https://doi.org/10.33271/nvngu/2022-4/017

**L. F. Mullagaliyeva**[1],
orcid.org/0000-0003-1168-4076,
**S. K. Baimukhametov**[1],
orcid.org/0000-0002-7130-5560,
**V. S. Portnov**[1],
orcid.org/0000-0002-4940-3156,
**V. M. Yurov**[1],
orcid.org/0000-0002-7918-9656,
**D. A. Ibragimova**[2],
orcid.org/0000-0002-2588-3028

1 – Karaganda Technical University, Karaganda, the Republic of Kazakhstan, e-mail: m_liliya88@mail.ru
2 – JSC "Shubarkol Komir", Karaganda, the Republic of Kazakhstan

# NANOSTRUCTURES OF COAL BEDS IN THE SHERUBAYNURINSKY SECTION OF THE KARAGANDA BASIN

**Purpose.** To determine the thickness of thin films of coal matter in the Sherubaynurinsky area of the Karaganda basin and their effect on the physical properties of these films.

**Methodology.** In order to calculate the thickness of the surface layer of the coal substance using our proposed formula, one needs to know the molar mass and density. We will use the well-known work where it is shown that such a characteristic as the "molecular weight" of coal reflects rather well the degree of metamorphism, and is also decisive for the study on the composition and structure of coal raw materials.

**Findings.** The role of the thickness of the surface layer of coal in the course of most physical processes is shown. A thin layer of coal matter differs significantly from metals and other compounds. But it is close to the structure of higher fullerenes. One fundamental parameter, the atomic volume of the surface layer, determines all the properties of the nanostructure of this layer.

**Originality.** For the first time, the thickness of the surface layer of the coal substance has been determined, which is two orders of magnitude greater than the thickness of pure metals. The thickness of the surface layer of higher fullerenes $C_{96}$ (135 nm) is close to that for OC coal (146 nm). The average statistical structural unit of coal corresponds to higher fullerenes with the number of carbon atoms in the cluster > 100, which is a unique feature of coal matter. The thickness of the surface layer of coal in the Sherubaynurinsky area of the Karaganda basin with a size of ~ 150–200 nm was obtained. This structure is a nanostructure. In this layer, the physicochemical properties of nanomaterials occur: a change in the crystalline (supramolecular) structure of coal; a change in its electronic structure and its electrical conductivity; change in the conditions of the stress state of coal; change in the conditions of methane diffusion in coal seams and many other phenomena.

**Practical value.** The natural gas content $C_0$ depends linearly on the reciprocal of $d(I)$. For coal seam *k*, where $d(I) = 180.8$ nm, it was obtained – $C_0 = 19$ m$^3$/t. After the release of coal and gas, the average value of $C_0 = 216$ m$^3$/t at a seam depth of 430 m, and in the Sherubaynurinsky area $C_0 = 14$ m$^3$/t at an average thickness of the surface layer $d(I) = 170$ nm. Hence, after the explosion $d(I)_v = 35$ nm, i. e. the layer thickness decreases by almost 5 times, leading to the formation of coal dust. We have considered only a part of the nanostructure issues: porosity and gas content, explosiveness and moisture content of coal seams, and have shown that all physical phenomena in a thin layer of coal have a dimensional dependence and determine structures unexplored until now, and phenomena studies on which are necessary for the practice of mining.

**Keywords:** *Karaganda basin, nanostructure, surface layer thickness, coal, molar mass, density, size effect, carbon, fullerene*

**Introduction.** In his thermodynamics, J. Gibbs considered the surface layer as a geometric analogue without regard to its thickness. On the contrary, in the thermodynamics of surface phenomena, the approach of van der Waals, Guggenheim, Rusanov is used. According to this approach, which corresponds to modern concepts, the size of the surface layer is on the order of the interatomic distance [1]. This layer has a completely different structure and is in thermodynamic equilibrium with the rest of the crystal [1]. However, the size of this layer was experimentally determined only for some atomically smooth metals [1]. Theoretically, in [2], a formula was obtained for the size of the layer of some metals (Table 1). This formula has the form: $d(I) = 0.17 \cdot 10^{-9}$ M/ρ, where M is the molar mass (g/mol), ρ is the density (g/cm$^3$).

Table 1 shows that the metals have a layer size of the nanometer range. If $d(I)$ is divided by the crystal lattice constant *a*, then we get the number of monolayers in the metal layer ($d(I)/a = n$). So, for gold $n = 6$ – six monolayers in which reconstruction or relaxation occurs [1]. It was shown in [3] that a thin layer of coal matter differs significantly from metals and other compounds. But it is close to the structure of higher fullerenes. In [4], the consideration of the nanostructure of coal and their connection with the main characteristics is continued.



**Identification of the main problem.** In the Karaganda coal basin at the Sherubaynura site, the amount of methane reaches 22–25 m$^3$/t. The total thickness of coal seams is up to 50 m. The grade of coal is K, KZh and OS. According to GOST 25543-88, according to the reflection of vitrinite $R_o$, %, coals are divided into three types: brown coals, hard coals and anthracites. Those, in turn, are divided into 50 classes based on the average vitrinite reflection $R_o$, % according to GOST 12113-94. Brown coals have $R_o < 0.60$ %, hard coals have $R_o = 0.40–2.59$ %, anthracites have $R_o = 2.20$ % or more. Professor Ermekov established a connection between $R_o$ and metamorphisms of Karaganda coals (Satibekova S. B., 2019). For the main grades of coal, they are shown in Table 2.

However, the nanostructure of coal seams has not been studied. The main purpose of the work is to build a model of the surface layer of coal in the Sherubaynurinsky area and describe their properties.

**Literature review.** The nanostructure of coal began to be explored only in the *21st* century, although the term nanotechnology was first used by Norio Taniguchi in 1974. In [5, 6], the diffusion of methane in coal nanopores was studied. Using the small-angle neutron scattering method, it was found that gases can enter (and exit) nanopores of 10–20 nm in size in the inertinites of the coals of the Sydney Basin; however, these gases have difficulty penetrating through nanopores of the same size in the inertinites of American and European coals. These

*Table 1*

Layer size (I) of metals [2]

| *M* | $d(I)$, nm | *M* | $d(I)$, nm | *M* | $d(I)$, nm | *M* | $d(I)$, nm |
|---|---|---|---|---|---|---|---|
| Li | 0.7 | Sr | 5.8 | Sn | 1.4 | Cd | 1.3 |
| Na | 1.5 | Ba | 6.2 | Pb | 1.8 | Hg | 0.6 |
| K | 2.6 | Al | 1.5 | Se | 1.3 | Cr | 2.7 |
| Rb | 2.9 | Ga | 0.6 | Te | 2.5 | Mo | 4.6 |
| Cs | 3.6 | In | 1.1 | Cu | 1.6 | W | 5.8 |
| Be | 1.3 | Tl | 1.9 | Ag | 2.2 | Mn | 2.0 |
| Mg | 2.2 | Si | 3.4 | Au | 2.3 | Tc | 3.6 |
| Ca | 4.9 | Ge | 2.8 | Zn | 1.1 | Re | 4.6 |

*Table 2*

Parameters of coal metamorphism (Satibekova S. B., 2019)

| coal brand | $R_o$, % | coal brand | $R_o$, % |
|---|---|---|---|
| *D* | 0.58 | *K* | 1.40 |
| *G* | 0.79 | *OC* | 1.80 |
| *Zh* | 1.07 | *T* | 2.37 |
| *KZh* | 1.24 | *A* | 2.77 |

pores are too small to be detected by optical microscopy, which is one of the reasons this difference has not been observed before. Thus, the nanostructure of coals affects the transport of gas in coal. In [7] carbon nanospheres (50–60 nm in diameter) and in [8] carbon nanotubes (outer diameter 20–30 nm) were synthesized from brown coal in the presence of ferrocene as a catalyst. In [9], carbon nanostructures were also obtained from high-ash coals using microwave pyrolysis. By rapid pyrolysis of pulverized coal in an atmosphere of oxygen and steam, a nanostructured carbon material was obtained from activated coke powder in one step. In [10], carbon nanofibers and carbon nanorods are synthesized by coal particles (<44 μm).

**Presentation of the main material.** We use a modification of works [3, 4].

$d(I)$, nm is the thickness of the surface layer of coal; $C_V$, J/kg K is the heat capacity of coal; W, % is coal moisture; $V^{daf}$, % is yield of volatile substances; $Q^G$, kcal/kg is heat of combustion; $C_0$, $m^3/t$ is natural gas content. From Table 3 it follows that with an increase in the degree of coal metamorphism from brown to anthracite, the following increase linearly: $Q^G$, $C_0$; and also decrease linearly – $R(I)$, $C^V$, $W$, $V^{daf}$.

*Table 3*

Thickness $d(I)$ and properties of coals [3, 4]

| Coal brand | $d(I)$, nm | $C_V$, mJ/kg K | *W*, % | $V^{daf}$, % | $Q^G$, kcal/kg | $C_0$, $m^3/t$ |
|---|---|---|---|---|---|---|
| *B* | 214.2 | 1.44 | 15 | 41 | 7,500 | 8 |
| *D* | 198.7 | 1.38 | 10 | 39 | 8,000 | 9 |
| *G* | 198.5 | 1.33 | 7 | 36 | 8,600 | 10 |
| *Zh* | 190.4 | 1.28 | 5 | 30 | 8,700 | 12 |
| *K* | 180.8 | 1.08 | 3.5 | 20 | 8,700 | 18 |
| *OC* | 176.2 | 1.33 | 2 | 15 | 8,780 | 24 |
| *T* | 172.8 | 1.16 | 1 | 12 | 8,750 | 30 |
| *A* | 151.5 | 0.82 | 2.4 | 8 | 8,750 | 45 |

Let us determine the thickness of the surface layer of coal in the Sherubaynura area of the Karaganda coal basin, using the equation [11] to calculate the molar mass.

Table 4 shows that the thickness of the surface layer $d(I)$ of the coal substance is two orders of magnitude greater than the thickness of pure metals (Table 1) ~0.36 nm) between coal macromolecules, determined using X-ray scattering.

Dependence of the natural gas content of the Sherubaynurinsky area on the thickness of the surface layer.

The natural gas content $C_0$ will depend linearly on the reciprocal of $d(I)$, that is, $C_0 = \alpha/d(I)$, where α is a constant coefficient to be determined.

If we use the technique [12], we get $C_0 = \gamma/d(I) = 3.5 \times 10^{-10}/d(I)$. Let us check it for coal seam *k*, where $d(I) = 180.8$ nm. It is easy to obtain – $C_0 = 3.5 \cdot 10^{-10}/d(I) = 3.5 \times 10^{-10}/181 \cdot 10^{-9} = 19 \cdot 10^{-3}$ $m^3/kg = 19$ $m^3/t$. This is close to the average value for formation K (Table 3). Finally, we have

$$C_0 = 3.5 \cdot 10^{-10}/d(I), \quad (1)$$

m, and in the Sherubaynura area $C_0 = 14$ $m^3/t$ at an average thickness of the surface layer $d(I) = 170$ nm. This means that after the explosion $d(I)_v = 35$ nm, i. e. the layer thickness (1)

After the release of coal and gas, the average value of $C^0 = 216$ $m^3/t$ at a seam depth of 430 decreases by almost 5 times, leading to the formation of coal dust. This process is similar to the transformation of α-carbine, where $d(I) = 196.7$ nm in β-carbine, where $d(I) = 40$ nm (in our case, 170 and 35 nm). The β-carbine crystal has a high order (like anthracite). The thickness of the surface layer of carbine differs significantly from those for diamond ($d(I) = 8.2$ nm) and graphite ($d(I) = 1.7$ nm), but is closer to carbon materials, namely, fullerenes and coal.

**Dependence of the natural gas content of the Sherubaynura area on humidity.** If we use the technique [12], we get

$$C_0 = 35/W, \quad (2)$$

where $C_0$ is gas content ($m^3/t$), W is hygroscopic humidity (%). From Table 5 it follows that the gas content of the coal seam is affected by its moisture rather strongly [13]. So, for example, an increase in humidity by 1 % leads to a decrease in gas content of about 4 $m^3/t$.

Table 5 shows the calculations of the gas content $C_0$ ($m^3/t$) of Karaganda coals according to (2), and in parentheses are the values of the gas content of $k_{12}$, $k_{11}$ and $k_{10}$ seams, measured from coal cores by the Langmuir method [13]. The above comparison shows good accuracy. With an increase in the depth of the coal seam, moisture usually drops in the coal, and the gas content increases.

The hygroscopic moisture in the series of coals varies in accordance with the degree of their metamorphism (Table 3). Hygroscopic humidity in brown (*B*), long-flame (*D*) and gas (*G*) coals is high, and then it decreases to lean (*T*) coals, but in anthracite (*A*) it increases again due to its high porosity.

Humidity values in Table 6 are calculated using (2). From Table 6 after the release of coal and gas, the average value of $C_1 = 216$ $m^3/t$, and the humidity $W_1 = 0.31$, with a seam depth of 430 m, and for the Tentek suite in the Sherubaynura area,

*Table 4*

The thickness of the surface layer of medium coal seams

| Site | Coal grade | *M* – molar mass (g/mol) | ρ density ($g/cm^3$) | d(I), nm |
|---|---|---|---|---|
| Sherubaynurinsky | *K* | 1,351 | 1.27 | 180.8 (502) |
| | *KZh* | 1,376 | 1.42 | 164.7 (458) |
| | *OC* | 1,340 | 1.56 | 176.2 (489) |

*Table 5*

Influence of humidity on the gas content of Karaganda coals [13]

| Carbonic layer | Sampling depth, m | Humidity $W$, % | Gas content $C_0$, (m$^3$/t) |
|---|---|---|---|
| $k_{15}$ | 191.3 | 1.20 | 29.2 |
| $k_{15}$ | 190.9 | 1.25 | 28.0 |
| $k_{15}$ | 193.1 | 1.10 | 31.8 |
| $k_{14}$ | 238.4 | 1.10 | 31.8 |
| $k_{14}$ | 238.8 | 0.90 | 38.9 |
| $k_{13в}$ | 305.4 | 0.85 | 41.2 |
| $k_{13в}$ | 306.2 | 0.80 | 43.8 |
| $k_{13в}$ | 306.6 | 1.05 | 33.3 |
| $k_{12}$ | 501.5 | 0.80 | 43.8 |
| $k_{12}$ | 502.4 | 1.15 | 30.4 |
| $k_{12}$ | 506.2 | 0.80 | 43.8 |
| $k_{12}$ | 289.0 | 1.28 | 27.3 (24.6) |
| $k_{10}$ | 429.5 | 1.36 | 25.7 (27.1) |
| $k_{12}$ | 224.2 | 1.23 | 28.5 (25.0) |
| $k_{11}$ | 352.5 | 1.34 | 26.1 (24.1) |

*Table 6*

Average values of parameters for sudden outbursts of coal and gas [14]

| Mine | Depth, m | Humidity W, % | Gas content $C_0$, m$^3$/t |
|---|---|---|---|
| Shakhtinskaya | 300 | 0.71 | 44 |
| Lenin | 410 | 0.47 | 66 |
| Lenin | 427 | 0.19 | 161 |
| Lenin | 350 | 0.45 | 69 |
| Lenin | 317 | 0.76 | 41 |
| Kazakh | 466 | 0.34 | 91 |
| Kazakh | 478 | 0.15 | 208 |
| Lenin | 545 | 0.04 | 860 |
| Lenin a | 580 | 0.05 | 650 |
| Tentekskaya | 542 | 0.08 | 381 |
| Tentekskaya | 485 | 0.29 | 107 |
| Kazakh | 524 | 0.39 | 79.8 |
| Kazakh | 636 | 0.16 | 192 |
| Average | 429 | 0.31 | 215.9 |

our average value of $C_2 \approx 30$ m$^3$/t, and the humidity $W_2 =$ = 2.0 %. The ratio $C_1/C_2 \approx 7$, and the ratio $W_2/W_1 \approx 7$, which indicates the validity of (2).

Oil reservoirs practically do not interact with water, and the solubility of the reservoirs is at the level of 1 % or less. Let us use f (2) and find out the water content by gas saturation $G_f$ in oil [15]:

- $G_f < 50$ m$^3$/t – low gas content in oil, $C_0 = 35/\text{W}$, $W =$ = 0.50 %;
- $G_f = 150$–$300$ m$^3$/t – increased gas content in oil, $C_0 =$ = 35/W, $W = 0.12$ %;
- $G_f = 300$–$600$ m$^3$/t – high gas content in oil, $C_0 = 35/\text{W}$, $W = 0.06$ %;
- $G^f >$ = 800–900 m$^3$/t – gas condensate system, $C_0 =$ = $35/W$, $W = 0.04$ %.

Comparing the oil reservoir with the gas condensate system, where $W = 0.04$ %, with Table 6, where the gas content is $C_0 = 860$ m$^3$/t, $W = 0.04$ %, their great similarity is found. It is known that the high gas content of oil is accompanied by a high saturation pressure, at which the gas dissolved in it is rapidly released. This process, in many ways similar to the sudden outburst of coal and gas, is shown in Table 6. Sudden outbursts of gas condensate occurred at fields in Uzbekistan, Ukraine, and Kazakhstan. The largest sudden release of a gas-condensate mixture occurred in 1980 at the Kumzhinskoye gas condensate field [16]. The cause of such accidents is still not clear, as well as emissions of coal and gas in coal deposits. For the first time such an accident was recorded in England in 1834.

However, the results of our study show that the state of moisture in both coal and oil (gas condensate) formations plays an important role. It becomes too small $W = 0.04$ % for coal and gas condensate systems at the moment of a sudden explosion of coal and gas and at the moment of formation of a gas fountain in certain mineral deposits.

**Dependence of the natural gas content of the Sherubaynura area on the release of volatile substances.** If we use the technique [12], we get

$$C_0 = 340/V^{daf}, \qquad (3)$$

where $C_0$ is the gas content (m$^3$/t); $V^{daf}$ is the yield of volatile substances (V)%.

The yield of LS in brown, long-flame and gas coals is high, and then it decreases to lean coals and anthracites (Table 7). Oriented gas-bearing values from literature data are given in parentheses. There is a good correlation.

**Dependence of the natural gas content of the Sherubaynurinsky area on the electrical resistance of coal.** If we use the technique [12], we get

$$C_0 = 10^{-8}\rho_K \cdot h/T, \qquad (4)$$

where $\rho_K$ is the electrical resistance of coal; $h$ is the depth of the coal seam; $T$ is its temperature.

Now let us turn to Table 6 and take the value from the depth $h = 410$ m and the specific gas emission of 66 m$^3$/t. These are average values for $k_{10}$ reservoir during sudden outbursts. Let us make a calculation using (4) at $T = 600$ K. It gives $\rho_K \approx$ $\approx 0.9 \cdot 10^6$ (Ohm m). At a temperature of $T = 600$ K, the electrical resistance of grade $K$ coals is $9 \cdot 10^6$ (Ohm · m), and grade *Zh* coal is $23 \cdot 10^6$ (Ohm · m). (4) gives the electrical resistance of coals with sudden outbursts of coal and gas 10 times (for grade $K$) and 20 times (for grade *Zh*) of a lower value, which may be a sign of zones with increased gas recovery. Thus, if the resistance $\rho_K < 4 \cdot 10^6$ (Ohm · m) (at $T = 300$ K), then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters the zone with increased gas recovery.

**Dependence of the natural gas content of the Sherubaynura area on the intensity of gamma-gamma radiation in coal.** If we use the technique [12], we get

*Table 7*

Yield of LS and gas content of the genetic series of coals

| Coal brand | LS $V^{daf}$, % | $C_0$, (m$^3$/t) | Coal brand | LS $V^{daf}$, % | $C_0$, m$^3$/t |
|---|---|---|---|---|---|
| B | 41 | 8.3 (4–6) | K | 20 | 17 (15–18) |
| D | 39 | 8,7 (6–9) | OC | 15 | 22.7 (20–24) |
| G | 36 | 9.4 (9–10) | T | 12 | 28.3 (25–30) |
| Zh | 30 | 11.3 (10–12) | A | 8 | 42.5 (40–45) |

$$C_0 = 1.7 \cdot 10^2 \cdot (1 - J^0), \tag{5}$$

where $J^0$ is the relative parameter of the gamma-gamma method, which is related to the electrical resistance $\rho_E$ through the ash content $A^{\circ}$ in a linear way, such as $J^0$ (μR/h) = $\varphi\rho_E$ (Ohm · m), where the coefficient φ provides a ratio of dimensions. Now let us turn to Table 6 and take the value of the depth $h = 410$ m and the specific gas release $C_0 = 66$ m$^3$/t for the $k_{10}$ formation, with the ash content $A^{\circ} = 10.7$ % we will get $(1 - J^0) = 0.38$. Substituting the relative parameter $J^0$ for the $k_{10}$ coal seam into (5), we obtain: $J^0 \approx 0.61$.

Thus, if the relative parameter $J^0 < 0.61$ (μR/hour), then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters the zone with increased gas recovery.

**Dependence of the natural gas content of the Sherubaynura area on the speed of sound in coal.** If we use the technique [12], we get

$$C_0 = \delta / V_S, \quad C_0 = \eta / V_P, \tag{6}$$

we imply

$$K = \delta / \eta = V_S / V_P, \tag{7}$$

where $V_S$ is the low frequency component; $V_P$ is a high-frequency component of the spectrum of acoustic signals.

If we take an estimate of the relationship between gas content and electrical resistance of coals from (4), and take $\rho_E$ of coal at temperatures $T_1 = 873$ and $T_2 = 973$ K, then we will get $-\delta V_P / \eta V_S = 4.3 \cdot 10^2$. Taking for coal $V_S = 1{,}280$ and $V_P = 2{,}373$ m/s from (7), we have for the value $K = 0.5$. The expression $K = A_2^{max}/A_1^{max} = 18.2/90.7 = 0.2$ can be interpreted as a low degree of danger of a sudden outburst of coal and gas or a rock burst. With a sudden outburst of coal and gas, $K$ exceeds the previous value by 10 times, i. e. $K = 5$.

Thus, if parameter $K = V_S / V_P < 3$, then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters a zone with increased gas recovery.

**Porosity of coal seams.** The existing nomenclature, adopted by the International Union of Theoretical and Applied Chemistry IUPAC, distinguishes three categories of pore size depending on their diameter: microporous <2 nm, mesoporous 2–50 nm, and macroporous >50 nm [14]. The porosity of the coal matter in the Sherubaynurinsky area can be judged by the Langmuir isotherms, which, as an example, are shown in Fig. 1.

To measure the isotherms of methane sorption, after the coal desorption process, three sub-samples of coal were prepared from core samples No. 5/1, 5/4 and 6/14 for coal seams *k,* KZh and OS. Langmuir's sorption capacity varies from 29.09 m$^3$/t for sample *K*, from 30.05 m$^3$/t for sample CL and from 31.25 m$^3$/t for sample OC. When the pressure changes, the sorption capacity of coals obeys the dimensional law from the formula $A(h) = A_0[1 - d(I)/h]$ [2], where $A(h)$ is the sorption capacity, $h = P$. This is because the Langmuir isotherm reflects the phenomena on the thickness of the surface layer. From Table 1 it follows that the sorption capacity of coal is inversely proportional to the thickness of the surface layer. Using an electron microscope, it was noticed that the distribution of pores in the studied coals was uniform, but a fuzzy orientation along the layering was noted. Moreover, coals are extremely heterogeneous in terms of pore development. In coals of grades K, Zh and OS, large pores are observed, which are slightly compressed and have an elongated and oval shape.

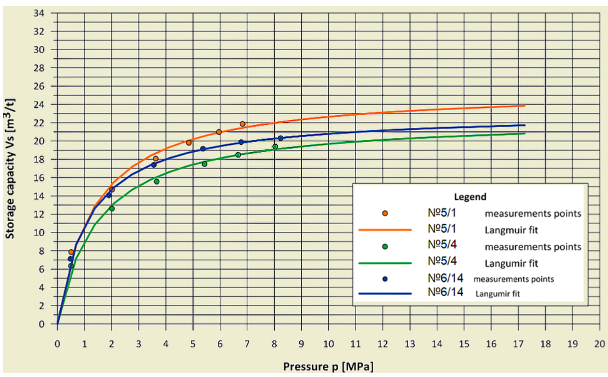


*Fig. 1. Langmuir isotherms*

**Gas content of coal seams.** The study on the gas content of coal seams was carried out mainly by core sampling. Gas survey was carried out to check the reliability and clarify the data obtained during sampling by core sampling stations. Comparison of the values of gas content was carried out using the methods of mathematical statistics. The nature of the increase in gas content with depth for strata $k_{18}$-$k_6$ is shown in Fig. 2.

From Fig. 2 it follows that the gas content of coals obeys the dimensional law from (3).

Explosion hazard of a coal seam. In [16], a study was made on the fire hazard of coal and its mixtures with dust and combustible gases and an assessment of the danger of ultrafine particles to spontaneous combustion. Let us consider the size effect with the temperature of coal, assuming in the first formula expressions (3) instead of $A(h) = Tm$ (melting point in layer $d(I)$), and $A_0 = T_0$ is the melting point of bulk coal, which, according to various sources, takes a value from 1,200 to 1,600 °C. Let us take an average temperature of 1,500 °C (1,773 K), and from Table 1 thickness $d(I)$) for layers *K*, *KZh* and *OS* (Table 7).

Investigations by the method of electron microscopic analysis of coal particles of coals of all stages of metamorphism made it possible to establish, in [16], the presence on the surface of the particles of film coatings formed as a result of the combination of coal with atmospheric oxygen. With decreasing particle size, the proportion of the coating volume increases and changes on average from 100 to 150 nm (compare with our Table 1). Then, if in this surface oxyfilm of coal, peroxide complexes initiate reactions that cause decomposition and oxidation of coal matter, then energy is released and, according to the equation in [16], one can estimate the increment in the particle temperature as a result of its heating. Consequently, the temperature of a carbon nanoparticle at the initial temperature $T_0 = 300$ K will be at least $T_m = 872$ K.

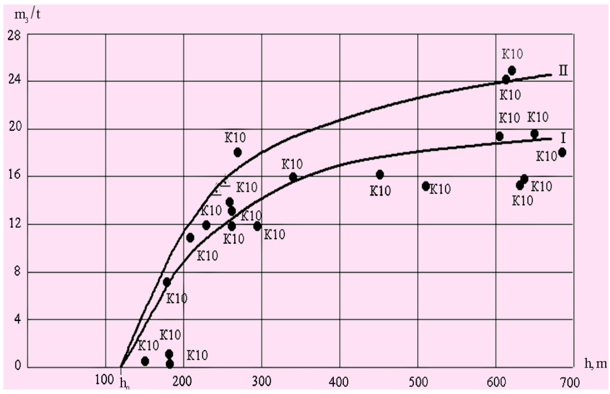


*Fig. 2. Graphs of changes in gas content with depth (stratum $k_{10}$) [15]*

*Table 8*

Size effect for coal temperature

| Brand coal | $T_0$, K | $T_m$, K $r = 50$ nm | $T_m$, K $r = 100$ nm | $T_m$, K $r = 150$ nm | $T_m$, K $r = 200$ nm |
|---|---|---|---|---|---|
| K | 1,773 | 385 | 633 | 805 | 933 |
| KZh | 1,773 | 412 | 677 | 862 | 998 |
| OS | 1,773 | 452 | 762 | 948 | 1,098 |

According to our Table 8, this corresponds to particles of the order of half a micron. In [16], it is considered proven that coal particles with a radius of about one micron (or our half a micron) in the case of decomposition of coal matter, due to the negative heat of formation of coal molecules, warm up to temperatures at which nanoparticles can spontaneously ignite. Another important conclusion is that during the decomposition of coal matter, flammable gases are released, which, in the case of spontaneous combustion of coal nanoparticles, also ignite, and their mixtures-aerosols with air explode. The simultaneous presence of methane and other combustible gases in the dust and gas aerosol reduces the lower concentration limit of the explosion of coal dust.

**Conclusions.** We tried to show the importance of the role of the thickness of the surface layer in the course of most of the processes occurring during interaction with the external environment, especially since these interactions are carried out through the surface. A thin layer of coal matter differs significantly from metals and other compounds. But it is close to the structure of higher fullerenes. One fundamental parameter, the atomic volume of the surface layer, determines all the properties of the nanostructure of this layer.

The size effects in the $d(I)$ layer are determined by the entire collective of atoms in the system (collective processes). Such "semiclassical" size effects are observed only in nanoparticles and nanostructures; they are also called type II size effects. In this layer, the physicochemical properties of nanomaterials occur: a change in the crystalline (supramolecular) structure of coal; a change in its electronic structure and its electrical conductivity; change in the conditions of the stress state of coal; change in the conditions of methane diffusion in coal seams and many other phenomena.

The natural gas content $C_0$ linearly depends on the reciprocal of $d(I)$. For coal seam $k$, where $d(I)$ = 180.8 nm, it was obtained – $C_0 = 19$ m$^3$/t. After the ejection of coal and gas, the average value of $C_0 = 216$ m$^3$/t at a seam depth of 430 m, and in the Sherubaynurinsky area $C_0$ = 14 m$^3$/t at an average thickness of the surface layer $d(I) = 170$ nm. Hence, after the explosion $d(I)_v = 35$ nm, i.e. the layer thickness decreases by almost 5 times, leading to the formation of coal dust.

If the resistance $\rho_E < 4 \cdot 10^6$ (Ohm · m) (at $T = 300$ K), then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters a zone with increased gas recovery.

If the relative parameter $J^0$ < 0.61 (μR/h), then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters the zone with increased gas recovery.

If the parameter $K = V_S/V_P < 3$, then the coal seam in the Karaganda basin is dangerous for sudden outbursts of coal and gas, that is, it enters the zone with increased gas recovery.

We have considered only a part of the issues: porosity and gas content, explosion hazard and moisture content of coal seams, but the literature is already discussing the diffusion of methane through nanopores, the production of nanofibers, nanorods from coal, and others.

The authors hope that studies on the surface layer of the unique coal matter will continue. We will assist in the continuation of work with KazTransGas JSC and Baker Hughes Kazakhstan LLP on the utilization of methane at the coal fields of the Karaganda basin.

**References.**

**1.** Mamonova, M.V., Prudnikov, V.V., & Prudnikova, I.A. (2016). *Surface Physics: Theoretical Models and Experimental Methods*. CRC Press. ISBN: 9780367379377.
**2.** Yurov, V.M., Guchenko, S.A., & Laurinas, V.Ch. (2018). Surface layer thickness, surface energy, and atomic volume of an element. *Physicochemical aspects of studying clusters, nanostructures and nanomaterials*, *10*, 691-699. https://doi.org/10.26456/pcascnn/2018.10.69.
**3.** Yurov, V.M., Makhanov, K.M., & Portnov, V.S. (2020). Nanostructures in a thin layer of coal substance. *Physicochemical aspects of studying clusters, nanostructures and nanomaterials*, (12), 746-757. https://doi.org/10.26456/pcascnn/2020.12.746.
**4.** Portnov, V., Yurov, V., Reva, M., Mausymbaeva, A., & Imanbaeva, S. (2021). Nanostructures in surface layers of coal matter. *Visnyk of Taras Shevchenko National University of Kyiv. Geology, 4*(95), 54-62. https://doi.org/10.17721/1728-2713.95.07.
**5.** Sun, Y., Yuan, L., & Zhao, Y. (2018). $CO_2$-ECBM in coal nanostructure: Modelling and simulation. *Journal of Natural Gas Science & Engineering, 54*, 202-215. https://doi.org/10.1016/j.jngse.2018.04.007.
**6.** Jia, T., Liu, C., Wei, G., Yan, J., Zhang, Q., Niu, L., ..., & Zhang, Y. (2021). Micro-Nanostructure of Coal and Adsorption-Diffusion Characteristics of Methane. *Journal of Nanoscience and Nanotechnology, 21*(1), 422-430. https://doi.org/10.1166/jnn.2021.18733.
**7.** Ding, J., Chen, S.-M., & Jisheng, P. (2019). Rapid Pyrolysis of Pulverized Coal for the Preparation of Nanostructured Powder Activated Coke. *Materials Science Forum, 962*, 63-69. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/MSF.962.63.
**8.** Hashemipour, H., Danafar, F., & Rad, S.A. (2020). Direct and one-stage conversion of coal into carbon nanostructures with spherical, rod, tube and plate geometry by chemical solid synthesis method. *Journal of Applied Chemistry, 15*(56), 179-194. https://doi.org/10.22075/CHEM.2020.17820.1639.
**9.** Reddy, B.R., Ashok, I., & Vinu, R. (2020). Preparation of carbon nanostructures from medium and high ash Indian coals via microwave-assisted pyrolysis. *Advanced Powder Technology, 31*(3), 1229-1240. https://doi.org/10.1016/j.apt.2019.12.017.
**10.** Fathabadi, M.V., Rafsanjani, H.H., & Danafar, F. (2018). Experimental Study on Catalytic Effect of Iron Compounds During Synthesis of Carbon Nanostructures from Coal. *Iranian Journal of Analytical Chemistry, 5*(1), 39-43.
**11.** Moskalenko, T.V., Mikheev, V.A., & Vorsina, E.V. (2018). Mathematical model for calculating the molecular weight of coal. *Modern high technologies*, (10), 82-85.
**12.** Maussymbayeva, A.D. (2018). Distribution of iron-containing minerals in the coal and rocks of Shubarkol deposit. *XIX Ural Youth Scientific School in Geophysics,* (pp.112-114). *Yekaterinburg: IGP UB RAN.*
**13.** Zeinullin, A.A., Khasen, B.P., Ozhogin, T.V., Krysin, A.V., & Lis, S.N. (2016). Key parameters of coals of the Karaganda basin for the production of coal-bed methane. *Geology and mineral resources protection, 2*(59), 12-23
**14.** Korotcenkov, G. (2015). *Porous Silicon: From Formation to Application: Formation and Properties*, (Vol. 1). CRC Press. https://doi.org/10.1201/b19342. ISBN 9781482264548.
**15.** Drizhd, N.A., Kamarov, R.K., Akhmatnurov, D.R., Zamaliyev, N.M., & Shmidt-Fedotova, I.M. (2017). Coal bed methane Karaganda basin in the gas balance Republic of Kazakhstan: status and prospects. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* (1), 12-20.
**16.** Kalyakin, S.A. (2013). Fire and explosion hazard of coal and dust and gas mixtures in mines. *Visti of Donetsk State University, 1*(32), 127-144.

# Наноструктури вугільних пластів на Шерубайнуринській ділянці Карагандинського басейну

*Л. Ф. Муллагалієва*[1], *С. К. Баймухаметов*[1], *В. С. Портнов*[1], *В. М. Юров*[1], *Д. А. Ібрагімова*[2]

1 – Карагандинський технічний університет, м. Караганда, Республіка Казахстан, e-mail: m_liliya88@mail.ru
2 – АТ «Шубарколь Комір», м. Караганда, Республіка Казахстан

**Мета.** Визначити товщину тонких плівок вугільної речовини на Шерубайнуринскій ділянці Карагандинського басейну та їх вплив на фізичні властивості цих плівок.

**Методика.** Щоб за запропонованою формулою розрахувати товщину поверхневого шару вугільної речовини, потрібно знати молярну масу та щільність. Ми скористаємося відомою роботою, де показано, що така характеристика як «молекулярна маса» вугілля досить добре відображає ступінь метаморфізму, а також є ви-

значальною для вивчення складу й будови вугільної сировини.

**Результати.** Показана роль товщини поверхневого шару вугілля в перебігу більшості фізичних процесів. Тонкий шар вугільної речовини суттєво відрізняється від металів, інших сполук. Але близький до структури вищих фулеренів. Один фундаментальний параметр – атомний об'єм поверхневого шару – визначає всі властивості наноструктури цього шару.

**Наукова новизна.** Уперше визначена товщина поверхневого шару вугільної речовини, що на два порядки більша за товщину чистих металів. Товщина поверхневого шару вищих фулеренів $C_{96}$ (135 нм) близька до такої для вугілля ОС (146 нм). Середньостатистична структурна одиниця вугілля відповідає вищим фулеренам із числом атомів вуглецю у кластері $>100$, що є унікальною особливістю вугільної речовини. Отримано показник товщини поверхневого шару вугілля на Шерубайнуринській ділянці Карагандинського басейну розміром ~150–200 нм. Ця структура є наноструктурою. У цьому шарі відбиваються фізико-хімічні властивості наноматеріалів: зміна кристалічної (надмолекулярної) структури вугілля; зміна його електронної структури та його електропровідності; зміна умов напруженого стану вугілля; зміна умов дифузії метану у вугільних пластах і багато інших явищ.

**Практична значимість.** Природна газоносність $C_0$ лінійно залежить від зворотної величини $d(I)$. Для вугільного пласта $k$, де $d(I) = 180.8$ нм, отримано – $C_0 = 19$ м$^3$/т. Після викиду вугілля та газу середнє значення $C_0 = 216$ м$^3$/т за глибини залягання пласта 430 м, а на Шерубайнуринській ділянці $C_0 = 14$ м$^3$/т за середньої товщини поверхневого шару $d(I) = 170$ нм. Отже, після вибуху $d(I)_в = 35$ нм, тобто товщина шару зменшується майже у 5 разів, що призводить до утворення вугільного пилу. Ми розглянули лише частину питань, пов'язаних із наноструктурою: пористість і газоносність, вибухонебезпечність і вологість вугільних пластів та показали, що всі фізичні явища в тонкому шарі вугілля мають розмірну залежність і визначають досі недосліджені структури та явища, вивчення яких необхідно у практиці гірничих робіт.

**Ключові слова:** *Карагандинській басейн, наноструктура, товщина поверхневого шару, вугілля, молярна маса, щільність, розмірний ефект, вуглець, фулерен*

*The manuscript was submitted 04.12.21.*