

The Simulation of the Dust Grain Movement by Sediment Transport Model around Mining Area in Northern Sweden

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Abstract

A simple sediment transport model has been utilized to simulate the dust grain movement in the area flow. The transport model can be used as a tool to estimate the dust grain transport situation in a mining area with consideration of the local topographical profile. The case study of the local dust characteristics survey proves the model works fairly well compared to the field calibration.

Keywords: Dust transport, Sediment transport model.

1 Introduction

Wind and water transport particles in suspension saltation and as surface creep. The movement of the particles up or down the velocity gradient takes place in laminar and turbulent flow conditions (Oliver[1], Segre and Silberberg[2]; Jeffery and Pearson[3]; Willets[4]). Most if not all the work carried out in this field is theoretical due to the complex variables involved and the unknown effect of some of them on the motion of the sediment.

Transport of particles is an important issue in any mining industry all over the world due to environmental problem involved. Yi, et al [5] designed a model to calculate and predict the dust transported in certain time of period. The model used Bagnold's [6] equation to calculate

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the critical shear velocity for certain grain size of the particle. Hsu's [7] equation was used to find out the critical velocity at different heights. Comparing stresses imposed by the wind velocity with the critical shear velocity of a certain grain size, it can predict how much dust is transported. This had been applied on a case study in Malmberget mine site as a first step so that it can be tested, and then it might be suitable for implementation on other sites.

The case study was carried out in the Malmberget mine in the northern Sweden. The Malmberget mine operated by the company LKAB is one of the most important iron mines in Sweden. It is located at Gällivare (Figure.1a), 75km south from Kiruna, and contains about 20 kinds of ore bodies. The mine covers a huge area spreading over approximately 5km from east to west and 2.5 km from north to south. Mining operations began in 1892, from then over 350Mt of ore rock was extracted. In 2006, it produced around one third of LKAB's total production of 23.3MT of iron-ore products (Net Resources International [8]). Surface open pit mining method (Figure.1b) was firstly used to reach and exploit ore minerals, with a huge depression left on site thereafter large-scale sub-level became the predominant mining technology in Malmberget iron mine. The dust properties information was collected and supplied by the small collectors installed around the residential area. Not only the dust from collectors, but also the ground dust around the mining facilities was measured. [9]



Figure 1: a) The city of Gällivare b) the mining open pit mining method

In order to illustrate the motion of the dust grains, a sediment transport model is suggested here to illustrate the influence of the coarse particles transported from mining areas to the environmental and residential areas within the vicinity of the mining site. The mathematical model is designed to illustrate the movement of these particles based upon the

wind profile data in the city of Gällivare. This sediment transport model would illustrate the motion of the particles in another way, and the result can be used to calibrate the previous one's result.

2 Method

This new model was firstly designed by Al-Ansari [10] and Al-Ansari et al [11] for sediment transport in rivers for the simulation of the motion of the particle grains. It was used to track the motion of the sediment grains of various sizes using the velocity data in the rivers. Once the particles is displaced from the surface, the motion of a particle is assumed would be controlled principally by its settling weight against the vertical velocity of turbulence. Once the grain is picked up from the bed, the particle's motion is determined by comparing its settling velocity (v_{ss}) with the instantaneous velocities at that moment and at subsequent time interval until either the particle is re-deposited on the bed or is kept in suspension.

2.1. The velocity profile

The wind velocity profile was supplied by the SMHI (Swedish Meteorological and Hydrological Institute).The computation and calculation of the wind velocity profile was carried out using these input data. The critical shear velocity for certain size of the particle was calculated using Eq.1 (Bagnold [6])

$$u_{*t} = A_t \sqrt{\frac{(\rho_s - \rho_a)gD}{\rho_a}} \quad \text{Eq.1}$$

where ρ_s is the mass density of the sediment; ρ_a is the mass density of the air; A_t is a dimensionless constant ($A_t = 0.118$ for air).

The effect of moisture that increases the critical shear stress was not considered here. Bagnold found that the height of the focus, which we will call k at which the wind velocity is zero, is approximately equal to 1/30 of the diameter of the grains or stones. Based on this assumption, the height of the focus was calculated and used for the wind profile estimation. Eq.2 was used to compute the wind profile in different heights with the height of focus (velocity equals zero). This information was used to calculate the wind velocity profile. (Hsu's equation[7]):

$$u_* = \frac{\kappa(U_{z2} - U_{z1})}{\ln\left(\frac{Z_2}{Z_1}\right)} \quad \text{Eq.2}$$

where Z_2 and Z_1 are the two different heights; U_{z2} and U_{z1} are the velocities at the two different heights; κ is the von Karman's constant ($\kappa = 0.4$)

2.2. Particles in motion

The velocity components was compared between the selected zones to estimate the motion conditions of the particles with certain size and velocity, which can visualize the image of the particles transport clearly, although with the assumption of the simultaneous changes for horizontal and vertical velocity components.

The zones were defined with one meter interval in the height. In this the total height case was assumed to be 10 meters (Figure 2).

Zone 1: Between the surface of the ground and 1 m height with velocity v_1

Zone 2: Between 1 and 2 meters height above the ground surface with velocity v_2 .

Zone 3: Between 2 and 3 meters height above the ground surface with velocity v_3 .

...

Zone 10: Between 9 and 10 meters height above the ground surface with velocity v_9 .

The motion of the particles would be described in all the Zones by the code.

For example:

In zone 1: (near the surface)

If $v_1 > \tau_c$,

$v_1 \leq v_{ss}$, the grain remains in suspension;

while $v_1 > v_{ss}$, the grain moves up into zone 2 and either remains in suspension or motion in upper layers.

If $v_1 \leq \text{critical } \tau_c$ the grain is deposited on the bed

In zone 2: (motion in the air)

if $v_2 \leq v_{ss}$, the grain will be suspended between zones 1 and 2

otherwise if $v_2 > v_{ss}$ then the grain moves up into next zone and the motion determined in the next layer.

The code repeats and decides the motion for the other upper zones.

where v_{ss} is the settling velocity, τ is the critical velocity, v_1 to v_{10} stand for the instantaneous velocity at different heights. τ_c is the critical shear velocity to start the motion of the dust particle;

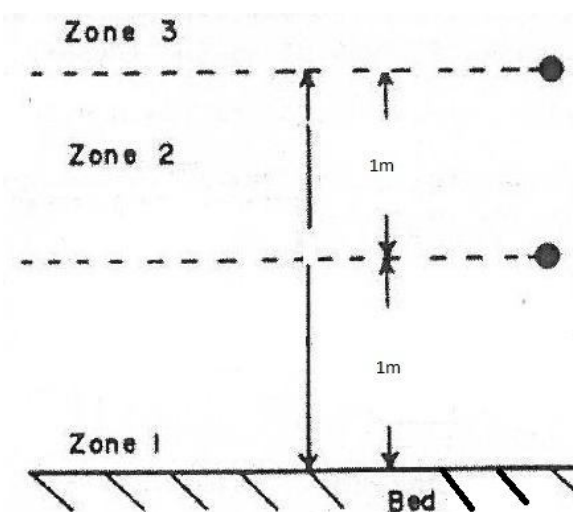


Figure 2: Model Zones used for the simulation of grain movement.

2.3. Motion prediction according to the settling velocity

The settling velocity, or the fall velocity, is directly related to relative flow condition between the sediment particle and the fluid during condition of sediment entrainment, transportation, and deposition. Cui, B. Komar P and Bara J [12] evaluated the equations for the settling velocity of natural sand grains in air by experiments and emphasized equations for the irregular natural sand grains. Equation 3 which is perfectly fit the experimental data is used here for calculation. But it was assumed that the particles in the research are finer than 0.2mm, which can be considered as spherical ones.

$$w_{gs} = \frac{-3\mu + \sqrt{9\mu^2 + gr^2\rho(\rho_s - \rho)(0.0088 + 0.180r)}}{\rho(0.0066 + 0.135r)} \quad \text{Eq.3}$$

where μ is the absolute or dynamic viscosity of air, ρ_s and ρ are the grain and air densities respectively and $r = D/2$ is the grain's radius. All parameters must have cgs units.

Viscosity is primarily a function of temperature. The variation is provided in Crane Company [13] as a graph for hydrocarbon vapors and natural gases, and as an equation for other common gases. The average temperature is shown below.

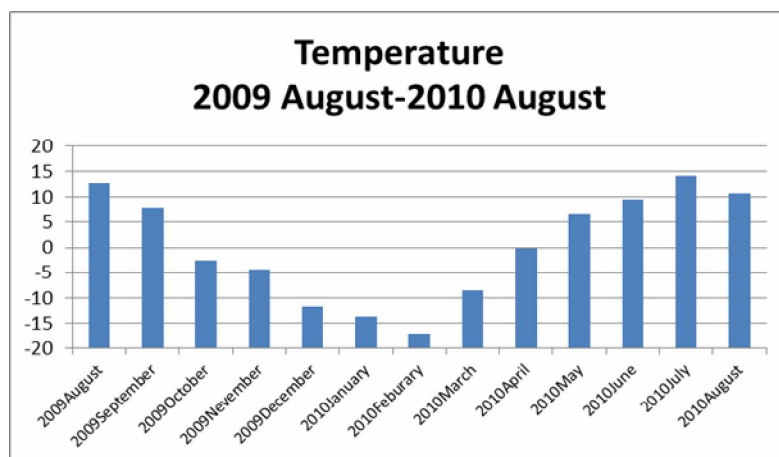


Figure 3: Monthly average temperatures in the test area from SEMI.

2.4. Computer computation

The computer code used was Matlab (under working) which can help with calculations. It was designed to analyze the motion of the sediment particles. Information about the critical shear stresses and settling velocities for grains of different sizes were used as input data in the Mat lab. Data representing four different cases from Malmberget mine were used. The code computed the instantaneous shear stress τ_1 , and then compared it with the critical shear stress for certain grain size.

When the instantaneous shear stress exceeded the critical shear stress it was assumed that the particle was picked up from the ground. At that moment the settling velocity of the particle (v_{ss}) was compared with that of v_1 . If v_1 is greater than v_{ss} , then the particle is moving upward otherwise it is still in suspension in zone1. Such particles kept in zone 1 are redeposited when the instantaneous shear stress is less than their critical value and their v_{ss} is more than v_1 , or they might move upward when v_1 is greater than v_{ss} . Once the particle moves upward to the upper zones, then its settling velocity v_{ss} is compared with v_2 . If v_2 is greater than v_{ss} then the particle may move upward to zone 3; on the other hand is v_{ss} is greater than v_2 and less than v_1 the particle is assumed to be hanging in zone 2 in the suspension state until v_{ss} is less than that of v_2 or greater than v_1 . In the first case the particle will move upward, while it moves down when the second set of conditions occur. The complicated calculation will be performed by the computer code to illustrate the particle grain movement with certain size. Therefore, the simulation of the grain movement can help on monitoring the dust transport, further on, to calculate the transport amount as predicted.

3 Results and Discussion

The simulation code was designed with Matlab GUI's visible tools. There are three steps for the code to complete the task:

3.1 Input of the necessary data.

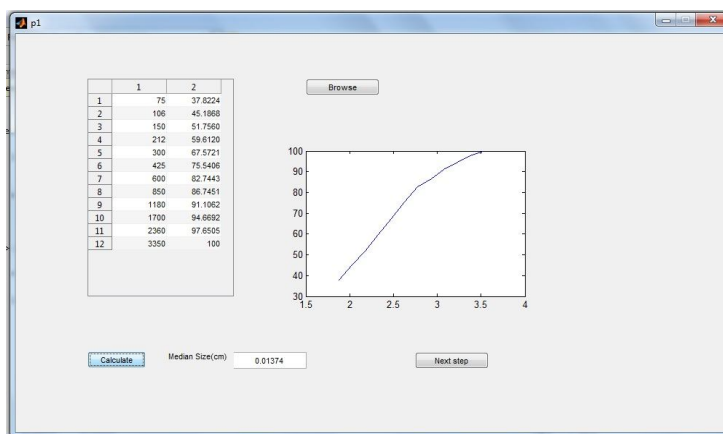


Figure 4: The input winds for the characteristics of the dust collected.

The first window (Figure 4) requires the input of the particle characteristics of the dust collected in the field, and analyze them by plotting a accumulative curve. The nominal diameter which is the 50% percentage of the particle size from the cumulative curve is chosen to represent the particle size of the sample.

3.2. Choose the field criteria.

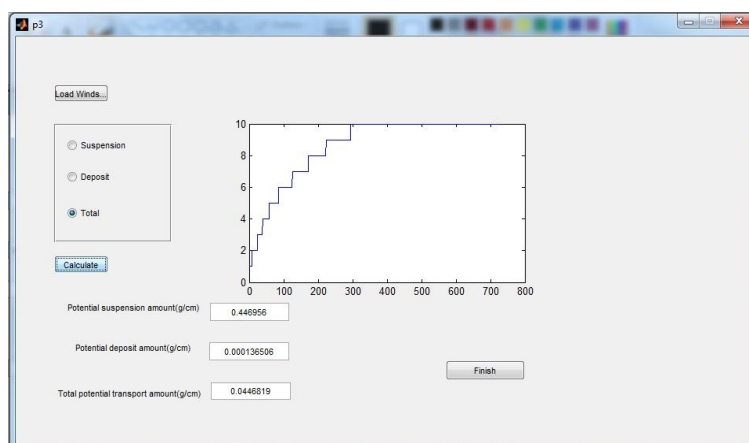


Figure 5: The criteria choice window.

The second window (Figure 5) request input of the particle density and the height of the collectors. And the important part is to choose the correct temperature for the viscosity and

air density criteria, which will serve to calculate the critical shear velocity and the settling velocity for the given particles.

3.3 Result part.

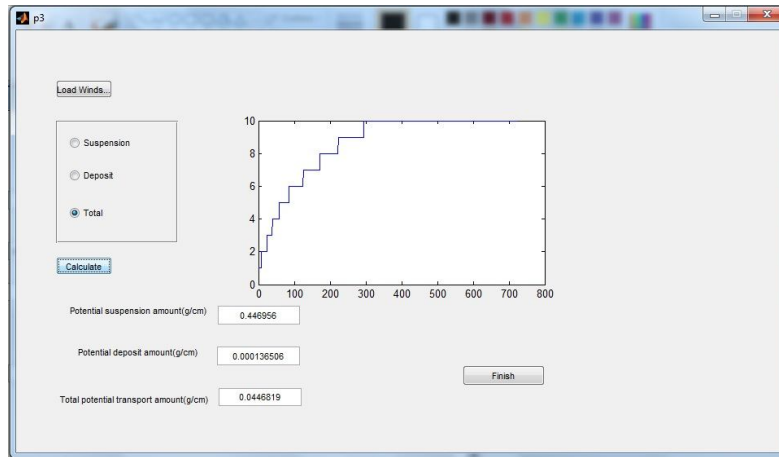


Figure 6: The result part of the particle transport prediction and motion illustration.

The last window will calculate the particles in motion according to the model (Figure 2). The velocity profile will be calculated by Bagnold's and Hsu's Eq. (1, 2). This part gives the right illustration of the particle in motion with the given wind profile. The calculated wind velocities at different heights are required to compare with the critical shear velocities and the settling velocity. Then the model plots the moving particles with the velocity higher than the critical shear velocity. To distinguish the suspension part and settling part, the model compares the velocity with settling velocity. The settling part would be the part where settling velocity is higher than the wind velocity, while the suspension part is vice versa. Then the potential dust transported will be calculated at the last.

The result are plotted to compare the result from the Yi,H.et al [5] first prediction model made for the same case study. The result gave perfect fit, with the one hour dust transport amount while the first model gave the three hours transport amount result.

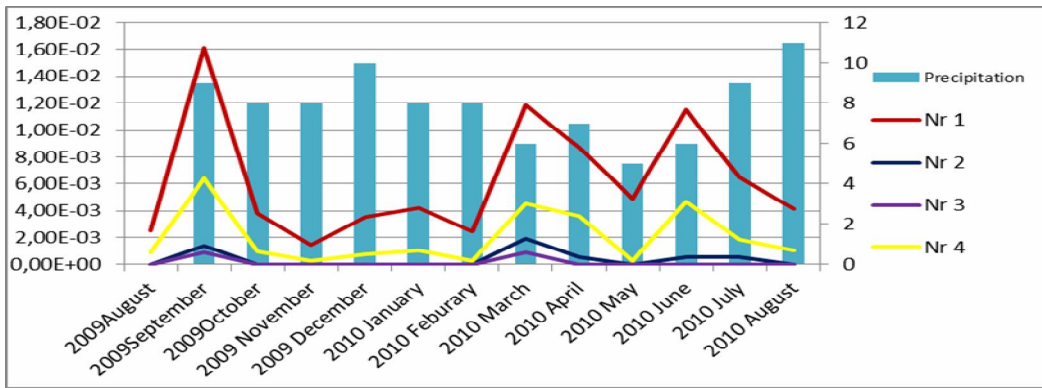


Figure 7: The results from the prediction model made by Yi.H (2012).

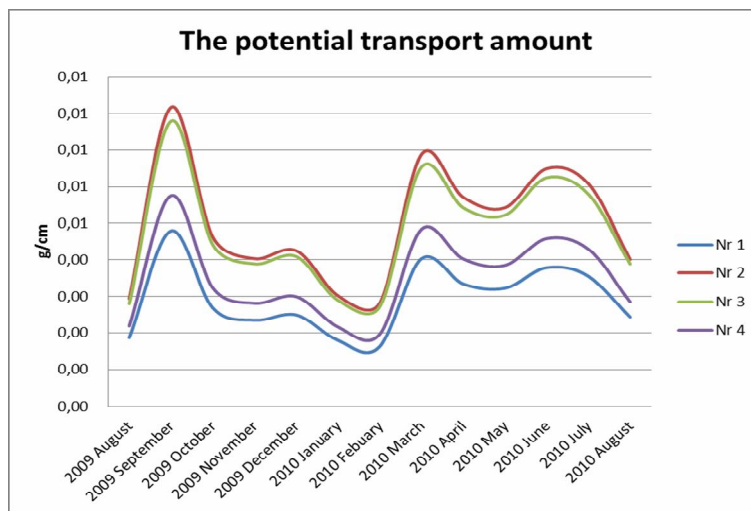


Figure 8: The potential transport amount of dust for the four samples in the case study.

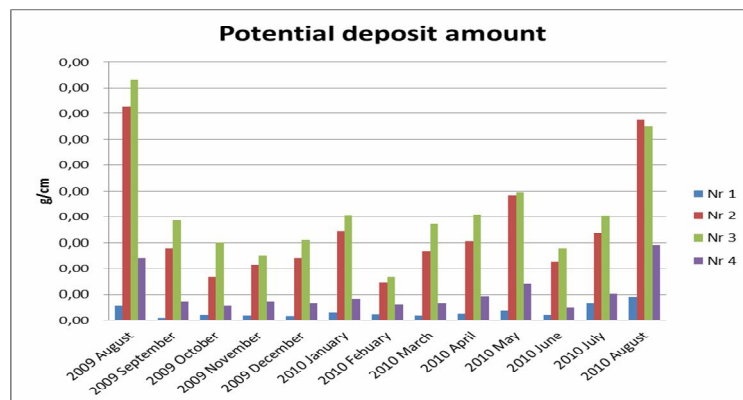


Figure 9: The potential deposition in the case study.

The last figure is the plot of the deposition part from the model result. This might explain the deposition amount of the dust in the test period, Nr 2 and Nr 3 samples should be protected more from the particle erosion than the other samples.

4 Conclusion

The sediment motion description model used in river sediment engineering can be a good tool for air erosion dust particles. With modern computer science, we could use computer code (eg. Matlab) to illustrate the dust motion easily and rapidly. This primary estimate of the motion of dust is a good extension of the dust transport, and describes how dust is transported in a certain period of time. The results of this model were perfectly fit with those of the prediction model result. This implies that the model can be used for calculation and prediction of dust grains correctly. The amount of deposition dust can be interesting so that suitable measures can be taken to minimize the pollution.

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