Essential Readings in Light Metals: Alumina and Bauxite.
Edited by Don Donaldson and Benny E. Raahauge.

"MEASUREMENT OF SANDY ALUMINA DUSTINESS"

S. Perra

Eurallumina S.p.A.
09010 Portoscuso - (Cagliari)
ITALY

The paper intends to offer a contribution for the quantitative determination of such intrinsic characteristic of the alumina.

Simple apparatus (pulvimeter) has been designed and built to measure on both weighted and numerical basis, the tendency of the alumina to produce dust (primary pulvation).

The pulvimeter enables to weight the free dust produced by an alumina after diffusion as settled in the measurement cell.

The alumina dust is then analyzed for the numerical counting (via Celloscope) (1) and for the weighted and numerical determination of the granulometric distribution.

The reproducibility of the method as realized is better than 5%.

Applying the above procedure to various alumina samples, the following conclusions have been reached:

- Alumina dustiness depends marginally from its -325 mesh content. It is on the contrary more related to the quality of -325 mesh fraction.

- On weighted terms, alumina dustiness in function of -20 microns content, even tough it has been observed that by increasing 5 times the content of -20 microns fraction, the weighted primary pulvation index increases only by 60%.

- In numerical terms, the alumina primary pulvation index is directly proportional to its -20 microns content.

Introduction

The study of dust levels in alumina is a problem which is so sensitive with end-users of alumina as to influence their choice of producers with whom they deal.

Producers, for their part, have responded to the problem by taking extreme care to control product fineness and by allocating a substantial part of their production costs and investment money to the problem.

However, it is authoritative opinion that both end-users and producers are subject mainly to emotional factors rather than hard facts. This makes it imperative to create a sound basis on which to work, such as the direct measurement of the tendency of a given alumina to produce dust, the identification of parameters which among alumina's physical characteristics are the catalysts of the phenomenon, and a criterium to establish the alumina specification based on facts, not emotions.

Conclusions

An instrument (the dust-meter) has been designed, constructed and tested to provide direct measurement of the "dust factor" of all types of alumina ; the instrument does this simply, reliably, and precisely.

The dust meter eliminates the need to extrapolate this important feature of alumina from other physical properties, since such results are not always realistic.

It has been demonstrated that the specification which requires maximum 10% on the -325 mesh is soundly based only to the extent that, generally speaking, the superfines increase as the -325 mesh increases.

On a weighted basis, the dust level index of alumina is correlated with its content of -20μor $-10\mu(r^2 = 0.82)$ in such a way that, however, when there is a fivefold increase of superfine content, the weighted dust level index (Weighted Primary Dust Content Index = W.P.D.C.I.) increases by barely 60%.

This signifies that whatever means (operational or plant equipment based) are used to reduce superfines in the finished product, this will never produce a return on investment if the objective is to reduce losses of alumina during handling operations.

Table I summarizes the results of weighted dust content tests conducted on our alumina having -20μcontent of between 0.95 and 5%.

The table also gives the results of weighted dust content tests conducted on our aluminas from which, by wet seiving, the -45, -30 and $-20\,\mu$ have been removed, respectively.

From *Light Metals 1984*, J.P. McGeer, Editor

Table I.

Weighted Primary Dust Content Index Versus -20μContent in Alumina

- 20μ (%)	W.P.D.C.I. (Kg/t Allumina)
5	1.78
1.68	1.15
0.95	1.04
2.03	1.36
1.5	1.27
2.4	1.49
1.0	1.36
1.6	1.20
3.2	1.62
4.01	1.82

CORRELATION INDEX

$r^2 = 0.82$

W.P.D.C.I. = 0.18 x (% -20μ) + 0.98

Weighted Primary Dust Content Index of +45, +30, +20 Microns

SAMPLES	W.P.D.C.I.
AS IS	1.29
+45µ	0.18
+30µ	0.52
+20µ	0.80

Reasoning in numerical terms, which is the most correct approach from the standpoint of industrial hygiene (in the United States, for example, the inert dust limit in work environments is expressed as the number of suspended particles per unit volume), the numerical dust content index (Numerical Primary Dust Content Index = N.P.D.C.I.) is directly proportional to the -20μcontent in alumina.

By regressing linearly the data given in Table II it has been found that:

$$N.P.D.C.I. = \frac{\text{(millions of particles)}}{\text{gr of alumina}} = 1.235\ (\% -20\mu) - 0.08$$

with a CORRELATION INDEX (r^2) of 0.99.

This happens because as superfines increase in the product, even with a slight increase of weighted dust content, the grain size distribution of the generated dust is increasingly finer (i.e. more particles for same weight).

CORRELATION INDEX

$r^2 = 0.99$

N.P.D.C.I. = 1.235 x (% - 20 μ) - 0.08

NOTE: All size distribution analysis are measured with the Celloscope.

Table II. Pulvation Test on Aluminas with Different Contents of Superfines

-20 μ on the alumina sample (% weight)	N.P.D.C.I. millions of particles gr. of alumina	NUMERICAL DISTRIBUTION (%)										DISTRIBUTION BY WEIGHT (%)										Nº of part. Alumina as is millions gr
		Dust Deposited				Alumina as is				Dust Deposited				Alumina as is								
		+45 μ	+20 μ	+10 μ	+5 μ	+2 μ	+45 μ	+20 μ	+10 μ	+5 μ	+2 μ	+45 μ	+20 μ	+10 μ	+5 μ	+45 μ	+20 μ	+10 μ	+5 μ			
1.4	1.79	0.02	1.05	18.52	40.51	100	7.96	17.9	25.1	42.67	92.79	6.13	58	77.77	93.45	80.62	98.64	99.59	99.88			22.8
2.0	2.16	0.021	0.93	6.03	28.49	94.14	6.18	14.97	24.79	43.49	93.79	6.45	51.2	76.72	93.77	80.06	98.03	99.5	99.88			28.5
2.1	2.63	0.01	0.61	4.34	25.58	93.57	4.56	10.37	17.24	37.91	91.71	5.15	45.01	70.09	91.06	81.32	97.94	99.29	99.85			38
1.5	1.73	0.02	0.95	5.30	27.78	93.44	5.05	12.39	16.74	31.35	84.26	10.15	57.71	78.92	94.03	79.17	98.54	99.48	99.8			31
3.9	4.77	0.005	0.32	2.15	22.87	94.8	1.26	3.28	5.75	20.57	92.77	3.64	36.12	55.27	83.61	74.7	96.13	97.93	99.13			134

In any case, if there is no threshold of superfines above zero for which with lower values we can reasonable state that the alumina is not "dusty" (since it has been widely demonstrated that the function is continuous) we can still fix as a criterium for superfines specification an alignment with the best products on the market.

The best approach, however, would be a large-scale use of a test making direct measurement of dust indexes.

Alumina Dust and Industrial Hygiene

The following concentration limits (TVL) of alumina dust are recommended for occupational environments:

SOURCE		TVL
I. SAX (2)	:	50 m.p.p.c.f.
Italian Chemical industry contract	:	30 m.p.p.c.f. or 10 mg/m^3

REMARKS: TVL is the maximum concentration to prevent damage to normal individuals exposed to alumina dust 8 hours per day.

m.p.p.c.f. = millions of particles per cubic foot.

m.p.p.c.m. = millions of particles per cubic meter.

Wishing to express the above limits in m.p.p.c.m., we have:

SOURCE		TVL
I. SAX	:	$\frac{50 \times 1000}{28.3168} = 1766$ m.p.p.c.m.
Italian Chemical industry contract	:	$\frac{30 \times 1000}{28.3168} = 1059$ m.p.p.c.m.

Since the Italian Chemical Industry Contract sets concentration limits in terms of both number of particles and weight, we can calculate particle diameter (in μ) which satisfies the following equation:

$$1059 \text{ m.p.p.c.m.} = 30 \text{ m.p.p.c.f.} = 10 \text{ mg/m}^3$$

$$\text{EQUIV. DIAMETER} = \sqrt[3]{\frac{(\text{mg/m}^3)}{(\text{m.p.p.c.m.}) \times \frac{4}{3} \times \pi \times \gamma}} \times 2 \times 10^4 =$$

$$= \sqrt[3]{\frac{10}{1059 \times 10^6 \times \frac{4}{3} \times 3.14 \times 3.56 \times 1000}} \times 2 \times 10^4 = 1.72 \ (\mu)$$

This means that with a particle concentration of 10 mg/m^3, we also have a particle numerical concentration equal to 1059 m.p.p.c.m. provided that average numerical diameter is 1.72 μ .

If average numerical diameter is lower, the number of particles per cubic meter definitely surpasses the chemical contract limit. Likewise, the number of particles per cubic meter will be below the chemical contract limit whenever the average numerical diameter surpasses 1.72 μ .

In order to obtain reference values corresponding to our case in practice, on 3 February 1983 plant personnel took a sample of air in the tunnel of a belt conveyor during the loading of a ship from a storage silo.

The sample was taken 80 cm above the belt surface corresponding to the vertical gangway on the belt's outer edge.

The results were as follows:

a) particle concentration = 44 mg/m^3

b) properties of the dust:

- number of particles per mg of dust = 3.5×10^6

- grain size distribution	in numbers	in weight
+ 100 μ (%)	0.0000	0.0000
+ 45 μ "	0.0002	0.144
+ 20 μ "	0.028	2.34
+ 10 μ "	3.71	31.92
+ 5 μ "	27.66	81.41
+ 3 μ "	68.95	97.16
+ 2 μ "	93.58	99.74

In the case of particle matter generated by our sandy alumina the dust concentration in weight required to reach the numerical limit set by the chemical contract, is rather high:

Concentration of particle matter equivalent to 1059 x 10^6 particles per m^3, in the case of dust generated by our sandy alumina =

$$= \frac{1059 \times 10^6}{3.5 \times 10^6} = 303 \quad mg/m^3$$

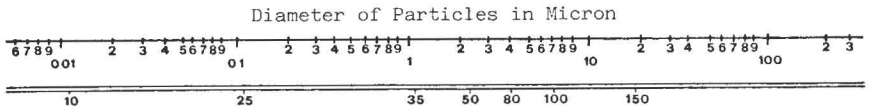
as Table III indicates, this concentration is about four times greater than the visual perception limit (for approx. 4 μ of average numerical diameter, the visibility threshold is about 80 mg/m^3) and thirty times the maximum weighted limit provided for by the chemical contract.

Experiences with the dust meter on our alumina allows us to evaluate the pollution potential of our sandy product.

It should be borne in mind that the values to be computed are only potential figures, but still do represent the maximum reachable as the effect of air diffusion and/or transport from the environment in which the dust is freed into the atmosphere.

Table III.

Visual Perception Limit in mg/m^3 in Function of Particles Diameter in Micron



These pollution potentials are as follows, for each phase of alumina handling (jump):

$$\text{In weight} : \frac{1.4 \times 10^6 (\overline{W.P.D.C.I.})}{10} = \frac{140{,}000 \text{ m3 of air}}{\text{ton of alumina handled}}$$

$$\text{In numbers} : \frac{2.1 \times 10^6 (\overline{N.P.D.C.I.}) \times 10^6}{1059 \times 10^6} = \frac{2{,}000 \text{ m3 of air}}{\text{ton of alumina handled}}$$

Of course the diffusion of alumina dust in the environment at its maximum potential value will be localized in the emission point.

From the emission point the dust is then subjected to a depositing phenomenon which reduces the concentration as the dust moves further away from said emission point.

The depositing phenomenon follows Stokes' law:

$$V = \frac{2 \times g \times r^2 \times (d_s - d_a)}{9 \times \mu \times 10^8}$$

where:

V = settling rate (cm/sec)
g = acceleration due to gravity (978 cm/sec^2)
r = radius of particle matter (μ)
d_s = density of particle matter (3.56 g/cm^3)
d_a = density of air (0.00121 g/cm^3 at 18°C)
μ = viscosity of air (182.7×10^{-6} poises at 18°C)

By computing the speed of sedimentation for several diameters, we have the following situation:

dia. 2 μ V = 0.042 cm/sec
" 4 μ V = 0.169 "
" 10 μ V = 1.058 "
" 20 μ V = 4.233 "
" 45 μ V = 21.43 "

Therefore, the spreading distance from emission point, for each meter of vertical drop, depending on air speed which moves horizontally, is as follows:

		AIR SPEED (m/sec)				
DIAMETER OF PARTICLES (μ)		0	0.5	1	5	10
2	Spreading Distances (meters)	0	1190	2381	11905	23810
4		0	296	592	2959	5917
10		0	47	95	473	945
20		0	12	24	118	236
45		0	2	5	23	47

On the basis of analysis made with our dust-meter and through grain size control in the belt tunnel during ship loading, we may conclude that our interest is towards the behaviour of dust having diameter of 10 μ and less.

Method used to determine Primary Dust Content of Sandy Alumina

Basis of Method

A weighed sample of alumina is dropped through an orifice plate onto the base of a funnel fitted onto a conical diffuser, and from there onto a flat surface inside a closed chamber.

Part of the dust thus generated (primary dust content) settles onto a calibrated measuring cell. The resulting increase in cell weight constitutes the weighted primary dust content index (W.P.C.D.I.). The dust which has settled on the measuring cell is then analyzed by CELLOSCOPE to determine its numerical primary dust content index (N.P.D.C.I.).

Field of Application

The method can be used with all sandy alumina samples and with all dust matter having diameter not greater than 1 millimeter and angle of repose not greater than 35°.

When matter has an angle of repose greater than 35° (such as floury alumina), measurement is difficult because the matter does not "flow" with natural regularity through the orifice plate of the intake funnel.

Precision of method

5 percent.

Procedures

- Using a precision balance, weight out 250 grams +/- 0.1 grams of alumina taken by reduction of the whole sample by riffles.
- Assemble the dust meter apparatus, bearing the reference points in mind in order to guarantee the same relative position of the parts for each analysis (see attached figure 1 showing the dust meter and its dimensions).
- Using an analytical balance with tolerance range of +/- 0.0001 grams (P_1), weight the sedimentation cell which has been carefully cleaned beforehand.
- Position the sedimentation cell on its support bracket inside the dust meter.
- Using a suitable rubber plug, shut the funnel orifice plate.
- Pour 250 grams of weighed alumina into the funnel.
- Agitate the funnel to level its contents.
- Free the intake cone orifice by raising the rigid rod connected withe the rubber plug.
- Allow the sample to flow naturally through the orifice.
- Re-plug the orifice, start the timer.
- After 5 minutes have been timed, open the door provided (during all previous work, the door has been kept tightly shut).
- Remove the sedimentation cell.
- Brush-clean the outside surfaces of the sedimentation cell.
- Using an analytical balance with tolerance of +/- 0.0001 gram (P_2), weigh the sedimentation cell containing the dust.
- By means of electrolyte wash, transfer the settled dust inside the sedimentation cell into a special beaker for use with Celloscope; increase the total electrolyte volume to 100 ml.
- Analyze beaker contents using the Celloscope assembled with the 300 μ orifice, following the same general standard procedure used for hydrate of aluminum controls.

  The sole variation will consist in the procedure to correct the figures computed; therefore in response to the compute question: "FINAL DILUTED VOLUME", insert the result of the following equation:

$$\text{FINAL DILUTED VOLUME (300 micron orifice)} = \frac{100}{(P_2-P_1) \times 1000} = \frac{0.1}{(P_2-P_1)}$$

- Record the following data produced by computer:
  - correct counts of particles greater than 15.79 μ (C + 15.79 expressed in counts/mg)
  - percentages in numbers at + 104, + 75, + 45, + 30, + 20 microns
  - total volume of particles greater than 15.79 microns (V + 15.79)
  - percentages in volume (weight) at +104, +75, +45, +30, +20 microns

- Repeat the dust meter analysis using a portion of the same sample, this in order to carry out the CELLOSCOPE analysis of settled dust using the 48 micron orifice.

- Transfer the dust from the sedimentation cell into a 200 ml flask, passing the dust through a 20 micron micro-sieve using electrolyte.

- In order to correct the computations, answer the computer's question: "FINAL DILUTED VOLUME" by inserting the result of the following equation;

  FINAL DILUTED VOLUME (48 micron orifice) $= \frac{200}{(P_2-P_1)\times 1000} = \frac{0.2}{(P_2-P_1)}$

- Using the CELLOSCOPE, analyze the contents of the 200 ml flask using the 48 micron orifice.

- Record the following data produced by computer:

  - correct counts of particles smaller than 15.79 μ (C-15.79 expressed in counts/mg)

  - percentages in number to +15, +10, +5, +3, +2 microns

  - total volume of particles smaller than 15.79 μ (V-15.79)

  - percentages in volume (weight) to +15, +10, +5, +3, +2 microns.

Calculations

Weighted Primary Dust Content Index (W.P.D.C.I.)

$$W.P.D.C.I. = \overline{(P_2-P_1)} \times \frac{D_p^2}{D_C^2} \times \frac{1000}{250} = \overline{(P_2-P_1)} \times \frac{220^2}{39^2} \times \frac{1000}{250} =$$

$$= \overline{(P_2-P_1)} \times 127.28$$

Where:

D_p = diameter of dust meter (= 220 mm)

D_C = diameter of measuring cell (= 39 mm)

P_2 = weight of measuring cell, with dust, expressed in grams (average of two determinations)

P_1 = weight of measuring cell expressed in grams.

Numerical Primary Dust Content Index (N.P.D.C.I.)

$$N.P.D.C.I. = \left[C_{+15.79} \times (P_2-P_1) + C_{-15.79} \times (P_2-P_1)_2\right] \times 1000 \times \frac{D_p^2}{D_C^2} \times \frac{1}{250 \times 10^6} =$$

$$= (C_{+15.79}+C_{-15.79}) \times (P_2-P_1) \times 1000 \times \frac{220^2}{39^2} \times \frac{1}{250 \times 10^6} =$$

$$= (C_{+15.79} + C_{-15.79}) \times (P_2-P_1) \times 1.273 \times 10^{-4}$$

Where:

$C_{+15.79}$ = correct counts obtained with 300 microns orifice plate

$C_{-15.79}$ = correct counts obtained with 48 microns orifice plate

Remark: the difference $(P_2 - P_1)$ of each of the two test must be used in combination with the relative value C±15.79 to have a more accurate result.

Grain Size Distribution by Number

- Normalizing factor (F.N. + 15.79) (300 micron orifice)

$$F.N._{+15.79} = \frac{C_{+15.79}}{\left[(C_{+15.79}) + (C_{-15.79})\right]}$$

- Normalizing factor (F.N. -15.79) (48 micron orifice)

$$F.N._{-15.79} = \frac{C_{-15.79}}{\left[(C_{+15.79}) + (C_{-15.79})\right]}$$

- Gran Size Distribution by Number

+ 104 μ = (percentage in the CELLOSCOPE + 104 μ) x F.N. +15.79

+ 75 μ = (" " + 75 μ) " "

+ 45 μ = (" " + 45 μ) " "

+ 30 μ = (" " + 30 μ " "

+ 20 μ = (" " + 20 μ) " "

+ 15 μ = [(percentages in the CELLOSCOPE + 15 μ) x F.N.-15.79] + F.N.+15.79

+ 10 μ = [(" " + 10 μ) " "

+ 5 μ = [(" " + 5 μ) " "

+ 3 μ = [(" " + 3 μ) " "

+ 2 μ = [(" " + 2 μ) " "

Gran Size Distribution by Weight

- Normalizing factor ($FV_{+15.79}$)
  (300 micron orifice)

$$FV_{+15.79} = \frac{V_{+15.79}}{V_{+15.79}+V_{-15.79}}$$

- Normalizing factor ($FV_{-15.79}$)
  (48 micron orifice)

$$FV_{-15.79} = \frac{V_{-15.79}}{V_{+15.79}+V_{-15.79}}$$

- Gran Size Distribution by Weight

Use with a computation structure similar to the one described in gran size distribution by number but replacing:

- $F.N._{+15.79}$ with $FV_{+15.79}$

- $FN_{-15.79}$ with $FV_{-15.79}$

- the numerical percentages in the Celloscope with the volume (weight) percentages.

Apparatus

- Dust meter as per attached figure n° 1

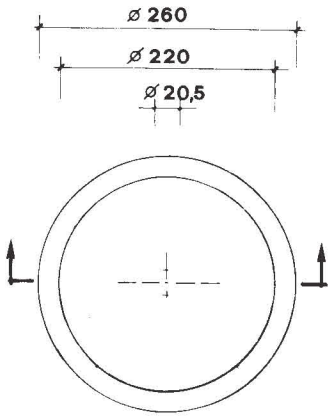
- Precision balance; tolerance: 0.1 gram.

- Analytical balance: tolerance: 0.0001 gram.

- Soft bristle brush

FIG. 1 - DUST METER APPARATUS

(all dimensions in mm.)



VIEW FROM THE TOP

1 - MOVABLE FEEDING FUNNEL

2 - CYLINDRIC BOX

3 - SUPPORT AT 120 DEGREES OF THE DEFLATION CONE

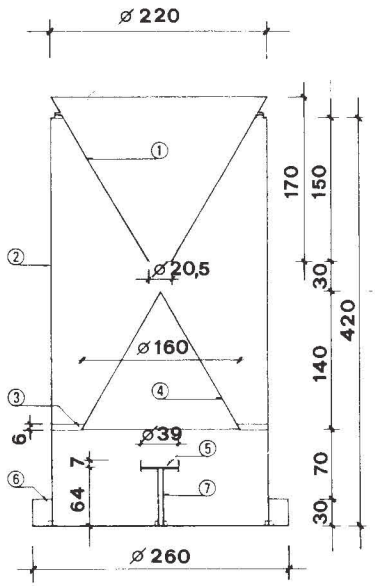
4 - MOVABLE DEFLATION CONE

5 - SEDIMENTATION CELL

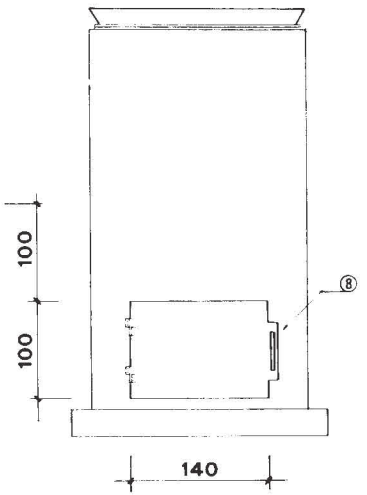
6 - COLLECTING BASIN

7 - SUPPORT

8 - LOCK DOOR



SECTION



FRONT VIEW

- Celloscope with 300 and 48 micron orifice, volume cross-sections: 200 and 5000 micron litre; beaker: 100 ml.
- Calibrated flask: 200 ml.
- 20 micron micro-sieve

Chemicals

- Distillate water
- Electrolyte for Celloscope (solution of trisodium phosphate in water with conductibility range of 16,500 to 20,000 microsimens/cm, filtered to 0.2 micron.
- Calibration materials for Celloscope: polystyrene micro-spheres; diameter : 10 and 60 microns.

Checking the Dust-Meter for Trouble-Free Operation

Reproducibility Check

The same sample (250 grams) was analyzed 10 times and gave the following W.P.D.C.I. results:

Test N°	W.P.D.C.I. (Kg/ton alumina)	
1	1.76	
2	1.85	
3	1.91	
4	1.93	W.P.D.C.I. = 1.80 av.
5	1.86	standard error =
6	1.78	=0.09 (5%)
7	1.76	
8	1.63	
9	1.76	
10	1.71	

W.P.D.C.I. and N.P.D.C.I. on basis of sample weight

Three series of tests (each series consisting of four tests) were made on another sample. 100, 250 and 500 grams of sample of alumina were used for each series, respectively.

Average test results were as follows:

Sample weight	W.P.D.C.I. Kg/T Al	N.P.D.C.I. million of particles/ gr Al
100 gr	1.03	1.64
250 gr	0.96	1.43
500 gr	1.37	1.52

As the data given in Table IV shows, in the 100 to 250 range, in addition to the relative consistency of the weight primary dust content index, there is also a well comparable grain size quality, both numerical and weighted.

With 500 grams of sample weight, the dust meter reacts with an increase in the weighted dust content index coupled with an increase of the granulometry of the deposited dust.

However, it is interesting to note that in spite of the increase in sample weight, the numerical dust content index does not increase appreciably, not even with 500 grams of sample; additionally, the numerical grain size distribution remains fairly constant.

There is a remarkable affinity between the quality of dust observed inside the dust meter and the dust wich naturally develops during the handling operations of our plant's alumina.

If we accept that the sample weight to be used in tests must be standard and such as to use the meter within its linear range (250 gr), then the weight of dust deposited in the measuring cell in function with sample weight varies according to the following law:

$$\text{Weight of deposited dust (g)} = A \times EXP^{B \times (\text{weight of sample})} \quad (P_2 - P_1)$$

Where:

A is a constant wich varies from one alumina to another depending on its dust properties

B is a constant which depends on the instrument.

In the case reported above, A equals 2.14×10^{-3}, and B equals 4.676×10^{-3}.

Table IV. Pulvation Test on Different Quantities of the same Sample

Quantity taken From the sample	NPDCI	MILLION PARTICLES/mg			FV	FV	CUMULATIVE GRANULOMETRIC DISTRIBUTION (%)						
	million gr	N 48	N 300	NT	48	300	+70 μ	+45 μ	+30 μ	+20 μ	+10 μ	+5 μ	+3 μ	+2 μ
100 gr	1.84	1.583	0.012	1.595	0.992	0.008	0.000	0.01	0.112	0.47	5.89	33.11	72.86	95.06
250 gr	1.43	1.479	0.015	1.494	0.990	0.010	0.000	0.02	0.17	0.63	5.37	32.25	72.52	94.46
500 gr	1.52	1.095	0.016	1.991	0.986	0.014	0.001	0.03	0.30	0.98	6.87	33.03	71.17	94.40
	WPDCI Kg/t	μ^3/mg			FN 48	FN 300								
		V 48	V 300	VT										
100 gr	1.03	3.2665×10^8	1.91192×10^8	5.1784×10^8	0.631	0.369	0.96	4.37	17.29	31.53	64.17	91.55	98.78	99.91
250 gr	0.96	2.83238×10^8	2.51722×10^8	5.3496×10^8	0.529	0.471	0.3	5.93	23.66	41.28	68.18	92.28	98.91	99.90
500 gr	1.37	2.35287×10^8	3.19079×10^8	5.5437×10^8	0.424	0.576	1.00	8.72	32.36	52.26	77.48	94.67	99.17	99.93

References

1. Celloscope furnished by Particle Data, Inc., P.O. Box 265 Elmhurst, Ill - 60126.

2. SAX " Dangerous Properties of Industrial Materials" Radiological Sciences Laboratory, New York State Health Department, Albany N.Y. Third Edition - 1968 Page 389.