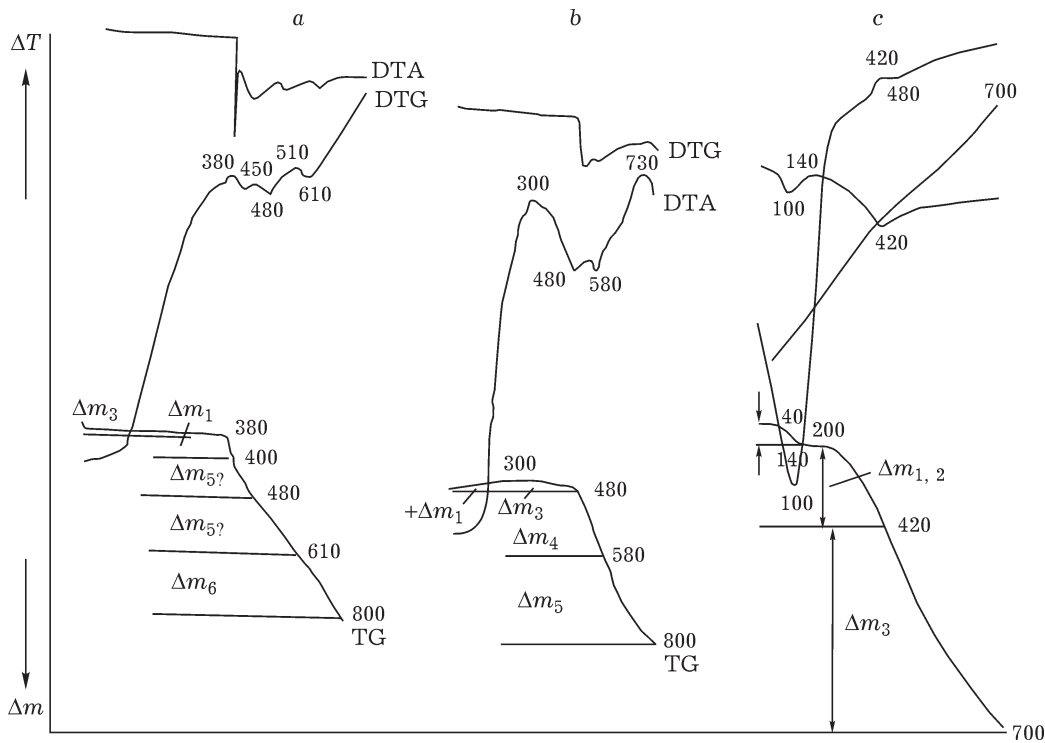


Fig. 3. DTGA data for the sample 11-03 (the central part of Ulugh coal bed): a - original sample; b, c - samples after preliminary mechanical activation for 1 and 10 min, respectively.

reflect a phase course of the mass loss process in the following temperature sequence (%): up to 380 °C - 0.5, 380-400 °C - 2.8, 400-480 °C - 7.6, 480-610 °C - 10.3, 610-800 °C - 10.8. Thus, the low-boiling phases formed begin to distill off from the sample already at 380 °C, *i. e.* simultaneously with the melting of fusible coal components. The total mass loss under the thermography procedure at temperature values less than 800 °C amounts up to 28.2 %.

Preliminary coal activation determines to a significant extent the nature of transformations in the course of thermolysis thereof. The extent of these changes depends on the duration of activation. Thus, when heating the material of samples 05-03, 08-03, 11-03, after the activation for 1 min (see Table 2 and Figs. 1-3) the endothermic effect of melting and boiling are significantly shifted towards lower temperature values. The beginning thereof is observed at 210-300 and 370-525 °C, respectively. At the same time there is some extension of the temperature range of the melting endothermic effect and the boiling endothermic effect superimposed. The character of thermographic profiles is almost unchanged, but already 1 min

of activation is sufficient for a significant change in the structure of coal sample. The explosion-like character of the effect of boiling remains unchanged for coal samples 05-03 and 08-03 (see Figs. 1, 2). Sample 05-03 also exhibits a high explosion-like boiling temperature (600 °C) to remain. For the rest samples of coal, a smooth course of the boiling process is characteristic, which is mainly realized simultaneously with the melting of fusible components. The process of the distillation of low-boiling fractions in this case takes place, as a rule, without explosion-like boiling, which is exhibited on the TG curves by abrupt bends with no collapsing the curve, whereas the DTG curve exhibits a peak with no pronounced needle-shaped burst.

After a more profound mechanical activation of a sample (*e. g.*, in the mode of activation during 3 min and 10 min) the product of grinding exhibits a finely dispersed structure and a slightly reddish shade. In the course of their thermolysis, an increased effect on the degradation of the material is exerted by the duration of the initial activation, which is confirmed by the DTGA data. So, with thermo-

graphing, all the DTA and DTG curves exhibit remaining the only relics of the formation effects for fusible and low boiling phases observed on the DTGA curves inherent in the original coal samples. The relics are exhibited to a greater extent on the thermographic profiles of samples after 3 min of activation to a lesser extent after 10 min of activation. At the same time, the character of the integral mass change curves (TG) is about the same, but the mass loss value for these samples are slightly lower as compared to the value for non-activated original samples.

The DTG and DTA thermographic profiles of activated samples exhibit also thermal effects at the temperature values up to 200–250 °C, this is to a greater extent in the case of activation for 10 min and to a lesser extent in the case of activation for 3 min. This temperature range is characterized by an almost 3.5 % increase in the mass of the sample. To all appearance, this is caused by the ability of the sample material subjected to activation, for the absorption of moisture, oxygen from ambient air and various gaseous components resulted from oxidation and hydration reactions those occur on activated centres. When heated, moisture removal and partial product oxidation occurs, whereby, to all appearance, the occurrence of profound endothermic effects on DTA curves at 80–90 °C could be caused.

The experiments on revealing the temperature ranges for the isolation of individual coal fractions under the conditions of the vacuum created, and of the suction of steam and gas thermolysis products in a closed system at a heating temperature within the range of 180–200 °C demonstrate beginning the formation of vapour, its condensation on the cold side of the quartz ampoule and the subsequent accumulation of small liquid layer within a cold zone of the ampoule. The first signs of sublimates in the form of a liquid condensate in the collecting suction system were observed at the temperature ranging within 350–400 °C. Further slow heating within the temperature range of 400–550 °C was followed by the distillation and condensation of the main amount of subliming fractions. At the temperature of 650–660 °C the process of distillation almost completed.

The mass loss of the original sample was equal to 34.8 %. The solid residue represents a strong enough gray-black, slightly silvery cake with a porous structure, which cake can be destroyed only by applying some effort. Alongside with the solid residue, the thermolysis results in the formation of a small amount of a viscous substance in the cold part of the ampoule and a condensate of distilled sublimates. In the case of performing the experiments in a continuous heating mode the condensate represents a dark, slightly oily viscous liquid that upon holding is segregated to give two layers: the bottom layer, bitumen, and the top layer, low viscous dark brown liquid.

In the experiments with holding at phase transformation temperature values (350–400, 500–560, 600–660 °C), the condensate is separated into a bitumen layer and a transparent pale-yellow liquid already in the course of the experiment. The latter being in contact with the bottom layer over time exhibits darkening and thickening. To all appearance, this could be connected with a partial dissolution of the bottom bituminous layer therein.

In this case, the mechanical activation also affects the dynamics of the thermal decomposition of the material of the samples. There occurs a reduction in the temperature of appearing the steam and condensate in the cold part of the ampoule before about 150 °C. Furthermore, there is a more distinct separation of the low boiling non-viscous fraction and the bituminous component under the sublimation and condensation thereof. With increasing the activation time, there occurs an increase in the amount of a low boiling liquid fraction of sublimates and a decrease of the amount of the bituminous component. It should be noted that if the solid residue after thermolysis of initial coal samples represents a sufficiently sintered product, the activated samples subjected to thermolysis exhibit changing the structure of the material. With increasing the time of activation and an increased holding temperature (700–800 °C) the material becomes less strong and more loose. The greatest loosening level of the material is noted on holding for 1.5 h at 700 °C and preliminary activation for 10 min.

CONCLUSIONS

1. Low melting and volatile fractions contained in the composition of the Tuva coal species under investigation determine the properties and behaviour of the material in the course of the thermolysis thereof. Depending on the composition, under heating the sample there sets a sequence of melting and boiling stages for the organic component of coal. This is especially inherent in the samples "Zh" grade coal from the Chadan bed. Melting the organic part thereof is realized within a temperature range from 380–400 to 460–500 °C, whereas the boiling and sublimation is observed within the range from 540–560 to 575–600 °C, respectively. In the course of the thermolysis of samples from the Ulugh bed (coal grades G–GZh and G) the temperature ranges for the stages of melting and boiling are superimposed.

2. A preliminary mechanical activation of coal samples leads to a decrease in the temperature of melting onset for the organic component down to 300 °C and below. The onset temperature values for boiling and sublimation are shifted, too. Some extension is observed for the temperature range of the endothermic effect of melting the endothermic effect of boiling superimposed therewith. To all appearance, the mechanical activation leads to a significant change in the structure of the material. The explosion-like nature of boiling for coal samples 05-03 and 08-03 remains the same. Sample 05-03 also exhibits a high explosion-like boiling temperature to remain equal to 600 взрывная температура вскипания – 600. For the remaining samples of coal the overall picture is characterized by even boiling that mainly takes place simultaneously with the melting of fusible components. The process of the sublimation of boiling fractions occurs in this case, as a rule, with no explosion-like effect of effervescence.

In the course of thermographic studying the samples with a more profound activation (3 and 10 min) there were only relics registered for the effects of the formation of fusible and low boiling phases, being mainly exhibited for the samples after 3 min of activation and to a smaller extent for the sample after 10 min of activation. Furthermore, the emergence of new thermal effects at the temperature values up

to 200–250 °C, could be, to all appearance, connected with the fact that the sample material obtains absorbent properties, whereby it is rapidly saturated with moisture, atmospheric oxygen and gaseous components formed in the course of mechanical activation. Heating within the temperature range of 80–100 °C results in removing the moisture and other gaseous constituents; further, up to a temperature nearly 250 °C, the formation of carbonate-ion structure occurs with the subsequent destruction and removal thereof in the form of CO₂. The material obtained after the TGA of activated samples is significantly different from the thermolysis products of original non-activated coal: the sinterability thereof is reduced; with an increase in the activation time the material becomes less strong and loose. The experiments on the thermolysis of activated coal samples demonstrated that after holding for 1 month they retained all the properties obtained during the activation.

3. The coal species from the Tuva deposit could be used to produce briquettes. At the same time, the gaseous and condensable thermolysis products evolved could serve as a raw material for the coal chemical industry. The coal of the Chadan open-cast mine are the most promising in this respect. For the coal of the Ulugh bed, the briquetting temperature should be restricted by the limits close to the melting onset temperature inherent in the organic component. The operation of briquetting could be problematic for the coal species from the central part of Kaa-Khem open-cast mine (sample 11-03), since the stages of melting and sublimation, according to DTGA, exhibit the same temperature range.

REFERENCES

- 1 Kaminskiy Yu. D., Polugrudov A. V., Kulikova M. P., Kopylov N. I., Soyana M. K., Moldurushku M. O., Kara-Sal B. K., Kotelnikov V. I., Burdin N. V., Sozdaniye Tekhnologiy i Oborudovaniya Vysokoeffektivnoy Ekologicheskoy Bezopasnoy Pererabotki Mineralnogo Syr'ya i Tekhnogennykh Otkhodov (na primere Ob'ektov Gorno-Promyshlennoy Aglomeratsii Tuvy i Sopredelnykh Regionov) (Report No. 28.4.8, 2004–2006), Izd. TuvIKOPR SO RAN, Kyzyl, 2006.
- 2 Semenov P. P., *Koks Khim.*, 6 (1958) 10.
- 3 Loskutov E. Zh., *Uch. Zap. TNIIYALI*, 7 (1959) 210.
- 4 Timofeev P. P., in: *Trudy Geologicheskogo Instituta (Treatises)*, in A. V. Peyve (Ed.), Nauka, Moscow, issue 94, 1964.

- 5 Losev A. P., Ugolnye Basseyiny i Mestorozhdeniya TuvASSR, vol. 8, Nedra, Moscow, 1964.
- 6 Reshetko A. N., Zhuravleva D. D., Tematicheskiy Sbornik Nauchnykh Trudov VUKhIN (Treatises), Metallurgiya, Moscow, 1971, issue 9, p. 14.
- 7 Fatkulin I. Ya., Stukov M. I., Olshanetskiy L. G., Kiselev B. P., *Koks. Khim.*, 7 (1987) 7.
- 8 Rusyanova N. D., Maksimova N. E., Polyakova I. A., *Khim. Tv. Topl.*, 2 (1989) 32.
- 9 Shibanov V. I., Yakovlev I. Yu., *Khim. Tv. Topl.*, 6 (1989) 52.
- 10 Maksimova N. E., Polyakova I. A., Rusyanova N. D., *Koks. Khim.*, 11 (1992) 2.
- 11 Shibanov V. I., Obobshcheniye Rezultatov Geologo-Razvedochnykh Rabot po Ulugh-Khemskomu Ugolnomu Basseyinu po sostoyaniyu na 01.01.1993 g. (Report), Izd. TFGI, 1994.
- 12 Fatkulin I. Ya., Olshanetskiy L. G., Panteleev E. V., Kiselev B. P., *Koks. Khim.*, 7 (1994) 2.
- 13 Gabeev V. A., Otsenka Prognoznnykh Resursov Tverdykh Poleznykh Iskopyemykh Respubliki Tuvy po Sostoyaniyu na 01.01.1998 (Report), Izd. TFGI, Kyzyl, 1998.
- 14 Lebedev V. I., Kuzhuget K. S., Mineralno-Syryevoy Potentsial Respubliki Tuvy (Report), Izd. TuvIKOPR SO RAN, Kyzyl, 1998, pp. 22–24.
- 15 Svodny Otchetny Balans Zapasov po Respublike Tuve za 2001g. (Report), Izd. TFGI, Kyzyl, 2002.
- 16 Sodnam N. I., Shchipko M. L., Kuznetsov B. N., *Khim. Tv. Topl.*, 6 (1987) 12.
- 17 Sodnam N. I., Bondarenko O. D., Shklyayev A. A., *Khim. Tv. Topl.*, 1 (1989) 22.
- 18 Kulikova M. P., Saaya A. A., *Vestn TyvGU. Estestv. Nauki*, 1 (2009) 38.
- 19 Kulikova M. P., Saaya A. A., Khamnagdaev S. A., 9 Mezhdunar. Konf. "Prirodnye Usloviya, Istoriya i Kultura Zapadnoy Mongolii i Sopredelnykh Regionov" (Proceedings), Mongolia, Khovd, 2009, pp. 259–266.
- 20 Kulikova M. P., Kaminskiy Yu. D., 7 Vseros. Konf. "Goreniye Tverdogo Topliva" (Proceedings), Novosibirsk, 2009, pp. 78–82.
- 21 Kaminskiy Yu. D., Kopylov N. I., Kulikova M. P., Kaminskaya N. A., Nauchnye Trudy TuvIKOPR SO RAN (Treatises), Kyzyl, 2005, issue 8, pp. 123–128.
- 22 Kopylov N. I., Kaminskiy Yu. D., Kulikova M. P., *Khim. Tekhnol.*, 9, 4 (2008) 168.