UDC 519.6:504.054
DOI: 10.30838/J.BPSACEA.2312.261223.143.1017

EXPERIMENTAL STUDY OF THE INTENSITY OF COAL DUST REMOVAL

BILIAIEV M.M.[1], *Dr. Sc. (Tech.), Prof.,*
BERLOV O.V.[2*], *Cand. Sc. (Tech.), Assoc. Prof.,*
BRAZALUK Yu.V.[3], *Cand. Sc. (Phys.-Math.), Assoc. Prof.,*
KOZACHYNA V.A.[4], *Cand. Sc. (Tech.), Assoc. Prof.,*
OLADIPO M.O.[5], *PhD*

[1] Department of Hydraulics, Water Supply and Physics, Ukrainian State University of Science and Technologies, 2, Lazaryana St., Dnipro, 49010, Ukraine, tel. +38 (056) 373-15-09, e-mail: biliaiev.m@gmail.com, ORCID ID: 0000-0002-1531-7882
[2*] Department of Life Safety, Prydniprovska State Academy of Civil Engineering and Architecture, 24-a, Architect Oleh Petrov St., Dnipro, 49005, Ukraine, tel. +38 (056) 756-34-57, e-mail: berlov.oleksandr@pdaba.edu.ua, ORCID ID: 0000-0002-7442-0548
[3] Department of Aerohydromechanics and Energy and Mass Transfer, Oles Honchar Dnipro National University, 72, Haharina Ave., Dnipro, 49000, Ukraine, tel. +38 (056) 373-15-09, e-mail: brazaluk_jv@ukr.net, ORCID ID: 0000-0001-6448-8525
[4] Department of Hydraulics, Water Supply and Physics, Ukrainian State University of Science and Technologies, 2, Lazaryana St., Dnipro, 49010, Ukraine, tel. +38 (056) 273-15-09, e-mail: v.kozachyna@gmail.com, ORCID ID: 0000-0002-6894-5532
[5] GeoLab Drilling, Bill Rutledge Road, 800, Winder, 30680, USA, tel. +38 (056) 273-15-09, e-mail: oladipo.toye@outlook.com, ORCID ID: 0000-0001-7945-6657

Abstract. ***Problem statement.*** Industrial sites where coal storages are located are intensive sources of dust pollution of the environment. There is an important problem of assessing the intensity of dust removal into the atmospheric air from polluted areas. Knowledge of the intensity of dust removal into the atmospheric air makes it possible to scientifically assess the impact of contaminated sites on the pollution of the environment and work zones at industrial sites. The solution to this problem can be obtained experimentally. ***The purpose of the article.*** An experimental study of the value of the air flow velocity at which the detachment of dust particles from the surface with coal begins and their removal into the air and the determination of the intensity of the emission of coal dust from the contaminated surface. ***Methodology.*** The intensity of removal of coal dust from the contaminated area was studied experimentally in laboratory conditions. The research was conducted on coal samples from DTEK "Pavlohradvuhillya", grade "ДГ. During the research, the velocity of the air flow at which the process of movement of dust particles along the emission source began and the velocity of "detachment" of dust particles and their removal from the emission source were determined. At the second stage of experimental research, the intensity of removal of coal dust from the polluted area was determined. ***Scientific novelty.*** The values of the air velocity at which the removal of coal dust particles from the contaminated area begins were determined experimentally. The regularity of the intensity of the removal of coal dust depending on the velocity of the air flow over the contaminated area was obtained. ***Practical significance.*** The obtained experimental data make it possible to determine under which weather conditions there is a risk of dust formation and the removal of dust into the atmosphere. The empirical dependence obtained by processing experimental data can be used for a scientifically based assessment of the level of pollution of working areas at industrial sites where there are coal storage facilities. ***Conclusions.*** The value of the velocity of the air flow at which the movement of dust particles on the contaminated surface begins, as well as the value of the velocity of the air flow at which the removal of dust particles into the air begins, was determined experimentally. The resulting empirical model can be used to estimate environmental damage due to dust pollution of atmospheric air.

Keywords: *coal dust; atmospheric pollution; dust emissions; laboratory experiment*

ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ІНТЕНСИВНОСТІ ВИНОСУ ВУГІЛЬНОГО ПИЛУ

БІЛЯЄВ М. М.[1], *докт. техн. наук, проф.,*
БЕРЛОВ О. В.[2*], *канд. техн. наук, доц.,*
БРАЗАЛУК Ю. В.[3], *канд. фіз.-мат. наук, доц.,*
КОЗАЧИНА В. А.[4], *канд. техн. наук, доц.,*
ОЛАДІПО М. О.[5], *докт. філософії*

[1] Кафедра гідравліки, водопостачання та фізики, Український державний університет науки і технологій, вул. Лазаряна, 2, Дніпро, 49010, Україна, тел. +38 (056) 373-15-09, e-mail: biliaiev.m@gmail.com, ORCID ID: 0000-0002-1531-7882

[2*] Кафедра безпеки життєдіяльності, Придніпровська державна академія будівництва та архітектури, вул. Архітектора Олега Петрова, 24-а, Дніпро, 49005, Україна, тел. +38 (056) 247-16-01, e-mail: berlov.oleksandr@pdaba.edu.ua, ORCID ID: 0000-0002-7442-0548
[3] Кафедра аерогідромеханіки та енергомасопереносу, Дніпровський національний університет імені Олеся Гончара, пр. Гагаріна, 72, Дніпро, 49000, Україна, тел.+38 (056) 373-15-09, e-mail: brazaluk_jv@ukr.net, ORCID ID: 0000-0001-6448-8525
[4] Кафедра гідравліки, водопостачання та фізики, Український державний університет науки і технологій, вул. Лазаряна, 2, Дніпро, 49010, Україна, тел. +38 (056) 273-15-09, e-mail: v.kozachyna@gmail.com, ORCID ID: 0000-0002-6894-5532
[5] GeoLab Drilling, Bill Rutledge Road, 800, Winder, 30680, USA, тел. +38 (056) 273-15-09, e-mail: oladipo.toye@outlook.com, ORCID ID: 0000-0001-7945-6657

Анотація. ***Постановка проблеми.*** Промислові майданчики, де розташовуються сховища вугілля, − це інтенсивні джерела пилового забруднення навколишнього середовища. Виникає важлива проблема оцінювання інтенсивності виносу пилу в атмосферне повітря від забруднених ділянок. Знання інтенсивності виносу пилу в атмосферне повітря дає можливість науково обґрунтовано оцінити вплив забруднених ділянок на забруднення довкілля та робочих зон на промислових майданчиках. Рішення проблеми може бути отримане експериментальним шляхом. ***Мета роботи*** − експериментальне дослідження значення швидкості повітряного потоку, за якої починається відрив часток пилу від поверхні з вугіллям та винос їх у повітря і визначення інтенсивності емісії вугільного пилу від забрудненої поверхні. ***Методика.*** Інтенсивність виносу вугільного пилу від забрудненої ділянки досліджувалася експериментальним шляхом у лабораторних умовах. Дослідження проводилися на зразках вугілля з ПрАТ «ДТЕК Павлоградвугілля», марки ДГ. Визначалася швидкість повітряного потоку, за якому починався процес руху частинок пилу вздовж джерела емісії та швидкість відриву частинок пилу та їх винос від джерела емісії. На другому етапі експериментальних досліджень визначалася інтенсивність виносу вугільного пилу від забрудненої ділянки. ***Наукова новизна.*** Експериментальним шляхом обчислено значення швидкості повітря, за якої починається винос частинок вугільного пилу від забрудненої ділянки. Отримано закономірність інтенсивності виносу вугільного пилу залежно від швидкості повітряного потоку над забрудненою ділянкою. ***Практична значимість.*** Отримані експериментальні дані дають можливість визначати, за яких метеоумов виникає ризик пилоутворення та винос пилу в атмосферне повітря. Емпірична залежність, отримана шляхом обробки даних експериментів, може бути використана для науково обґрунтованої оцінки рівня забруднення робочих зон на промислових майданчиках, де є сховища вугілля. ***Висновки.*** Експериментальним шляхом визначено значення швидкості повітряного потоку, за якої починається рух частинок пилу на забрудненій поверхні, а також значення швидкості повітряного потоку, за якої починається винос у повітря частинок пилу. Отримана емпірична модель може бути використана для оцінювання екологічних збитків унаслідок пилового забруднення атмосферного повітря.

Ключові слова: *вугільний пил; забруднення атмосфери; емісії пилу; лабораторний експеримент*

Problem statement. Assessing the level of dust air pollution at industrial sites is an important issue in the field of occupational health and environmental safety [3; 4]. At industrial sites, where there are coal storage facilities, areas of coal contamination of the site's underlying surface are always formed (Fig. 1).

Fig. 1. Pollution of the industrial site territory (https://www.shutterstock.com/ru/search/coal-production)

It should be emphasized, that areas with small fractions of coal dust are formed on the underlying surface of these sites. Even at low wind velocities, these areas become secondary sources of dust pollution in the working areas of the industrial site. Therefore, there is an important problem of protecting the air in the working areas of the industrial site from dust pollution. This problem attracts special attention, since coal is widely used in the energy sector of the world and coal storage facilities are widely used at industrial sites of thermal power plants, boiler houses, enterprises.

In solving this problem, it is important to determine at what wind velocity the dust particles begin to detach from the coal surface and are carried into the air. In addition, it is very important to determine the intensity of dust emissions under different meteorological conditions, primarily at different wind

velocities. This information makes it possible to determine under what meteorological conditions there is a risk of secondary dust air pollution at an industrial site. It should be emphasized, that the value of the wind velocity, at which the movement of dust particles begins and they are carried into the air, makes it possible to assess the effectiveness of protective measures planned to reduce the intensity of dust formation at industrial sites.

It should be noted, that the solution of problems in the field of dust pollution is based on the widespread use of experimental research methods [1−9]. Conducting field studies is associated with many difficulties. Therefore, an important method of analysis is a laboratory experiment.

The purpose of the article. Experimental study of the value of the air flow velocity, at which dust particles begin to detach from the surface with coal and are carried away into the air, and determination of the intensity of coal dust emission from the contaminated surface.

Methodology. The experimental study was carried out in laboratory conditions. The scheme of the experimental setup is shown in Fig. 2 [1].

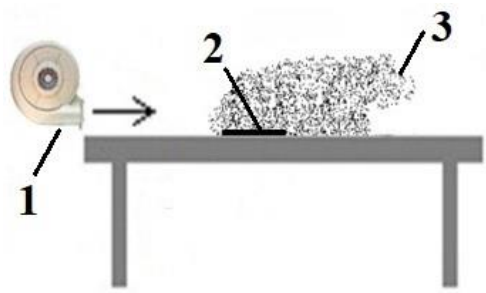

Fig. 2. Scheme of the experimental setup: 1 – blower; 2 – emission source; 3 – dust plume

The laboratory study was carried out using coal from DTEK "Pavlohradvuhillya" PJSC, grade "ДГ'. A section of coal was placed on a table in the form of a "beach'; the shape of this source of dust emission is a rectangle, length 5 sm, width 5 sm (Fig. 2). A blower was used to create a flow with different velocities v_i over the "beach". The airflow velocity was measured using GM8908 anemometer. Since the measurement was carried out in a turbulent flow, the velocity shown by the anemometer is in a certain range. The air temperature during the experiment was 20 °C.

Results. During the experiment, the air flow velocity was visually recorded at which the process of movement of dust particles along the emission source began (the *"creep"* type velocity v_{cr}) and the velocity of "etachment" of dust particles and their removal from the emission source (the "*suspension"* type velocity v_{su}). The measurement results are as follows:

v_{cr} = 0,8 m/s–1,1m/s;

v_{su} = 1,5m/s–1,7m/s.

Figure 3 shows the dust pollution zone formed near the emission source during the experiment.

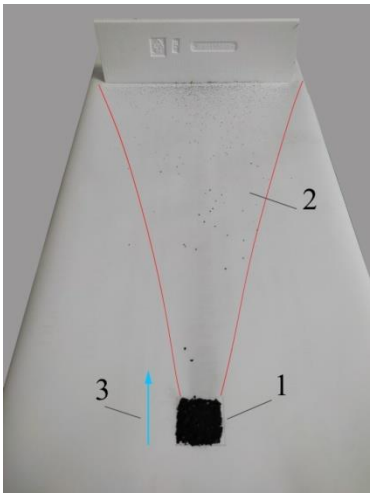

Fig. 3. Dust contamination zone: 1 – emission source; 2 – contamination zone; 3 – wind flow direction

As can be seen from Figure 3, a "cone" shaped contamination area is formed near the emission source. The most intense contamination occurs near the source of emission, as evidenced by the darker color of the contamination zone. The following should also be noted: the area of the source of pollution was 25 sm^2, but the area of the pollution zone (Fig. 3) was about 1 600 sm^2. Thus, the removal of dust particles from an insignificant in size emission source forms a very significant zone of secondary pollution.

At the second stage of the experiment, the amount of coal dust blown off the surface during a specific period of time was estimated. The blowing took place for 30 seconds. After that, the mass of dust, that

was blown off the beach during this time, was determined by measuring it on the scales. Further, the intensity of dust emission from a unit area of the beach was calculated at the selected air flow velocity:

$$q_i = \frac{M_i}{t \cdot S}\left[\frac{\text{g}}{\text{cm}^2 \cdot \text{s}}\right],$$

where M_i is the mass of coal dust blown off the beach in time t at air velocity v_i; S is "beach" area.

The results of processing the experiments to determine the q_i parameter are shown in Figure 4 – where the dependence of the dust emission intensity on the unit area of the beach surface at different air flow velocities is shown.

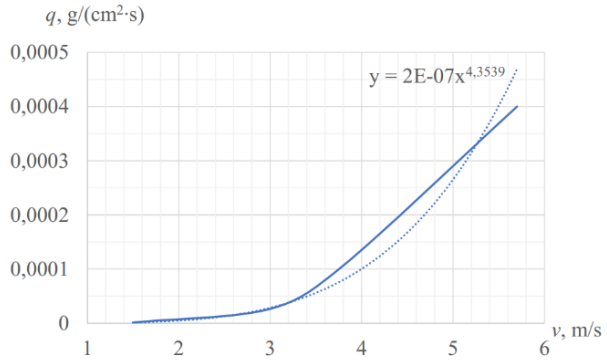

Fig. 4. Intensity of coal dust emission from the beach surface $\left(g/(cm^2 \cdot s)\right)$ *at different air flow velocities*

Based on the results of processing the experimental data, the following mathematical dependence was obtained for calculating the amount of coal dust q carried away from unit surface the beach per time:

$$q = 2 \cdot 10^{-7} \cdot v^{4.35}, \frac{\text{g}}{\text{cm}^2 \cdot \text{s}},$$

where v – air flow velocity, m/s.

This relationship can be used to quickly estimate the amount of coal dust carried away from contaminated surfaces formed at industrial sites.

Scientific novelty and practical value. The critical air flow velocity at which the emission of coal dust from a contaminated area at an industrial site into the atmosphere begins has been determined experimentally. Based on the processing of the experimental data, a dependence was obtained that makes it possible to calculate the intensity of coal dust emissions from a contaminated area at an industrial site. The results of the experiment can be used to assess the risk of dust formation at industrial sites with coal storage facilities.

Conclusions

1. The value of the air flow velocity at which the movement of dust particles on the contaminated surface begins, as well as the value of the air flow velocity at which the removal of dust particles into the air begins, was determined experimentally.

2. A dependence (empirical model) was obtained that allows determining the intensity of coal dust removal from a contaminated surface at different wind velocities.

3. The obtained empirical model can be used to assess environmental damage caused by dust pollution of the atmospheric air.

REFERENCES

1. Biliaiev M.M., Biliaieva V.V., Berlov O.V. and Kozachyna V.A. *CFD-modelyuvannya v analizi efektyvnosti system zaxystu dovkillya ta pracivnykiv na robochyx miscyax : monografiya* [CFD modeling in the analysis of the effectiveness of environmental protection systems and workers at workplaces : monograph]. Dnipro : Zhurfond Publ., 2022. (in Ukrainian).

2. Biliaiev M.M., Oladipo M.O. and Kirichenko P.S. *Zashhyta okruzhayushhej sredы pry transportyrovke uglya : monografiya* [Environmental protection during coal transport : monograph]. Kryvyj Rig : Vydavecz R.A. Kozlov, 2018. (in Russian).

3. Ikonnikova N.A, Yurchenko A. A., & konnikov M. Yu. *Eksperimentalnyye issledovaniya koeffitsiyenta zakhvata zhelezorudnoy pyli kaplyami vody pri eye oroshenii* [Experimental studies of the coefficient of capture of iron ore dust by water droplets during irrigation]. *Zbirnyk naukovyx pracz Nacionalnogo girnychogo universytetu* [Collection of scientific works of the National Mining University]. 2018, vol. 54, pp. 363−377. (in Russian).

4. Methodical instructions. *Ocinka ryzyku dlya zdorovya naselennya vid zabrudnennya atmosfernogo povitrya* [Assessment of the risk to public health from atmospheric air pollution]. In accordance with the order of the Ministry of Health of Ukraine dated April 13, no. 184, 2007. (in Ukrainian).

5. Serebrenikov E.V. *Rozrobka metodyky vyznachennya koncentraciyi pylu na dilyankax robochyx zon karyeriv pry perevantazhenni girnychoyi masy : avtoreferat dysertaciyi* [Development of a methodology for determining the

concentration of dust in the areas of the working zones of quarries when mining mass is overloaded : the abstract of the dissertation]. Kryvyj Rih, 2010. (in Ukrainian).

6. Robert Kotchenruther. *Fugitive Dust from Coal Trains Factors Effecting Emissions & Estimating PM2.5*, EPA Region 10, NW–AIRQUEST, 2013. URL: http://lar.wsu.edu/nw-airquest/docs/201306_meeting/20130606 Kotchenruther_coal_trains.pdf

7. Oladipo M.O., Biliaiev M.M. and Kozachyna V.A. Numerical analysis of atmosphere pollution from coal train. East European Scientific Journal. 2019, vol 3 (43), pp. 10−15.

8. Ferreira A.D., Viegas D.X. and Sousa A.C.M. Full-scale measurements for evaluation of coal dust release from train wagons with two different shelter covers. Journal of Wind Engineering and Industrial Aerodynamics. 2003, vol. 91 (10), pp. 1271−1283.

9. Ferreira A.D. and Vaz P. A. Wind tunnel study of coal dust release from train wagons. Journal of Wind Engineering and Industrial Aerodynamics. 2004, vol. 92, pp. 565–577.

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

1. Біляєв М. М., Біляєва В. В., Берлов О. В., Козачина В. А. CFD-моделювання в аналізі ефективності систем захисту довкілля та працівників на робочих місцях : монографія. Дніпро : Журфонд, 2022. 268 с.

2. Беляев Н. Н., Оладипо М. О., Кириченко П. С. Защита окружающей среды при транспортировке угля : монографія. Кривой Рог : Изд. Р. А. Козлов, 2018. 132 с.

3. Иконникова Н. А, Юрченко А. А., Иконников М. Ю. Экспериментальные исследования коэффициента захвата железорудной пыли каплями воды при ее орошении. *Збірник наукових праць Національного гірничого університету. 2*018. № 54. С. 363−377.

4. Оцінка ризику для здоров'я населення від забруднення атмосферного повітря : методичні вказівки (у відповідності із наказом МОЗ України від 13.04.2007 р. № 184.)

5. Серебреніков Е. В. Розробка методики визначення концентрації пилу на ділянках робочих зон кар'єрів при перевантаженні гірничої маси : автореф. дис. канд. техн. наук. Кривий Ріг, 2010. 20 с.

6. Robert Kotchenruther. Fugitive Dust from Coal Trains Factors Effecting Emissions & Estimating PM2.5, EPA Region 10, NW–AIRQUEST, 2013. URL : http://lar.wsu.edu/nw-airquest/docs/201306_meeting/20130606_ Kotchenruther_coal_trains.pdf

7. Biliaiev M. M., Kozachyna V. A., Oladipo M. O. Numerical analysis of atmosphere pollution from coal train. *East European Scientific Journal*. 2019. Vol 3 (43). Pp. 10−15.

8. Ferreira A. D., Viegas D. X., Sousa A. C. M. Full-scale measurements for evaluation of coal dust release from train wagons with two different shelter covers. *Journal of Wind Engineering and Industrial Aerodynamics*. 2003. Vol. 91 (10). Pp. 1271−1283.

9. Ferreira A. D., Vaz P. A. Wind tunnel study of coal dust release from train wagons. *Journal of Wind Engineering and Industrial Aerodynamics*. 2004. Vol. 92. Pp. 565–577.

Надійшла до редакції: 18.11.2023.