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# Thermodynamic Evaluation of Asphalt Concrete Properties and its Mixing Energy Consumption by Exergy Structure

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**Abstract.** The relevance of solving the problem of energy saving, today, is enhanced by the requirements of an environmental nature, united by the term "green energy". Solving the problems of climate conservation is inseparable from solving the problem of energy saving. Green, hydrogen energy, about which there has been a powerful and aggressive debate over the past decade, turned out to be directions far from solving the problems of both energy saving and environmental protection. The solution of both problems of energy saving and environmental protection at the present time and in the foreseeable future is being solved on the basis of the use of traditional primary energy resources, primarily natural gas. In this regard, the need to solve the problem of quantifying the thermodynamic perfection of heat-technological process for producing an asphalt concrete mixture becomes extremely relevant. This assessment is most simply carried out on the basis of the exergy method of thermodynamic analysis with the determination of the exergy structure of the asphalt concrete mixture flow, including thermomechanical, concentration and reaction components. The value of the concentration component of the exergy of the asphalt concrete mixture allows us to assess the energy efficiency of its production at asphalt concrete plants based on the modern exergy method of thermodynamic analysis; gives a quantitative estimate of the energy consumption for the process of mixing the ingredients of the asphalt concrete mixture in the mixing unit of asphalt concrete plants. The paper defines the structure of the exergy of the asphalt concrete mixture, in which the transit reaction component dominates, which determines the specificity of the exergy of the asphalt concrete mixture. The value of the specific mass concentration component of the exergy of the asphalt concrete mixture in comparison with the thermal component is small and the error in determining the concentration component, which cannot be objectively eliminated, does not affect the results of thermodynamic analysis.

**Keywords:** asphalt concrete mixture, thermodynamic analysis, exergy method, exergy, exergy structure, asphalt concrete pavement

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# Термодинамическая оценка свойств и энергозатрат смешения асфальтобетона по структуре эксергии

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**Реферат.** Актуальность энергосбережения в наши дни усиливается требованиями экологического характера, объединенными термином «зеленая энергетика», а сохранение климата неотделимо от проблемы энергосбережения. Такие

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направления, как зеленая, водородная энергетика, о которых мощно и агрессивно велись дебаты в последнее десятилетие, оказались далекими от решения задач и энергосбережения, и защиты окружающей среды. В настоящее время и в обозримом будущем доминирующим остается использование традиционных первичных энергоресурсов, прежде всего природного газа. В этой связи чрезвычайно важна количественная оценка термодинамического совершенства теплотехнологического процесса получения асфальтобетонной смеси. Наиболее просто ее провести на базе эксергетического метода термодинамического анализа с определением структуры эксергии потока асфальтобетонной смеси, включающей термомеханическую, концентрационную и реакционную составляющие. Значение концентрационной составляющей эксергии асфальтобетонной смеси позволяет проводить оценку энергетической эффективности ее производства на асфальтобетонных заводах на базе современного эксергетического метода термодинамического анализа; дает количественную оценку затрат энергии на проведение процесса смешения ингредиентов асфальтобетонной смеси в смесительном агрегате. В статье определена структура эксергии асфальтобетонной смеси, в которой доминирует транзитная реакционная составляющая. Значение удельной массовой концентрационной составляющей эксергии асфальтобетонной смеси в сравнении с термической составляющей невелико, и погрешность в определении концентрационной составляющей, которая объективно не может быть устранена, не влияет на результаты термодинамического анализа.

**Ключевые слова:** асфальтобетонная смесь, термодинамический анализ, эксергетический метод, эксергия, структура эксергии, асфальтобетонное покрытие

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## Introduction

The materials of the paper are a continuation of research on the use of the exergy method of thermodynamic analysis [1], aimed at creating a scientific and information environment necessary for in-depth studies on heat- and mass transfer, aimed at improving the quality, efficiency and environmental friendliness of hard road surfaces with the use of various asphalt concrete materials (ACM). With the help of exergy, as it is known, it is possible to assess the thermodynamic efficiency of the heat technology for obtaining ACM. The formation and assessment of the state of the road surface based on the thermodynamic theory of the life cycle of the asphalt concrete road surface from design to repair [2–6] can be used to calculate the duration of the operational, overhaul period of the road surface. This, in turn, reduces the environmental impact of the entire repair complex by reducing the frequency of these works. In the same context of reducing the environmental load from the creation of road asphalt concrete pavement, it is necessary to substantiate the possibility of involving waste asphalt concrete in the re-use of materials based on an assessment of changes in the concentration component of ACM exergy [7, 8]. The above emphasizes the relevance of an objective quantitative determination of the assessment of thermodynamic efficiency of both ACM heat technology in general and its constituent stages, in particular. The mentioned concentration component of the exergy of the asphalt concrete mix $E_{k,\ ACM}$ determines the energy minimum cost of an ideal mixer, the value of which is necessary for an objective assessment of the operation of the mixer in terms of its energy consumption [9]. The promotion of the processes of creating asphalt concrete pavement towards the so-called “green energy”, among other things, stipulates for the involvement in the re-use of the used pavement. The possibility of such use of materials while maintaining the ACM quality can be assessed by changing the concentration component of the ACM exergy, which does not depend on the temperature of the mixture, and of course, on the temperature of the paving. Strength, life cycle of asphalt concrete pavement both during hot laying and during laying at normal temperature is associated with the concentration component of exergy, determined by the fineness of the mineral materials that make up the ACM, the porosity of the layer and the energy of their adhesive interaction with the ACM bituminous binder. In this context, it seems very useful to consider the determining factors on which the indicated concentration component $E_{k,\ ACM}$ depends.

## Determining factors of the exergy concentration component of the asphalt concrete mixture

The factors that determine the value of $E_{k,\ ACM}$ of asphalt concrete materials include: specific energy of adhesive interaction; specific surface of mineral materials; content and ratio of structured (oriented) and bulk bitumen in ACM.

It has been shown in [1] that when ACM is obtained in a mixer, the energy costs for its operation must exceed the concentration component of the ACM exergy. This final process of obtaining ACM completes the formation of its structure, which is characterized by wetting and enveloping with a bituminous binder of mineral materials (MM), during which the physicochemical properties of these interacting materials are manifested: wetting, enveloping, sorption by the surface of some mineral active components of the bituminous binder. From this physical model, it follows that active structure formation during the interaction of mineral with bituminous binder is a dependent, secondary factor determined by the ratio of the power of the energy flow supplied to the mixer, the value of $E_{k,\ ACM}$ of asphalt concrete materials and the internal irreversibility of the process, carried out in the mixer. The mentioned irreversibility in the volume of the mixer is determined by the values of external and internal friction of the ACM constituent components. From this it follows: in accordance with the specific set of ACM components and the design of the mixers, it is necessary to determine the exposure time to ensure the required energy supply for proper mixing. Ignoring the need to overcome the value of the minimum energy impact during mixing leads to erroneous results of experimental studies on the effect of additives introduced into the ACM composition on the quality of asphalt concrete.

Thus, the value of the concentration component $E_{k,\ ACM}$ is one way or another connected with the achievement of the quality of ACM and the possibility of obtaining a quantitative estimate of the energy consumption for the mixing process in the case of carrying out thermodynamic analysis at the level of exergy assessments.

Ensuring the energy potential of the adhesive interaction of the bituminous binder with the mineral components of ACM is the main task of mixing in the mixer, and the concentration component of the exergy makes it possible to obtain a quantitative assessment of this process.

In [4], an analytical dependence is given, which allows determining the energy of adhesive interaction with some mineral materials (granite, quartzite, marble, limestone) for road bitumen, J/m$^2$:

$$W_{adh} = \sigma_{liq.-gas}\left(1+\cos\theta\right), \qquad (1)$$

where $\sigma_{liq.-gas}$ – bitumen surface tension, N·m; $\theta$ – wetting angle of bitumen with one or another MM.

Table 1 shows the results of determining the work of adhesion for the listed MM and road bitumen.

*Table 1*

**Energy of adhesive interaction of bitumen with the surface of stone materials**

| Bitumen brand | Value of adhesive interaction energy, J/m$^2$ | | |
|---|---|---|---|
| | Quartzite | Granite | Marble |
| БНД [BND] 60/90 | 0.06367 | 0.05977 | 0.0659 |
| БНД [BND] 90/130 | 0.05982 | 0.05548 | 0.061 |
| БНД [BND] 130/200 | 0.05424 | 0.05055 | 0.0555 |
| БНД [BND] 200/300 | 0.053 | 0.053 | 0.054 |

The amplitude of change in the adhesive interaction energy, according to Tab. 1, is about 10 %, which allows us to consider the work of the adhesive interaction of the bituminous binder and MM at the level of 0.06 kJ/m$^2$. The error in determining $E_{k,\ ACM}$ of asphalt concrete materials in connection with the proposed averaging is quite acceptable.

The size of the surface of MM particles significantly determines the properties of ACM and, it should be noted, has not been sufficiently studied. A very complete analysis of works on finding the specific surface area of MM is given in [10, 11].

The mineral materials included in the ACM differ from each other in particle sizes hundreds and thousands of times: for cubic shape of particles with a density $\rho = 2.65$ t/m$^3$, the surface increases from 15.8·102 to 15.8·107 m$^2$/t. The edges of the cube have dimensions from 10 mm to 0.1 μm, respectively.

In [10] it is stated that “the surface and volume of the grain are expressed through the average size of the sieve opening *d*, defined as the arithmetic mean of the larger *D* and smaller *d* sieve openings that sifted out this fraction, with which the surface and volume of one grain are associated. It is known from granulometric analysis that this transition is sufficiently acceptable only with a normal size distribution of MM fractions. The deviation of the real distribution is another source of error in determining the specific surface area of MM”. To calculate the specific area of a disperse system represented by MM, the following relations are used [10]:

$$S = \alpha d^2, \text{ m}^2, \quad (2)$$

$$V = \beta d^3, \text{ m}^3, \quad (3)$$

where $\alpha$ – surface factor; $d$ – average sieve opening size, m; $\beta$ – form factor.

The work [10] notes a variety of approaches to determining the surface of MM used, for example, in France, Switzerland and Poland. The following dependencies are offered in France (4)–(6):

$$sj = \frac{6g_j}{\rho_j \sqrt{d_j D_j}}, \text{ m}^2/\text{kg}, \quad (4)$$

where $g_j$ – mass fraction of the $j$-fraction in the mixture, %; $\rho_j$ – material density of the $j$-th fraction, kg/m$^3$; $d_j$, $D_j$, – smallest and largest sieve opening diameter, mm.

For the entire mixture, it is required to sum the specific surfaces of all $n$ fractions of the mixture [5]

$$s_{cm} = \sum_{j=1}^{n} s_j, \text{ m}^2/\text{kg}. \quad (5)$$

The French method for calculating the MM surface also uses the dependence [10]

$$s_{cm} = (0.25g_1 + 2.3g_2 + + 12g_3 + 135g_4)10-2, \text{ m}^2/\text{kg}, \quad (6)$$

where $g_1$ – content of crushed stone larger than 5 mm in the mixture, %; $g_2$ – sand content of fractional composition from 5 to 0.315 mm, %; $g_3$ – content of sand with particle sizes from 0.08 до 0.315 mm in the mixture, %; $g_4$ – content of mineral powder with particle sizes less than 0.08 mm, %.

In Switzerland, to calculate the MM surface, it is proposed to use [10]

$$s_{cm} = \frac{2K}{\rho} \sum_{j=1}^{n} \frac{2g_j}{d_j + D_j}, \text{ m}^2/\text{kg}, \quad (7)$$

where $K$ = 3, 4, 5 – respectively for grains rounded, with faces twice broken and with faces once broken.

In Poland, to calculate the surface of the MM mixture, the dependencies are used

$$s_{cm} = (127g_1 + 15.25g_2 + 3.17g_3 + + 0.62g_4 + 0.13g_5) \cdot 10-2, \text{ m}^2/\text{kg}, \quad (8)$$

where $g_1$ – content of particles less than 74 μm in the mixture, %; $g_2$ – the same for the interval 74–297 μm, %; $g_3$ – 297–2000 μm, %; $g_4$ – 2000–8000 μm, %; $g_5$ – larger than 8 mm.

Table 2 shows the calculation results of the above calculation methods.

*Table 2*

**Specific surface area of mineral materials included in the asphalt concrete materials, determined by the ratios of different countries in Europe [10]**

| Fraction size, μm | Fraction content in mixture, % | Specific surface area, m$^2$/kg | | | |
|---|---|---|---|---|---|
| | | France | Poland | Switzerland | |
| | | | | $K$ = 3 | $K$ = 5 |
| 590–297 | 42.80 | 2.31 | 1.36 | 2.18 | 3.64 |
| 297–147 | 53.70 | 5.82 | 8.68 | 5.48 | 9.10 |
| 147–74 | 3.20 | 0.70 | – | 0.66 | 1.09 |
| 74–5 | 0.30 | 0.34 | 0.38 | 0.17 | 2.28 |
| Total | 100.00 | 9.17 | 10.42 | 8.49 | 16.11 |

The error of the data in the Table is from 50 to 100 %, which is unacceptable and this indicates the feasibility of using experimental methods for determining MM surfaces using the relationship between the porosity and aerodynamic resistance of the blown fixed MM layer and the diameter of the grains that make up the layer, using the law Darcy, for calculating the aerodynamic drag of the channel. As a result, the dependence is used to determine the surface of the layer material

$$s = 14\sqrt{\frac{1}{K\nu} \cdot \frac{\varepsilon^3}{1-\varepsilon^2}}, \text{ m}^2, \quad (9)$$

where $\varepsilon$ – layer porosity; $\nu$ – viscosity of the medium blown through the layer, Pa·s; $K$ – filtration coefficient, cm/s; $s$ – specific volumetric surface area of MM layer, cm$^{-1}$.

A method for finding the surface of a polydisperse MM layer, which uses the enveloping of grains with an oil film, is more reliable. 100 g of a dry mixture with a known granulometric composition is placed in a tissue vessel and 40 cm$^3$ of machine oil is poured for one minute. Then we centrifuge for 4 min to remove excess oil. To determine the mass of oil remaining on the surface of the particles of the MM mixture of each mineral fraction, the particles of which are wetted with oil, one more weighing is carried out and the desired result is obtained by the difference in weights after and before the above manipulations. Next, for a MM with a mass of 100 g, the surface of the constituent particles is found

$$s_0 = \frac{G_{100}}{\rho_m \delta_{film}}, \text{ cm}^2, \quad (10)$$

where $G_{100}$ – mass of the oil film on the surface of a MM with a mass of 100 g; $\rho_m$ – used oil density, g/cm$^3$; $\delta_{film}$ – thickness of the oil film in question, cm.

The next step is experimentally establish the thickness of the oil film on a plate of mineral material that is the same as the investigated MM. It is assumed that the thickness of the oil film does not depend on the surface configuration and is constant. It should be noted that there is an uncertainty factor in the result obtained due to the possible partial aggregation of fine fractions, and also due to the porosity of the material. Then, the required value of the surface of the MM included in the ACM is calculated from the established specific surface of the MM particles and the granulometric composition of the MM mixture using the relation

$$s_{cm} = \sum_{j=1}^{n} \frac{s_{0,j} g_j}{100}, \text{ cm}^2, \quad (11)$$

where $s_{0,j}$ – specific surface of 100 g of each $j$-th fraction of the mixture, cm$^2$.

From everything follows the complexity, cumbersomeness and the presence of errors in the results obtained in all methods, and the expediency of using differentiated methods for fine and coarse material is obvious: blowing the layer with air for fine fractions, for large fractions – to use the water permeability of the layer. Table 3 shows the specific surface area of the main MM.

From the analysis of Tab. 3, the following conclusion follows: the specific surface of the fractions that make up the ACM ranged from 1.3 m$^2$/kg for crushed stone of 25–15 mm, to 340 m$^2$/kg for particles smaller than 71 μm. In addition, although the mass fraction of mineral powder in the ACM composition is small and lies within 6 %, its surface primarily makes the main contribution to the total surface area of mineral materials. This should be taken into account in the ACM mixing technology. The data given in Tab. 3 are reasonably approximated by the dependence

$$s = aDn. \quad (12)$$

*Table 3*

**Specific surface of main mineral materials with density of 2.65 t/m$^3$ [10]**

| Particle size, mm | Limestone, m$^2$/kg | Granite, m$^2$/kg | Quartz sand, m$^2$/kg | Diorite, m$^2$/kg |
|---|---|---|---|---|
| Less than 0.071 | 340 | 290 | 190 | 286 |
| 0.071–0.14 | 70 | 67 | 40 | 87 |
| 0.14–0.315 | 25 | 28 | 12 | 22 |
| 0.315–0.63 | 13 | 14 | 8,0 | 10.5 |
| 0.63–1.25 | 6 | 6.5 | 5,8 | 5.5 |
| 1.25–3 | 3.5 | 3.7 | 2,5 | 3.6 |
| 3–5 | 1.6 | 1.7 | 1,0 | 1.45 |
| 5–10 | 0.71 | 0.74 | – | 0.71 |
| 10–15 | 0.4 | 0.44 | – | 0.42 |
| 15–25 | – | 0.28 | – | 0.30 |
| 25–40 | – | 0.17 | – | – |

The values of the coefficients for various MM in calculations by formula (12) are given in Tab. 4 [10].

*Table 4*

**Coefficients of approximating dependence (12) for calculations with different mineral materials**

| Material | Value of coefficients | |
|---|---|---|
| | *a* | *n* |
| Granite | 68 | –1.04 |
| Dense limestone | 70 | –1.07 |
| Quartz sand | 42 | –1.04 |

Table 5 gives the results of calculated and experimental determinations of the surface of various MM fractions [10].

An analysis of the data in the Table shows that for granite and limestone, the calculation method of the tetrad shape of grains is more acceptable, for sand – the calculated ratios for the cubic shape of particles [5]. The calculation method makes it possible to take into account the size of the fractions and the shape of the particles, which gives a number of advantages. For this reason, it is the main method for calculating the surface of the mineral components of the ACM.

*Table 5*

**Comparison of methods for finding the specific surface of various mineral materials fractions (calculated and experimental methods for determining while using methods of air and water permeability)**

| Mineral material | Fraction size, mm | Average diameter Dave, mm | Specific surface area, m²/kg | | | |
|---|---|---|---|---|---|---|
| | | | Calculation method for | | | Measurement |
| | | | ball $\frac{6}{d\rho}$ | cube $\frac{8,5}{d\rho}$ | tetrahedron $\frac{14,7}{d\rho}$ | Method: air and water permeability |
| Mineral powder | 0.0005–0.001 | 0.00075 | 3000 | 4250 | 7360 | – |
| | 0.001–0.002 | 0.0015 | 1500 | 2120 | 3680 | – |
| | 0.002–0.004 | 0.003 | 750 | 1060 | 1840 | less then 0.071 |
| | 0.004–0,008 | 0.006 | 378 | 535 | 925 | 300–500 |
| | 0.008–0.017 | 0.012 | 189.0 | 268 | 463 | – |
| | 0.017–0.035 | 0.026 | 86.0 | 122 | 210 | – |
| | 0.035–0.071 | 0.05 | 44.5 | 63 | 109 | – |
| Sand | 0.071–0.14 | 0.115 | 19.5 | 27.6 | 48 | 70 |
| | 0.14–0.315 | 0.23 | 9.8 | 14.0 | 24.1 | 25 |
| | 0.315–0.63 | 0.47 | 4.8 | 6.8 | 11.7 | 13 |
| | 0.63–1.25 | 0.94 | 2.41 | 3.4 | 5.9 | 6 |
| | 1.25–3.0 | 2.12 | 1.07 | 1.52 | 2.62 | 3.5 |
| Rubble | 3.0–5 | 4.0 | 0.57 | 0.80 | 1.39 | 1.6 |
| | 5.0–10 | 7.5 | 0.30 | 0.43 | 0.74 | 0.71 |
| | 10.0–15 | 12.5 | 0.18 | 0.26 | 0.44 | 0.43 |
| | 15.0–25 | 20.0 | 0.113 | 0.16 | 0.28 | – |
| | 25.0–40 | 32.5 | 0.07 | 0.10 | 0.17 | – |
| | 40.0–70 | 55.0 | 0.04 | 0.06 | 0.10 | – |
| The density of the material is assumed to be 2.65 t/m³. | | | | | | |

## Structure of the exergy of the asphalt concrete mixture

The exergy of the ACM flow is determined by three components [1, 12–15]: thermomechanical $e_{pT,ACM}$, concentration $e_{c,ACM}$, and reaction $e_{r,ACM}$. The numerical values of the indicated components of the exergy of the substance in the flow for ACM can be found on the database given in the previous section.

The thermomechanical component of ACM exergy is determined [1]

$$e_{pT,ACM} = \sum g_j \overline{c}_p \Big|_{t_0}^{t_{ACM}} \left(t_{ACM} - t_0\right) - T_0 \ln\left(T_{ACM}/T_0\right), \text{ MJ/t.} \quad (13)$$

Temperatures in the example are taken: finished ACM $t_{ACM}$ = 160 °C, environment $t_0$ = 20 °C.

The heat capacity ACM, specific mass, isobaric, average in the temperature range of 20–160 °C for mixtures is determined by the given composition and heat capacity of the components

$$\overline{c}_p\Big|_{20}^{160} = \sum_{j=1}^{3} \overline{c}_{p,j}\Big|_{20}^{160} g_j = 0.84 \cdot 0.06 + 0.84 \cdot 0.06 + 1.6 \cdot 0.88 = 1.51, \text{ kJ/(kg·K).}$$

The mass fractions of the ACM components are given above, the mentioned heat capacities of the components are given in [9].

The value of the thermomechanical component of ACM exergy is found

$$e_{pT,ACM} = 1{,}51\left[(160-20) - (273 + 20) \times \ln\left(273 + 160\right)/293\right] = 38.6 \text{ MJ/t.}$$

The reaction component of the exergy of the ACM flow is calculated [1]

$$e_{r,ACM} = \sum g_j e_{\mu,j}, \text{ MJ/t,} \qquad (14)$$

where $e_{\mu,j}$ – chemical exergy of ACM, MJ/t.

In the general case, the constituent mineral components of ACM: mineral powder (MP), SGM (sand-gravel mixture), bitumen. The reaction component of the SGM exergy is $e_{\mu,\,min.aggr} = 0$, this is due to the fact that it is represented primarily by silicon dioxide $SiO_2$, and its chemical exergy is zero [11]. In the same place [11] we find the value of chemical exergy $e_{\mu,\ MP}$ = 1045 MJ/t for dolomite $CaCO_3$ since dolomite most often makes up the MP. The reaction component of the bituminous binder $e_{\mu} = 41$ MJ/kg is given in [9]. Then, from relation (14), it is easy to calculate the reaction component of ACM exergy based on its average mass composition [1]

$$e''_{r,ACM} = \sum g_j e_{\mu,j} = 0.82 \cdot 0 \; +$$

$$+ \; 0.06 \cdot 1045 \; + \; 0.06 \cdot 41 \cdot 103 \; = \; 2523 \text{ MJ/t,}$$

Based on the previously described method, the concentration component of ACM exergy is calculated

$$e_{c,ACM} = s_{cm} W_{adh}, \text{ MJ/t.} \qquad (15)$$

As a result, we find the desired exergy of the substance in the flow for ACM

$$e_{ACM} = e_{pT,ACM} + e_{c,ACM} + e_{r,ACM} =$$

$$= 38.6 + 4.76 \cdot 10 - 3 + 2523 = 2561 \text{ MJ/t.}$$

From the analysis of the ratio of the values that make up the ACM exergy, it follows that the reaction component has the main specific gravity. It is two orders of magnitude higher than the next thermomechanical component in terms of specific gravity. The value of the concentration component of the ACM exergy is relatively small and comparable with the error in finding the exergy. The reaction component of ACM exergy is a transit component in the technological chain of transformation of initial ingredients into ACM and, for this reason, can be excluded. The need to exclude transit energy on the analysis results makes it possible to block its "noise" in the analysis of changes in the exergy relative characteristics that are necessary to establish the thermodynamic efficiency of the components of the ACM production processes.

The revealed circumstances of the concentration component of ACM exergy remove the question of uncertainty about the influence of the error of its calculation on the results. "With a relatively small value of the concentration component of ACM exergy, the presented ideas about the relationship of its value with the energy costs for the mixing process are consistent with the empirical data that take place in the operation of the ACP mixing units: the minimum specific energy required for mixture formation based on the value of the concentration component of the ACM exergy turns out to be equal to ≈5 kJ/t" [10]. This value is in good agreement with the real costs, determined by the duration of the mixing process, the power of the mixer drive and its loading [15].

**CONCLUSIONS**

1. Thermodynamic analysis of technological processes in road construction is gaining more and more recognition [2, 3]. The analysis of the studies shows the impact on the durability and strength of the materials that make up the pavement, especially at different temperatures, is exerted by internal stresses arising from the mismatch of the thermophysical coefficients of the mineral materials that make up the ACM, including scrap ($d_y$ = 5–30 mm) and bituminous binder. In this context, it is important to increase the proportion of ACM oriented bitumen by changing the dispersion and shape of particles of mineral materials.

2. The promotion of the processes of creating asphalt concrete pavement towards so-called "green energy" presupposes the reuse of the used pavement. The possibility of such use of materials while maintaining the quality of the ACM can be assessed by changing the concentration component of the ACM exergy, regardless of the ACM laying technology.

3. A physical model has been considered and a calculation method has been developed that makes it possible to relate the energy of adhesive interaction and the specific surface of mineral materials with the value of the concentration component of the asphalt concrete mixture.

4. The value of the concentration component of the exergy of the asphalt concrete mixture:

allows to evaluate the energy efficiency of its production at asphalt concrete plants based on the modern exergy method of thermodynamic analysis; gives a quantitative estimate of the energy consumption for carrying out the process of mixing the ingredients of the asphalt concrete mixture in the mixing unit of asphalt concrete plants.

5. The following steps need to be taken: studies to clarify the energy of adhesive interaction with various mineral materials involved in circulation when reusing used road pavement, with a dispersed composition, its uniformity and the shape of particles of mineral material; development of methods for determining and calculating the surface of particles of mineral dispersed materials; studies on the impact of the ratio between oriented bitumen and bulk bitumen in ACM on pavement performance.

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