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Reducing of coal dust release from train wagon with barrier

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Abstract. Intensive environment pollution takes place during coal transportation in open wagons. Emission of coal dust from the coal wagons cause contamination of atmosphere and territory adjacent to the railway track. Different ways to reduce coal dust emission from the wagon are used in the world. Unfortunately, in Ukraine, this problem is far from solution and there is no serious research work in this field. The aim of this work was laboratory study of coal dust emission from the wagon model which had different barriers installed on the wagon. Laboratory experiments were carried for coal wagon without barrier and for coal wagon which had barriers of two types. Barrier of the first type had downwind wing. Barrier of the second type had upwind wing. The contamination zones, concentration near the model were studied. The obtained results illustrate that installation of barriers influence intensity of transport corridor contamination. Also a numerical model was developed to estimate wind flow and coal dust dispersion from the coal wagon. Equation of potential flow and equation of coal dust dispersion were used. Implicit difference schemes of splitting were used for numerical simulation of governing equations. Results of numerical experiment, which were performed, are presented.

1. Introduction

Exploitation of railway transport and development of railway infrastructure [1] has a different effect on environment. Many problems arise, which are connected with ballast layer contamination, noise and emission of harmful compounds [2, 3], waste management [4] etc.

Worthy of note, that coal trains have an intensive negative impact on environment [5-7]. Transportation of coal in open wagons results in cargo loss and intensive environment pollution. Reducing of coal dust emission from trains is a very important problem [8, 9]. Coal dust emission intensity depends on the following factors: train velocity, cargo shape in the wagon, moisture etc. There are two important tasks in the current problem. The first task is prediction of the atmosphere and underlying surface pollution from coal train. The second task is minimization of coal dust emission intensity from wagon. In order to solve the second task, various methods are used, for example, shelter



cover systems [10, 11], canvas usage, special solutions usage, watering of coal, etc. Analysis of scientific publication showed that, in Ukraine, there is not research work connected with reducing of coal dust emission from wagons. The purpose of the work was study of barrier installation on coal wagon to reduce coal dust emission. In this paper authors show results of laboratory study which was performed in Dnipro National University of Railway Transport named after academician V. Lazaryan (Ukraine, Project 0115U007227 «Environment protection at the elements of transport infrastructure»).

2. Experimental setup

The laboratory experiments were performed for a 1:100 scale model of the open wagon. This model (scenario #1) is shown in Figure 1. Laboratory experiments to study the efficiency of barrier installation on the coal wagon to reduce the coal dust environment pollution were performed at Hydraulics department of the University.



Figure 1. Model of the coal wagon without barrier (scenario #1).

Two types of barriers on the coal wagon were studied. The first type of barrier was the barrier with downwind wing (scenario #2). This type of the barrier is shown in Figure 2.



Figure.2. Model of the coal wagon with barrier: 1 – barrier (barrier + downwind wing, scenario #2).

The second type of the barrier was the barrier with upwind wing (scenario #3). This type of the barrier is shown in Figure 3.



Figure 3. Model of the coal wagon with barrier: 1 – barrier (barrier + upwind wing, scenario #3).

Sketch of the laboratory setup is shown in Figure 4. The industrial fan was used to initiate wind flow over the wagon model (Figure 4). The Reynolds number in the experiments was $Re = 10^5$. The length of the wagon as the characteristic dimension for calculation Re number was chosen. Coal from Mezhdurechenskaya Central Enriching Factory was used in the experiments. During the experiments concentration of coal dust PM_{2.5} has been measured behind the model. The Air Quality Detector WP6910 was used to measure coal dust concentration near the coal wagon model. To measure air speed anemometer GM8908 was used.

To weight coal dust which was emitted from the wagon model and set near the model the balance KL168 was used.

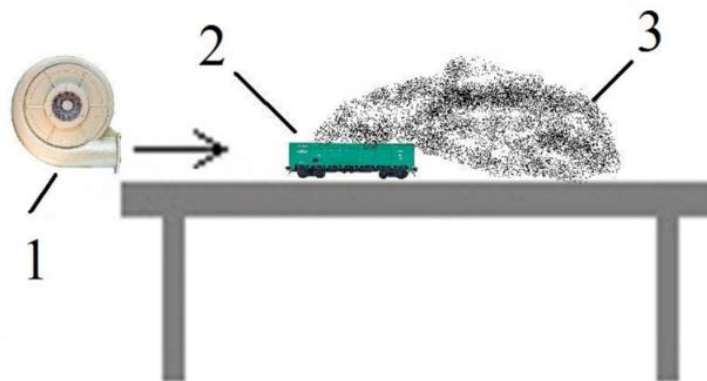


Figure 4. Sketch of laboratory setup: 1 – fan; 2 – model of the coal wagon; 3 – coal dust dispersion.

3. Results

During the laboratory experiments some aspects of the problem connected with coal dust emission from wagon were studied. First of all, form of contamination zone on the ground near the wagon model was investigated. Figures 5–7 show contamination zones for all three scenarios.

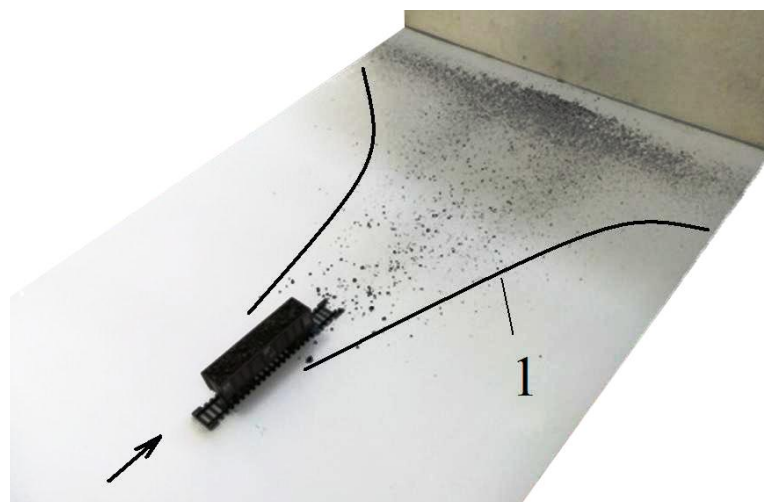


Figure 5. Contamination zone near the coal wagon (no barrier on the wagon, scenario #1).

The contamination zone, which was formed near the wagons, was quite different for each scenario (Figures 5–7). For the case when an open wagon without barrier is used (Figure 5) this contamination zone has intensive “black” color which indicates on the intensive emission of coal dust from the

wagon. This contamination zone has conical form. For this scenario the ballast layer and the ground adjacent to the railway track will be hardly contaminated.

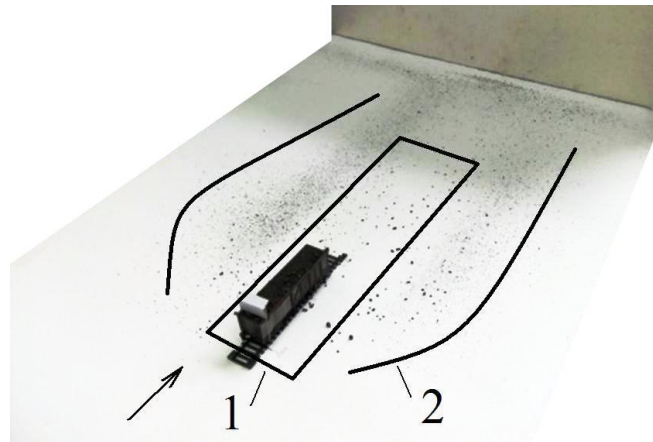


Figure 6. Contamination zone near the coal wagon with barrier (barrier + downwind wing, scenario #2): 1 – internal subregion with low contamination; 2 – boundary of second subregion.

For the case when an open wagon with “barrier+ downwind wing” is used, the contamination zone can be separated in two subregions (Figure 6). The first subregion (first contamination zone) is light colored and it is situated inside the whole contamination zone and it covers railway track. The second subregion is a boundary, like a belt, for the first subregion. It has «black» color, but less intensive as in scenario #1 (coal wagon without barrier). The first contamination zone has a rectangular form. In this case the region near the track is not contaminated hardly. The pollutant mostly set in another part of the ground, far from the track. That means that in this scenario ballast layer will be less contaminated then in scenario #1.

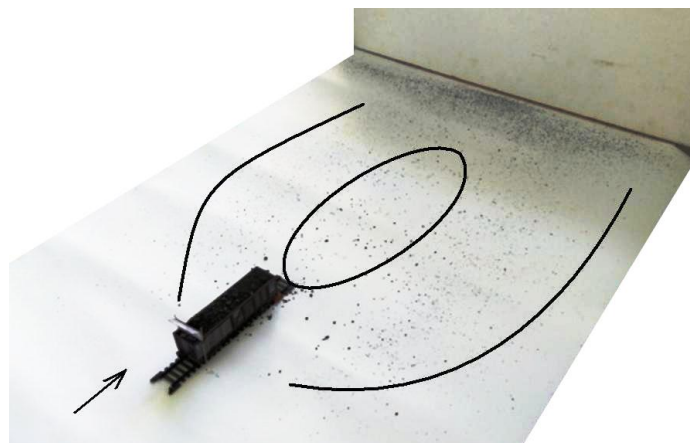


Figure 7. Contamination zone near the coal wagon with barrier (barrier + upwind wing, scenario #3).

For the case when an open wagon with «barrier + upwind wing» is used, the contamination zone can be separated in two subregions too (Figure 7). The first subregion (first contamination zone) has about an oval form.

In Table 1 coal dust concentration (PM2.5) is presented, which was measured at different distances from the model of a coal wagon. The concentration was measured at the distances $L, 2L, 3L$, where L is the length of the wagon. The concentration was measured at height of the wagon.

Table 1. Coal dust concentration for considered scenarios.

Distance	Dust concentration ($\mu\text{g} \cdot \text{m}^{-3}$)		
	scenario #1	scenario #2	scenario #3
L	500	95	23
$2L$	128	54	17
$3L$	68	36	11

It is clear (Table 1), application of barriers allows to reduce air pollution near the coal wagon. If the mass of coal dust which is emitted from the model without barrier is equal to 100%, then for scenario #2 (barrier + downwind wing) mass of emitted coal dust is about 89% and for scenario #3 (barrier + upwind wing) mass of emitted coal dust is about 84%.

4. Mathematical model

For practice, it is necessary to have mathematical models to predict air pollution near the coal wagon which allow quickly to perform numerical experiment to study the process of coal dust emission from wagons. To simulate air pollution near coal wagon the following modeling equations were used [12, 13]:

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial (v - w_s)C}{\partial y} = \frac{\partial}{\partial x} \left(\mu_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu_y \frac{\partial C}{\partial y} \right) + \sum q_i \delta(x - x_i) \delta(y - y_i), \quad (1)$$

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} = 0; u = \frac{\partial P}{\partial x}, v = \frac{\partial P}{\partial y}, \quad (2)$$

where C is coal particles concentration; t is time; μ_x, μ_y are turbulent diffusion coefficients; (x_i, y_i) are coordinates of coal particles emission point source; $\delta(x - x_i) \delta(y - y_i)$ is Dirac's delta-function; q_i is coal particles emission rate form the cargo surface; w_s is coal particles fallout speed; u, v are wind velocity components; P is velocity potential.

Parameters μ_x, μ_y, w_s are computed using empirical formulae [13].

Boundary conditions and initial ones are discussed in [14]. To form cargo surface in wagon markers technique was used [14]. Emission rate q of coal dust from each part of cargo surface depends on local speed and was calculated using empirical formula [15].

5. Numerical integration

Wind flow near the coal wagon is computed on the base of equation (2). Before integration of this equation, it was written it in the following form [16]:

$$\frac{\partial P}{\partial t} = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2}, \quad (3)$$

where t is fictitious time.

To solve equation (3), the following two steps scheme of splitting was used [16]:

$$\frac{P_{i,j}^{n+\frac{1}{2}} - P_{i,j}^n}{\Delta t} = \left[\frac{-P_{i,j}^{n+\frac{1}{2}} + P_{i-1,j}^{n+\frac{1}{2}}}{\Delta x^2} \right] + \left[\frac{-P_{i,j}^{n+\frac{1}{2}} + P_{i,j-1}^{n+\frac{1}{2}}}{\Delta y^2} \right], \frac{P_{i,j}^{n+1} - P_{i,j}^{n+\frac{1}{2}}}{\Delta t} = \left[\frac{P_{i+1,j}^{n+1} - P_{i,j}^{n+1}}{\Delta x^2} \right] + \left[\frac{P_{i,j+1}^{n+1} - P_{i,j}^{n+1}}{\Delta y^2} \right]. \quad (4)$$

At each step of splitting an explicit formula is used to calculate P . The computation procedure is finished if the following condition is fulfilled:

$$|P_{ij}^{n+1} - P_{ij}^n| \leq \varepsilon, \tag{5}$$

where ε is a small number (e.g., $\varepsilon = 0.001$); n is an iteration number.

Air velocity vector components are computed at the sides of computational cell:

$$u_{ij} = \frac{P_{ij} - P_{i-1,j}}{\Delta x}, v_{ij} = \frac{P_{ij} - P_{i,j-1}}{\Delta y}. \tag{6}$$

For the numerical integration of equation (1) the change–triangular difference scheme was used [14]. To create code, FORTRAN language was used.

In Figures 8, 9 results of numerical simulations which were performed on the basis of developed numerical model are presented. These figures show dimensionless concentration in per cents from the maximum concentration C_{max} . In these figures numbers are printed using format «Integer». It means, for example, if concentration is equal to 15.34%, then the printed number is 15%. Worthy of note, that computational time was 5 s.

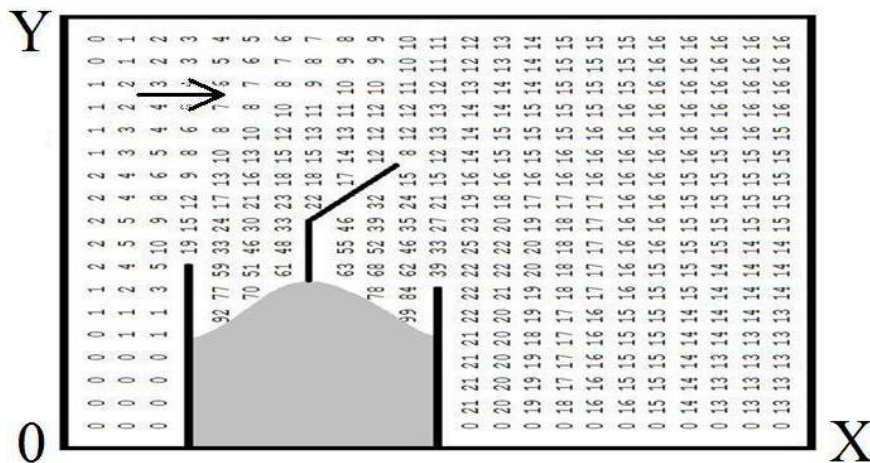


Figure 8. Computed coal dust concentration near the coal wagon with barrier (barrier + downwind wing, scenario #2), $C_{max} = 32.82$.

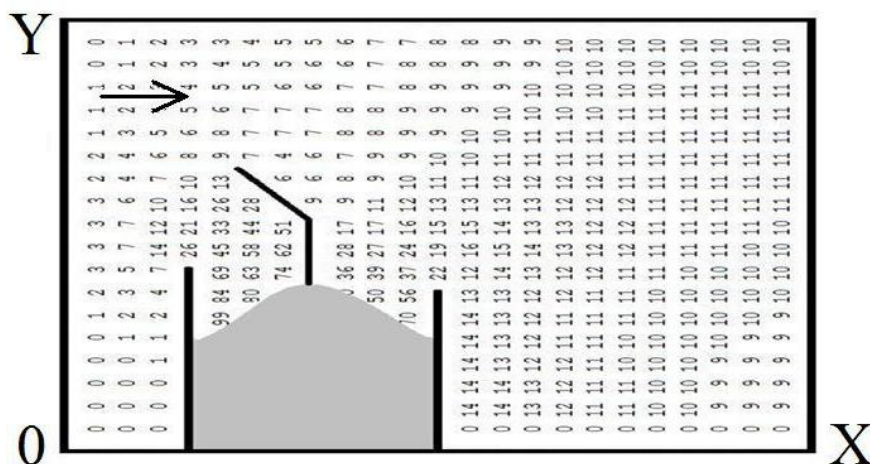


Figure 9. Computed coal dust concentration near the coal wagon with barrier (barrier + upwind wing, scenario #3), $C_{max} = 35.58$.

6. Conclusions

Coal dust emission from trains has a negative impact on environment. To minimize coal dust emission from the wagon, it was proposed to use barriers which are installed on the wagon. Results of laboratory experiments are presented. The experiments were performed to study the influence of barriers having different forms. During the laboratory experiments some aspects were studied: form of ground contamination zones, influence of barrier form on the coal dust emission rate and coal dust concentration near the wagon. Results discussed are preliminary ones and the experiments will be continue for another conditions. Numerical model was developed to compute coal dust concentration field near wagons with barriers. This model takes into account air flow velocity, diffusion, different coal dust emission rate from different parts of cargo in wagon, geometrical shape of barrier which is placed on the wagon. Model allows to obtain very quickly coal dust concentration near the coal wagon and near the railway tracks. This information can be used to evaluate level of pollution at different zones for different barriers installed on the coal wagon.

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