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CHANGE OF COAL'S GAS CONTENT DURING TRANSPORTATION TO THE TEMPORARY STORAGE

Gendler S.G., Stepantsova A.Yu., Mozzhanov D.B.

Purpose. Definition of correlation between residual gas content in coal stored in closed temporary storages and coal's natural gas content, which depends on the weather, train's transportation time and the amount of air ventilating closed storage needed to maintain methane concentration below threshold limit value.

Methods. Analysis of the transportation process from excavation site to the temporary storages, which takes into account transportation duration, carriages type and atmospheric temperature; experimental determination of effective diffusion coefficient for methane in coal fragments; theoretical research of thermal pattern dynamic for coal mass in train carriages; computational analysis of coal's gas content dynamic during transportation and correlation between residual coal's gas content and required airflow rate for temporary storage ventilation.

Findings. This paper represents the results of research of change of coal's gas content during excavation, transportation to the surface and further transportation to temporary storages by train by evaluating influence of physical and chemical properties of coal, effective diffusion coefficient in particular, and mean atmospheric temperature. According to procured data, value of effective diffusion coefficient, which depends on coal transportation time and its mean particle diameter, increases with the rise of mean coal mass temperature. Calculation of mean coal mass temperature per unit of volume during transportation is based on approximate method of Bubnov – Galerkin. Residual coal's gas content after transportation is calculated as difference between value of coal's gas content after loading into carriages and coal's gas content after delivery to temporary storages. Correlation between residual coal's gas content and required airflow rate for temporary storage ventilation has been established.

Application field of research. The results of the study can be used to ensure methane safety during temporary storage of coal raw materials in closed warehouses.

Keywords: bituminous coal, bituminous coal transportation, coal's seam gas content, residual gas content, methane, threshold limit concentration, coal storage, temporary coal storage.

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Introduction

The purpose of temporary storage of coal in port terminals, thermal power plants and boiler houses is to create the necessary stock of coal products to ensure sustainable operation of sea transportation, generation of heat and electric power, obtaining raw materials for metallurgical, chemical and other industries.

In 2022 206,5 million tons of coal were transported through coal seaports in Russia – Ust-Luga, Vanino, Vostochny, Taman and Nakhodka, which is greater than in 2021 by 1.8 %. [1–3].

The vast majority of warehouses for temporary storage of coal are open areas, where coal is placed, pre-stacked in a stack, having, as a rule, the geometric shape of a trapezoid. One of the most significant disadvantages of this storing method is not only its quality drop due to exposure to weather, but also the wind erosion, which leads to generation and spread of coal dust thus negatively affecting the environment [4–6]. As an alternative way for temporary coal storing using closed temporary storages can minimize all negative factors of open type storing [7; 8].

While storing in closed temporary storages is obviously better from ecological standpoint, this method can lead to dangerous concentrations of gas in the storage's atmosphere, which may become the reason for storage employees' health issues. These can be caused by methane inflow from stored coal, which remained in coal fragments after excavation and transportation. Residual coal's gas content value should be considered as the main factor that determines possible violation of threshold limit value (1 % of volume)[1].

While storing coal in closed temporary storages the most rational way to maintain threshold limit value of gas is ventilation. Its necessity and parameters, including value of air inflow, mostly depend on residual coal's gas content before its unloading in closed temporary storages.

Therefore, the determination of required air inflow for closed temporary storage should be based on credible information about residual coal's gas content. It defines relevance of this paper's problem. Full research cycle was conducted for coal from Kuznetsk basin with grades G and J, which have natural gas content higher than 15 m^3/t reaching up to 25 m^3/t at certain depths [9]. Another point of this research is that these types of coal have the biggest commercial interest for marine export and, thus, for maintaining ecological safety during temporary storing in port terminals.

Problem formulation

According to scientific literature [10–12], coal's gas content (methane content) after excavation and transportation to the surface is significantly lower than natural gas content in natural environment. Calculations, which were conducted according to instructional guidelines «Coal mine ventilation system design guide», showed that prolonged coal storing in the mine working greater than 10 days lowers coal's gas content by more than 2.5 times.

However, with high initial coal's gas content it doesn't decrease significantly even after transportation to the surface. For example, with natural coal's gas content of 30–40 m^3/t, transportation to the surface may decrease the content only to 12–15 m^3/t.

Further decrease in coal's gas content will continue during transportation by train. The dynamic of this process depends on the type of carriage, trains' velocity V_t (km/h), coal's swell factor K_s.

Coal is transported by train mostly with the use of open and closed four-axle carriages [13; 14], also recently open top containers started getting used.

Average coal transportation takes from 7 to 14 days depending on the distance traveled. Within this whole time the process of methane desorption from coal continues without interruptions. Gas release intensity of transported coal significantly depends on the value of effective diffusion coefficient D_{eff} (m^2/s) [15–17], value of which was determined by us during experimental research [9].

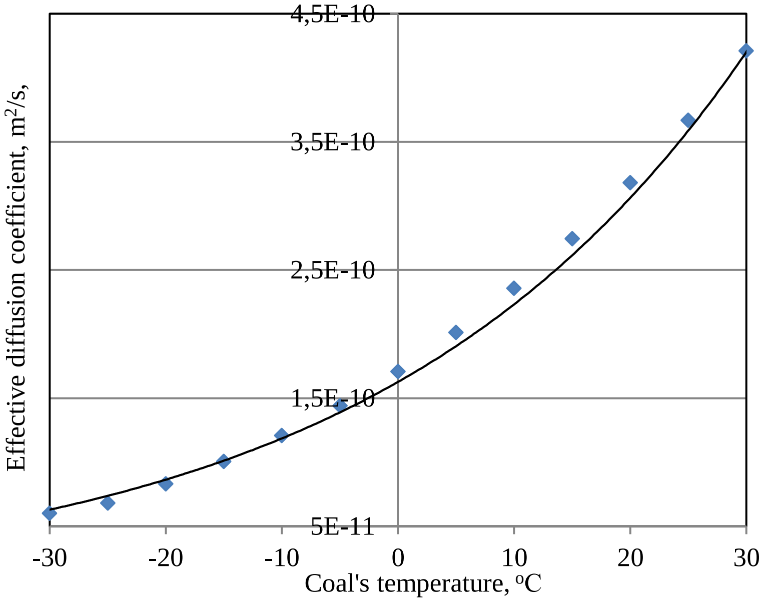

Figure 1. – Correlation between effective diffusion coefficient and mean coal mass temperature

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[1] On approval of Federal norms and rules in the field of industrial safety «Safety rules for processing, preparation and briquetting of coal»: Order of the Federal Service for Environmental, Technological and Nuclear Supervision, No. 428, October 28, 2020: registered in the Ministry of Justice of Russia, December 21, 2020.

The presented graph in figure 1 suggests that the value of effective diffusion coefficient depends on coal mass temperature. Since coal's temperature during transportation can change depending on atmospheric air's temperature, it is proposed to set the value of the effective diffusion coefficient by the mean integral over the transportation period and volume average temperature of coal mass in railcars.

In order to calculate mean and averaged temperatures per unit of coal volume during the transportation process following conditions will be applied:

1. Inhomogeneous coal mass in carriages will be considered as homogeneous and defined by three effective thermophysical properties: thermal conductivity coefficient λ_{eff} (W/(m·K)), specific heat capacity C_{eff} (J/(kg·K)) and thermal diffusivity α_{eff} (m^2/s), values of which are applied according to recommendations from suggested studies [18; 19].

2. Four-axle carriage's complex shape will be considered as a cylinder with equivalent radius R_{car} (m), which will be calculated using the following formula:

$$R_{\text{car}} = 2S_{\text{car}} / u_{\text{car}}, \tag{1}$$

where S_{car} – four-axle carriage's cross-section area, m^2;

u_{car} – carriage's perimeter, m.

Heat dissipation coefficient α_{n} can be calculated with the following empirical formula [20]:

$$\alpha_{\text{n}} = \alpha_{\text{n.r}} + \frac{0.7(V_{\text{t}} + 15)}{L_{\text{car}}^{0.2}}, \tag{2}$$

where $\alpha_{\text{n.r}}$ – radiant component of heat dissipation, $\text{W/(m}^2\text{·K)}$ ($\alpha_{\text{n.r}} = 9$ $\text{W/(m}^2\text{·K)}$ under summer conditions);

L_{car} – carriage's length, m;

15 – dimensional coefficient, km/h;

0.7 – dimensional coefficient, $\frac{\text{W}}{\text{m}^{1.8}\cdot\text{K}}\Big/\text{km/h}$.

The results of α_{n} calculations indicate that at train speeds greater than 60 km/h, the value of α_{n} exceeds 50 $\text{W/(m}^2\text{·K)}$. This gives us justification to assume that heat transfer intensity between carriages' surfaces and atmospheric air can be calculated with first-type boundary conditions.

The solution of calculating the heat transfer with equivalent thermophysical properties that models a rail carriage is done approximately and is based on Bubnov – Galerkin method [21].

The correlation between dimensionless mean integral temperature $\bar{\theta}$ and cylinder's cross-section has the following form:

$$\bar{\theta} = 0.693e^{-5.78F_0^{\text{coal}}} + 0.197e^{-36.88F_0^{\text{coal}}}, \tag{3}$$

where F_0^{coal} – Fourier diffusion number for coal ($F_0^{\text{coal}} = \alpha_{\text{eq}}\tau / R_{\text{car}}^2$; α_{eq} – equivalent thermal diffusivity m^2/s; τ – transportation duration, s).

Dimensionless mean temperature of coal mass during transportation to temporary storage can be calculated using correlation (3) and the following ratio:

$$\bar{\theta}_{\text{m}} = \frac{1}{F_0^{\text{coal}}}\int_0^{F_0^{\text{coal}}} \bar{\theta}\, dF_0^{\text{coal}} \approx \frac{0.12}{F_0^{\text{coal}}}\left[1 - e^{-5.78F_0^{\text{coal}}}\right] + \frac{0.00534}{F_0^{\text{coal}}}\left[1 - e^{-36.88F_0^{\text{coal}}}\right]. \tag{4}$$

Then, the average temperature of the coal mass $\bar{T}_{\text{m}}$ (K) is calculated by the following formula:

$$\bar{T}_{\text{m}} = t_{\text{air}} + \bar{\theta}_{\text{m}}(T_0 - t_{\text{air}}), \tag{5}$$

where t_{air} – air temperature, K;

T_0 – initial coal mass temperature, K.

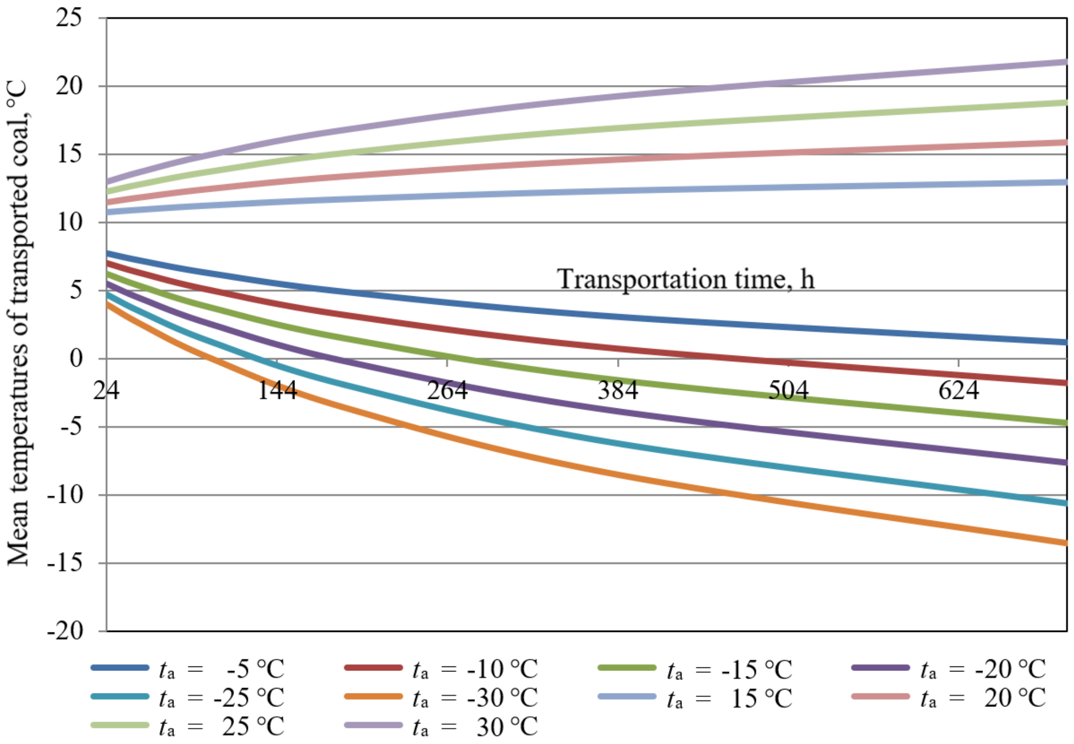
Research's results discussion

The following calculations were done using correlation (4) for base data (table 2) with atmosphere's temperature and transportation time as variables.

Table 1. – Thermophysical properties of coal mass and its components

Thermal conductivity, W/(m·K)		Specific heat capacity, J/(kg·K)		Relative volume		Effective properties of heterogeneous environment		
						Thermal conductivity λ_{eff}, W/(m·K)	Specific heat capacity C_{eff}, J/(kg·K)	Thermal diffusivity α_{eff}, m^2/s
coal	air	coal	air	coal	air			
0.25	0.031	1300	1005	0.7	0.3	0.145	1212	0.0000013

Results are represented in Figure 2.



t_a – air temperature

Figure 2. – Average temperature of coal mass during transportation to temporary storage

Analysis of the procured data shows that with prolonged transportation, depending on the weather, average temperature of coal mass can decrease by 10–20 °C in winter season and increase by 50–10 °C in summer season.

Change in coal's gas content inside carriage X_τ (m^3/t) relative to the initial value is equal to the difference between initial value X_0 and the total value of gas release:

$$X_\tau = X_0 \left(1 - 2\frac{F_{sur}\rho_{coal}}{P_{car}}\sqrt{\frac{D_{eff}\tau}{\pi}}\right), \qquad (6)$$

where F_{sur} – coal's surface inside the carriage, m^2;

ρ_{coal} – coal density, kg/m^3;

P_{car} – carriage's load capacity, kg.

Airflow rate that maintains methane concentration inside coal's storage below 1 % is calculated based on methane airflow and total side surface of coal pile.

Joint graph for coal's gas content (methane content) calculation during transportation depending on different atmospheric air's temperatures and airflow rate is represented in figure 3.

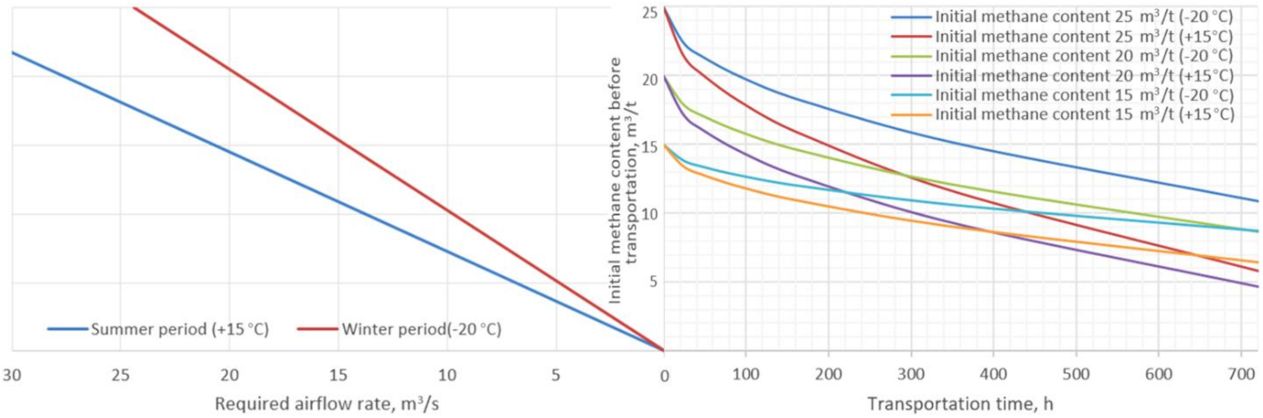


Figure 3. – Graph for residual coal's gas content and required airflow rate determination for closed temporary storage's ventilation during 5 days of storing

As the represented graph from figure 3 shows, the required airflow rate that will maintain safe exploitation of closed temporary storage with methane release depends on residual coal's gas content (methane content) before transportation and transportation duration. For example, during 10-day transportation in winter season coal's gas content will drop from 20 to 13 m^3/t and the value of the required air flow rate will be 17 m^3/s.

Conclusion

1. Determination of purposefulness of ventilation installation in order to prevent methane concentration higher than 1 % should be based on credible information about residual coal's gas content after excavation, transportation to surface and to temporary storages.

2. Gas release intensity of transported coal significantly depends on the value of effective diffusion coefficient D_{eff}, which, in turn, depends on the average value of coal mass temperature: coal mass's temperature increase quickens the rate of methane desorption from coal fragments, which decreases residual coal's gas content of coal mass during its transportation compared to winter season.

3. Calculation of the average temperature of the coal mass loaded into cars over the transportation period can be carried out assuming the possibility of replacing a heterogeneous coal mass with a homogeneous one with equivalent thermophysical properties based on the approximate Bubnov – Galerkin method.

4. Coal's gas content monotonically decreases during its transportation. With residual coal's gas content value of 15 m^3/t, a gradual decrease in coal's gas content can be observed during its transportation to temporary storage. Thus, after seven days of coal mass transportation during winter season at -20 °C the residual coal's gas content will be approximately equal to 11 m^3/t, after 15 days – lower than 8 m^3/t, in summer season at +15 °C it will be 9,5 m^3/t and lower than 6 m^3/t accordingly.

5. Airflow that is required to decrease methane concentration below 1 % increases with higher residual coal's gas content before unloading in the temporary storage. Thus, in order to ensure normal methane concentration for 5 days with residual coal's gas content of 15 m^3/t, required airflow rate will be equal to 15 m^3/s during winter season and 20 m^3/s during summer season.

REFERENCES

1. Potekhina A.M., Potekhina A.M., Dekanova N.P. Perspective volumes of cargo transportation at the Eastern polygon up to 2030. *Proc. of VII All-Russian scientific-practical conf. «Modern Russian science: current issues, achievements and innovations», Penza, March 15, 2024*. Penza: Nauka I Prosveshchenie, 2024. Pp. 17–21. (rus). EDN: CAUCXR.

2. Krivopishina M.E. Rational equipment of the seaport terminal for export coal. *Scientifically technical and economical cooperation in Asia-Pacific countries in the 21st century*, 2021. Vol. 1. Pp. 86–90. (rus). EDN: GOGGJT.
3. Cherepanov R.Yu., Solov'ev A.S. Environmental safety at the coal terminal in the port of Vanino. Proc. of X All-Russian (with international participation) scientific-technical conf. of young researchers «Actual problems of construction, housing and communal services and technosphere safety», Volgograd, April 24–29, 2023. Volgograd State Technical University, 2023. Pp. 319–320. (rus). EDN: GNVHYJ.
4. Kostyunichev D.N., Otdelkin N.S. Assessment of the meshed screens operability to reduce dust emissions of bulk cargo from the ports open warehouses. *Vestnik Gosudarstvennogo universiteta morskogo i rechnogo flota imeni admirala S.O. Makarova*, 2024. Vol. 16, No. 1. Pp. 55–63. (rus). DOI: 10.21821/2309-5180-2024-16-1-55-63. EDN: KKAQND.
5. Rodionov V.A., Tursenev S.A., Skripnik I.L., Ksenofontov Y.G. Results of the study of kinetic parameters of spontaneous combustion of coal dust. *Journal of Mining Institute*, 2020. Vol. 246. Pp. 617–622. (rus). DOI: 10.31897/PMI.2020.6.3. EDN: AWHZJW.
6. Rush E.A., Vlasova N.V. Promising measures aimed at environmental protection when working with coal at the production sites of the terminal and storage complex. *Modern Technologies. System analysis. Modeling*, 2023. No. 2 (78). Pp. 20–32. (rus). EDN: EFGFKC.
7. Al'mukhametova S.G. Transition of open coal stockpiles to closed ones as a solution to the problem of dust emissions into the environment. *Proc. of XIX Youth intern. scientific-practical conf. of students and young scientistson «Step into the future: theoretical and applied researches of modern science», St. Petersburg, May 19-20, 2020*. Morrisville, NC, USA: Lulu Press, 2020. Pp. 25–28. (rus). EDN: MDUDDQ.
8. Tankov A.M., Salikhov V.A. Assessment of the impact on the environment of coal storage conditions in open and closed coal warehouses in Kuzbass [Electronic resource]. *Proc. of XIX Intern. scientific-practical conf. «Natural and intellectual resources of Siberia. Sibresurs 2022», Kemerovo, November 23–24, 2022*. Kemerovo: T.F. Gorbachev State Technical University, 2022. Article 116. 5 p. (rus). EDN: DZPLFS.
9. Gendler S.G., Vasilenko T.A., Stepantsova A.Yu. Investigation of mass transfer of hard coal during its transportation to the place of temporary storage. *Mining information and analytical bulletin*, 2023. No. 9-1. Pp. 135–148. (rus). DOI: 10.25018/0236_1493_2023_91_0_135. EDN: KLQAFM.
10. Guo J., Gao J., Yan K., Zhang B. Unintended mitigation benefits of China's coal de-capacity policies on methane emissions. *Energy Policy*, 2023. Vol. 181. Article 113718. DOI: 10.1016/j.enpol.2023.113718.
11. Vasilenko T.A., Islamov A.H., Kirillov A.K., Doroshkevich A.S. Investigation of the hierarchical structure of pores of fossil coals by non-destructive methods. *Mining information and analytical bulletin*, 2018. No. S49. Pp. 33–48. (rus) DOI: 10.25018/0236-1493-2018-11-49-33-48. EDN: YSTLRR.
12. Starikov G.P., Yurchenko V.M., Mel'nik T.N., Khudoley O.G., Kravchenko A.V. Activation of methane diffusion in coal under varied mechanical and thermodynamical parameters of a coal seam. *Physics and High Pressure Technology*, 2019. Vol. 29, No 3. Pp. 122–130. EDN: SZNRTE.
13. Churashev V.N. Prospects for transportation of coal of Siberian deposits. *ECO*, 2015. No. 5. Pp. 82–98. (rus). EDN: TRSNPR.
14. Astafurov N.A. Coal transportation in Russia. *Scientific forum. Siberia*, 2015. No 1. Pp. 84–85. (rus). EDN: VXEDML.
15. Vasilenko T.A., Kirillov A.K., Molchanov A.N., Pronskii E.A. An NMR study of the ratio between free and sorbed methane in the pores of fossil coals. *Chemistry of Solid Fuel*, 2018. Vol. 52, No. 6. Pp. 361–369. DOI: 10.3103/S0361521918050087. EDN: JPANAG.
16. Gaidarov B.A. Review of the key characteristics of experimental methods for coalbed methane diffusion coefficient measurment. *Trudy Instituta geologii Dagestanskogo nauchnogo centra RAN*, 2022. No. 4 (91). Pp. 24–31. (rus). DOI: 10.33580/2541-9684-2022-91-4-24-31. EDN: UOBFYT.
17. Fel'dman E.P., Vasilenko T.A., Kalugina N.A. Physical kinetics of coal-methane system: mass transfer, pre-outburst events. *Journal of Mining Science*, 2014. Vol. 50, No 3. Pp. 448–464. DOI: 10.1134/S1062739114030077. EDN: XNLHZZ.
18. Kudryakov O.V., Varavka V.N., Arefeva L.P. Engineering-physical method for determining the thermal conductivity of objects with micrometric thickness and a complex structure. *Safety of Technogenic and Natural Systems*, 2023. Vol. 7, No. 2. Pp. 80–89. (rus). DOI: 10.23947/2541-9129-2023-7-2-80-89. EDN: ETRLSY.

19. Gribovskiy G.V., Shuplyakov M.Yu. Review of methods for determination of heat exchange coefficient for different surfaces under MMG conditions. *Proc. of Sixth conference of geocryologists of Russia «Monitoring in Cryolite Zone» with participation of Russian and foreign scientists, engineers and specialists. Lomonosov Moscow State University, June 14-17, 2022*. Moscow: Dobrosvet, 2022. Pp. 595–599. (rus). EDN: FQSKIT
20. Balalayev A.N., Mokshanov A.S., Parenyuk M.A. Thermal properties of carriages and containers made of extruded aluminum panels. *Transport of the Russian Federation*, 2014. No. 1 (50). Pp. 58–60. (rus). EDN: SCCIIV.
21. Sukhoterin M.V., Sosnovskaya A.A., Pizhurina N.F. Shear buckling of ship structures rectangular elements. *Vestnik Gosudarstvennogo universiteta morskogo i rechnogo flota imeni admirala S.O. Makarova*, 2023. Vol. 15, No. 6. Pp. 1054–1065. (rus). DOI: 10.21821/2309-5180-2023-15-6-1054-1065. EDN: UWSTSW.

Изменение газоносности углей при транспортировке до места временного хранения

Change of coal's gas content during transportation to the temporary storage

Гендлер Семен Григорьевич
доктор технических наук, профессор

Федеральное государственное бюджетное образовательное учреждение высшего образования «Санкт-Петербургский горный университет императрицы Екатерины II», кафедра безопасности производств, заведующий кафедрой

Адрес: Васильевский остров, 21-я линия, 2, 199106, г. Санкт-Петербург, Россия
Email: Gendler_SG@pers.spmi.ru
SPIN-код: 4043-5453

Semyon G. Gendler
Grand PhD in Technical Sciences, Professor

Federal State Budgetary Educational Institution of Higher Education «St. Petersburg Mining University of Empress Catherine the Great», Chair of Industrial Safety,
Head of the Chair

Address: Vasilyevsky Island, 21st Line, 2, 199106, St. Petersburg, Russia
Email: Gendler_SG@pers.spmi.ru
ORCID: 0000-0002-7721-7246
ScopusID: 56168675100
ResearcherID: I-9283-2017

Степанцова Анастасия Юрьевна

Федеральное государственное бюджетное образовательное учреждение высшего образования «Санкт-Петербургский горный университет императрицы Екатерины II», кафедра безопасности производств,
аспирант

Адрес: Васильевский остров, 21-я линия, 2, 199106, г. Санкт-Петербург, Россия
Email: s215060@stud.spmi.ru
SPIN-код: 4509-5158

Anastasiia Yu. Stepantsova

Federal State Budgetary Educational Institution of Higher Education «St. Petersburg Mining University of Empress Catherine the Great», Chair of Industrial Safety,
postgraduate student

Address: Vasilyevsky Island, 21st Line, 2, 199106, St. Petersburg, Russia
Email: s215060@stud.spmi.ru
ORCID: 0000-0002-5027-4742
ScopusID: 58723881500

Мозжанов Дмитрий Борисович

Специалист в области горного дела

Адрес: г. Санкт-Петербург, Россия
Email: mozzhanof904@yandex.ru

Dmitry B. Mozzhanov

Specialist in mining engineering

Address: St. Petersburg, Russia
Email: mozzhanof904@yandex.ru
ORCID: 0009-0003-2112-5785

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ИЗМЕНЕНИЕ ГАЗОНОСНОСТИ УГЛЕЙ ПРИ ТРАНСПОРТИРОВКЕ ДО МЕСТА ВРЕМЕННОГО ХРАНЕНИЯ

Гендлер С.Г., Степанцова А.Ю., Мозжанов Д.Б.

Цель. Установление взаимосвязи между остаточной газоносностью углей, размещаемых на временное хранение в закрытых угольных складах, относительно начальной газоносности в природных условиях, зависящей от продолжительности транспортировки и метеорологических условий во время транспортирования угольной массы по железной дороге, и количеством воздуха, обеспечивающим при проветривании закрытого склада нормативную концентрацию метана.

Методы. Анализ процесса транспортировки углей от места добычи до их временного складирования, учитывающего время транспортировки, тип вагонов и значение температуры наружного воздуха; экспериментальное определение коэффициента эффективной диффузии метана из угольных отдельностей; теоретические исследования динамики температурных полей в угольной массе, находящейся в железнодорожных вагонах; расчетный анализ динамики газоносности углей во время транспортировки и взаимосвязи остаточной газоносности с расходом воздуха для проветривания закрытого угольного склада.

Результаты. В работе представлены результаты исследований изменения метаноносности угля в процессе добычи, извлечения его на поверхность и последующей транспортировки железнодорожным способом до мест временного хранения на основе оценки влияния физико-химических свойств угля, в частности эффективного коэффициента диффузии, а также средней температуры окружающей среды. Показано, что значение эффективного коэффициента диффузии, зависящее от времени транспортировки угля и его среднего диаметра частиц, увеличивается при повышении средней температуры угольной массы. На основе приближенного метода Бубнова – Галеркина получена средняя температура угольной массы на единицу объема за период транспортировки. Остаточная газоносность угля после транспортировки вычислена как разница между величиной газоносности после его погрузки в вагоны и газоносностью после доставки угля к месту временного хранения. Установлена взаимосвязь между величиной остаточной газоносности углей и расходом воздуха, необходимым для проветривания закрытого склада.

Область применения исследований. Результаты исследования могут быть использованы для обеспечения метанобезопасности при временном хранении угольного сырья на закрытых складах.

Ключевые слова: каменный уголь, транспортировка каменного угля, газоносность угольных пластов, остаточная газоносность, метан, предельно-допустимая концентрация, угольный склад, временное хранение угля.

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ЛИТЕРАТУРА

1. Потехина, А.М. Перспективные объемы грузоперевозок на восточном полигоне до 2030 года / А.М. Потехина, А.М. Потехина, Н.П. Деканова // Современная российская наука: актуальные вопросы, достижения и инновации: сб. статей VII Всероссийской науч.-практ. конф., Пенза, 15 марта 2024 г. – Пенза: Наука и Просвещение (ИП Гуляев Г.Ю.), 2024. – С. 17–21. – EDN: CAUCXR.
2. Кривопишина, М.Е. Рациональное оснащение терминала морского порта для экспортного угля / М.Е. Кривопишина // Научно-техническое и экономическое сотрудничество стран АТР в XXI веке. – 2021. – Т. 1. – С. 86–90. – EDN: GOGGJT.
3. Черепанов, Р.Ю. Экологическая безопасность на угольном терминале в порту Ванино / Р.Ю. Черепанов, А.С. Соловьев // Актуальные проблемы строительства, ЖКХ и техносферной безопасности: материалы X Всероссийской (с международным участием) научно-технической конференции молодых исследователей, Волгоград, 24–29 апр. 2023 г. – Волгоград: ВолгГТУ, 2023. – С. 319–320. – EDN: GNVHYJ.

4. Костюничев, Д.Н. Оценка работоспособности сетчатых экранов по снижению пылевыбросов сыпучих грузов с открытых складов портов / Д.Н. Костюничев, Н.С. Отделкин // Вестник Государственного университета морского и речного флота имени адмирала С.О. Макарова. – 2024. – Т. 16, № 1. – С. 55–63. – DOI:10.21821/2309-5180-2024-16-1-55-63. – EDN: KKAQND.
5. Родионов, В.А. Результаты исследования кинетических параметров самовозгорания каменноугольной пыли / В.А. Родионов [и др.] // Записки Горного института. – 2020. – Т. 246. – С. 617–622. – DOI: 10.31897/PMI.2020.6.3. – EDN: AWHZJW.
6. Руш, Е.А. Перспективные мероприятия, направленные на экологическую защиту при работе с углем на производственных участках терминально-складского комплекса / Е.А. Руш, Н.В. Власова // Современные технологии. Системный анализ. Моделирование. – 2023. – № 2 (78). – С. 20–32. – EDN: EFGFKC.
7. Альмухаметова, С.Г. Переход открытых складов угля к закрытым как решение проблемы выбросов пыли в окружающую среду / С.Г. Альмухаметова // Шаг в будущее: теоретические и прикладные исследования современной науки: материалы XIX Молодежной международной научно-практической конференции студентов, аспирантов и молодых ученых, Санкт-Петербург, 19–20 мая 2020 г. – Morrisville, NC, USA: Lulu Press, 2020. – С. 25–28. – EDN: MDUDDQ
8. Танков, А.М. Оценка влияния на экологию условий хранения угля в открытых и закрытых угольных складах Кузбасса / А.М. Танков, В.А. Салихов // Природные и интеллектуальные ресурсы Сибири. Сибресурс 2022: сб. материалов XIX Междунар. науч.-практ. конф., Кемерово, 23–24 нояб. 2022 г. – Кемерово: Кузбас. гос. техн. ун-т им. Т.Ф. Горбачева, 2022. – Статья 116. – 5 с. – EDN: DZPLFS.
9. Гендлер, С.Г. Экспериментальные исследования параметров массопереноса в каменных углях / С.Г. Гендлер, Т.А. Василенко, А.Ю. Степанцова // Горный информационно-аналитический бюллетень. – 2023. – № 9-1. – С. 135–148. – DOI: 10.25018/0236_1493_2023_91_0_135. – EDN: KLQAFM.
10. Guo, J. Unintended mitigation benefits of China's coal de-capacity policies on methane emissions / Jinling Guo, Junlian Gao, Kejia Yan, Bo Zhang // Energy Policy. – 2023. Vol. 181. – Article 113718. – DOI: 10.1016/j.enpol.2023.113718.
11. Василенко, Т.А. Исследование иерархической структуры пор ископаемых углей неразрушающими методами / Т.А. Василенко [и др.] // Горный информационно-аналитический бюллетень. – 2018. – № S49. – С. 33–48. – DOI: 10.25018/0236-1493-2018-11-49-33-48. – EDN: YSTLRR.
12. Стариков, Г.П. Активация диффузии метана в угле под воздействием изменяющихся механических и термодинамических параметров пласта / Г.П. Стариков [и др.] // Физика и техника высоких давлений. – 2019. – Т. 29, № 3. – С. 122–130. – EDN: SZNRTE.
13. Чурашев, В.Н. Перспективы развития транспортировки угля сибирских месторождений / В.Н. Чурашев // ЭКО. – 2015. – № 5. – С. 82–89. – EDN: TRSNPR.
14. Астафуров, Н.А. Транспортировка угля в России / Н.А. Астафуров // Научный форум. Сибирь. – 2015. – № 1. – С. 84–85. – EDN: VXEDML.
15. Василенко, Т.А. ЯМР-исследование соотношения свободного и сорбированного метана в порах ископаемых углей / Т.А. Василенко [и др.] // Химия твердого топлива. – 2018. – № 6. – С. 21–29 – DOI: 10.1134/S0023117718050092. – EDN: YNNNPN.
16. Гайдаров, Б.А. Обзор основных характеристик экспериментальных методов измерения коэффициента диффузии метана угольных пластов / Б.А. Гайдаров // Труды института геологии дагестанского научного центра РАН. – 2022. – № 4 (91). – С. 24–31. – DOI: 10.33580/2541-9684-2022-91-4-24-31. – EDN: UOBFYT.
17. Фельдман, Э.П. Физическая кинетика угольный пласт-метан: массоперенос, предвыбросные явления / Э.П. Фельдман, Т.А. Василенко, Н.А. Калугина // Физико-технические проблемы разработки полезных ископаемых. – 2014. – № 3. – С. 46–65. – EDN: SMIDIZ.
18. Кудряков, О.В. Инженерно-физический метод определения теплопроводности объектов микрометрической толщины со сложной структурой / О.В. Кудряков, В.Н. Варавка, Л.П. Арефьева // Безопасность техногенных и природных систем. – 2023. – № 2. – С. 80–89. – DOI: 10.23947/2541-9129-2023-7-2-80-89. – EDN: ETRLSY.
19. Грибовский, Г.В. Обзор методик по определению коэффициента теплообмена для различных поверхностей в условиях ММГ / Г.В. Грибовский, М.Ю. Шупляков // Сборник докладов Шестой

конференции геокриологов России «Мониторинг в криолитозоне» с участием российских и зарубежных ученых, инженеров и специалистов. МГУ им. М.В. Ломоносова, 14–17 июня 2022 г.: сб. статей. – М.: «КДУ», «Добросвет», 2022. – С. 595–599. – EDN: FQSKIT.

20. Балалаев, А.Н. Теплотехнические свойства вагонов и контейнеров из экструдированных алюминиевых панелей / А.Н. Балалаев, А.С. Мокшанов, М.А. Паренюк // Транспорт Российской Федерации. – 2014. – № 1 (50). – С. 58–60. – EDN: SCCIIV.
21. Сухотерин, М.В. Устойчивость прямоугольных элементов судовых конструкций при чистом сдвиге / М.В. Сухотерин, А.А. Сосновская, Н.Ф. Пижурина // Вестник Государственного университета морского и речного флота имени адмирала С.О. Макарова. – 2023. – Т. 15, № 6. – С. 1054–1065. – DOI: 10.21821/2309-5180-2023-15-6-1054-1065. – EDN: UWSTSW.