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STUDY OF THE GROUP COMPOSITION OF BITUMENS AND ITS POTENTIAL INFLUENCE ON PHYSICAL AND MECHANICAL PROPERTIES AND ENERGY EFFICIENCY

This article discusses bitumen materials as an important material in the energy sector due to its high energy intensity. The influence of the group chemical composition of road bitumen on their physical and mechanical properties during commissioning of production is studied. Particular attention is paid to the relationship between the chemical composition and properties of bitumen, which is important for its processing and use as a raw material for alternative energy sources. The results of a study of the influence of the group composition on the rutting of asphalt concrete, which is one of the main indicators of the performance of asphalt concrete, are also presented. These studies will help to adjust the oxidation process of tar to obtain high-quality bitumen material with specified characteristics that will meet all the requirements of regulatory and technical documentation. The findings of the study highlight the importance of detailed analysis of bitumen to optimize its use, improve energy efficiency and reduce environmental impact. The article aims to broaden the understanding of

the role of bitumen in the modern world and its potential in the context of sustainable development.

Keywords: resins, oils, asphaltenes, bitumen, chromatography.

Introduction

Bitumen plays an important role in the energy sector due to its unique properties, which are directly related to its chemical composition. Its thermal insulation properties and durability make it an indispensable material in infrastructure construction, which in turn contributes to energy efficiency. In addition, the composition of bitumen affects its processing into alternative energy sources, which opens up new horizons for the use of this material in energy technologies. Thus, bitumen not only serves as a building material, but also has the potential to be an important element in a sustainable energy future.

Bitumen is an organic material mainly composed of hydrocarbons, heteroatoms (oxygen, nitrogen and sulfur, traces of metals) [1, P. 2], and is becoming a viable option today due to its abundance and high energy density. Bitumen binder is an adhesive material that holds mineral aggregate particles together in a composite used in road paving processes [2, P. 18–20]. It is a product of a petroleum refining operation in which the residue obtained after distillation of crude oil is processed by air blowing or solvent methods to obtain a product that meets specifications for various types of road/highway construction and other applications [2, P. 20; 3, P. 26].

The number of different chemical structures in bitumen reaches almost 100,000, which makes it impossible to identify and study the behavior of each of these molecules. However, it is common practice to separate bitumen and other petroleum products into different fractions [4, p. 1].

Experience has shown that for solving a number of technical problems it is quite sufficient to determine the presence and content of individual classes or groups of substances that make up the bitumen. Typically, there are four general (but not chemical) classes of compounds (SARA) for bitumen binder [5, P. 1]:

1) saturated hydrocarbons, which correlate with the softening point of the material and are empirically measured by the penetration index;

2) aromatic and naphthenic components, which are partially hydrogenated aromatic compounds;

3) resins, sometimes called polar aromatics, which contain various alkyl residues and functional groups,

4) asphaltene molecules consisting of a conjugated carbon core containing functional groups and heterocyclic compounds and bearing alkyl side chains grafted directly onto these cores.

Asphaltenes are associated with highly aromatic (H/C~1.0–1.3) and high-molecular molecules [6, p. 2], while resins have a higher H/C ratio (1.2–1.7), lower aromaticity, and lower molecular weight than asphaltenes [7, P. 1; 8, P. 3-4]. Oils and resins are usually combined under the term maltenes. The division into these components is based on their solubility in various solvents. The ratio of these components determines the dispersed structure and characteristics of bitumens. In contrast to the elemental composition, the problem of fully identifying all hydrocarbons and other organic compounds that comprise bitumen is considered virtually insoluble [9, P. 24].

The different hydrocarbons in bitumen (paraffin, naphthenic, aromatic) have different energy characteristics. For example, aromatic hydrocarbons have a high calorific value, which can increase the energy efficiency of bitumen when processed into fuel. High asphaltene content can hinder the combustion process and reduce the overall energy released during combustion. However, some attempts have recently been made to utilize asphaltenes, including the development of a gasification method to convert asphaltenes into gaseous fuel [10, P. 15]; however, gasification is an expensive process that creates significant environmental pollution [11, p. 5]. Since bitumen composition affects both its energy characteristics and potential applications, it is necessary study the group composition of bitumen and its physicochemical properties to carefully.

The research in this paper is aimed at determining the effect of the group chemical composition of bitumen on its physicomechanical properties and possible ways of their effective application.

Materials and methods

Kazakhstan Road Research Institute JSC has been testing the group chemical composition of bitumen since 2008. The studies are conducted using the BashNII NP method on a Gradient M liquid chromatograph (Figure 1) manufactured in Ufa.

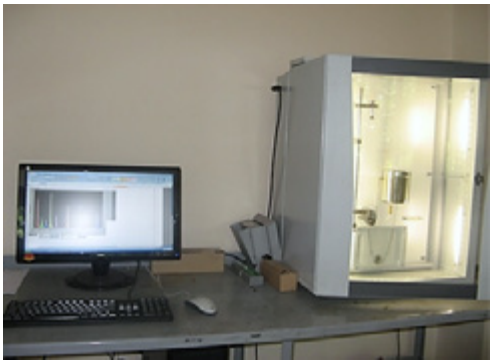

Figure 1 – Chromatograph «Gradient M»

The method is based on the principle of liquid adsorption chromatography with gradient displacement and separation of hydrocarbons into seven groups: paraffin-naphthenic hydrocarbons, aromatic hydrocarbons (light, medium and heavy aromatics), resins (petroleum-benzene (1) and alcohol-benzene (2)) and asphaltenes. Determination of the group chemical composition is carried out in a single chromatographic process.

For the chromatographic separation of heavy oil residues, eluents are used, which are two mixtures of solvents. The first is intended for separation of the maltene part, the second for desorption of asphaltenes. Silica gel ASK is used as an adsorbent.

To determine the group chemical composition, 0.1 g of the sample is taken from the analyzed bitumen sample, which is diluted with a sevenfold solution of benzene and cyclohexane in a ratio of 1:1. A sample of 1 μl is taken from the finished (solution) sample using a microsyringe and injected into a chromatographic column filled with silica gel. Then the column with the sample is installed in the chromatograph and studies are carried out to determine the group chemical composition: first, the maltene part is separated (the first 6 chromatographic peaks), then the asphaltene part (the 7th peak) [12, p. 151].

The bitumen chromatogram is shown in Figure 2.

These fractions, based on polarity, have unique properties for the overall composition. Asphaltenes, characterized by high molecular weight and aromatic nature, play a key role in viscoelastic properties. Maltenes, lighter and more soluble components, contribute to the flexibility and adhesive characteristics of the binder. In addition, the maltenes fraction can be further separated into so-called saturated (naphthenic) aromatics and resins (or polar aromatics) based on the polarity gradient in the material, which together with asphaltenes leads to the acronym “SARA” fraction.

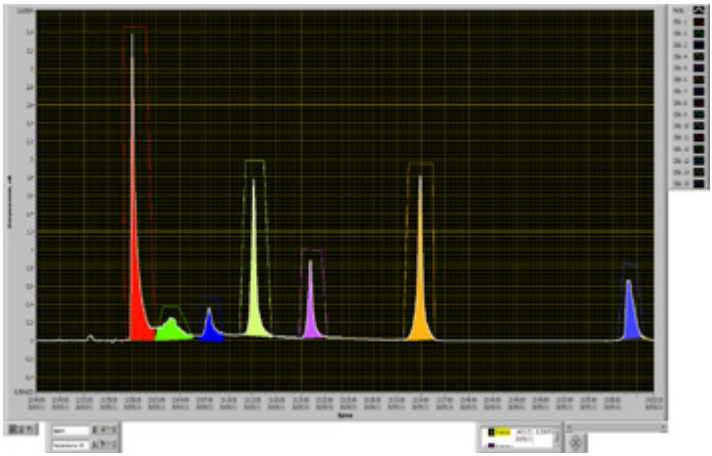

Figure 2 – Typical chromatogram of the group-chemical composition of road bitumen: paraffin-naphthenic hydrocarbons (peak No. 1), aromatic hydrocarbons (light (peak No. 2), medium (peak No. (3) and heavy aromatics (peak No. 4), resins (1 (peak No. 5) and 2 (peak No. 6) and asphaltenes (peak No. 7)

The chromatograms are calculated using the internal normalization method, by measuring the peak areas recorded on the cartogram according to the formula:

$$S = h \cdot a$$

where h is the peak height, mm

ɑ is the peak width, mm.

Results and discussion

Today, there are four major producers of road bitumen in the Republic of Kazakhstan, which produce bitumen grades road petroleum bitumen (BND) BND 35/50, BND 50/70, BND 70/100, BND 100/130, BND 130/200, BMP 35/50, BMP 50/70, BMP 70/100 and BMP 100/130. All grades of bitumen are obtained by oxidation of tar. For these bitumens, an analysis of the group composition was carried out and the grade of bitumen was determined. The group analysis of the analyzed bitumens is presented in Table 1.

Table 1 – Group chemical composition of Republic of Kazakhstan bitumens

Manufacturer	Bitumen brand	Asphaltenes, %	Oils, %	Resins, %
Manufacturer 1	BND 70/100	20-23	48-49	31-32
	BND 100/130	13-14	50-52	29,5-31

Manufacturer 2	BND 70/100	15-18	50-52	31-35,5
Manufacturer 3	BND 70/100	15-18	49-51	31-34
Manufacturer 4	BND 100/130	12-13	60-62	28-30
	BND 70/100	12-15	57-60	35,4

According to Table 1, it can be said that the asphaltene content in BND 70/100 grade bitumen is higher than that of BND 100/130 grade, which indicates that the higher the penetration, the lower the asphaltene content, which imparts hardness and heat resistance to bitumen. The oil content in BND 70/100 grade is less than in BND 100/130 grade, which reduces their viscosity, softening point and brittleness, increases penetration and flash point. The amount of resins does not depend on the grade of bitumen, is comparable in both grades and is responsible for the extensibility of the bitumen.

Table 2 shows the results of the study to determine the effect of group chemical composition on the physical and mechanical properties of BND 70/100 grade bitumen during commissioning of production.

Table 2 – Effects of group chemical composition on the physical and mechanical properties of BND 70/100 grade bitumen

Test date	P_{25}	KaSh	D_{25}	T_{xp}	Steam-naphthenes	Oils	Resins	Asphaltenes
04.02.22	71	49	>150	-20	24,2	48,2	33,9	17,9
12.04.22	74	49	>150	-20	28,7	49,8	31,9	18,3
04.05.22	83	48	>150	-23	32,3	53,3	29,7	17,0-
15.06.22	84	48	>150	-21	28,5	52,0	31,0	17,0
11.07.22	84	48	>150	-22	32,3	51,1	31,9	17,0
02.08.22	83	48	>150	-22	32,3	53,1	30,9	16,0
18.10.22	78	49	>150	-23	28,5	52	30,4	17,6
26.04.23	83	48	>150	-22	32,3	53,3	29,7	17,0
07.07. 23	73	49	>150	-21	28,2	48,8	32,7	18,5
20.09.23	88	47	>150	-22	33,1	54,1	29	16,9

The penetration index at 25 ºC is used to determine the grade of bitumen and characterizes the deformation resistance of bitumen. The softening temperature can be used to judge the plasticity of bitumen and the upper thermal limit of their

application. It follows from the literature that with an increase in the asphaltene content, the penetration of all the studied bitumen samples decreases, and the softening temperature increases, as shown in Table 2.

The brittleness temperature characterizes the state of the colloidal system of bitumen, at which they lose plasticity and turn into a solid. This indicator can be used to assess the frost resistance of bitumen and the lower temperature limit of their application. It is believed that with an increase in the oil content, the brittleness temperature decreases.

Resins have a positive effect on ductility (stretchability) at 25 °C. Ductility is a property that amorphous solids have. This indicator indirectly reflects the viscosity characteristics and determines the behavior of bitumen in the composition of asphalt concrete pavements under operating conditions in warm and cold periods of the year. In this case, the extensibility at 25 ° C is determined mainly by the resin content.

Using the example of the above bitumen manufacturers 1 and 4, we can trace the influence of the content of asphaltenes and oils on the quality of asphalt concrete. One of the tests that determines the quality of asphalt concrete is rutting resistance. This test was developed to assess the resistance of asphalt concrete to rutting in laboratory conditions, simulating the impact of motor vehicles on the road surface.

Figure 3 shows a graph where the track of the asphalt concrete mixture with bitumen from manufacturer 4 is 7.25 mm, and with bitumen of the same brand from manufacturer 1 is 4.85 mm.

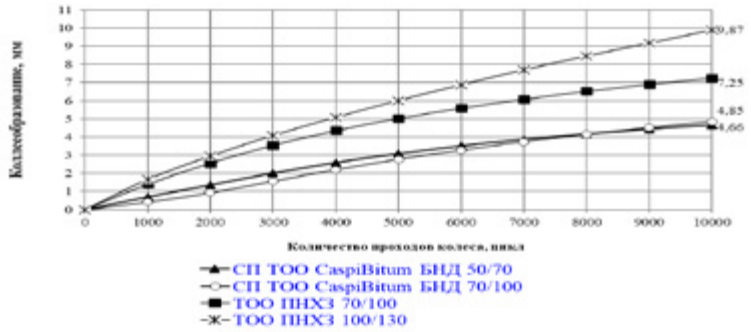

Figure 3 - Graph of the dependence of rut formation on the number (cycles) of wheel passage, where

▲– manufacturer 4 (BND 100/130); ○ – manufacturer 4 (BND 70/100);

■– manufacturer 1 (BND 70/100); × – manufacturer 1 (BND 50/70)

Based on the obtained group composition data, it follows that the higher the penetration, the higher the oil content and the lower the asphaltene content, which affects the rutting of asphalt concrete. Based on this, in the northern regions, it is recommended to use BND 100/130 bitumen with penetration values at 25 ° C not higher than 100-110×0.1 mm and a softening temperature above 45 ° C to increase the resistance of asphalt concrete to rutting.

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Conclusions

The study of bitumens and their group composition opens up new horizons in understanding their energy capacity and application. Bitumens not only serve as the main building material, but also have potential in the energy sector, which makes them important in the context of sustainable development. Determination of the group composition allows tracking changes in the composition of products during vacuum distillation, changes in the chemical composition during the oxidation of raw materials into bitumen, as well as changes in the component composition of bitumen during their accelerated aging, which is very important for establishing the true mechanism and intensity of various processes during bitumen aging. Based on the results of the physical and mechanical properties and group composition of bitumen, it is clear that at the beginning of the year, when adjustment work is underway after the plant is shut down for the winter, the bitumen is slightly worse in quality, although it meets the requirements of ST RK 1373 (needle penetration depth at 25 ºC and brittleness temperature at the limit of standard requirements). However, over time (May-June), the bitumen production technology is worked out, the quality of the bitumen improves, as evidenced by the results obtained. Understanding the relationship between the chemical composition of bitumen and its characteristics can lead to more efficient processing and use methods, as well as to a decrease in the impact on the environment. Future research in this area could lead to innovative solutions that will ultimately help optimize resource use and improve energy efficiency.

Improving the properties of bitumen will lead to more efficient use of the material, increasing overall energy efficiency and reducing the negative impact on the environment.

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БИТУМДАР ТОП ҚҰРАМЫН ЗЕРТТЕУ ЖӘНЕ ФИЗИКА-МЕХАНИКАЛЫҚ ҚАСИЕТТЕРГЕ ЖӘНЕ ЭНЕРГИЯ ТИІМДІЛІГІНЕ ОНЫҢ ӘЛЕУЕТТІ ӘСЕРІ

Бұл мақалада битумды материалдар жоғары энергия сыйымдылығына байланысты энергетикалық сектордағы маңызды материал ретінде қарастырылады. Өндірістерді іске қосу кезінде жол битумдарының топтық химиялық құрамының олардың физика-механикалық қасиеттеріне әсері зерттеледі. Битумның химиялық құрамы мен қасиеттері арасындағы байланысқа ерекше назар аударылады, бұл оны өңдеу және баламалы энергия көздерінің шикізаты ретінде пайдалану үшін маңызды. Сондай-ақ асфальтбетонның өнімділік сапаларының негізгі көрсеткіштерінің бірі болып табылатын асфальтбетонның ойықтарына топтық құрамның әсерін зерттеу нәтижелері берілген. Бұл зерттеулер нормативтік-техникалық құжаттаманың барлық талаптарына сәйкес келетін, көрсетілген сипаттамалары бар жоғары сапалы битум материалын алу үшін гудронның тотығу процесін реттеуге көмектеседі. Зерттеу нәтижелері оны қолдануды оңтайландыру, энергия тиімділігін арттыру және қоршаған ортаға әсерді азайту үшін битумды талдаудың маңыздылығын көрсетеді. Мақала қазіргі әлемдегі битумдардың рөлі және олардың тұрақты даму контекстіндегі әлеуеті туралы түсінікті кеңейтуге бағытталған.

Кілтті сөздер: шайырлар, майлар, асфальтендер, битумдар, хроматография.

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ИССЛЕДОВАНИЕ ГРУППОВОГО СОСТАВА БИТУМОВ \ И ЕГО ПОТЕНЦИАЛЬНОЕ ВЛИЯНИЕ НА ФИЗИКО-МЕХАНИЧЕСКИЕ СВОЙСТВА И ЭНЕРГЕТИЧЕСКУЮ ЭФФЕКТИВНОСТЬ

В данной статье рассматриваются битумные материалы как важный материал в энергетическом секторе ввиду его высокой энергоемкости. Исследуется влияния группового химического состава дорожных битумов на их физико-механические свойства во время пуско-наладочных работ производства. Особенное внимание уделяется взаимосвязи между химическим составом и свойствами битума, что имеет значение для его переработки и использования в качестве сырья для альтернативных источников энергии. Также представлены результаты исследования влияния группового состава на колеиность асфальтобетона, что является одним из основных показателей эксплуатационных качеств асфальтобетона. Данные исследования помогут корректировать процесс окисления гудрона для получения качественного битумного материала с заданными характеристиками, который будет соответствовать всем требованиям нормативно-технической документации. Выводы исследования подчеркивают важность детального анализа битумов для оптимизации их применения, повышения энергетической эффективности и снижения экологического воздействия. Статья направлена на расширение понимания роли битумов в современном мире и их потенциала в контексте устойчивого развития.

Ключевые слова: смолы, масла, асфальтены, битумы, хроматография.

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