

Nanostructured Bitumen with Nanocarbon

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Abstract

Physical and chemical indicators of bitumen quality of grade BND 70/100 with the added carbon nanopowder 2% by weight have been studied by laboratory test methods and analysis. High reaction ability of nanopowder particles and concentration of excess surface and internal energy in them have been determined, which provide the increase of low-temperature resistance, aggregate strength, and improvement of rheological properties of nanostructured bitumen. Essential structure variation has been proved: the increase of asphaltenes and oils content for 9% and 7.2% respectively due to the decrease of resins for 16.2% by weight. Methods have been discussed for preparing a liquid nanocarbon mix, adding of the mix into bitumen and homogenization of the bitumen. Some economic indicators have been represented which influence essentially the reduction for the cost value of the nanostructure bitumen.

Abbreviations

GDP – Gross Domestic Product
NSM – Nanostructured Materials
NCBB – Nanocarbon Bituminous Binder
RTFO – Rolling of Thin Film in the Oven
PAV – Pressure Aging Vessel
BBR – Bending Beam Rheometer
RTFOT – Rolling Thin Film Oven Test
MJ – Mega Joule
keV – Kiloelectron Volt

1. Introduction

The postindustrial economy being the main result of the Third industrial revolution is an economy of the developed high technology industry of intellectual labor, machinery production of a product and rendering services. Its main imperative is in the selling of a product and services as much as possible and it is measured by the volume of gross domestic product (GDP). Generally, GDP expressing the policy of “disposal cups” has nothing in common with resource-saving, and consequently, neither with energy efficiency nor with ecology.

Therefore the issues have risen sharply regarding resource providing of the world economy, its energetic and ecological safety.

These factors have set forward nanotechnology as a symbol of the Fourth industrial revolution, aimed at the real energy efficiency and energetics from the renewed sources, original resource-saving with non-waste and re-utilized (cyclization and recycling), at eco-friendly services and production of a product entrusting its production to additive 3D-print from nanopowders and materials right up to production of armaments and military machinery, construction of buildings and structures by the same method [1–4].

Production of large-capacity nanostructured materials (NSM) is the basis of modern machine engineering including atomic and space mechanical engineering and device engineering, mechanical engineering of atomic and controlled thermonuclear energetics for such branches of nanoindustry as nanoelectronics, nanooptics, nanoacoustics, nanodevices, nanobiotechnics, nanoelectrical chemistry, quantum nanogenerators and nanorobots [4–5]. Meanwhile, NSM represents by itself multicomponent, minimum two-component products where the main component is an ordinary large-capacity

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product named as a matrix, and nanoadditives as the second component or components in general named as components [5] and providing multiple improvements of operational and technological properties of these materials [6].

Such improvements occur despite minor participations of nanoadditives from several units of a percent to a tenth, a hundredth and even a thousandth proportion by weight of the product. At the same time NSM with low (percent and percent proportion) and high (tens of percent) weight contents of components are named nanomodified and nanocomposite materials respectively [5–6]. Due to the necessity of entering nanoindustry for the above NSM the issue occurs for the investigation of physical and chemical mechanisms of the interaction for component and matrix, energetic peculiarities of these interactions and regularities for their stimulating with the purpose of production optimization [6].

Recall that the production of NSM is a wide sphere of modern nanoindustry. Therefore we have chosen the investigation of the most common regularities for the interaction between matrix and components of NSM which are characteristic for all their varieties whether they are nanomodified or nanocomposite materials. This issue is especially of interest regarding nanomodified materials as there is an economic key to the reduction of their cost value here, and therefore, their cost at the market of nanomaterials.

This yields the objectives and tasks of our article. The objectives are in establishing the regularities for the interaction of matrix and component particles of NSM, a variation of molecular content and quality parameters of NSM. Whereas, the problems should be solved on energetic evaluation of structure variations to achieve these objectives, for example, of the modified bitumen, to establish upper limits of the energetic expenses for formation of some or other groups of hydrocarbon compounds in conversion to one chemical bond in kcal (kJ/mol) and to obtain real values for energy distribution at breaking of chemical bonds, at their reactivation with formatting of new bonds and difference between accumulated (absorbed) and consumed (reflected) energies both internal and external ones.

In spite of wide penetration of nanotechnology into all spheres of the world economy, the theory and scientific base for production methods of the nanomaterials lag too far behind the applied ones, i.e. direct apparatus methods for their production

and use in practice. Most often many processes are performed, as they say, “thumb-rule” before obtaining the required result, trial and error. Such an unfavorable situation is well recognized by the world leaders of nanoindustry – USA, Japan and China [2]. Therefore they have developed their national nanotechnological programs aimed at the crating of new NSM including those providing superconductivity, superfluidity, superstrength, supermagnetism, etc.

2. Increase of nanomodified bitumen low temperature stability

Carbon nanomaterials find more wide application in different fields. It is due to their specific properties, in particular, their ability to cold emission of electrons, good electric conductivity, sorption properties, chemical and thermal stability, high strength.

Traditionally various modifiers are used to increase the technological and operational properties of bitumens [7]. They are directed to an improvement of rheological, antioxidant and other characteristics. Together with it, as a rule, the improvement of bitumens properties is followed by the increase in its cost.

At present the possibility is shown for the use of nanoparticles of various structures as functional additives for bitumens [8]. Together with it, carbon nanoparticles have the largest affinity to bitumen. It is considered that the modification effect will be a maximum one in such a case [9–11].

In the considered work the impact is experimentally studied for the content of carbon nanopowder on the thermal stability of blown bitumen. Bitumen of grade BND 70/100 has been produced by Pavlodar petrochemical plant (Pavlodar, Kazakhstan). Nanopowder has been obtained from the coal of “Saryadyr” deposit, belonging to corporation “On-Olzha” (Kazakhstan), and has dimensions of 150–200 nm. However, particles of nanopowder are inclined to the increased aggregation due to their high surface energy, about which data certify, shown in Fig. 1.

Upon a closer view of this microphotograph, it is seen that large particles with dimensions of 5–6 μm represent by themselves the aggregates of smaller particles (0.5–1 μm). For a more detailed evaluation of aggregation rate for the obtained carbon nanoparticles it is necessary to carry out the analysis of electronic microscopy at bigger magnification.

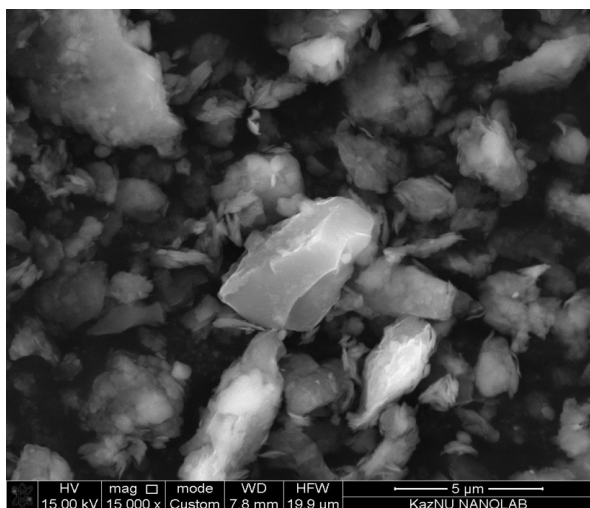


Fig. 1. SEM-microphotograph of carbon nanopowder.

First nanopowder was dispersed in kerosene with the purpose of uniform distribution provision of nanopowder particles in bitumen through the impact of ultrasound with the frequency of 20 kHz for 5 min at room temperature. Then the dispersion (kerosene + nanopowder) was added into bitumen at the temperature of 150 °C and continuous mixing for 30 min. The samples of nanocarbon bituminous binder (NCBB) with the content of carbon nanopowder from 0.1 to 2.0% by weight have been prepared in such a way.

The rational number of nanopowder was determined on indicators of bitumen resistance to aging. Bitumen “is aged” in the process of preparation of hot asphalt concrete mix, light fractions volatilize, bitumen becomes more brittle, less frost resistant.

The following main standard indicators of pure bitumen and NCBB have been determined by corresponding methods of laboratory tests: the penetration depth of the needle at the temperature of 25 °C (State system of technical regulation of the Republic of Kazakhstan (ST RK) 1226), softening point (ring and ball) (ST RK 1227), ductility at the

temperature of 25 °C (ST RK 1374), Fraas point (ST RK 1229).

Aging of the binder during mixing of asphalt concrete mix in a mixer and its laying occurs in the conditions of high temperature and air inflow. To model such a form of aging the method of rolling of the thin film in the oven (RTFO) is used under standard ST RK 1224.

To model aging, during operation, the accelerated aging test is used in the device pressure aging vessel (PAV) under high pressure and at high temperature for 20 h under standard ST RK 2435. The samples of binder, aged in PAV, have already been aged under method RTFO. The remainder of binder after aging under method PAV represents by itself the binder, subjected to the impact of all these factors of the environment, to which it is subjected during the production of asphalt concrete mix and operation of asphalt concrete pavement.

In accordance with the technical system “Superpave” low-temperature stability of bituminous binders is evaluated on the stiffness modulus value, determined at load duration of 60 sec (AST-MD 6648) on bending beam rheometer (BBR). In this work stiffness modulus of pure bitumen and NCBB was determined at the temperatures of -24, -30 and -36 °C.

The main standard indicators of bitumen and NCBB, determined under the abovementioned standards, are represented in Table 1. The results of Table 1 data analysis have shown that adding nanocarbon powder (2.0%) decreases ductility to 26%; softening point is practically not changed, and depth of the needle penetration is increased by 16%.

It should be specially noted that bitumen aging under method RTFO increases Fraas point for 4 °C from -28.5 °C to -24.5 °C, and adding of nanocarbon powder (2.0%) reduces Fraas point and already with nanopowder content of 0.5% the Fraas point of pure bitumen is recovered, i.e. becomes equal to -28.5 °C.

Table 1
Main standard indicators of pure bitumen and NCBB

Indicators	Content of nanopowder, %								
	Pure bitumen	Pure bitumen after aging (RTFO)	0.1	0.2	0.3	0.5	0.7	1.0	2.0
Depth of needle penetration at 25 °C, 0.1 mm	75	55	47	61	62	59	59	64	61
Softening point, °C	47.5	51	55	53.5	53	53	52	51	51
Ductility at 25 °C, cm	118	69	41	53.5	45	32	54	31	51
Fraas point, °C	-28.5	-24.5	-27.1	-27.2	-26.9	-28.5	-28.0	-24.3	-27.6

Table 2
Stiffness modulus of pure bitumen and NCBB at low temperatures

Temperature, °C	Content of nanopowder, %		
	0	0.5	2.0
-24	104.21	58.27	55.49
-30	220.11	137.08	152.89
-36	322.50	231.40	221.99

Table 2 gives stiffness modulus values for pure bitumen and NCBB at lower temperatures, obtained by testing at BBR.

As it is seen (Table 2) nanopowder decreases considerably the stiffness modulus of bitumen, i.e. increases low-temperature stability. The modification effect is especially clearly shown with the content of nanopowder of 0.5%. So, the stiffness modulus of bitumen with such concentration of nanopowder at the temperatures of -24, -30 and -36 °C is 46 MPa (44.1%), 83 MPa (37.7%) and 91 MPa (28.2%) respectively.

Thus, one can conclude that modification of bitumen of grade BND 70/100 by nanocarbon powder increases considerably its low-temperature stability.

3. Variation of group chemical composition of the nanomodified bitumen

Investigating issues of growth of low-temperature stability for the nanomodified bitumen, it is necessary to understand the main reasons and to explain due to what such growth occurs. Therefore it is necessary to study the group chemical compositions of the original bitumen and nanomodified one with the addition of carbon nanopowder in a quantity of 0.5%, 0.7% and 2.0% by weight.

Let us note that nanopowder was added to the bitumen of grade BND 100/130 produced by Pavlodar petrochemical plant heated up to the temperature of 160 °C at the constant stirring of a mix from a matrix (bitumen) and filler (nanocarbon).

Three test specimens of the modified nanobitumen with nanocarbon portion of 0.5%, 0.7% and 2.0% by weight and also a sample of the original commercial bitumen of grade BND 100/130 have been manufactured in such a way, (RTFOT). The group chemical compositions of the original bitumen and samples of the nanomodified bitumen were determined by the Gradient chromatograph in the laboratory of the Kazakhstan Road Research Institute in accordance with the method described in more details in the work [12].

The obtained data regarding group content of the original bitumen and its modified samples are represented in Table 3.

From Table 3 we can see the progressing decrease in the content of resins with the increase of filler portion, from 0.5 to 2.0%. At 2.0% of the added nanopowder portion the portion of resins is decreased by 16.2% by weight and the portion of asphaltenes and oils is increased by 9.0% and 7.2% by weight respectively.

It is necessary to expect the same quantity of the weight loss in original bitumen and samples of the nanomodified bitumen with their heating up to the temperature of 160 °C due to the volatility of light fractions in them. Assuming validity of such offer, proceeding from conservation law of weight and considering the added weight of nanopowder in 2.0%, we will have, first, the decrease of a resin portion by 16.52% by weight, secondly, growth of asphaltenes and oils portion up to 9.18% and 7.34% by weight respectively in terms of the changed weight of a sample in 2%.

Table 3
Group chemical content of pure bitumen and NCBB

Bitumen	Asphaltenes, %	Resins, %				Oils, %			
		Petrol and benzol	Ethanol and benzol	Amount of resins	Paraffin and naphthenic	Light aromatic	Medium aromatic	Heavy aromatic	Amount of oils
BND 100/130 RTFOT	11.8	24.5	20.4	44.9	20.6	3.6	4.3	14.9	43.4
BND 100/130 RTFOT + 0.5% NANO	17.0	15.2	19.2	34.4	23.3	5.1	4.5	15.7	48.6
BND 100/130 RTFOT + 0.7% NANO	17.8	17.0	16.6	33.6	23.6	4.3	4.6	16.1	48.6
BND 100/130 RTFOT + 2.0% NANO	20.8	10.7	18.0	28.7	23.1	5.5	5.3	16.7	50.6

Considering these values let us follow the discussion of the results and evaluation of these results in terms of energetics.

4. Energetic evaluation of results

So, we have three groups of hydrocarbon compounds:

- oils with a ratio of hydrogen H portion to carbon C portion in them, i.e. H:C, varied from 11 to 13% by weight;
- resins with the number of H:C from 9 to 11% by weight;
- asphaltenes with the number of H:C from 7 to 9% by weight.

Considering the lack of clear boundaries between these compounds, we can state only the relativity of the value H:C and their nonsaturation by hydrogens. For example, H:C for heavy diesel fuel is not less than 15% as even if such fuel consists only of $C_{20}H_{42}$, the H:C will be 14.5%. In other words, hydrogen saturation is from 7 to 13% maximum in the original bitumen. At the same time, the hydrogen saturation of nanopowder of the coal having a carbon of 80.42% and hydrogen of 5.26% is 6.15% maximum.

From here follows that the chromatographic analysis of the group chemical composition of a nanomodified bitumen sample had to show 2% growth maximum gain for the asphaltenes at the most. And the expected result consisted of an insignificant change of asphaltenes content against the background of which some volume would be found (about 2%) for the substance of the uncertain nature. Instead of such pictures, we observe that the activated (high-energy) carbon nanopowder with a size from 150 to 200 nm in a hydrocarbon matrix behaves as hydrocarbon compounds with the raised number of H:C, it shows the properties of oil solvent with the high content of aromatic hydrocarbons with the condensed benzene kernels and brings the significant amount of energy required for decomposition of hydrocarbon molecules of resins into molecules of oils, for low-molecular hydrocarbon compounds from the recombination of which the high-molecular compounds of asphaltenes and perhaps carbenes (carboids) are formed together with hydrocarbons of coal powders.

Thus, we do not find a particle of the uncertain nature which in principle had to be formed of carbon nanopowder substances. On the basis of data from Table 3, we can see decomposition of

high-molecular compounds of resins, asphaltenes, and carbon nanopowder into low-molecular hydrocarbon compounds from which molecules of oils and asphaltenes are synthesized. You should not exclude decomposition of molecules of oils into more low-molecular compounds from which low-molecular compounds of resins, asphaltenes and even coal powder molecules of oils could be synthesized. In other words, we do not see current conditions, but we certify the final provision of the nanomodified bitumen by the analysis. Therefore we proceed from the final condition of bitumen, and we consider conservation laws of weight and energy at power assessment of the nanomodification process of the bitumen. Then the first line of Table 3 will have the following form: nanocarbon – 2.0%; asphaltenes – 11.56%; resins – 44.00%; oils – 42.44%. Comparing these figures with the last line of Table 3, we will have: nanocarbon – 0%, asphaltenes – 20.8%; resins – 28.7%; oils – 50.6%. In other words, we have the following structural changes for the group composition of the nanomodified bitumen in comparison with the structure of the original one: $\Delta_{np} = -2\%$; $\Delta_a = +9.24\%$; $\Delta_r = -15.40\%$; $\Delta_o = +8.16\%$. Considering these ratios, we notice that nanopowder and resins in the value of 17.40% undergo decomposition into low-molecular oils and, being recombined, give high-molecular asphaltenes. Such processes with the smallest number of chemical reactions can be carried out if a molecule of both powder and resins are divided into three parts, i.e. they are tested for two ruptures of chemical bonds. As each bond is a double one and it has a binding energy +619 kJ/mol, the total power costs will be about 8.3 MJ. We assume that one part of these low-molecular bonds in the value of 5.8% passes into oils, and two other parts have to be recombined with something else. As such bonds are necessary for recombination with low-molecular fragments of resins and nanopowder, we will consider low-molecular compounds of asphaltenes. For this purpose, we assume that 7.08% of asphaltenes by weight also undergo decomposition with a rupture of their bonds. Power costs for such ruptures will be 3.6 MJ.

We assume that one part of new-formed low-molecular bonds in the value of 2.36% becomes molecules of oils, making the total amount of oils $5.8+2.36 = 8.16\%$. The remaining two parts of fragments for molecules of asphaltenes are recombined with two parts of fragments for molecules of resins and nanopowder forming high-molecular compounds of asphaltenes. Meanwhile, we

will have $(5.8+5.8+2.36+2.36) = 16.32\%$ of new molecules for asphaltene which taking into account the value in 7.08% of the molecules subjected to decomposition gives $(16.32-7.08) = 9.24\%$ of the molecules for asphaltene.

The chemical reaction of synthesis for molecules of asphaltene providing rehabilitation for one ordinary bond emits energy in 1.3 MJ. Then the total power costs for the whole process will be $(8.3+3.6-1.3) = 10.6$ MJ. The value of power costs for bitumen nanomodification of the grade BND 100/130 with the addition of carbon nanopowder 2% by weight is calculated provided that bitumen has a density of 1100 kg/m^3 , and coal – 1600 kg/m^3 . Energy consumption for a bitumen mix heating with nanopowder from 20 to $160 \text{ }^\circ\text{C}$ is 336 MJ.

Note that from only $5 \cdot 10^{-4}$ portion of the specified value of thermal energy falls to the share of electrons, i.e. 0.18 MJ. Naturally it much less energy which is required for rupture of double C-C – bonds and successful realization of the process for bitumen modification. Moreover, if to consider that approximately 10^{-2} portion of all electrons participates in forming of C-C – bonds (2 electrons for one atom of carbon), then one-hundredth part is consumed from the value of 0.18 MJ or 0.0018 MJ for rupture of the specified bonds which is four orders less than 10.6 MJ. In other words, energy for heating of the bitumen mix with nanopowder up to $160 \text{ }^\circ\text{C}$ or $140 \text{ }^\circ\text{C}$ ($160 \text{ }^\circ\text{C} - 20 \text{ }^\circ\text{C}$) does not provide the process of bitumen modification according to the results of Tables 1–3 in any way.

Nevertheless, the process is in progress; it has sustainable frequency and demonstrates total disappearance of powder molecules with their transformation into molecules of asphaltene and oils in a hydrocarbon matrix at the temperature of heating of $160 \text{ }^\circ\text{C}$. Therefore the question now arises regarding the adequate mechanism of the process for bitumen modification with the addition of nanocarbon powder in it which perhaps comprises the required energy.

For this purpose, we will consider again the energy consumed for heating of one ton of the bitumen mix with 2% of nanocarbon for $140 \text{ }^\circ\text{C}$ which is 336 MJ and only 2% of which falls to the share of nanopowder and has a value of 6.72 MJ. It is comparable to the energy of 10.6 MJ required for the process of bitumen modification with the rupture of double C-C – bonds of nanopowder molecules, portion of molecules of asphaltene and resins, on the one hand, and with the subsequent assembly (synthesis or rehabilitation of C-C – bonds) mole-

cules of oils and asphaltene. However, it is generally also not sufficient for realization of the specified chemical reactions which are nevertheless in progress and give results in strict accordance with values of Tables 1–3. The mentioned processes are not in progress if to heat bitumen without adding of nanopowder. Therefore, the mechanism (physical, physical and chemical and chemical) consists of nanopowder and the coal nanoparticles composing it. Therefore it is necessary to consider the last.

Nanopowder of 20 kg with a density of 1.25 kg/l has a value of 16 l or 0.7 mol with primary particles of $4 \cdot 10^{23}$ according to Avogadro's law [13]. Each nanoparticle has an average radius of 175 nanometers, volume in $(4\pi/3) 5.359 \cdot 10^{-21} \text{ m}^3$ or $2.245 \cdot 10^{-20} \text{ m}^3$. Then there are $7 \cdot 10^{17}$ nanoparticles in 16 l and there are up to $6 \cdot 10^5$ of primary particles in each nanoparticle. The specific thermal energy falling on one nanoparticle and on primary particle has the values of $Q_n = 6.72 \text{ MJ} : 7 \cdot 10^{17} = 10^8 \text{ eV}$ and $Q_p = 10^8 : 10^5 = 10^3 \text{ eV}$ respectively. The specific energy of 10^8 eV effecting one nanoparticle is very high energy. If we consider that the external surface of each nanoparticle is screened by energetically exciting electrons of primary particles making it with the number of no more than 10^3 , then we will receive an assessment of specific energy for one electron from 10^3 to 10^5 eV . As the electrons of the specified primary particles are excited and energy to 10^5 eV effects on them, there will be an emission of high-energy electrons. The emission makes a large flow (we told about it in our reports [14, 15]). Considering the energy of rupture for double bonds of carbon in the value of 6.5 eV and the whole thermal energy (6.72 MJ) consumed by the excited electrons including the bonds forming them, we will receive that the specified energy is quite sufficient for bitumen modification process. Really, according to our calculations, the electrons with the area density of $\rho_e = 10^{15} \text{ e/cm}^2$ [14] or $\rho_e = 10^{21} \text{ e/m}^2$ are concentrated on a spherical surface of a nanopores and microcracks, proper energy of excitement for each of them is estimated at tens, and even at hundreds of kiloelectron volt (keV) [14]. Therefore the total value of the applied thermal energy to electrons and their proper energy of excitement can surpass considerably the energy in the value of 10.6 MJ required for bitumen modification.

Thus, several factors are monitored. First, the nanosizes of carbon powder are the critical parameter participating in all calculations including power ones. Secondly, the correlation is found between the values of the applied thermal energy and

the energy required for bitumen modification process realization. At the same time, the volume of the nanopowder added to bitumen in the value of 0.7 mol is essential. Thirdly, the correlation is found between the values of energy of excitement and the applied thermal energy through the area density of the excited electrons with the energies ($10 \div 100$) keV. In other words, the results of experimental investigations represent the natural phenomena which can be explained from the point of view of modern chemistry and physics following the conservation laws and transforming from one type into another both for energy and weight.

5. Discussion and results

Note that the content of high-molecular tar compounds is from 5 to 25% by weight with the boiling temperature start at 450 °C and higher in natural oils including high-viscosity heavy and superheavy bituminous ones. The resins considerably (more than by 4 times) surpass asphaltenes in weight in the tars. It is known that the maximum content of asphaltenes in bituminous oils including natural petroleum bitumens does not exceed 10% by weight [16–18].

Table 3 according to standards for bitumens of industrial production shows the value of 56.7% for asphaltene and resins fractions, and the ratio of resins and asphaltenes portions is 3.8: 1 (44.9: 11.8). Thereby the general regularity is confirmed by data of Table 3 (the first line) (4: 1) for natural oil in relation to petroleum bitumens of industrial production [15, 18].

However, the last line of Table 3 demonstrates a violation of the mentioned regularity in relation to the nanomodified bitumen. Here the ratio of resins and asphaltenes portions is already 1.4: 1 (28.7: 20.8), i.e. the content of resins in bitumen has dropped more than by 36% by weight, and the content of asphaltenes, on the contrary, has increased more than by 43% involving growth of content for the oils more than for 7% by weight.

Asphaltenes are the chemically active compounds that are easily oxidized and capable forming of carbenes with a high concentration of carbon and low content of hydrogen (less than 7–8%) [19, 21]. Therefore they possess binding and waterproofing properties higher than resins. In its turn, lower temperatures of hardening and kinematic viscosity are characteristic of oils in comparison with similar characteristics of resins. Therefore, oils provide good volume filling of empty and po-

rous spaces in bitumen, a high degree of protection against water and reliable moisture impermeability. According to the state standards, the content of resins of the original bitumen (44.9%) prevails over the content of oils (43.4%) for 1.5% by weight. However, the specified difference is shifted to oils in the nanomodified bitumen (the last line) and it has a value of 21.9% by weight. In other words, the difference in the content of pitches and oils has been increased from the negative value of minus 1.5% to positive value of plus 21.9% or in absolute expression – nearly 16 times.

The total growth of content for asphaltenes and oils has been increased to 71.4% by weight in the modified bitumen from their content of 55.2% in the original (standard) bitumen. It demonstrates the considerable improvement of operational (standard and rheological) properties of the modified bitumen (Tables 1 and 2). In its turn, these improvements show the efficiency of the nanocarbon with a size up to 200 nm and purity up to 96% produced from coal rocks under our technology and used as an additive to road oil bitumens of industrial production.

The issue of optimal quantity for carbon nanopowder in terms of “the price and quality” requires experimental and industrial tests of the nanomodified bitumen taking into account the influence of transport loads, weather climatic conditions and design and technological features. At the same time consideration of the method is not less important for compaction of materials for each pavement layer and their compatibility which depends significantly not only nor does how much on a static load of rollers, as on dynamic load of vibration effects and on their amplitude and partial characteristics. In this regard, the destructive effect of sign-variable low-frequency wave efforts from wheels of a moving vehicle on a pavement, in general, and on an asphalt concrete pavement, especially, needs careful investigations. In our opinion, possessing the improved technical and process parameters, the nanomodified bitumen will be crucial in the durability of pavement and extension of service life for the whole highway. In other words, the nanomodified bitumen becomes an effective remedy of control for the destructive actions of the wave processes, climatic conditions, and moisture. In general, it is necessary to accept (on the level of laboratory investigations) the high effect for the use of nanocarbon as the cheap and environmentally friendly modifier of road petroleum bitumen of the industrial production. The absolute economic benefit from

the wide use of the nanomodified bitumen in road construction will be determined by the results of trial tests of a nanostructured asphalt concrete pavement of highways. Such assessment will be based on the fact how nanomodified bitumen will extend the highway service life, on the one hand, and how the volume will be reduced for the expensive modifying additives to bitumens, on the other hand. These effects depending on the mass character of production and the use of carbon nanopowders are not axiomatic. However, special proofs are not required for the fact that coal rocks represent the cheapest raw materials for nanocarbon and contain an insignificant amount of sulfur and phosphorus. Therefore, coal favorably differs from oil which reserves are exhausted with incredible speed.

6. Conclusions

The stated results allow formulating of some conclusions:

- the nanocarbon with a size up to 200 nm and purity not less than 96% produced from coal rocks of any ash-content is the effective modifier for oil road bitumens and allows increasing of its operational and technological qualities;
- the nanomodified bitumen through the use of nanocarbon in the value of up to 2% by weight has the increased technical parameters and provides production of nanostructured asphalt concrete material of the improved strength and moisture impermeability, flexibility and adaptability to the external static and dynamic loads including shock and wave influences;
- nanostructured road bitumen promotes the service life extension for an asphalt concrete pavement of highways;
- the way of production for the various nanostructured materials on the basis of the nanopowders manufactured from the most different types of minerals and coal rocks can serve for the development of the nanotech industry in the country and abroad.

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