

Effect of Cavitation on the Properties of Coal-Tar Pitch as Studied by Gas–Liquid Chromatography

M. I. Baikenov, T. B. Omarbekov, Sh. K. Amerkhanova, G. G. Baikenova,
V. A. Khrupov, R. M. Shlyapov, and A. S. Uali

Buketov State University, ul. Universitetskaya 28, Karaganda, 470074 Kazakhstan

e-mail: amerhanova@ok.kz

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Abstract—The applicability of the cavitation-wave effect to coal-tar pitch processing is considered. The results of the GLC analysis of the test material before and after rotor-pulsation cavitation treatment are given. The organic matter of coal-tar pitch was found to degrade upon cavitation; as a result of this, the yields of light and medium fractions considerably increased.

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The gas-and-oil industry and the coal-processing industry belong to the most economically important components of the fuel and energy complex. Promising priority branches of petroleum chemistry and power engineering include the studies of fuel and chemical raw materials obtained as processing coproducts. Thus, for example, coal-tar pitch is an alternative source of valuable coke by-products such as dyes, varnishes, fertilizers, explosives, pharmaceuticals, impregnating and binding pitches, carbon electrodes, graphite products, etc. [1].

Kazakhstan possesses considerable coal reserves (coal basins of the Karaganda, Maikubensk, Karazhar, Kendyrylyk, etc., coal fields). In particular, Shubarkol coal, which is produced by the open-cut method, is characterized by a low ash content (3–5%), a high concentration of hydrogen in the organic matter of coal, a low degree of metamorphism, and a high yield of volatile products.

The search of more efficient, environmentally friendly, and safe nontraditional technologies for the

deep processing of fuel and energy resources is of increasing current interest. It is well known [2] that a mechanical effect produced by wave cavitation is an effective technique for the processing of heavy hydrocarbon raw materials. Gas–liquid chromatography (GLC) is of considerable current use for the analysis of various petroleum, gas, and coal products [3]; the chemical composition of coal-tar pitch in the course of mechanical degradation can be studied in detail with the use of GLC.

We used heavy coal-tar pitch obtained from coals of the Shubarkol strip mine (Central Kazakhstan) as a test material. The elemental composition of the coal-tar pitch was as follows (%): C, 91.3; H, 7.5; S, 0.2; N, 0.5; O, 0.52. The density of the coal-tar pitch was $d_4^{20} = 0.9341 \text{ g/cm}^3$.

Table 1 summarizes the technical characteristics and the elemental composition of the coal.

The aim of this work was to study the effect of wave cavitation on the coal-tar pitch using GLC analysis.

Table 1. Technical characteristics and elemental composition of coal from the Shubarkol strip mine

Elemental composition, wt %				Technical characteristics	
C	H	S	N + O	Ash content of coal, %	5–7
76.9	5.4	0.4	17.3	Moisture content, %:	
Petrographic composition, %				maximum	15.3
				analytical	6
vitrinite		liptinite		fusinite	
85–88		3–5		5–7	
humic acids		bitumens		pitch	
3.5		4.7		9.2	
				Yield of volatile substances, %	43.4
				Reflectance R_0 , %	0.5
				Heat content Q , MJ/kg	24–26

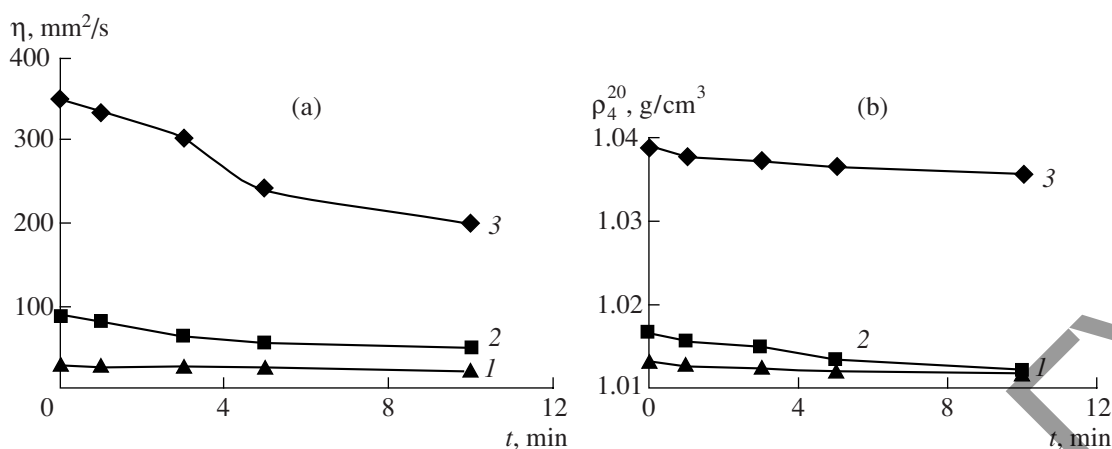


Fig. 1. Effects of various factors on changes in the (a) kinematic viscosity and (b) density of the coal-tar pitch under the action of rotor-pulsation cavitation at (1) 80, (2) 60, and (3) 40°C.

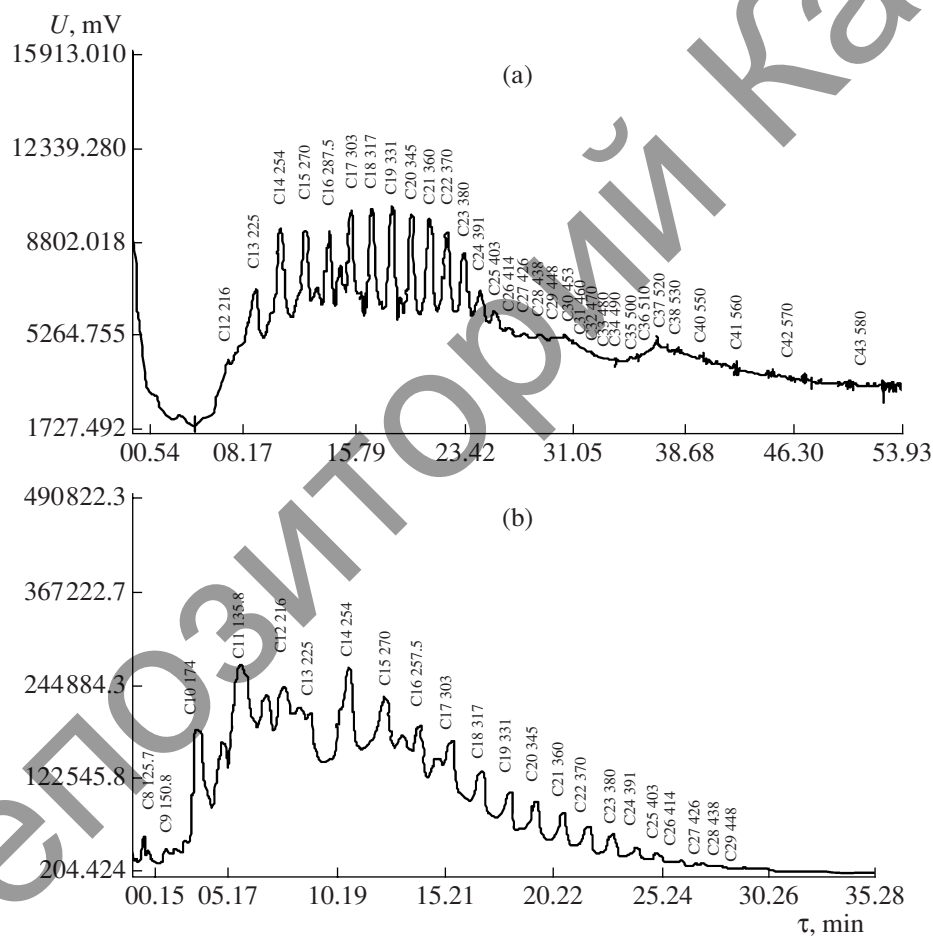


Fig. 2. Chromatograms of the component composition of (a) the parent coal-tar pitch and (b) the coal-tar pitch treated using rotor-pulsation cavitation: C8–C43 are the numbers of carbon atoms in corresponding compounds, and 125.7–580 are the boiling temperatures (°C).

EXPERIMENTAL

The test sample was exposed with the use of a rotor-pulsation cavitator, which consisted of an electric drive

and dispersing elements as flow batch apparatuses with a profiled channel for tar passage. The coal-tar pitch obtained in the course of Shubarkol coal semicoking was used as the starting raw material. The test sample

was treated by rotor-pulsation cavitation; the speed of rotation was 300000 rpm, and the exposure times were 1, 3, 5, and 10 min in the temperature range 40–60°C. The component, group, and fractional compositions of the coal-tar pitch were analyzed on a Chrom 5 chromatograph with a capillary column using an individual triterpene hydrocarbon. The column length was 100 m. Argon and hydrogen served as a carrier gas and an auxiliary gas, respectively. The samples were injected using a 1- μ l Gazokhrom-101 syringe with taking 0.5- μ l samples for analysis at 30, 55, 80, and 100°C. To calculate quantitatively the concentrations of components, chromatograms obtained at 30–53 and 100°C to the completion of boiling of a fraction were used.

RESULTS AND DISCUSSION

It is well known [4] that a cavitation-wave effect is due to complex multigradient field action on the test sample. The dispersion of solids and liquids results from transverse and tensile stresses, sonic and ultrasonic elastic vibrations, cavitation-cumulative influences, and hydraulic shocks.

In the course of this work, we studied the effect of cavitation-wave exposure time on changes in the rheological characteristics, namely, the kinematic viscosity and density, of the coal-tar pitch at 40–80°C (Fig. 1).

As can be seen in Fig. 1, the kinematic viscosity and density of the coal-tar pitch at 40–80°C decreased over the entire range of rotor-pulsation-cavitation exposure times. This was likely due to the degradation of high-molecular-weight compounds, aromatic hydrocarbons, and polycyclic hydrocarbons, which constitute the organic complex of the coal-tar pitch.

We found that the cavitation vortex effect resulted in a maximum change in the rheological properties (i.e., in a decrease in the kinematic viscosity and density) under the following conditions: $t = 40^\circ\text{C}$, $\tau_{\text{treatment}} = 5$ min, and $v_{\text{rotation}} = 30000$ rpm. In this case, the above time, temperature and speed of rotation were optimal for the degradation of the coal-tar pitch. In addition, we measured the dependence of the kinematic viscosity of a treated sample on exposure time (1, 3, and 5 h). As a consequence, we found that the cavitation-wave action resulted in a noticeable decrease in the viscosity of the test sample; however, the viscosity increased after 5 h to become much higher than the initial value of η .

In accordance with current concepts, mechanical degradation is considered as a continuous process with competing degradation and synthesis reactions occurring at the individual steps of this process. To study heavy hydrocarbon conversion processes, GLC analysis is in current use. This technique provides valuable information on structural transformations in the organic complex of compounds. In this context, the next stage in the study of the effect of rotor-pulsation cavitation was the GLC analysis of the component, group, and fractional compositions of the coal-tar pitch. Figure 2

Table 2. Fractional composition of the parent coal-tar pitch

Degree of distillation, %	Distillation temperature (°C)		Degree of distillation, %	Distillation temperature (°C)	
	by weight	by volume		by weight	by volume
5	225	216	55	380	270
10	254	225	60	391	270
15	271	225	65	414	270
20	287	225	70	448	270
25	303	225	75	470	270
30	317	253	80	510	270
35	317	253	85	530	287
40	331	253	90	560	287
45	345	253	95	570	287
50	370	253			

Table 3. Fractional composition of the coal-tar pitch treated by rotor-pulsation cavitation

Degree of distillation, %	Distillation temperature (°C)		Degree of distillation, %	Distillation temperature (°C)	
	by weight	by volume		by weight	by volume
5	174	174	55	271	225
10	196	196	60	271	254
15	196	196	65	287	254
20	216	196	70	287	254
25	216	196	75	303	271
30	216	216	80	303	271
35	225	216	85	317	271
40	225	216	90	345	287
45	254	225	95	370	287
50	254	225			

shows the chromatograms of the component compositions of (a) initial and (b) degraded coal-tar pitch samples.

Tables 2 and 3 summarize the results of the determination of the fractional compositions of the initial and treated coal-tar pitch, respectively. We also determined the group compositions of the initial and degraded samples and performed a comparative analysis (Table 4).

As a result of the cavitation-wave treatment of the parent coal-tar pitch, the weight concentration of a light fraction with $T_b < 200^\circ\text{C}$ increased to 25.1%. In addition, the amount of a fraction with $T_b = 200\text{--}370^\circ\text{C}$ increased and the yield of a heavy fraction dramatically decreased from 25.2 to 3.4%. This was likely due to the degradation of high-molecular-weight compounds that constitute the parent coal-tar pitch [5]. We found that

Table 4. Group composition of the coal-tar pitch (1) before and (2) after cavitation-wave treatment

Fraction; T_b , °C	Weight fraction, %		Volume fraction, %		Mole fraction, %	
	1	2	1	2	1	2
<200	0	25.1	0	29.1	0	27.7
200–370	53.8	75.6	100.0	71.0	68.5	70.3
370–500	25.2	3.4	0	0	20.1	2.0
>500	21.0	0	0	0	11.4	0

the use of wave cavitation for coal-tar pitch processing resulted in a considerable increase in the yield of gasoline and diesel fractions; however, an opposite effect was observed in the case of heavy fractions.

CONCLUSIONS

The exposure of coal-tar pitch obtained from coals of the Shubarkol strip mine to wave cavitation resulted in a positive effect, as evidenced by an increase in the yields of light and medium fractions. Thus, the use of the cavitation effect as a new approach to solve problems in the processing of heavy hydrocarbon raw materials is promising.

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REFERENCES

1. Akhmetov, S.A., Ishmiyarov, M.Kh., Verevkin, A.P., et al., *Tekhnologiya, ekonomika i avtomatizatsiya protsessov pererabotki nefiti i gaza* (Technology, Economics, and Automation of Oil and Gas Processing), Moscow: Khimiya, 2005.
2. Nurzhanova, S.B., *Doklady III mezhdunarodnykh nauchnykh Nadirovskikh chtenii: Nauchno-tekhnologicheskoe razvitiye neftegazovogo kompleksa* (Proc. III Int. Nadir Sci. Readings: Scientific and Technological Development of Oil and Gas Complex), Almaty, 2005, p. 183.
3. Chuikin, A.V., Grigor'ev, S.V., and Velikov, A.A., *Materialy II Vserossiiskoi konferentsii "Analiticheskie pribory"* (Proc. II All-Russia Conf. "Analytical Instruments"), St. Petersburg, 2005, p. 335.
4. Amerkhanova, Sh.K., Baikenov, M.I., Nikol'skii, S.N., and Uali, A.S., *Materialy mezhdunarodnoi konferentsii "Perspektivy razvitiya khimicheskoi pererabotki goryuchikh iskopaemykh"* (Proc. Int. Conf. "Prospects of the Development of the Chemical Conversion of Fossil Fuels"), St. Petersburg, 2006, p. 215.
5. Nadirov, N.K., *Vysokovyazkie nefiti i prirodnye bitумы* (High-Viscosity Crude Oils and Natural Bitumens), vol. 3: *Netraditsionnye metody pererabotki* (Nontraditional Processing Methods), Almaty: Gylim, 2001.