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INITIAL TRIALS OF A PROPOSED PARTICLE COUNTER FOR UNDERGROUND USE

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by

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ABSTRACT

A particle counter has been developed for use in non-certified underground mines. The counter is a light diffraction based unit which counts and sizes single airborne particles by their near forward scattered light as they are drawn through a sensing chamber. The counter sizes each airborne particle into one of six manufacturer set threshold size ranges that span 0.5 to 20.0 μm.

Detailed is a preliminary underground test that was performed during the fabrication of two units. The test to evaluate various elements of the counter design, conducted in a conveyor way with typical dust concentrations, 0.4 mg/m^3 average and 6.0 mg/m^3 peak, showed all elements to be suitable. The test confirmed the requirement of a diluter in the final design to avoid excessive particle coincidence.

The instrument trial also provided information on the distribution of particles by number for operational and non-operational periods of the conveyor. After converting counts to unit mass, the mass distribution by size has been defined by a log normal approximation which provided the mean optical volumetric diameter (MOVD) and geometric standard deviation (GSD). Two average distributions obtained, were: 2.22 μm MOVD and 2.17 GSD, for a running empty or no belt condition; and 3.87 μm MOVD and 1.74 GSD, for the belt carrying material. This demonstrated the much larger airborne product when material was being conveyed.

Key words: Dust; Environmental monitoring; Mine environment; Aerosols.

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PREMIERS ESSAIS D'UN COMPTEUR DE PARTICULES PROPOSÉ DESTINÉ À ÊTRE UTILISÉ SOUS TERRE

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RÉSUMÉ

On a mis au point un compteur de particules destiné à être utilisé dans des mines souterraines non certifiées. Le compteur est un appareil basé sur la diffraction de la lumière qui compte et classe les particules individuelles en suspension dans l'air d'après leur lumière diffusée quasi vers l'avant lorsqu'elles traversent une chambre de détection. Le compteur classe chaque particule en suspension dans l'air suivant six seuils d'intervalles de dimensions établis par le fabricant et qui couvrent la plage de 0,5 à 20,0 µm.

On décrit un essai souterrain préliminaire qui a été effectué pendant la fabrication de deux appareils. L'essai visant à évaluer divers éléments du modèle de compteur, réalisé dans une galerie de convoyeur à des concentrations de poussières types, moyenne de 0,4 mg/m³ et maximum de 6,0 mg/m³, a montré que tous les éléments étaient adéquats. L'essai a confirmé la nécessité d'un diluteur dans le modèle final en vue d'éviter une coïncidence excessive des particules.

L'essai de l'instrument a aussi permis de recueillir des données sur la distribution des particules par nombre pour les périodes de fonctionnement et d'arrêt du convoyeur. Après avoir converti les valeurs en masse unitaire, on a défini la distribution de masse par taille au moyen d'une approximation lognormale qui a permis d'obtenir le diamètre volumique optique moyen (MOVD) et l'écart-type géométrique (GSD). On a obtenu les deux distributions moyennes suivantes : MOVD de 2,22 µm et GSD de 2,17 en condition à vide ou sans courroie; et MOVD de 3,87 µm et GSD de 1,74 lorsque la courroie transportait des matières. Ces résultats montrent que la quantité de particules en suspension dans l'air est beaucoup plus élevée lorsque la courroie transporte des matières.

Mots-clés : poussière; surveillance de l'environnement; environnement minier; aérosols.

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INTRODUCTION

A portable aerosol counter enables immediate in situ analysis of a dust source and flexibility of dust survey measurements (1). The unit also allows for an unlimited number of samples to be taken at any point and facilitates surveying numerous work sites in a work period. Generally, a single such instrument removes the reliance of assessing dust sources away from a multiplicity of gravimetric samplers, which normally require pre- and post-weighing of filters or collection substrates. An aerosol counter giving the particulate size distribution of a sampled cloud also reduces the need for time consuming optical microscope counting of particles.

Such portable aerosol counters are commercially available for use in relatively clean and controlled working environments such as laboratories and some factories. Development and continued use of such units in the extreme and hazardous mining environment could not be found.

It is expected that an aerosol counter suitable for underground use would increase productivity and aid the recognition and analysis of major dust sources throughout Canadian mines.

The development and supply of two customized aerosol counting systems for use in underground mines was undertaken by Mono Research Ltd., Brampton, Ontario. This work was awarded to Mono for their proposal on contract 26SQ.23440-6-9148 entitled "Production of a portable microprocessor controlled, multi-size range aerosol counting system for use in underground environments". The units are required to determine the total concentration and size distribution of airborne particulates produced from underground mining.

After eight months of the contract an initial trial of elements of the proposed particle counter configuration were performed in an enclosed belt conveyor way of a local uranium mine. The conveyor transported broken ore or waste from a crusher to an interim storage bunker. A gravimetric respirable dust analysis of this area on another occasion indicated that the time-weighted average dust concentration was ~0.4 mg/m^3, with peak concentrations 4.0 to 6.0 mg/m^3 (2). These values would be typical of the expected operating conditions for the aerosol counters.

Mono Instruments intended to use one of two commercially availale HIAC/ROYCO based units for modification. There was either a unit which employs the near forward scattering of visible light to detect and size particles, (the 4100 series), or a unit that employs right angle scattering and a Helium-Neon laser, (the 5100 series). During the instrument development and the findings of this trial, the laser-based unit option was discounted because of envisaged problems in maintaining laser alignment in a instrument subjected to regular movement, possible shock and vibration.

UNDERGROUND TRIAL EQUIPMENT

The underground trial used a HIAC/ROYCO 4102 particle counting system, a 1200 sensor and 252 diluter. Data was recorded on the unit standard Digitech printer. These are now used in the finished production model.

Initially the system has the following detection configuration:

Channel No.	Detection Threshold
1	0.5 μm
2	1.5 μm
3	3.0 μm
4	5.0 μm
5	10.0 μm
6	15.0 μm

These thresholds are normally factory set and may only be changed by a technically competent person. This was possible during the trial, and the detection threshold of channel 1 was reduced to 0.3 μm for part of the evaluation.

The normal sampling flow rate for the majority of the trial was 2.8 L/min except for some occasions when the lower threshold was changed and an optional diluter was included.

The tests in the conveyor way fell into two categories. Firstly, determining unit suitability with respect to using the 0.3 or 0.5 μm lower detection limit, including built in switchable flow rates, and secondly, evaluating an external diluter.

In the duration of the first category of tests, three mining operational conditions were experienced: no operations in the conveyor way; only the belt conveyor running; and the belt conveyor running and carrying material be it ore or muck. In the second category, the unit was tested at four different sampling flow rates.

AEROSOL COUNTER RESULTS

The aerosol counter was operated with the optional printer to log count results, in both a cumulative and differential format. Table 1 presents the results from all the tests in the differential form (3). On each occasion the results are an average of three test counts performed by the instrument.

Throughout Tests 1 to 9, the counter/sensor was positioned at approximately 6 m from the belt. In this position the three operational conditions were measured. On moving the counter/sensor closer to the belt, within 1.5 m, for the remainder of the trial. Tests 10 to 12 demonstrated differing increases in counts per channel. For channel 1, the increase was marginal at 11%, larger for channel 2 at 50%, most dramatic in channels 3 and 4, 3 to 10μm, at 166% and 133%, respectively, and then lower again for channel 5 at 32%. If the loading of muck onto the belt conveyor 200 m below

Table 1 - Count data from the particle counter under varying operating conditions and modes.

Test No.	#1b 0.3 μm	#1a 0.5 μm	#2 1.5 μm	#3 3.0 μm	#4 5.0 μm	#5 10 μm	#6 15 μm	Sample Flow L/min	Activity
	Channel Differential Counts								
<u>Operation Tests</u>									
1-3		288016	49298	2235	159	10	3	2.8	No operations
4-6		372102	86612	3226	285	8	2	2.8	Belt running
7-9		612365	234155	21225	2107	59	8	2.8	Belt & ore
10-12		678709	351643	56441	4925	78	2	2.8	" " "
13-15	736045		446096	197788	24866	2257	27	2.8	" " "
16-18	105521		41621	10619	780	71	2	0.28	" " "
<u>Dilution Tests</u>									
19-21		504377	1165575	4418	266	2	0	2.8	No diluter x1
22-24		73280	8328	260	20	1	0	0.28	No diluter x10
25-27		5131	595	5	0	0	0	2.8	Diluter x100
28-30		532	64	1	0	0	0	0.28	Diluter x1000

the sampling point was the prime dust generator, homogeneous concentrations and repetitive counts would be expected regardless of distance from the belt. As belts themselves are a dust generator this rise was not unexpected.

The counts in channels 2 to 6 continued to increase in Tests 13 to 15. On this occasion the major increase in channel 1, in part, is attributable to the lowering of the detection limit to 0.3 μm.

In Tests 16-18 the optional flow rate was invoked, which reduced the sampling rate to 0.28 L/min, a factor of ten. Between Tests 13-15, and 16-18, the only channel not to show dilution by 10 or greater is channel 1. This could be an indication that in some of the previous tests saturation of the sensor was being reached. This is also supported by the dilution of channel 1 between Tests 19-21 and 22-24. Generally, the rate of occurrence of particle doublets and triplets being counted by the sensor starts to increase rapidly beyond counts of 700,000 and a saturation limit is reached beyond 1.4 million particles.

Prior to Tests 16 to 18, the continued increase in counts could be a function of the dust concentration building up with time to:

i) a steady state after the belt starts to move and ore was being transported: or

ii) a peak due to some other influence associated with the belt.

Subsequent to this test the dilution corrected counts, however, continued to decrease, in most cases, beyond the dilution ratio. Therefore, this series of tests would seem to have captured a peak in the dust concentration in the conveyor way. As the belt was always running after Test 3, and always carrying broken material beyond Test 6, the cause of the peak is probably external to the conveyor way. It could be a function of the crusher which intermittently stocks a bunker that discharges onto the belt. The bunker acts as a surge bin to even out the supply from the crusher to the demand of the belt.

Through Tests 19 to 30, the counted dust containing sample flow rate was stepped down by factors of 10. The results show the dilution to be generally producing diluted count results of the right order. Only tests under controlled laboratory conditions with constant concentration aerosols would produce more exact diluted counts. These were taken under conditions where the concentration could be extremely variable.

The dilution tests do indicate, however, that dilution makes the unit increasingly insensitive to larger particles. This insensitivity would limit size distribution analysis and should be minimized. The best dilution factor can only be determined with further field trials in diverse operating conditions and concentrations.

MASS DISTRIBUTIONS BY SIZE DETERMINED BY AN AEROSOL COUNTER

The aerosol counters purely count the particles into size ranges and in its basic form will give particle number concentrations. Simple calculations will also provide the percentage numerical distribution by size of the aerosol. In certain instances this is useful engineering information, but another possibly more valuable representation of the data is in terms of mass, unit volume, or equivalent number of unit size spheres. In the subsequent analysis all numerical particle counts have been converted by an equivalent volume ratio. This treatment provides the equivalent number of particles by volume (or mass) having the same log mean diameter as those particles in the 3.0 and 5.0 μm range.

The equivalent volume multiplication factor corrections span 0.005 for size range 0.3 to 1.5 μm through to 89.43 for size range 15 to 20 μm. Once converted, both a total equivalent volume and a percentage volume distribution by size range can be determined. By presenting the data in a cumulative

Table 2 - Mean optical volumetric diameter (MOVD), geometric standard deviation and linear regression correlation from the size distribution analysis for each set of tests (n=5).

Test No.	MOVD μm	Geometric Standard Deviation	Regression Correlation Coefficient	Activity
1-3	2.20	2.27	0.967	No operations
4-6	2.28	2.01	0.975	Belt running
7-9	3.18	1.84	0.993	Belt and ore
10-12	3.40	1.63	0.999	" " "
13-15	4.92	1.60	0.991	" " "
16-18	4.20	1.71	0.994	" " "
1-6	2.22	2.17	0.970	Average background
7-18	3.87	1.74	0.994	Average belt & ore

undersize format it is possible to obtain the mean optical volumetric diameter (MOVD) and geometric standard deviation (GSD) of the volume distribution for the measured dust cloud. This analysis uses the upper limit of each size range as the undersize cut point and plots them against the cumulative undersize volume on log probability scales to linearize the distribution. The line of best fit is determined through a regression analysis of the linear coordinate locations of the log probability plot. This gives the best log normal distribution approximation of the measured dust cloud size distribution.

Table 2 lists the results of the mass distribution analysis for the series of operational tests. Evident in the Table is the increase in mean diameter, MOVD, with the commencement of the belt running and transporting material. Prior to material transportation, the average background dust cloud had an MOVD of 2.22 μm and 2.17 GSD whether the belt was moving or not. When muck was being transported and the average dust cloud had a larger MOVD of 3.87 μm and 1.74 GSD. Statistical analysis of the two distributions prior to material transport demonstrates the distributions to be the same with a >90% confidence level (4).

The log normal approximation of the distribution for the tests are given in Figure 1, and for the two averages in Figure 2. Visual inspection of the two average distributions shows them to be obviously different. This can be supported statistically at a >90% confidence level. Table 2 also exhibits the high regression correlation coefficients for each series of tests, which demonstrates the high correlation between the measured dust cloud mass distributions by size and the log normal distribution approximation.

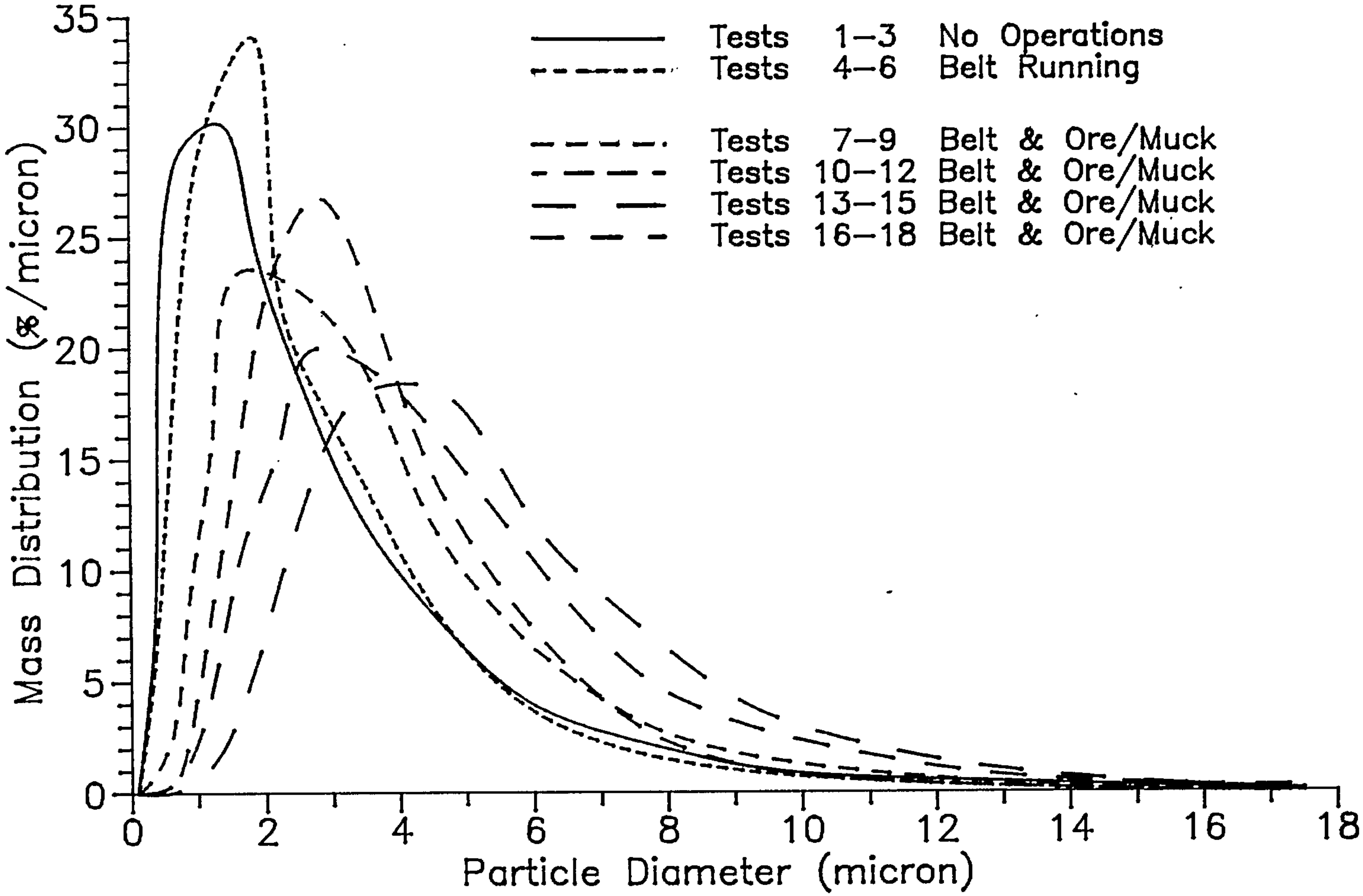

Fig. 1 - Lognormal approximation curves of the relative mass distribution by size of airborne dust for operations in a conveyor belt. (From optical data.)

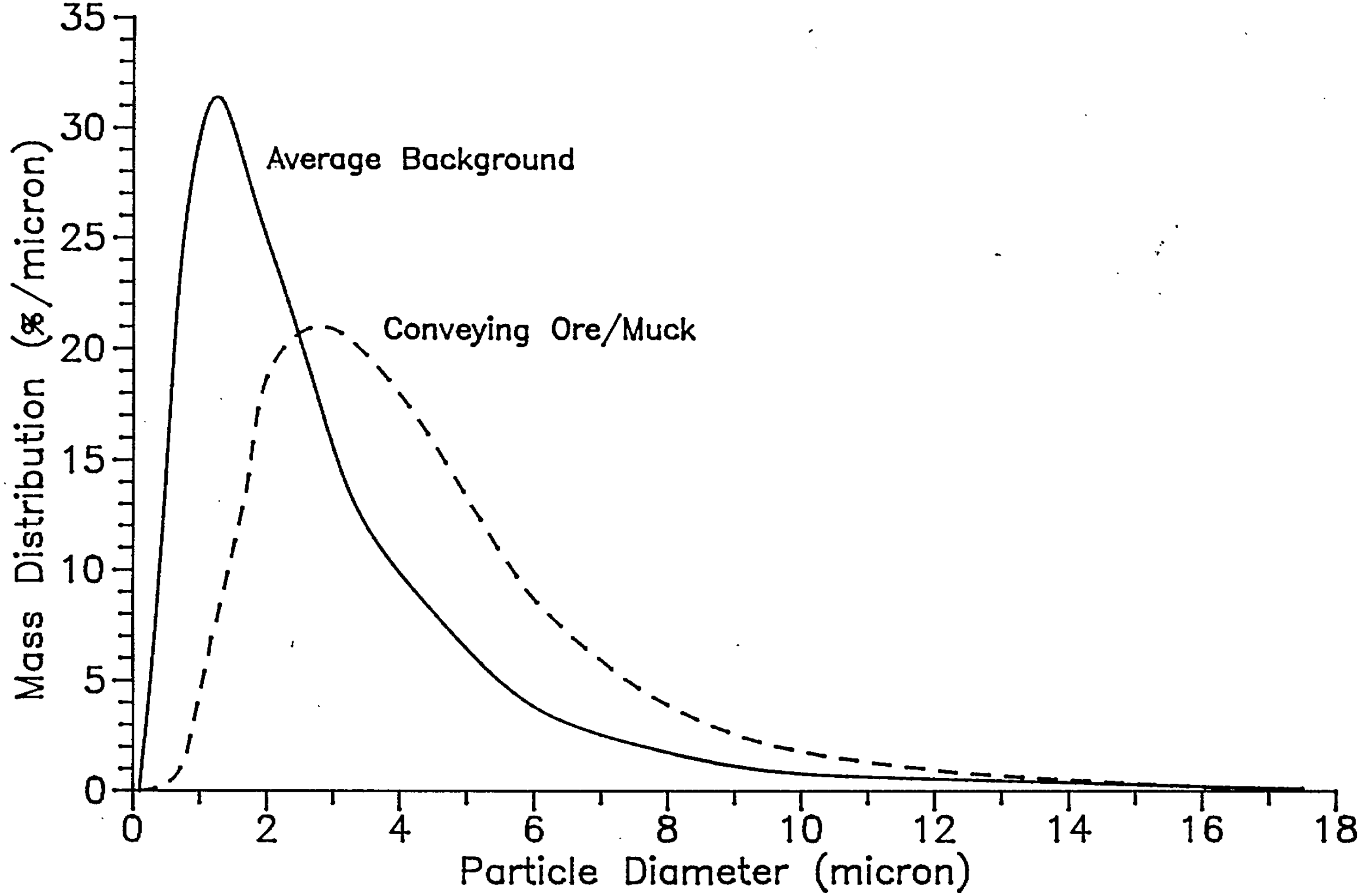

Fig. 2 - Average lognormal approximation curves of the relative mass distribution by size of airborne dust for material conveying and other conditions. (From optical data.)

DISCUSSION AND CONCLUSIONS

Elements of what is now the production aerosol counter design were successfully tested in a typical mining environment while measuring standard respirable dust concentrations. The tests demonstrated that a HIAC/ROYCO 4100 series sensor with an 0.5 μm lower detection limit was the most suitable for the final unit. It uses a visible light source and counts and measures a particle by the near forward scattered component of the light diffracted by the particle. The physical handling, movement, shock and vibration of transporting instruments to locations underground demonstrated to the manufacturers that the more sophisticated laser based 5100 sensor series would not survive. Tests were also performed with an 0.3 μm unit, but it was envisaged that such a unit would prove unable to maintain its sensitivity with prolonged exposure to the mining environment.

The test results showed some evidence that particle counting coincidence was occurring for the normal sampling flow rate, 2.8 L/min, at peak concentrations of dust. The coincidences were easily removed by diluting the sampled air. Dilution factors tested were 10, 10^2 and 10^3 to 1. Of these the optimum appears to be between 10 and 100 to avoid losing detail of the larger particle counts. The maximum of 100:1 is used in the initial production aerosol counters. This should provide an upper count limit of 25 million particles per litre without significant coincidence.

The counters sampled during three operational states in the conveyor way: no conveying; running an empty conveyor; and conveying ore. The basic count results show an increase with the start of operations and a peak during the ore conveying period. This peak was probably a function of the intermittent operation of a crusher feeding the conveyor.

The data issuing from the counters is purely a count for each of six size ranges. Using a mean diameter and standard geometry the counts can be converted into volumes or unit mass for further analysis. Mass distribution by size analyses of the data demonstrated that for each operational condition a log normal distribution gave a very good approximation of the measured dust distribution. Using the log normal approximation a mean optical volumetric diameter (MOVD) and geometric standard deviation (GSD) were obtained for each dust cloud for each series of tests.

A statistical analysis showed that the mass distribution by size of airborne dust in the conveyor way did not change when the belt started. For these two conditions the mass distribution is defined by 2.22 μm MOVD and 2.17 GSD. When the belt was transporting ore the mass distribution was significantly different with a much larger MOVD, 3.18 to 4.92 μm. During ore transport the average distribution is defined by 3.87 μm MOVD and 1.74 GSD.

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