Development and operation of an improved turntable dust feeder

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Abstract

An improved version of a dry dispersion turntable aerosol feeder has been developed which provides greater variation, control, and reliability in aerosol output. The heart of the system is a rotating dust cylinder that permits steady delivery of dust to a turntable groove where it is picked-up by an adjustable aspirator. This design feature eliminates the need for vibrators and ensures a smooth dust flow to the dust pick-up point. Depending on the cylinder diameter, unattended operating time can be greatly increased. The aspirator incorporates an adjustable venturi and pick-up apparatus. By varying venturi adjustment and air pressure, dust pick-up under differing operating conditions can be assured. A large range in aerosol output can be achieved using different groove widths, locations, and turntable speeds. Operational performance tests show steady aerosol output over the delivery range of 100 mg/min to 50 g/min, depending on the size of the feeder. To date, two sizes of the turntable aerosol feeder have been utilized effectively resulting in dust concentrations ranging from 100 μg/m^3 to 560 mg/m^3. © 2000 Elsevier Science S.A. All rights reserved.

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1. Introduction

Aerosol feeders that consistently disperse a dry powder aerosol are required for diverse applications such as pharmaceutical production, high power laser machining, studies related to aerosols, and inhalation exposures. In each case, a fundamental requirement is an aerosol generation mechanism that provides a constant and reproducible aerosol source. The selection of such a device is driven by the ultimate use of the aerosol; whether there will be static or dynamic systems, low or high particulate concentrations, and homogeneous or heterogeneous particle size distributions.

For example, for filtration research, the aerosol system, and consequently the aerosol feeder, is largely determined by whether the thrust of the investigation is towards microscopic, that is, studying theoretical properties such as measuring a particular mechanism, as opposed to macroscopic properties such as overall filter performance. Investigation on the microscopic scale stresses quality with emphasis on using an idealized monodisperse aerosol at low concentration. On the macroscopic scale, the emphasis is on quantity and reproducibility; here, it is desirable to use aerosols of varied size distributions along with heavy dust loading to simulate actual field conditions as well as shorten testing time.

An important constraint placed on an aerosol feeder is its ability to constantly deliver test dust over the duration of the experiment. In the past, feeders producing idealized aerosols had outputs which were so low as to be useless for macroscopic research. On the other hand, feeders producing high aerosol concentrations that could be adapted to filter performance studies were generally difficult to manage and required constant attention. It was with these thoughts in mind that this improved turntable dust feeder was designed and fabricated. The feeder has been able to support a wide variety of both laboratory-scale and pilot-plant-scale aerosol research projects.

2. The dust feeder design

Presently, there are several dry dust feeder designs that employ air streams, fluidized beds, and fluid energy jet mills [1–3]. Some dust feeder systems have even been

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linked to a microcomputer processing system [4]. However, it has been our experience that these dust feeders were excellent for specific dusts in select applications, but were often not satisfactory as general laboratory dust feeders to be used for a variety of dusts of different compositions. Iinoya and Masuda [5] discussed the limits of several dust feeders in their aerosol studies.
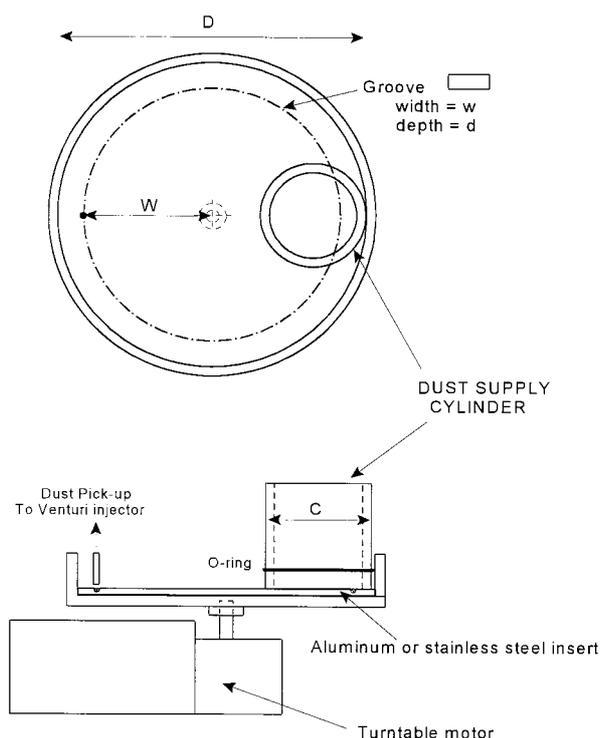
Since our present and future needs required generation of a variety of aerosols and outputs, it appeared as if the pneumatic re-dispersion or dry dispersion class of turntable feeder would be most suitable for development. One advantage of this type of feeder is that it can generate a wide variety of powdered materials, thus allowing the use of powders found under field conditions as well as the large variety of materials available on the market. It was also thought that a dry dispersion feeder would lend itself more readily to modifications in order to give a wide range of output.

The turntable-type dust feeder [6–8] had been used in the past by one of the authors with some success in

generating a variety of dry dusts. However, a major ongoing problem found with this design was failure of material to flow regularly and at even rates from the vibratory hopper to the turntable.

To alleviate the powder flow problem in the hopper, a radical change in design was instituted. Rather than use an inverted cone shape as found on most units, a cylinder, open at both ends, was placed on the turntable, held in place by an idler wheel and allowed to rotate freely by friction drive as the turntable rotated. The powder to be dispersed was placed in the cylinder, which, with its rotation, tended to wipe the powder across the turntable groove filling the groove uniformly with powder. Rotational speed could be varied up to about 3 rpm. At the same time the smooth, straight walls of the cylinder and its rotation kept the powder from clumping or bridging within the cylinder which otherwise could lead to intermittent dust loading of the groove. Fig. 1 shows a sketch of the dust feeder and Fig. 2a details of the cylinder arrangement.

Dust was picked-up from the turntable groove with an aspiration-type unit. Fig. 2b shows details of this unit. By adjusting the internal nozzle position relative to the pick-up line, the amount of suction on the aspirator could be controlled. This could also be controlled by adjusting the compressed air pressure applied to the unit, giving a wide range of flow rates through the aspirator. This adjustment was used to match dust pick-up capability against parameters that could degrade this capability such as turntable speed and/or dust characteristics.

3. Methods and materials

Although operating on the same principle, two different size versions of the design were constructed to exhibit the variable range of dust generation rates possible. The smaller version of the dust feeder was tested at target feed rates of 0.1 mg/min to 3.0 mg/min resulting in concentrations between 100 μg/m^3 and 3000 μg/m^3. For the larger model, using target concentrations of 0.1–500 mg/m^3, a feed rate of 30 mg/min to 50 g/min was required.

To evaluate the performance of the improved turntable dust feeder, the following tests were implemented.

(1) With the small dust feeder generating an aerosol using both organic and inorganic dusts at three target concentrations (approximately 100 μg/m^3, approximately 500 μg/m^3, and greater than 1000 μg/m^3), generation was carried out over a 1-h sampling period to evaluate the flexibility of the feeder.

(2) Using the small dust feeder to generate an organic dust at a low concentration (approximately 100 μg/m^3) over a 4-h time period to evaluate stability of the feeder.

(3) Using the large dust feeder with an inorganic dust to generate an aerosol at a high concentration (greater than
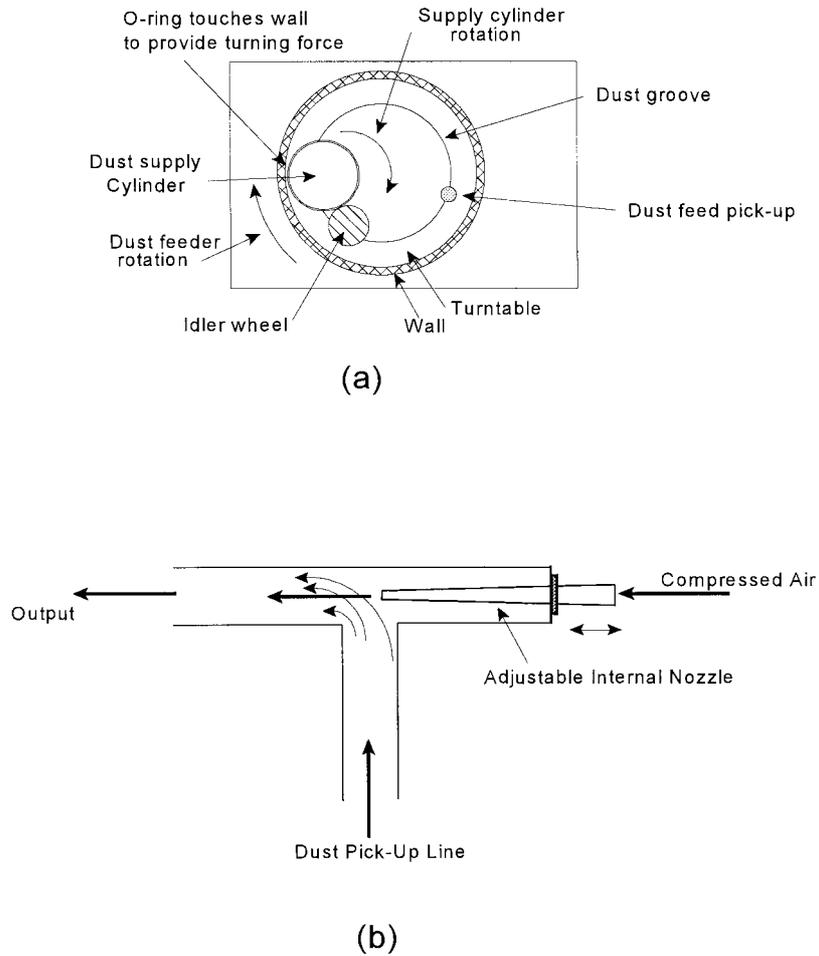

Typical Dimensions		
	Small unit	Large Unit
W	4 cm	8 cm
D	20.3 cm	30.5 cm
C	6 cm	10 cm
w	0.021 cm	0.1 cm
d	0.031 cm	0.05 cm

Fig. 1. Sketch of the turntable dust feeder as discussed in this paper.

Fig. 2. (a) Detail of the cylinder arrangement of the dust feeder. (b) Schematic diagram of the dust aspiration-type unit.

500 mg/m^3) over an extended period so that the degree of stability of the output could be monitored.

(4) Using the large dust feeder to generate an aerosol at a moderate concentration (approximately 1 mg/m^3) to show that the unit could be operated continuously with little attention as long as the dust cylinder contained dust.

3.1. Small dust feeder

Operational performance of the dust feeder design was evaluated during a series of chamber tests. During each chamber run, cellulose or Arizona road dust aerosols were aspirated into the aerosol chamber during a 60-min sampling period. Each source dust was selected to demonstrate the dust feeder's efficiency despite particle charge and composition. Each source dust was used in the dust feeder to generate three target dust concentrations; less than 100 μg/m^3, approximately 500 μg/m^3, and greater than 1000 μg/m^3.

The aerosol chamber consisted of Plexiglas and cinderblock and had a volume of 6.27 m^3. The chamber

utilized an exhaust ventilation system that removed entrained particles using a bag filter. The ventilation rate was variable, but was set at 13 air exchanges per hour (about 1.25 m^3/min) during the chamber studies.
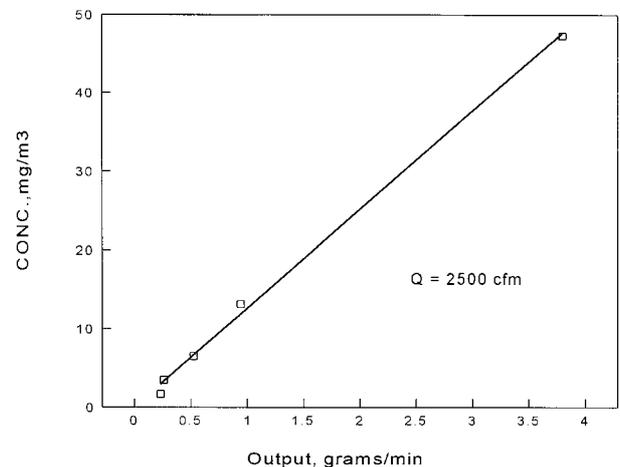

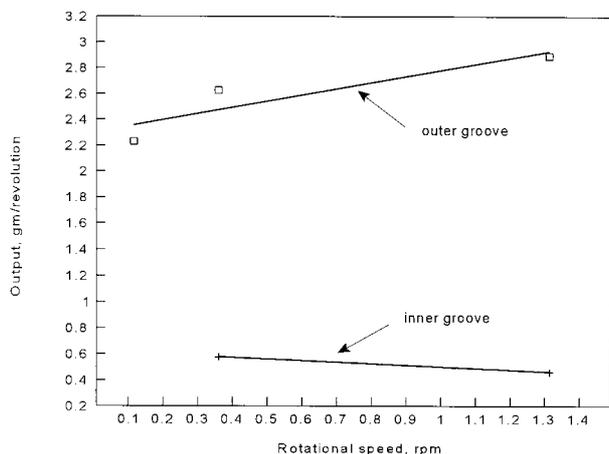Fig. 3. Test concentration as a function of dust feeder output.

Fig. 4. Output as a function of speed, showing stability of dust feeder.

unit runs all test conditions were held constant except feed rate and turntable speed, it was thought that concentration measurements gave a reasonable measure of feeder output, especially because the relaxation time for dust in the chamber was 5.3 s. This meant the chamber volume was completely replaced about every half minute. Fig. 3 shows an example of the linearity of concentration with variations in dust feeder output.

To insure that the dust concentrations were not dependent upon a particular aerosol monitor, two instruments were used during short and extended sampling programs. During each experimental run, the aerosol monitor was placed in the approximate center of the aerosol chamber, 0.92 m from chamber floor. To verify the stability of the dust feeder, the coefficient of variation (CV) was calculated from the logged data following each experimental run.

3.2. Large dust feeder

The large feeder was used to produce uniform dust concentrations for determining the steady-state operating characteristics of pulse-jet cleaned pleated air filters. Two series of tests were carried out. In the first, a dust concentration of about 570 mg/m^3 was desired with the dust being injected into a large volume of flowing air (3000 cfm). This required a dust input of about 50 g/min. For the second series of tests, a dust concentration of about 1 mg/m^3 was used, with injection into 1200 cfm. This required a dust input of about 50 mg/min. In both tests, the dust used was Arizona road dust.

The large dust feeder had a turntable diameter of about 30.5 cm and a supply cylinder diameter of 10 cm. The turntable could revolve at a maximum rate of 3 rpm. Because the effective maximum turntable speed was fairly slow, the wide range of concentrations was achieved by varying the width (w), depth (d), and radius (W) of the supply groove in the aluminum insert. For the high dust feed rate studies, the supply groove was rectangular in shape with a width of 1.0 cm, a depth of 0.5 cm, and a

The small dust feeder had a turntable diameter (D) of 20.3 cm and a supply cylinder diameter (C) of 6 cm. To obtain a small concentration in the chamber, the turntable groove was a V-cut at a 60° angle. The groove width (w) was 0.021 cm and the groove depth (d) at the vertex of the angle was 0.0381 cm. For concentrations greater than 1000 μg/m^3, a rectangular groove was used. It had a width of 0.3 cm and a depth of 0.1 cm. The aspirator for the small dust feeder can operate at a minimum pressure drop of 2 cm Hg, but was normally operated at a pressure drop of 6 cm Hg.

Inside the aerosol chamber, dust concentrations were monitored continuously and logged by either a Dataram aerosol monitor (Dataram, MIE) at a 10-s interval or Portable Continuous Aerosol Monitor (PCAM, PPM) at a 15-min interval. Measuring output variation has been a key issue in dust feeder development and evaluation. Some methods have been developed to determine output concentration based upon radioactive or fluorescent particle counters rather than aerosol monitors [9]. However, these methods were not practical for this application. Rather, it was necessary that we relied on dust concentration measurements to imply output performance. Since during the small

Table 1
Descriptive statistics. ARD — Arizona road dust, CD — cellulose dust

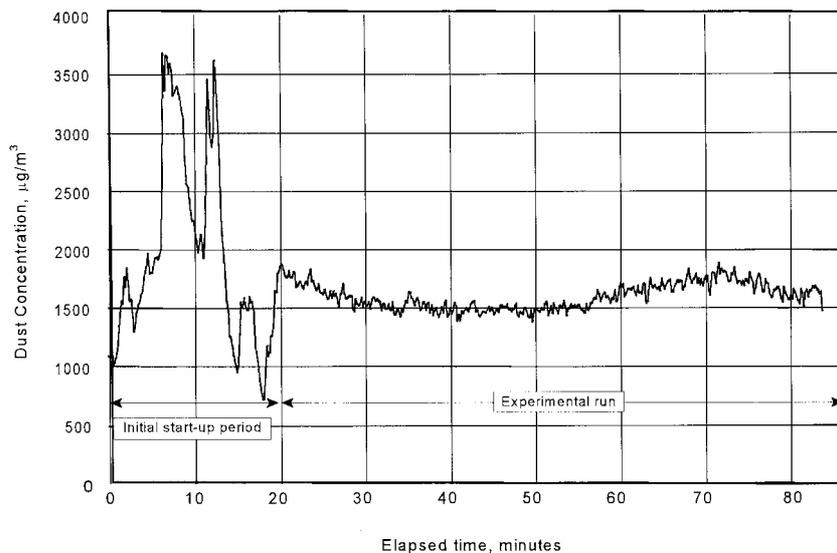| Dust (run ID)	Mean concentration (mg/m^3)	Std. dev.	Geo. SD	Coefficient of variance
ARD (01)	0.097	0.0261	1.303	27.2
ARD (02)	0.830	0.1106	1.142	13.3
ARD (03)	1.610	0.1109	1.071	6.90
CD (04)	0.095	0.0198	1.229	20.7
CD (05)	0.369	0.0348	1.099	9.21
CD (06)	2.626	0.3806	1.155	14.5
Overall average of all 6				15.3

Fig. 5. Chamber dust concentration as a function of time.

radius of 8 cm. For the intermediate feed rate studies the supply groove had a width of 0.1 cm, a depth of 0.05 cm, and a location of 5 cm. Fig. 4 shows turntable output as a function of rotational speed. It can be seen that to get large changes in output, the groove dimensional changes are more effective than changes in rotational speed. Rotational speed is used for fine adjustments only. The slight decline in output at high rotational speeds for the smaller groove width is probably a statistical anomaly since only two points were measured.

4. Results

4.1. Small dust feeder

Despite differences in composition and particle charge, cellulose and Arizona road dust were successfully applied through the small dust feeder and dispersed into the aerosol chamber during six chamber runs. Operator experience showed that the cellulose, an organic dust, was more challenging to disperse given its sticky and agglomeration

qualities. To successfully disperse cellulose dust, the pressure drop of the aspirating system was operated at 7 cm Hg, slightly higher than the pressure drop necessary for the Arizona road dust.

Cellulose and Arizona road dust were each applied through the dust feeder at three target concentrations for the dust chamber; approximately 100 $\mu g/m^3$, approximately 500 $\mu g/m^3$, and greater than 1000 $\mu g/m^3$. Data points throughout the sampling periods (after initial start-up stabilization) were statistically analyzed to determine the variation in dust feeder output. The coefficient of variation for all the chamber runs was 15.3%, demonstrating that the dust feeder works consistently well in diverse concentrations with either an inorganic or organic source dust. The statistical data from each of the runs are listed in Table 1. Fig. 5 depicts the dust concentration throughout the entire Arizona road dust (03) sampling run.

Three additional runs were conducted to demonstrate the stability of the dust feeder throughout an extended 4-h sampling period. The more challenging source dust, cellulose, was dispersed at the lowest concentration to create a worst-case sampling scenario. The statistical data from

Table 2
Four-hour sampling period. CD — Cellulose dust

Dust (run ID)	Mean concentration (mg/m^3)	Std. dev.	Geo. SD	Coefficient of variance
CD (07E)	0.115	0.0258	1.248	22.4
CD (08E)	0.124	0.0257	1.228	20.7
CD (09E)	0.113	0.0150	1.141	13.2
Overall average of all 3				18.8

these runs are presented in Table 2. The overall coefficient of variation for the extended cellulose runs was 18.7%. Since cellulose is a difficult source dust to disperse, the CV should be lower for other source dusts.

4.2. Large dust feeder

Because generation of large dust concentrations requires large quantities of dust, it is necessary that some attention be paid to the dust feeder during operation, although for a specific loading of the supply cylinder, dust output remains quite constant. In one instance with careful attention every 10 min, a 4-h test was accomplished with relatively small variation in output dust concentration. In another test, carried out over a 100-h continuous period, there was less attention paid to the dust feeder and hence, more variation. Even so, the cumulative concentration remained near the desired test concentration of 570 mg/m^3. The cumulative concentration represents the overall average dust concentration from the start of the test up to the time of measurement.

For the high-concentration tests, Fig. 6 shows an example of concentration stability for generator operation over a period of 100 h. Since concentrations were measured by a series of filter samples after the fact, individual variation, which could depend on such variables as changes in disk speed, moisture gain or loss by the dust over the course of the run, and operator error, could not be corrected for immediately. Hence, the relative variation of the incremental samples. However, considering the cumulative concentration, the target concentration of 570 mg/m^3 $\pm$ 10% was achieved during the 100-h test period by adjusting the dust loading up or down as necessary.

For shorter tests where there was less chance for human and equipment variation, there was less variation in the dust feeder output. This can be seen in Fig. 7 for a test lasting 4 h. There were only a few percent variation in the feeder output over the 4-h period.
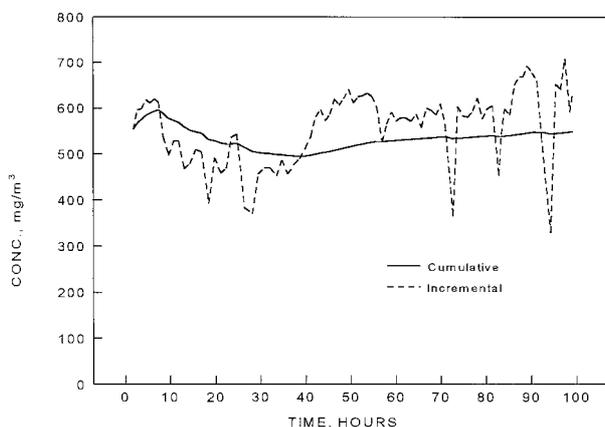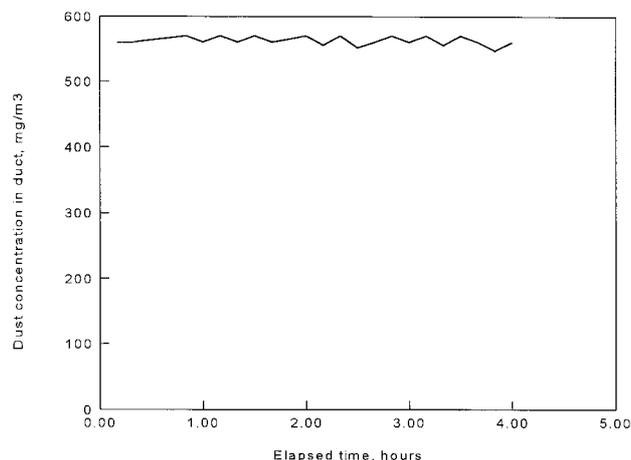

Fig. 7. Test concentration as a funnction of dust feeder output.

Agglomeration was minimized in the dust cloud generated by using filtered and dried compressed air supplied to the aspirator. Size analysis indicated that dust reaching the filter had approximately the same size distribution as the original AC fine dust.

5. Discussion

Innovative design has led to the development of an improved dry dispersion aerosol feeder which significantly improves the basic turntable design by providing better control and reliability in dust application while at the same time offering a wide range in aerosol output. The heart of the system is the rotating dust reservoir which no longer relies on agitator bars, vibrators or to a large degree on the ability of the dust to flow in order to ensure an adequate feed rate to the turn table. Instead, the test dust is continually wiped across the turntable groove giving good packing and a reproducible groove loading. The consistency and uniformity of the aerosol output from the dust feeder make it ideal for diverse laboratory and industry applications.

As shown by the operational performance, the improved dust feeder design has many advantages over other dust feeder designs. First, this dust feeder can be adopted for usage in many studies at a wide range of dust compositions and concentrations. This reduces the need and time for instrument development from application to application. Secondly, the improved turntable design has the ability to produce an aerosol at a multitude of concentrations depending upon the groove width and turntable speed of the instrument. Yet another asset of the dust feeder is the relatively minimal operator attention which it requires. After initial set-up and loading, the operator can be freed for other tasks with only periodic checks on the feeder necessary. Although not tested, it might be possible to use

Fig. 6. Average dust concentration, large dust feeder.

a conventional hopper feed set-up to feed dust into the rotating cylinder.

Acknowledgements

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