Sámuel Mikoviny Doctoral School for Earth Sciences

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INVESTIGATION OF THE DELIVERY FEATURES OF DUMPED MINE WASTE AND TAILINGS WITH SPECIAL REGARD TO THE RECLAMATION

Thesis statements of PhD dissertation
for being admitted into PhD degree

Location of research: Department of Mining and Geotechnology
Institute of Mining and Geotechnology
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Justification of research objectives

The objective of the research is to provide theoretical groundings for the numerical assessment of dust risk in broken surfaces, storage spaces and recultivation areas connected to mining activities. In deep mines, such materials are produced during stone drift driving, the deepening of shafts and continuous operations that get to refuse dumps. In the course of the mining of ores and minerals, a large amount of refuse is separated from the produced material during mineral processing, which is then usually broken and ground into micrometric size in order to recover useful components. In ore mines it often happens that 95-98% of the rock quantity brought to the surface gets to the refuse dump or sludge reservoir. In coal mines, this portion is 15-25% of the produced amount and following combustion, a further 15-25% of slag and fly-ashes gets to surface storage places, usually sludge reservoirs, causing continuous dust risk.

In open cuts, there is continuous burden removal, and parallel with this, there is refuse dump formation, which occasionally involves 10 ha areas remaining uncovered and presenting permanent dust risk for the environment. In the surroundings of these mines and dumping places, there is often considerable dust pollution not only during the production phase but decades later, too.

There are a large number of publications investigating the problems of the dusting out of different soils, with major research institutes and university departments involved in research in this field. However, the overwhelming majority of research projects are concerned with the deflation of agricultural areas, the dusting out of desert regions and the dust burden of areas surrounding deserts.

In the literature, there are hardly any publications concerning dust risk and its prevention in industrial and mining regions. Especially little attention is paid to the assessment of the dusting tendencies of the materials to be found there, for which I have found no generally applicable formula.

Because of this, at the Department of Mining and Geotechnology we decided to do research in this topic. The dissertation gives a summary of my first research results, which primarily concern the determination of the dusting tendency of the areas investigated.

Methods of research

In the first phase of the research project, I made experiments with samples from areas representative of problems in Hungary (sludge reservoir in Gyöngyösoroszi ore mine, slag and fly-ashes from the lignite-fired power plant in Visonta, mixed material from sludge reservoirs, loess used for covering the sludge reservoir of a uranium mine, sorted sand from gravel production).

There are several factors that affect the delivery of materials by wind, i.e. deflation, which include material properties, as well. I specified these properties partly on my own and partly with the help of other departments (grain distribution, average density, inner angle of friction). Relying on the literature, I defined the other factors affecting the delivery of grains, of which wind velocity and wind direction, the slanting of surfaces, the distribution (sorting) of grains on the surface and the effect of moisture appeared to be worth investigating. At the present level of our knowledge, it is not possible to give an exact definition based on theoretical correlations of the delivery of grains, due to the stochastic nature of the factors affecting delivery. Therefore, I designed a series of experiments to define the effect of the factors influencing delivery in a numerical way. By gradually reducing the maximum grain size of the samples, my intention was to clarify the effect of grain size on delivery while by varying wind velocity I investigated the effect of airflow intensity.

On the basis of the experimental results, I defined the function with regression analysis extended with dimensionless correction, which gives the approximate value of the mass rate (m) characteristic of the delivery tendency for horizontal plain surfaces for any of the materials investigated by taking the most important factors into account.

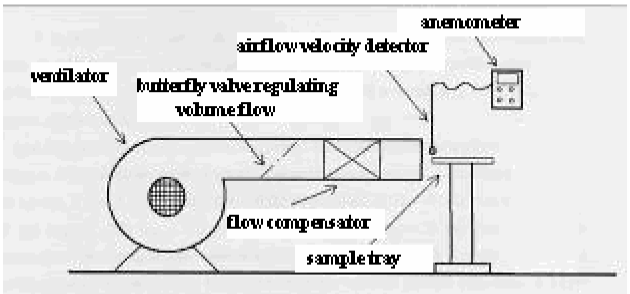
I performed the experiment with slanting surfaces, as well, where I found no reliable function-type correlation. However, here the expected value of the most important properties and delivery tendency (m) may also be specified for the different material types with individual analysis.

I likewise investigated the possibilities of reducing delivery. In this respect, I analysed the effect of moisture and covering with lumpy materials, and determined the expected rate of reduction as the function of the extent of moisture and coverage with lumpy materials.

In order to make the assessment of experimental results more exact, I analysed the forces affecting grains that are formed during delivery and affect the extent of it. As the assessment basically relies on the experiments, the analysis of force effects is of an approximate nature and only serves to detect the main effects.

Description of measurement equipment

In order to define dusting tendency, I set up a special measurement instrument system in the workshop hall of the University of Miskolc (see figure).



Measurement equipment

A 6 m long ventilation tubing with 0.5 m diameter, containing an airflow regulating element, is connected to the radial ventilator creating the airflow. In the system used for the calibration of anemometers, the airflow can be regulated and the desired air velocity can be set. For measuring air velocity, a hotwire anemometer was used, and the accuracy of measurement in the range in question was 0.5%.

The tray holding the dust sample was placed in the medium plane of the cross section of the tube diameter, 20 centimetres from the end of the ventilation tubing, where there was identical wind velocity in the whole width of the tray. The tray was placed on a turnable and tiltable stand.

Research results

I give a brief summary of my research results in the following thesis statements.

Thesis statement 1.

1.1 *On the basis of the analysis of the forces affecting dust grains, I came to the conclusion that the interpretation of the deflation phenomena investigated in the dissertation should focus on the moment when the grains are on the verge of displacement. It is possible to give a more exact definition of the value of delivery and the function-type correlation if forces forming at this phase of the processes are taken into account.*

1.2 *The analysis reveals that as the function of grain size, the forces affecting the grains have a maximum so in contrast to the commonly held view, it is not the smallest grain that may take off into the air most easily.*

1.3 *On the basis of the formula gained for dynamic lift and as the function of the different factors, it is possible to specify the range of grain size which is still affected by a resultant pointing vertically upwards.*

Thesis statement 2. *On the basis of the taking into account of the factors characteristic of delivery and the analysis of the deflation processes, it can be concluded that due to the large number of factors affecting the phenomena and processes and the random effects, they can only be investigated with stochastic methods.*

As we are concerned with stochastic phenomena and processes, experiments on the basis of which the properties of random phenomena can be determined are indispensable.

Thesis statement 3. *With my experiments, I managed to prove that in situ grain distribution should be taken into consideration in the determination of the dusting tendency prevalent in dumps and sludge reservoirs.*

In order to determine this, I elaborated a 'mild' screening process.

Just like the other investigated factors, in situ distributions should be handled as stochastic data.

Thesis statement 4. *The differences between the Gyöngyösoroszi samples in relation to the experimentally defined dusting tendency can partly be explained by differences in composition and partly by their different in situ grain distributions. From the considerable differences between the samples taken at small distances from one another, I concluded that the surface of refuse dumps and sludge reservoirs is not homogeneous, either, so that consistent sampling is needed to define dusting tendency with appropriate accuracy.*

In a longer period, the material of dumps and sludge reservoirs may undergo such physical and chemical transformations which may increase the inhomogeneousness mentioned above.

Thesis statement 5.

5.1 *On the basis of regression analysis, I proved that the extent of delivery (m) may be approximately estimated as the function of average grain size (d_a) and wind velocity (v). From the value of the square of the correlation index ($I^2 = 0.78$), it can be concluded that these two factors only affect the extent of delivery in 78% with the remaining 22% being determined by other parameters.*

5.2 *My experiments led me to the conclusion that for a more accurate estimation it is essential to take into account as independent variables the inner angle of friction (φ), grain density (ρ), the deviation of grain distribution (σ) and the resultant lifting force (f).*

5.3 *Furthermore, I concluded that the functional correlation between the listed parameters and delivery can be made more accurate with dimensionless parameter correction. Dimensionless parameters correct the value of average grain size according to the formula below:*

$$d_{korr} = d_a \cdot \left(\frac{9}{v}\right)^{2.5} \cdot \frac{\varphi}{34} \cdot \frac{2{,}64}{\rho} \cdot \left(\frac{\sigma}{d_a}\right)^{0{,}25} \cdot f$$

5.4 *My investigations proved that dusting tendency as the function of corrected grain size can most accurately be defined with the exponential formula below:*

$$m = 100 \cdot e^{-a \cdot d_{korr}^{b}}$$

5.5 *With the regression function defined on the basis of the 61 samples examined, the mass rate indicating a dusting tendency ($I = 0.960$, $I^2 = 0.922$, $D_{\Delta y} = \pm 9.10\%$) can be estimated with satisfactory accuracy*

$$m = 100 \cdot e^{-2{,}97 \cdot d_{korr}^{1{,}32}} \text{ , \%}$$

5.6 *I proved that a more accurate estimation can be done if regression equations are defined with the samples classified according to the location of occurrence or technology used.*

This is proved by the regression equation specifically defined for the Visonta samples and its closeness ($I^2 = 0.97$, $D_{\Delta y} = \pm 4.45\%$)

Thesis statement 6. *My experiments led me to the conclusion that the delivery (dumping) of REA-gypsum together with combustion residues in the Visonta sludge reservoir considerably reduces dusting tendency in the sludge reservoir surface, to about one fifth.*

Thesis statement 7. In the experiments performed with a tilted tray, result assessment is aided by the investigation of the forces affecting the grains. On the basis of the modelling of deflation phenomena in slant surfaces, I concluded that the behaviour of grains is different in the case of wind ahead and backwind.

7.1 *In the case of wind ahead, I proved that depending on wind velocity and bedding angle, grains of a particular size may either move upwards on the slope or may roll down. For wind ahead, I defined those two contact angles of the slope between which the grain of a given size does not move. In the case of tilting below this range, grains move upwards, in the case of tilting above this range, they roll downwards.*

7.2 From this, it follows that in the case of wind ahead on slopes, *a higher rate of deflation should be taken into account* if there is varying wind velocity than in the case of a wind of consistent velocity. This is because the fine grains moving upwards during gusts free such bigger grains that typically fall into the stationary range at the given wind velocity and consequently, due to reduced grip or impregnation roll downwards at a weakening or dying wind. This also results in the sorting out of the surface material, which may, in turn, affect slope rigidity, as well.

Thesis statement 8. On the basis of the experiments and theoretical considerations, the following conclusions can be drawn for backwind:

8.1 *In the case of a slope of a given tilting angle, the size of the resultant lifting force decreases parallel with the increase of the distance from the top edge so that only smaller and smaller grains are able to move upwards. On the basis of the formula gained for the resultant, at a given distance the grain size can be defined which is affected by the largest resultant lifting force.*

8.2 *In the case of a given grain size, the resultant lifting force working upwards appears at points located nearer and nearer to the top line as tilting angle increases.*

8.3 *With the decrease in grain size, the size of resultant decreases at a given distance from the top edge, however, it is present even at larger tilting angles.*

8.4 *In case of coarser fractions, if airflow velocity is not sufficient to lift the grain due to reduced impregnation resulting from the removal of smaller grains, on the slope the grains roll down to the bottom. Due to the rearrangement of the grains on the surface, other grains are freed that are open to deflation.*

Thesis statement 9.

9.1 *My experiments led me to the conclusion that delivery is always higher on slopes than in flat areas. On the basis of the investigations, I could not, however, detect a close, function-type correlation. Still, relying on measurement data and analyses, an estimation can be given for delivery tendency as the function of grain distribution, wind velocity and direction and angle of tilting with individual calculation analysis.*

9.2 *Investigations proved that in the case of finely grained materials (d_a< 1 mm) wind ahead removes more material than backwind does. In the case of coarsely grained materials (d_a> 2 mm), the situation is reverse because backwind causes higher delivery.*

Thesis statement 10. *In relation to delivery protection processes, I came to the conclusion that the necessary and sufficient water content of surface layers is 3-4% as this water content reduces dusting to the minimum..*

The water content necessary for protection may be specified for any material with the methods elaborated.

Thesis statement 11. With the experiments, I proved that in the case of the materials investigated a way of protection can be to cover surfaces with coarse grains.

11.1 *The covering of more finely grained materials with coarse materials may already be effective when surface coverage reaches 30-40%.*

11.2 *The specification with approximate accuracy of the necessary extent of coverage is possible from the regression functions set up between the extent of coverage and the decrease in delivery.*

Thesis statement 12. *In the case of disposable material with heterogeneous grain distribution, the coarse grain cover may be produced from the material itself by the separation of given grain sizes. The decrease in delivery may be specified in the knowledge of material properties on the basis of the separation grain size and the extent of coverage from the calculated regression functions.*

By the separation and selective dumping of the continuously delivered material, continuous coarse grain cover may be formed in dumps.

In the case when the deflation of material is low even in its original state, the separation method of protection cannot be applied.

Thesis statement 13. *I defined the conditions under which the protective effect of the coarse grain cover may be improved by the compaction of the surface layer:*

- *the material can be well compacted,*
- *material flow between the layers is limited,*
- *the material tends to adhere.*

Surface layer compaction slightly weakens the protective effect of the coarse grain cover if the bottom layer is finely grained and can be weakly compacted.

This can be accounted for by the fact that the larger grains of the upper layer are pressed into the finer bottom layer and thus their wind shadowing effect is reduced.

Publications related to the dissertation topic

Gy. Szarka, M. Vadászi: Considerations over Recultivation after Mining (Megfontolások a bányászati tevékenység utáni rekultivációról)
VI. Bányászati Kohászati Földtani Konferencia, Petrozsény, 2004. május 20-23.
Conference Proceedings: p. 81.

Gy. Szarka: Environmental Changes and Consequences Resulting from Abandoning Mines, the Necessity of Recultivation
Amireg2004, 1st International Conference, Advances in Mineral Resources Management and Environmental Geotechnology, Hania, 7-9 June, 2004
Conference Proceedings: pp. 467-471.

Gy. Szarka: Deflációs jelenségek meddőhányókon és zagytereken ('Deflation phenomena in refuse dumps and sludge reservoirs')
Doktoranduszok Fóruma, Miskolc, Miskolci Egyetem, 2004. nov. 4-9.
Conference Proceedings: pp. 40-46.

Gy. Szarka, V. Mádai: Investigation of dusting intensity in Gyöngyösoroszi flotation waste dump
MicroCAD 2005 International Scientific Conference, Miskolc
Conference Proceedings: B szekció: Energiagazdálkodás és környezetvédelem (Energy management and environment protection), pp. 69-74.

Szarka Gy.: Meddő anyagok szemeloszlásának vizsgálata a kiporzás szempontjából (Investigation of grain size distribution of dead material from the point of view of dusting)
VII. Bányászati Kohászati Földtani Konferencia, Nagyvárad, 2005. III.31.- IV.3.
Conference Proceedings: pp. 40.

Gy Szarka.: Analysis of dusting of bulk materials
XIII International Scientific & Practical Conference "Information Technologies: Science, Engineering, Technology, Education, Health" MicroCAD, 19-20 May, 2005, Kharkiv
Conference Proceedings: pp. 187-190.

Buócz, Z., Szarka Gy.: Lejtős felületek kiporzási tulajdonságainak vizsgálata (Investigation of dusting properties of slant surfaces)
"The 12th Symposium on Analytical and Environmental Problems", Szeged, 2005. szeptember 26.
Conference Proceedings: pp. 306-310.

Buócz, Z., Szarka Gy.: Meddőhányók és zagytározók kiporzása és a védekezési lehetőségek (Dusting in refuse dumps and sludge reservoirs and protection possibilities)
Geotechnika 2005, Ráckeve, Savoyai Kastély, 2005. október 18-19.
http://www.konferenciairoda.hu/geotechnika2005/indexmagyar.htm

Szarka Gy.: Lignittüzelésű erőmű égéstermékeinek kiporzás vizsgálata (Investigation of dusting in the combustion products of a lignite-fired power plant)
MicroCAD 2006 International Scientific Conference, Miskolc, 16-17 March, 2006
Conference Proceedings: C szekció: Környezetvédelem-Hulladékgazdálkodás (Environment protection – Waste Management), pp. 107-116.

Szarka Gy.: Dusting Investigation of Deposited Slag-Scale-REA Gypsum Materials; Bányászat és Geotechnika. A Miskolci Egyetem Közleménye A sorozat, Bányászat 68. kötet, Miskolci Egyetemi Kiadó, 2006. pp. 113-118.

F. Kovács Dr, B. Mang Dr, Szarka Gy.: Dusting Investigation of Deposited Slag-Scale-REA Gypsum Materials
XIV International Scientific & Practical Conference "Information Technologies: Science, Engineering, Technology, Education, Health" 18-19 May, 2006, Kharkiv
Conference Proceedings: pp. 286-291.

Buócz, Z., Szarka Gy.: Egyes anyagok kiporzási értékeinek előrejelzése regressziós vizsgálat alapján (Prediction of the dusting properties of materials on the basis of regression analysis)
MicroCAD 2007 International Scientific Conference, Miskolc, 22-23 March, 2007
Conference Proceedings: under publication