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# TRANSPORT MEANS 2021

Sustainability: Research and Solutions

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## PART II

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The proceedings of the 25th International Scientific Conference Transport Means 2021 contain selected papers of 9 topics: Aviation, Automotive, Defence Technologies, Fuels and Combustion, Intelligent Transport Systems, Railway, Traffic, Transport Infrastructure and Logistics, Waterborne Transport.

All published papers are peer reviewed.

The style and language of authors were not corrected. Only minor editorial corrections may have been carried out by the publisher.

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# PREFACE

25th international scientific conference TRANSPORT MEANS 2021 due to the COVID-19 pandemic in the world, for the second time was organized as a virtual event on 06-08 October, 2021. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

The conference aims to provide a platform for discussion, interactions and exchange between researchers, scientists and engineers.

The reports cover a vide variety of topics related to the most pressing issues of today's transport systems development.

The main areas covered in plenary session and in the sections are: design development, maintenance and exploitation of transport means, implementation of advanced transport technologies, development of defense transport, environmental and social impact, advanced and intelligent transport systems, transport demand management, traffic control, specifics of transport infrastructure, safety and pollution problems, integrated and sustainable transport, modeling and simulation of transport systems and elements.

In the invitations to the conference, sent five months before the conference starts, the instructions how to prepare reports and how to model the manuscripts are provided as well as the deadlines for the reports are indicated.

Those who wish to participate in the conference should send the texts of the reports that meet relevant requirements under indicated deadlines. Each report must include: a short description of the idea or technique being presented, a brief introduction orienting to the importance an uniqueness of the submission, a thorough description of research course and comments on the results.

The submissions are matched to the expertise according to the interests and are forwarded to the selected reviewers.

Scientific Editorial Committee revises, groups the properly prepared reports according to the theme and design the conference programme.

The Proceedings are compendium of selected reports presented at the Conference.

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Prof. V. Ostaševičius

# Watering of Cargo for Reducing Dust Emissions from Coal Wagon

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**Abstract**

Open topped coal wagons are widely used in different countries. The coal surface exposed to air emits intensively fugitive dust. Water application is used for reducing fugitive dust emissions from open topped coal trains. The objective of this research was to develop numerical model to study efficacy of water application on the surface of coal. To simulate air flow over coal wagon Euler equations were used. These equations were written in Helmholtz variables "vorticity–flow function". Finite difference schemes of splitting were used for numerical integration of Euler equations. To simulate coal dust dispersion from coal wagon mass transfer equation was used. This equation took into account air flow speed, turbulent diffusion, dust emission rate from cargo surface. To solve mass transfer equation change-triangle implicit difference scheme of splitting was used. To simulate water evaporation from cargo and dust emission rate dependence from moisture, empirical models were used. On the basis of developed numerical model computer code was developed using FORTRAN. Results of numerical experiments are presented.
**KEY WORDS:** *coal wagon, watering of cargo, atmosphere pollution, numerical simulation*

## 1. Introduction

Coal dust emissions from trains have been the subject of many studies in the world [1-6]. Emissions of particulate matter in the form of coal dust impact ambient air quality in transport corridor. Coal dust may contain traces of heavy metals. This coal dust is toxic for human being and people who live near the transport corridor and can be affected. Coal transportations by trains may have cumulative impact on people. That is why much attention is put to the development of different methods to reduce coal dust pollution. To reduce coal dust emissions different methods are used: load profiling of coal surface, veneering, application of special covers on the wagon, etc [1, 2]. One of the simplest approaches to reduce coal dust emissions is watering of cargo in the wagon. But during transportation water is evaporated from the cargo and coal dust emissions increase. That is why it is important to know time period when "protection" function of this method is vanished. Mathematical simulation is a powerful method to solve this problem

## 2. Mathematical Model

Coal dust is emmited from the surface of cargo in coal wagon. To simulate coal dust dispersion in atmosphere convective-diffusion equation was used [10, 12]:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial (v-w)C}{\partial y}=div(\mu\cdot gradC)+\sum_{i=1}^{N}Q_i(t)\delta(x-x_i)\delta(y-y_i) \tag{1}$$

where $C$ is coal dust concentration; $\mu_x, \mu_y$ are coefiicients of turbulent diffusion; $Q$ is coal dust emission rate from the cargo surfaceIt is considered that, $Q=f(x_i, y_i, M)$; $M$ is moisture content; $(x_i, y_i)$ are Cortesian coordinates; $\delta(x-x_i)\delta(y-y_i)$ is Dirac delta-function; $w$ is gravitation fallout; $t$ is time.

Surface of cargo is modelled using point sources and Delta function.

Parameters $\mu_x, \mu_y$ are computed using empirical formulae [11]. Initial and boundary conditions for governing equations are discussed in [10].

There are different formulas to calculate coal dust emissions from the coal surface. As a rule, these are empiric formulas. In this work to calculate coal dust emission rate the following empiric formula was used [6]:

$$Q = 4,2 \cdot (V - V_t), \tag{2}$$

where $V_t$ is threshold speed; $V$ is wind local velocity over the coal surface.

Watering of coal surface in the coal wagon changes coal moisture. Addition moisture enlarges the threshold wind velocity $V_t$ and that results in decreasing of emission rate. If moisture is large the emission rate is small. For practice, it is important to find out the relationship between emission rate and moisture or the relationship between moisture and threshold wind velocity. As a rule, empiric models are used to describe such relationship for different substances. For instance, relationship between moisture and threshold speed $V_t$ of sandy loam can be described as following [7]:

$$V_t = 4,97 + 0,268 \cdot W^{1,58}. \tag{3}$$

During coal wagon movement moisture content decreases as the result of water evaporation. The more coal train speed the bigger is the evaporation process. To describe this process the following empiric relation was used [8]:

$$Q_w = (5,83 + 4,1V) P_H \sqrt{M}, \tag{4}$$

where $Q_w$ is water evaporation rate (g/(m$^2$h)), $V$ is local wind velocity near the surface of coal; $P_H$ is water vapor saturation pressure; $M$ is water molecular mass.

If we supplied water volume $W_{wat}$ on the coal surface $S_{coal}$, then the depth of water penetration can be calculated as following:

$$h_{wat} = \frac{W_{wat}}{S_{coal} P_{coal}},$$

where $P_{coal}$ is porosity.

Change of coal moisture as a result of watering can be defined as:

$$W^n = \frac{M^n}{M_{coal}} \cdot 100\%,$$

where $M_{coal}$ is coal mass in watering zone; $M^n = M^n_{water} + m_0$ is mass of water in coal at current time step; $M^n_{water} = W^n \rho$; $\rho$ is water density; $m_0$ is initial water mass in this zone before watering.

Moisture content in coal will be changed during time as a result of evaporation and it can be calculated as following:

$$W^{n+1} = \frac{M^n - dm_0}{M_{coal}} 100\%,$$

where $dm_0$ is evaporated mass of water during time period $dt$; $M^n_{water}$ is mass of water in coal at previous time step.

To apply the empiric models (Eq. (2), Eq. (4)) it is necessary to compute local wind velocity at the surface of the cargo. This surface has a complex geometrical form and wind local velocity is different at different points of cargo surface. To simulate wind flow over the coal wagon with cargo Euler's equations were used. These equations were written using Helmholtz variables [9]:

$$\frac{\partial \omega}{\partial t} + \frac{\partial u\omega}{\partial x} + \frac{\partial v\omega}{\partial y} = 0; \tag{5}$$

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = -\omega, \tag{6}$$

$\omega = \partial v/\partial x - \partial u/\partial y$ is vorticity; $\psi$ is flow function; $u = \partial \psi/\partial y, v = -\partial \psi/\partial x$ are velocity components.

Initial and boundary conditions for Eq. (5), Eq. (6) are discussed in [9].

For numerical integration of governing equations rectangular grid was used. To "create" geometrical form of cargo in the coal wagon markers ("porosity technique") were used.

To solve numerically Eq. (5) two steps finite difference scheme of splitting was used [9]:

– at the first step of splitting finite difference equation was as follows ( $k=\frac{1}{2}$ ):

$$\frac{\omega_{i,j}^{k}-\omega_{i,j}^{n}}{\Delta t}+L^{+}{}_{x}\omega^{k}+L^{+}{}_{y}\omega^{k}=0; \tag{7}$$

– at the second step of splitting finite difference equation was as follows ( $k=\frac{1}{2}$ ):

$$\frac{\omega_{i,j}^{n+1}-\omega_{i,j}^{k}}{\Delta t}+L^{-}{}_{x}\omega^{n+1}+L^{-}{}_{y}\omega^{n+1}=0. \tag{8}$$

In Eq. (9), Eq. (10) the following relations were used:

$$\frac{\partial u\omega}{\partial x}=\frac{\partial u^{+}\omega}{\partial x}+\frac{\partial u^{-}\omega}{\partial x},$$

$$\frac{\partial v\omega}{\partial y}=\frac{\partial v^{+}\omega}{\partial y}+\frac{\partial v^{-}\omega}{\partial y},$$

$$u^{+}=\frac{u+|u|}{2},u^{-}=\frac{u-|u|}{2},$$

$$v^{+}=\frac{v+|v|}{2},v^{-}=\frac{v-|v|}{2},$$

$$\frac{\partial u^{+}\omega}{\partial x}\approx\frac{u_{i+1,j}^{+}\omega_{i,j}^{n+1}-u_{i,j}^{+}\omega_{i-1,j}^{n+1}}{\Delta x}=L_{x}^{+}\omega^{n+1},$$

$$\frac{\partial u^{-}\omega}{\partial x}\approx\frac{u_{i+1,j}^{-}\omega_{i+1,j}^{n+1}-u_{i,j}^{-}\omega_{i,j}^{n+1}}{\varDelta x}=L_{x}^{-}\omega^{n+1},$$

$$\frac{\partial v^{+}\omega}{\partial y}\approx\frac{v_{i,j+1}^{+}\omega^{n+1}{}_{i,j}-v_{i,j}^{+}\omega^{n+1}{}_{i,j-1}}{\varDelta y}=L_{y}^{+}\omega^{n+1},$$

$$\frac{\partial v^{-}\omega}{\partial y}\approx\frac{v_{i,j+1}^{-}\omega^{n+1}{}_{i,j+1}-v_{i,j}^{-}\omega^{n+1}{}_{i,j}}{\varDelta y}=L_{y}^{-}\omega^{n+1}.$$

Parameter " $\omega$ " was calculated from Eq. (9), Eq. (10) using explicit formulas of "running calculation" [9].

To solve Eq. (6) the following finite difference scheme was used [12]:

$$\frac{\psi_{i+1,j,k}-2\psi_{i,j,k}+\psi_{i-1,j,k}}{\varDelta x^{2}}+\frac{\psi_{i,j+1,k}-2\psi_{i,j,k}+\psi_{i,j-1,k}}{\varDelta y^{2}}=-\omega_{ij}\,. \tag{9}$$

Wind velocity compionents were calculated as follows:

$$u_{i,j}=\frac{\psi_{i,j+1}-\psi_{i,j}}{\varDelta y},v_{i,j}=-\frac{\psi_{i+1,j}-\psi_{i,j}}{\varDelta x}.$$

To solve numerically Eq. (1) it was split preliminarily as follows:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial v\,C}{\partial y}=0 \tag{10}$$

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}\left(\mu\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial C}{\partial y}\right) \quad (11)$$

$$\frac{\partial C}{\partial t}=\sum Q_i\delta(x-x_i)\delta(y-y_i) \quad (12)$$

We use here designation $v = v - w$.
At the next step the following approximations were made [9]:

$$\frac{\partial uC}{\partial x}=\frac{\partial u^{+}C}{\partial x}+\frac{\partial u^{-}C}{\partial x},$$

$$\frac{\partial vC}{\partial y}=\frac{\partial v^{+}C}{\partial y}+\frac{\partial v^{-}C}{\partial y},$$

$$u^{+}=\frac{u+|u|}{2},u^{-}=\frac{u-|u|}{2},$$

$$v^{+}=\frac{v+|v|}{2},v^{-}=\frac{v-|v|}{2},$$

$$\frac{\partial u^{+}C}{\partial x}\approx\frac{u^{+}_{i+1,j}C^{n+1}_{i,j}-u^{+}_{i,j}C^{n+1}_{i-1,j}}{\Delta x}=L^{+}_{x}C^{n+1},$$

$$\frac{\partial u^{-}C}{\partial x}\approx\frac{u^{-}_{i+1,j}C^{n+1}_{i+1,j}-u^{-}_{i,j}C^{n+1}_{i,j}}{\Delta x}=L^{-}_{x}C^{n+1},$$

$$\frac{\partial v^{+}C}{\partial y}\approx\frac{v^{+}_{i,j+1}C^{n+1}{}_{i,j}-v^{+}_{i,j}C^{n+1}{}_{i,j-1}}{\Delta y}=L^{+}_{y}C^{n+1},$$

$$\frac{\partial v^{-}C}{\partial y}\approx\frac{v^{-}_{i,j+1}C^{n+1}{}_{i,j+1}-v^{-}_{i,j}C^{n+1}{}_{i,j}}{\Delta y}=L^{-}_{y}C^{n+1}.$$

Finite difference scheme of splitting to solve Eq. (13) was as follows :

– at the first step of splitting finite difference equation was as follows ( $k=\frac{1}{2}$ ):

$$\frac{C^{k}_{i,j}-C^{n}_{i,j}}{\Delta t}+L^{+}{}_{x}C^{k}+L^{+}{}_{y}C^{k}=0\,; \quad (13)$$

– at the second step of splitting finite difference equation was as follows ( $k=\frac{1}{2}$ ):

$$\frac{C^{n+1}_{i,j}-C^{k}_{i,j}}{\Delta t}+L^{-}{}_{x}C^{n+1}+L^{-}{}_{y}C^{n+1}=0\ . \quad (14)$$

From Eq (13), Eq (14) parameter "*C*" was computed using explicit formulas of "running calculation" [9, 12].
To solve numerically Eq. (11) two steps difference scheme of splitting was used [12]:
– at the first step of splitting finite difference equation was as follows:

$$\frac{C^{n+\frac{1}{2}}_{i,j}-C^{n}_{i,j}}{\Delta t}=\left[\frac{-C^{n+\frac{1}{2}}_{i,j}+C^{n+\frac{1}{2}}_{i-1,j}}{\Delta x^{2}}\right]+\left[\frac{-C^{n+\frac{1}{2}}_{i,j}+C^{n+\frac{1}{2}}_{i,j-1}}{\Delta y^{2}}\right],$$

– at the second step of splitting finite difference equation was as follows:

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

From these dependencies, parameter "*C*" was computed using explicit formulas of "running calculation".

Euler's method was used for numerical integration of equation (13):

$$C_{ij}^{n+1}=C_{ij}^{n}+\Delta t\sum Q_i\delta(x-x_i)\delta(y-y_i)\ .$$

Computer code was developed on the basis of created numerical model. FORTRAN language was used for coding.

**3. Results**

Fig. 1-3 show coal dust concentration near the wagon for different time steps. The initial water content in coal was 4%. It was supposed that 1 liter of water was supplied on 1 $m^2$ of coal surface. Wind velocity was 18m/s, gravitational fallout was 0.001 m/sec. Computational domain was 33 m×21 m.

Every number in Fig. 1 – Fig. 3 shows concentration in percent from concentration $C = 120$ mg/m$^3$, which corresponds to the maximum coal dust concentration in computational region for the case without watering. This approach allows to analyze quickly concentration field change near the coal wagon for every specific time step.

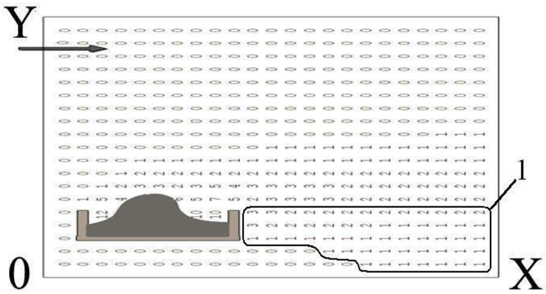


Fig. 1 Coal dust concentration near the wagon, $t$ = 200 sec:*1* – dust concentration in the range 1.2 mg/m$^3$–3.6 mg/m$^3$

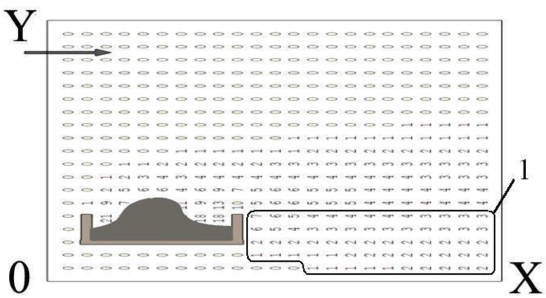


Fig. 2 Coal dust concentration near the wagon, $t$ = 2889 sec: *1* – dust concentration in the range 1.2 mg/m$^3$–8.4 mg/m$^3$

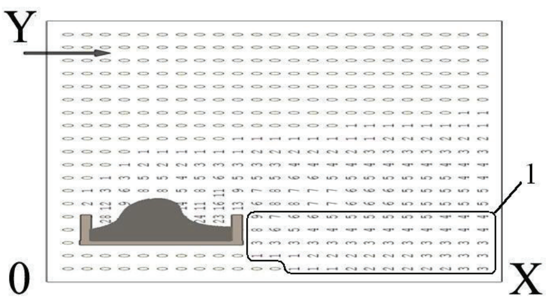


Fig. 3 Coal dust concentration near the wagon, $t$ = 4699sec:*1* – dust concentration in the range 1.2mg/m$^3$–10.8mg/m$^3$

From these Figures one can see that water evaporation from coal surface results in increasing of dust concentration near the coal wagon. During 75 min (from time $t$ = 200 sec till time $t$ = 4699 sec) maximum concentration increased in 3 times. It means that mitigating "capacity" of coal watering in wagon decreased quickly.

Worthy of note that computational time was 10sec.

## 4. Conclusions

In short, a new numerical model was developed to compute ambient air pollution from coal trains.

The model allows taking into account the effect of coal watering on the intensity of ambient air pollution.

The developed numerical model takes into account the most important physical factors which affect the coal dust pollution during coal transportation.

To predict wind flow over the coal wagon Euler equations were used. This approach allows predicting wind flow pattern over the coal wagon in 10 sec.

A developed numerical model can be used to assess the efficiency of coal watering in the wagon to reduce ambient air pollution.

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**Author's Index**

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