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NUMERICAL SIMULATION OF INFLUENCE ATMOSPHERIC BOUNDARY LAYER ON THE LOW-OXIDATION PROGRESS IN THE COAL STOCKPILE

NUMERICKÁ SIMULACE VLIVU MEZNÍ VRSTVY ATMOSFÉRY NA ROZVOJ NÍZKOTEPLOTNÍ OXIDACE VE SKLÁDCE UHLÍ

Abstract

The paper deals with formulation of CFD simulation, which describes fluid flow in atmospheric boundary layer in coal stockpile surround. The paper presents preliminary phases of global project, which aim to spontaneous ignition of coal matter in coal stockpile and coal dump. First part of the global task is focused on generation of Earth's surface topology on the basis of GIS data. Second task is focused on simplification of simulation domain and reduction of mesh size by substitution of mine building by porous subdomain. Simulations of flow in boundary layer include only eight dominant directions of wind which are specified by means of wind rose. The FFT analysis is applied to wind direction, intensity and temperature too. Spectrum of velocity and temperature were used to transient CFD simulation with real time 1 month.

Key Words

CFD, atmosphere boundary layer, coal stockpile, dump.

Abstrakt

Článek popisuje proudění větru v mezní vrstvě atmosféry kolem skládky uhlí. Tato úloha představuje dílčí úsek projektu, který řeší rozvoj nízkoteplotní oxidace ve skládkách uhlí a odvalech. Pozornost je věnována také tvorbě povrchu v okolí skládky na základě GIS dat, a následnému zjednodušení geometrie nahrazením budov porézní oblastí. Simulace proudění zahrnuje 8 dominantních směrů větrné růžice definovaných střední rychlostí. Pomocí FFT (fourierova analýza) byla provedena analýza složek okamžité rychlosti a teploty. Spektrum rychlosti a teploty v intervalu 1 měsíce bylo použito k nestacionární simulaci proudění v okolí reálné skládky uhlí.

Klíčová slova

CFD, mezní vrstva atmosféry, skládka uhlí, odval.

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1 INTRODUCTION

Flow in atmospheric boundary layer is characteristic time depending of velocity magnitude and direction vector of wind. Spontaneous ignition of coal matter in coal dump or stockpile is strongly dependent on local atmospheric condition. This case is relatively complicated because the flow in atmospheric boundary layer is fully turbulent but flow in coal dump or stockpile is laminar in terms of air flow. Flow in atmospheric boundary layer is unsteady and all phenomena occur in atmosphere at mass and heat transfer on the present. That is why the numerical simulation has to be strongly simplified and some phenomena have to be vanishing. Spontaneous ignition of coal matter is still pending problem and some phenomena of spontaneous ignition are not reliable interpreted. This process is dependent on temperature and velocity of the air which flow trough dump or stockpile. Air humidity influences this process too. A lot of questions are not answered in this branch. Decision procedure of the problem of spontaneous ignition of coal matter via air flow is proposed only because complex solution of this problem is impossible solution in relation to present computing power.

2 TOPOLOGY OF EARTH'S SURFACE

Reference case is coal stockpile of Orlova Lazy mine and this case is used to validation of numerical simulation of spontaneous ignition. Air flow in surround of coal stockpile is influenced by local atmospheric aerodynamic and Earth's surface as noted previously. That is why the geographic map in GIS format was used to define of domain. The map included significant buildings and structure of the mine. Dimension of the map was 4.3 x 4.3 km. The map was obtained as square ca 1.5 km x 1.5 km. Individual square of the map had to be merging. Product of merging was computation domain with dimension 4.3 x 4.3 km and 400 m high. Entering surfaces on all sides were necessary created by reason of identical inlet cross-section and boundary condition definition possibility. The cells equilibrium near the wall and ratio of cells had to be keep by reason of numerical stability of the turbulent quantities solution [1], [2]. Realization of these restrictions gave rise to large number of cells (1,5 million). Count of buildings and their height were problematic with reason of domain dimensions too. Hence the buildings were replaced by porous domain, which is aerodynamic equivalent, so the pressure drop of buildings and porous domain is identical. See values of resistance coefficients in Tab.1. This simplification was made with reference to hardware power and solution speed respectively. Replacing the building by porous domain was relatively primitive. Four velocity of air simulation with real buildings with were computed see Fig.1. The pressure loss was evaluated on the surface which bounded porous domain. These values were used to calculation of resistance coefficient of porous domain. This simplification three times reduced number of cells (523 thousand).

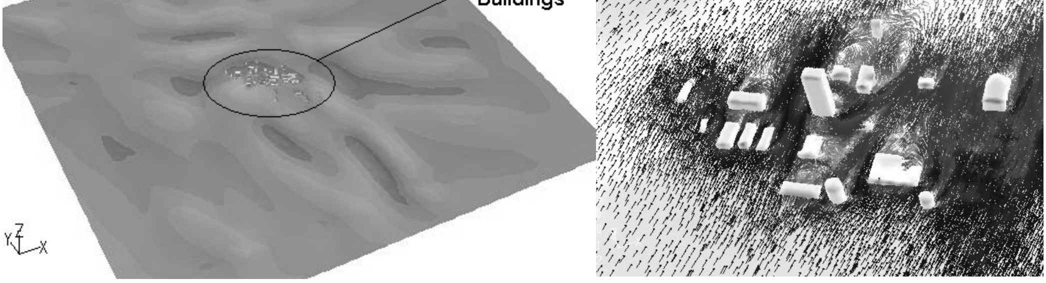

Fig.1. Geometry of Earth's surface with buildings (left) and detail of flow field near the buildings (right)

Tab.1. Calculation of resistance coefficient of porous domain

Inlet velocity	Outlet velocity	Velocity near buildings	Static pressure on boundary		Pressure difference Δp	Pressure drop	Lost coeff.	**Resistance coeff.**
$m.s^{-1}$			Pa				-	m^{-1}
17,4	22,7	21,3	378,2	72,8	305,4	176,17	0,632	**0,0021**
11,6	15,1	14,2	167,2	32,3	134,9	77,43	0,625	**0,0021**
5,8	7,6	7,1	42,2	7,8	34,4	19,98	0,645	**0,0022**
2,3	3,0	2,8	6,9	1,4	5,6	3,26	0,677	**0,0023**

3 ANALYSIS OF WEATHER CONDITIONS

The local weather condition had to be analyzing on account of spontaneous ignition of coal matter. Main parameters describing the atmospheric condition are wind velocity, direction of wind and temperature. This analysis was performed by statistic analysis, so the random function of velocity and direction of wind was substituted by eight elementary direction of wind, which is oriented equal to cardinal points. Every direction of wind was described by average velocity and percent occurrence. This statistic analysis is called wind rose. The wind rose can be performed for arbitrary time segment and it can be obtained from meteorological institution. In this case the reference time segment is July 2009. Time of record of wind with time period 15 minute was obtained and wind rose was calculated of these data. Time record included only velocity and direction of wind, so the data had to be modified before analysis. CFD simulation requires three Cartesian components of velocity. that is why the wind velocity was distributed into x and y direction see Fig.2. Z-direction velocity was zero, because convection up/downward direction of velocity is not commonly measured. Wind rose velocity analysis distributed into x, y components was usable as boundary conditions in CFD simulation see Tab.2Tab.. This CFD simulation represent statistic flow field in coal stockpile surround and static pressure on stockpile surface for eight reference direction of the wind.

Tab.2. Wind rose, distributed into x,y direction

	v_{10} [$m.s^{-1}$]	Direction vector	
		x	*y*
N	1,87	0	-1
NE	1,77	-0,7071	-0,7071
E	0,85	-1	0
SE	1,24	-0,7071	0,7071
S	2,28	0	1
SW	3,54	0,7071	0,7071
W	3,52	1	0
NW	1,95	0,7071	-0,7071

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Reference value of velocity and direction of wind are defined in altitude 10 m. Power function was used to definition boundary layer velocity profile. Power function is defined by means of reference value of velocity in altitude 10 m v_{10} (see Tab.2), [3] and power coefficient p, which is function of atmosphere state.

$$v = v_{10} \cdot \left(\frac{z}{10}\right)^{p} \tag{1}$$

v_{10} - reference value of velocity from wind rose [ms^{-1}]

z - is altitude [m] and

p - is power coefficient [-]

Power coefficient is $p = 0.22$ for stable state of atmosphere and industrial site.

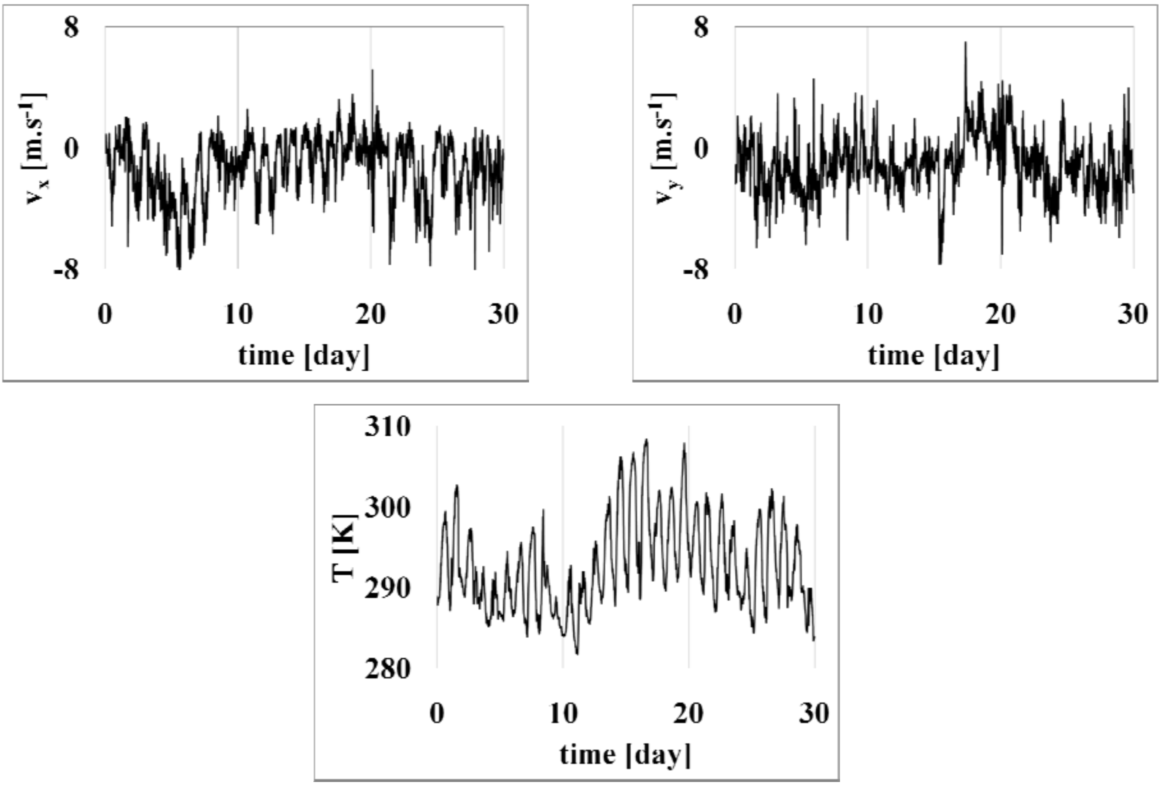

Fig.2. Time record of velocity distributed into velocity components, x component (left), y component (right) and time record of temperature (below) in July 2009

The steady simulations strongly simplified complex situation in atmosphere. Velocity and direction of wind are random functions of time. Spontaneous ignition is thus influenced by historic processes of atmosphere, like day-night turn, random variation velocity and direction of wind etc. That is why the FFT analysis of time record was performed. The FFT analysis transforms the time data to frequency spectrum. Spectrum was used to specification of amplitude and frequency of most frequently occurred fluctuation of velocity. Every signal can be described as sum of dominant sinusoidal signals, which can be evaluated from frequency spectrum. Random fluctuating signal have to be describe with infinity sum of sinusoidal signal in theory. Time record of velocity was relatively little, so only first eight sum sinusoidal signals was determine, see equation **Chyba! Nenalezen zdroj odkazů.**2) [4] and Fig.3.

$$v = v_0 + \sum_{i=1}^{8} a_i \sin(\omega_i \cdot t),\ T = T_0 + \sum_{i=1}^{8} a_i \sin(\omega_i \cdot t) \quad (2)$$

Frequency spectrum of velocity v_x, v_y and temperature contained only eight dominant sinusoidal frequencies and other was inexpressive. Correlation coefficient was for eight terms acceptable too. More accurately FFT analysis requires longer time record, which was not available.

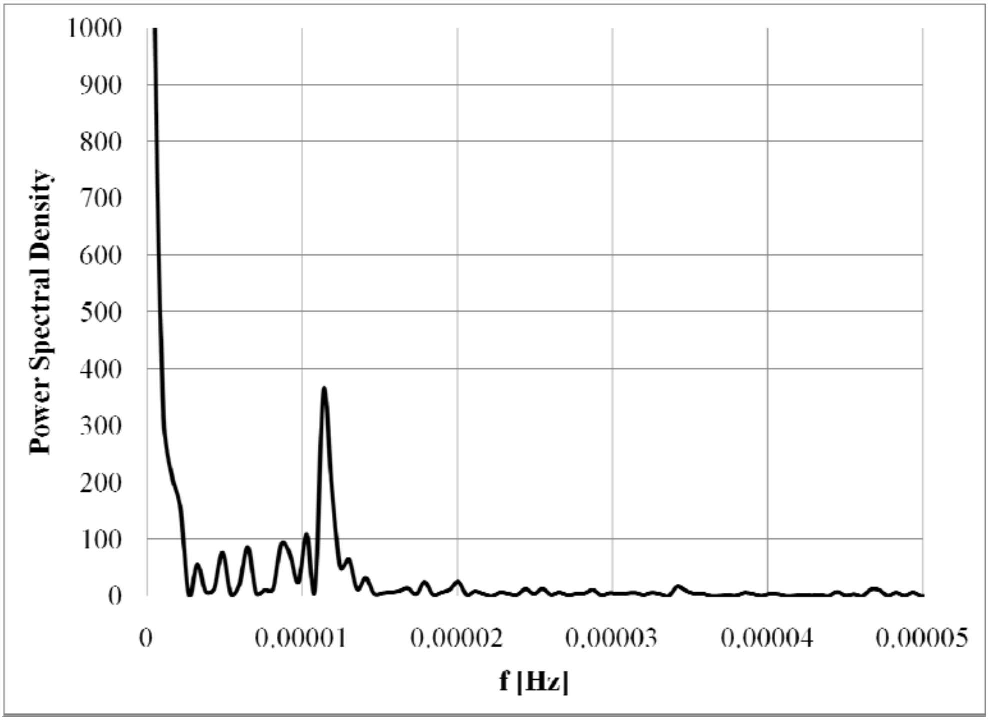

Fig.3. Power spectral density for velocity v_x

The FFT analysis was used to velocity v_x, v_y and temperature as a function of time definition, see Fig.4. With this definition of boundary conditions could be performed only one unsteady simulation, which includes simply form of historical processes in the atmosphere.

4 TASK DEFINITION AND BOUNDARY CONDITIONS

Flow in atmosphere boundary layer was solved for two types of CFD simulation.

4.1 Steady task

First type of task was steady and eight simulations for every direction of wind from wind rose were separately simulated. Velocity inlet was defined by power function in these cases see equation (1). Value of velocity v_{10} given directions was defined from wind rose in Tab.2 Temperature was defined s July time average $t = 19.65$ °C °. Turbulence parameters were defined by means of state of atmosphere and frictional velocity. Frictional velocity is defined by following equation

$$v_* = \frac{0.419\ v_{10}}{\ln((10 + z_0)/z_0)}. \quad (3)$$

the frictional velocity is function of roughness of terrain, velocity of wind v_{10} and cells high [1]. Parameter $z_0=0,1$ is in relation with high of first cell near the wall [1].

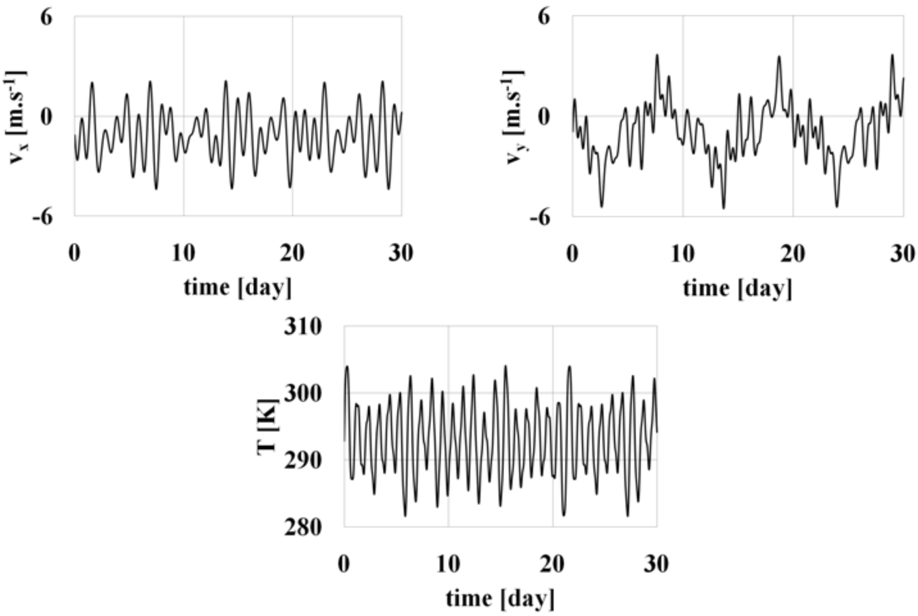

Fig.4. Time record of velocity v_x (left), v_y (right) and temperature (below) used in CFD simulation

Tab.3. Turbulent quantities

Direction of wind	Velocity v_{10} [m.s^{-1}]	Frictional velocity [m.s^{-1}]	Turbulent kinetic energy [m^2.s^{-2}]	Dissipation (altitude 10m) [m^2.s^{-3}]
N	1,87	0,170	0,096	0,00117
NE	1,77	0,161	0,086	0,00099
E	0,85	0,077	0,020	0,00011
SE	124	0,112	0,042	0,00034
S	2,28	0,207	0,143	0,00211
SW	3.54	0,321	0,344	0,00791
W	3,52	0,319	0,340	0,00778
NW	1,95	0,177	0104	0,00132

Turbulent kinetic energy was defined by means of frictional velocity by equation, which defines turbulent kinetic energy as a constant value.

$$k = \frac{v_*^{\,2}}{0.3}. \tag{4}$$

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Dissipation was defined as a function of frictional velocity and altitude z. So the dissipation is not constant but it is function of altitude. [2]

$$\varepsilon = \frac{v_*^{\,3}}{0.419 \cdot z} \cdot \qquad (5)$$

Turbulence quantities for eight dominant direction of wind from wind rose are evaluated in Tab3. The steady state, in which each direction of wind has been analysed individually, has been evaluated and measured with the effect of "velocity inlet" and "pressure outlet".

4.2. Unsteady task

Second type of task was unsteady i.e. function of time. In this simulation was included simplified time record of velocity and temperature in a month July. Boundary conditions were defined same as in first task. Only velocity v_x, v_y (see Fig.4) and temperature were defined as a constant value with respect to altitude and function of time. Both components of velocity were specified by sum of eight sinusoidal signal see equation (2). Temperature was specified by sum of eight sinusoidal signals which respect temperature variation during a day

The inlet was defined as velocity inlet boundary condition and outlet was defined as pressure outlet boundary condition in steady state simulation. Only velocity inlet boundary condition was specified in unsteady simulation with time function of velocity and temperature. Time step was only 60 s with respect to numerical stability and convergence criteria of the simulation.

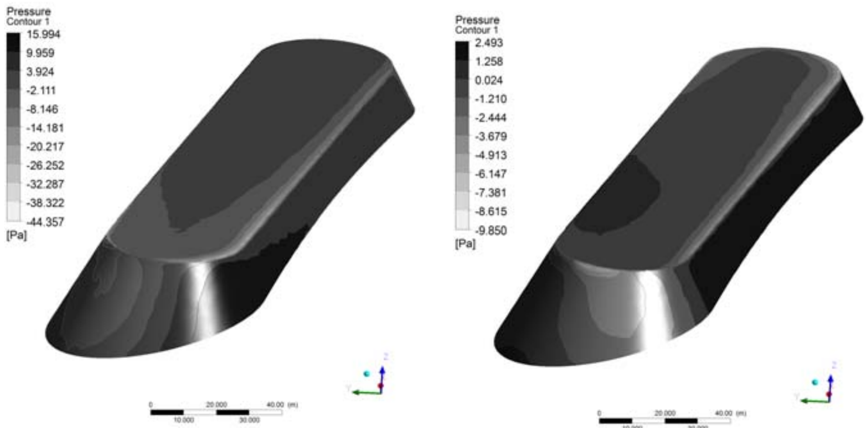

Fig.5. Example of results, static pressure distribution on coal stockpile surface, direction of wind SW (left), S (right)

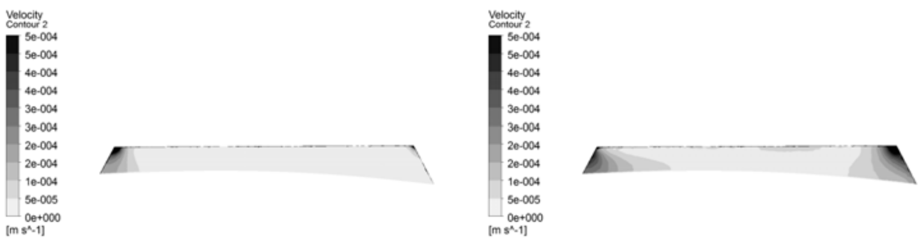

Fig. 6. Example of results, velocity distribution into coal stockpile, longitudinal plane of symmetry direction of wind SW (left), S (right)

5 RESULTS

CFD software Fluent 12.1 was used to numerical simulation. Main result of this simulations is static pressure distribution on surface of coal stockpile and velocity inside coal stockpile (Fig. 5 and 6). Spontaneous ignition of the coal matter zone can be forecast by means of velocity. Critical velocity of spontaneous ignition of coal matter is v_{crit} = 0,1–1 $m.min^{-1}$.

6 CONCLUSION

The CFD simulation of flow in atmosphere boundary layer was defined and verified. Proposed methods included simplified historical processes in atmosphere (random variation of velocity and direction of wind, and temperature oscillation during a day) of and real topology of Earth's surface.

The proposed methods cover the ways of implementing immediate changes in rate and direction of wind and temperature variation within the period of one month, which are necessary for numerical analysis of the simulation of the impact of the boundary layers movement on the low temperature oxidation of the coal.

The accuracy of the both calculations has been ensured, and thus bases for the next individual calculation have been prepared.

The proposed methods for solution of influence flow in atmosphere boundary layer on chemical processes in coal stockpile, which is other subsequential step of the whole project [5]. Spontaneous ignition is very complicated problem and big accent is dedicated to correct mesh generation of coal stockpile. Realisation of all requirements of correct simulation product the hardware sophisticated and long time solved simulation.

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