FACTORS AFFECTING DUSTCAKE DRAG IN A HOT-GAS FILTER SYSTEM COLLECTING COAL GASIFICATION ASH

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ABSTRACT

This paper discusses the use of laboratory drag measurements and filter operating data to analyze factors affecting dustcake flow resistance in a hot-gas filter at the Power Systems Development Facility (PSDF). The hot-gas filter is a Siemens-Westinghouse two-tier candle filter system that is collecting coal gasification ash from a KBR Transport Gasifier. Operating experience with this system has shown that the flow resistance of the dustcake is responsible for most of the pressure drop across the hot-gas filter, and the pressure drop varies substantially with the type of coal being gasified and the operating conditions of the gasifier and filter systems.

To analyze factors affecting dustcake drag, samples of gasification ash from various coals and various operating conditions were resuspended in a laboratory test apparatus, and the drag was measured as the dust was collected on a sintered metal filter. The lab-measured drag values were compared to actual values of transient drag determined from the increase in pressure drop, the inlet dust loading, and the face velocity in the hot-gas filter. After correcting the lab drag data to hot-gas filter conditions, good agreement was achieved between the lab measurements and the hot-gas filter transient drag values. Both types of measurements showed that drag was strongly influenced by coal type and carbon content.

INTRODUCTION

Coal currently accounts for over half of the electric power generation in the US, and coal will continue to be a major source of power well into the 21st century [1]. The sustained, long-term use of coal for power generation will require the implementation of advanced coal-based power systems that are more efficient and more environmentally acceptable than current plants. Integrated gasification combined cycle (IGCC) is one advanced coal-based power system that is attractive in terms of economics and environmental concerns. With recent increases in the cost of natural gas and with increasing pressures to reduce CO_2 emissions, many US utility companies are now expressing interest in coal-based IGCC to meet future electrical demands.

To maximize the potential of coal-based IGCC systems, the syngas generated in the coal gasifier must be cleaned before the gas is burned in the combustion turbine. Any particulate matter that enters the turbine could cause serious damage of the turbine blades by eroding the thermal barrier coating on the blades and by depositing alkali metals that could chemically attack the barrier coating. To date, the most promising technology for high-temperature particulate removal in IGCC systems appears to be the barrier filter using either porous ceramic or sintered metal filter elements.

At the Power Systems Development Facility (PSDF), a wide variety of different ceramic and metal filter elements have been tested in a hot-gas filter collecting gasification ash from a KBR Transport Gasifier. The hot-gas filter is a Siemens-Westinghouse, two-tier candle filter system that contains up to 91 candle-type filter elements. The Transport Gasifier is an advanced circulating unit that operates at considerably higher solids recycle rates, higher velocities, and higher riser densities than a conventional circulating fluidized bed. As of May 2005, the gasifier and hot-gas filter systems have accumulated over 6,400 hours of gasification operation with several different coals, including PRB (Powder River Basin) coal and various bituminous coals and lignites.

Operating experience with the Transport Gasifier has been discussed in detail in previous papers by Leonard et al [2], Smith et al [3], and Vimalchand et al [4]. Experience with the hot-gas filter system at the PSDF has been reviewed in previous papers by Davidson et al [5], Gardner et al

[6], and Martin et al [7]. Recent experience with the PSDF hot-gas filter is discussed by Guan et al [8] in a separate paper presented at this symposium. Experience with the hot-gas filter system at the PSDF has shown that it can operate reliably and achieve outlet particle loadings as low as 0.1 ppmw with iron aluminide filter elements [8].

One of the remaining issues with the hot-gas filter at the PSDF is the understanding of factors that affect the flow resistance of the dustcake. Dustcake drag is an important issue in this application, because most of the pressure drop across the hot-gas filter is associated with the cake. In previous test runs, we have observed considerable variation in transient dustcake drag with changes in coal type and gasifier configuration [9]. These variations in drag need to be understood so that the pressure drop of the hot-gas filter can be predicted and so that new hot-gas filters can be sized based on the expected dustcake drag.

APPROACH

In this study, factors affecting dustcake drag were examined using a laboratory system for resuspending samples of gasification ash, collecting the material on a sintered metal filter, and measuring the drag of the resulting dustcake. The system was described in detail in our previous paper presented at the 5th International Symposium on Gas Cleaning at High Temperature [9]. A simplified schematic of the system is shown in Figure 1.

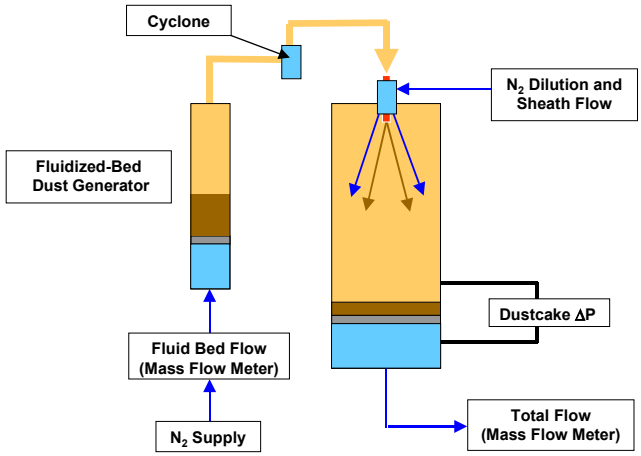

Figure 1. Laboratory Apparatus for Measuring Drag of Resuspended Gasification Ash

The system uses a fluidized bed to entrain the gasification ash and blow it over to a collection chamber where it is collected on a sintered-metal filter. The system incorporates various combinations of small cyclones to remove larger particles, allowing the production of dustcakes having mean particles sizes in the range of approximately 2 to 15 μm. The flow through the dustcake and the pressure drop across the cake are monitored as the cake builds up on the sintered-metal filter. Since the viscosity of the room-temperature nitrogen used in the lab system is much lower than the viscosity of the hot syngas, the compressive force of the gas on the cake is less than it is in the actual hot-gas filter. To compensate for this effect, the laboratory drag measurement system is operated at a face velocity that is higher than that of the actual hot-gas. Experience with the laboratory system has shown that a face velocity of about 6 cm/sec (12 ft/min) is required to simulate the dustcake compaction that occurs in the actual hot-gas filter [9].

After the buildup of the cake is complete, the system is disassembled to measure the cake thickness and to weigh the cake. Based on this information, the normalized drag of the cake (R) is determined from the pressure drop across the cake (ΔP_d), the areal loading of the cake (L_a), and the filter face velocity (V_f):

$$R = \frac{\Delta P_d}{(L_a \bullet V_f)} \tag{1}$$

By using the system with various combinations of small cyclones, it is possible to determine dustcake drag as a function of mean particle size. In our previous paper [9], we showed that such measurements could be described by a linear regression in logarithmic coordinates:

$$\log(R) = m \bullet \log(D) + b \tag{2}$$

in which D is the mass-median particle size. In our previous paper [9], we noted that the best-fit values of slope m varied from -0.9 to -1.1, suggesting that the drag was very nearly proportional to the inverse of the mean particle size.

EFFECT OF CARBON CONTENT ON DRAG IN ACTUAL HOT-GAS FILTER

As shown in Figure 2, we have observed that the transient dustcake drag in the actual hot-gas filter is related to both the coal type and the carbon content of the gasification ash.

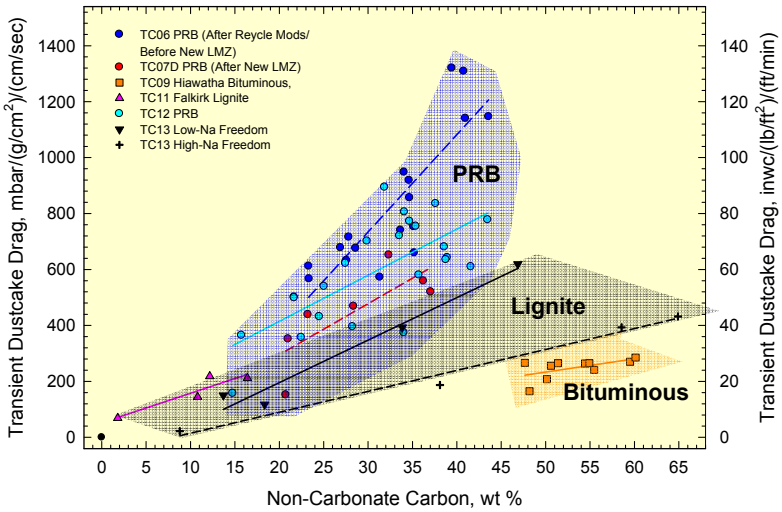

Figure 2. Effect of Carbon Content on Transient Dustcake Drag Based On Actual Hot-Gas Filter Observations

The carbon values plotted in Figure 2 represent only the carbon in the gasification ash and do not include any carbon from limestone or dolomite sorbents. The lines on the graph are simple linear regressions of drag versus carbon content and are not related to the regression fit of the lab measurements of drag versus particle size described by Equation 2. The transient drag values were calculated from the rate of rise in filter pressure drop, the rate of increase in the dustcake areal loading, and the filter face velocity. The rate of increase in the dustcake areal loading was calculated from the particulate mass loading and syngas flow rate measured at the inlet of the hot-gas filter, assuming that all of the solids entering the filter vessel reach the filter elements. For comparison with the lab-measured drag values, the values of transient dustcake drag calculated from the hot-gas filter performance were corrected to lab conditions as described in our previous paper [9]. For a given type of coal, the transient drag increases with increasing residual carbon content in the gasification ash.

VALIDATION OF LABORATORY TECHNIQUE

The laboratory drag measurement technique was validated by comparing the lab drag measurements with the hot-gas filter transient drag values (see Figure 3 below). The data points in

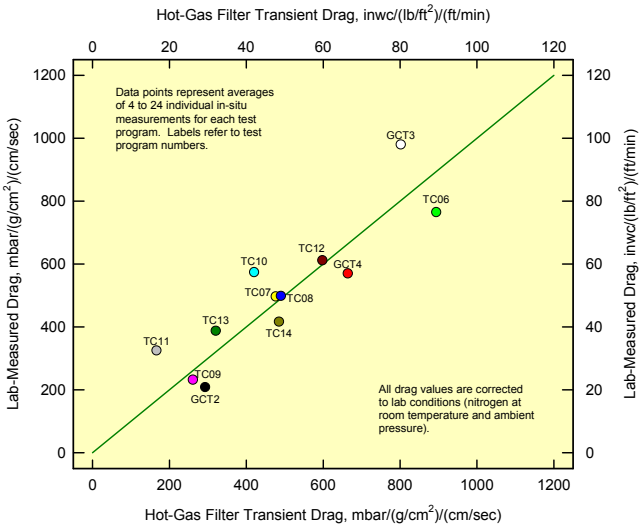

Figure 3. Comparison of Lab-Measured Drag with Hot-Gas Filter Transient Drag

Figure 3 represent averages of 4 to 24 separate data points for each test program. The labels associated with the data points refer to the test program number. Each test program represents between 250 and 1000 hrs of operation on coal. All but three of the test programs were done with PRB coal. Run TC09 was done on Hiawatha bituminous coal, Run TC11 was done on Falkirk lignite, and Run TC13 was done on Freedom lignite. As shown in the graph, the lab measurements generally do a good job of tracking the actual transient drag in the hot-gas filter. Assuming that the hot-gas filter transient drag values are correct, the error in the lab measurement is less than 25 percent for nine of the 12 test programs. There may also be some error in the hot-gas filter transient drag values due to dropout of solids in the filter vessel and due to errors in the measurements of particle loadings, gas flow, and pressure drop. Considering all of these potential sources of error, the lab measurements show excellent agreement with the transient drag values.

LAB MEASUREMENTS OF DRAG VS CARBON CONTENT

To better understand the mechanisms by which carbon content affects dustcake drag, the laboratory apparatus described previously was used to study the drag of gasification ash samples produced from PRB coal and from two North Dakota lignites from the Falkirk mine and the Freedom mine. With each coal type, samples having a range of carbon contents were selected so that we could study the effects of both coal type and carbon content. All of the samples were taken from the hopper of the hot-gas filter vessel. Results of the drag measurements are summarized in Figures 4-6. The lines in the figures are simple linear regressions of drag versus particle size. The intercept values obviously vary with the carbon content, but additional work will be required to determine the exact functionality.

With all three coal types, the laboratory drag measurements show that drag increases with increasing carbon content, although the differences in the three PRB char samples (Figure 5) may not be statistically significant. For the Falkirk lignite char, a change in carbon content from 30 to 11 percent does not have a major impact on drag, but the effect of carbon on drag becomes much more dramatic as the carbon content drops to values approaching zero. The Falkirk gasification ash sample that contains only 2 weight percent carbon exhibits drag that approaches the drag of combustion ash. This result is not surprising since complete conversion of the carbon would produce a material similar to combustion ash, which generally has drag below 100 mbar/(g/cm^2)/(cm/sec) or 10 inwc/(lb/ft^2)/(ft/min).

By analysis of various particle size fractions, we have determined that carbon content varies with particle size. However, over the particle size range of the laboratory drag measurements (2 to 15 μm) the carbon content of the gasification ash from the PSDF gasifier has been shown to be

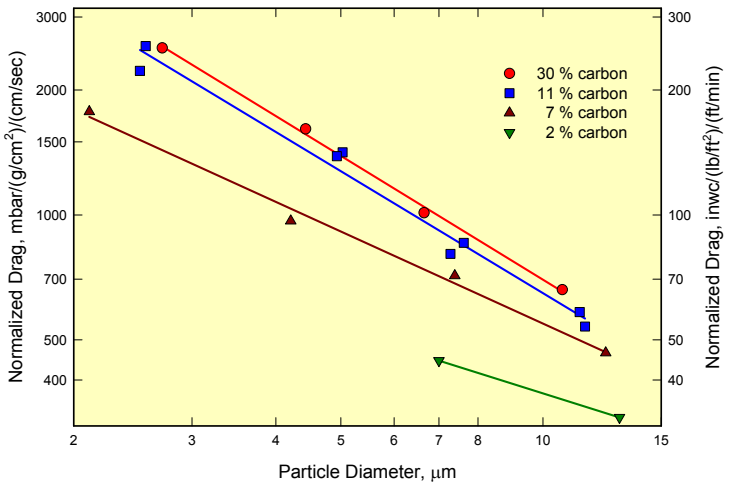

Figure 4. Lab Drag Measurements on Falkirk Lignite Gasification Ash

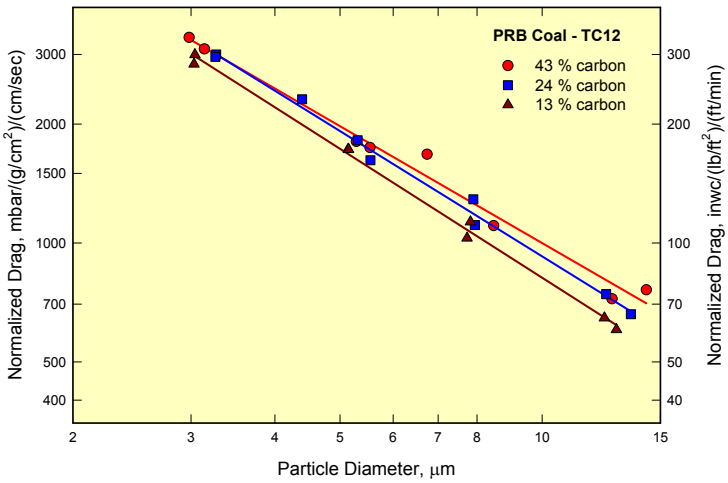

Figure 5. Lab Drag Measurements on PRB Gasification Ash

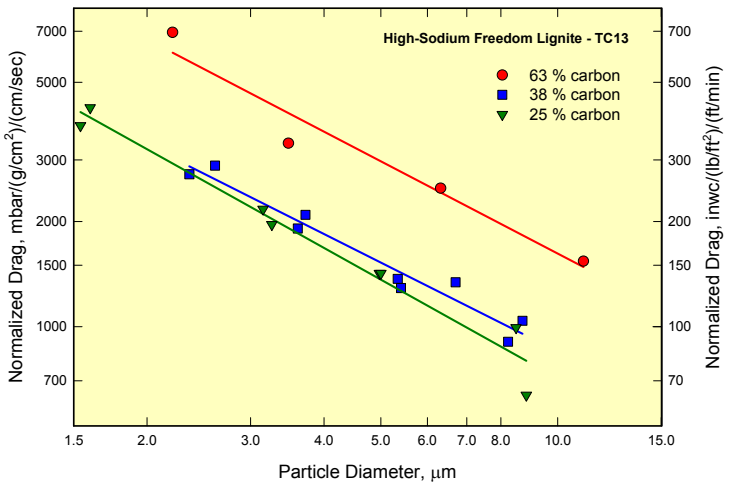

Figure 6. Lab Drag Measurements on Freedom Lignite Gasification Ash

essentially constant. Therefore, the effect of carbon on drag shown in Figures 4-6 cannot be attributed to a variation of carbon with particle size.

EFFECT OF CARBON ON PARTICLE MORPHOLOGY

To better understand the mechanism by which carbon content affects drag, selected samples from the drag studies were examined by scanning electron microscopy (SEM) and energy-dispersive x-ray (EDX) analysis. The SEM/EDX work was done on three sets of samples. Each set of samples consisted of a low-drag and a high-drag sample from one of the three different coal types (see Table 1).

Table 1. Samples Selected for SEM/EDX Studies

Sample Number	PSDF Run No.	Date	Type	Coal	Percent Carbon	BET Surface Area, m^2/g
AB12610	TC11	4/15/2003	Low Drag	Falkirk Lignite	3	19
AB12693	TC11	4/18/2003	High Drag	Falkirk Lignite	34	99
AB13458	TC12	7/14/2003	Low Drag	PRB Coal	13	74
AB13457	TC12	6/26/2003	High Drag	PRB Coal	43	185
AB14014	TC13	10/23/2003	Low Drag	Freedom Lignite	18	12
AB14150	TC13	10/27/2003	High Drag	Freedom Lignite	57	75

SEM photos of the low- and high-drag samples produced from each coal type are shown in Figures 7-9. The SEM photos show that the high-drag samples contain more particles that are angular, while most of the particles in the low-drag samples seem to have lumpy but relatively smooth surfaces. The more angular, shard-like particles would be expected to produce more flow resistance than the smoother lumps [10]. As shown in Table 1 above, the high-drag samples also have higher BET surface areas than do the low-drag samples, and BET surface area is another factor that contributes to flow resistance [10].

EDX analysis revealed that the angular, shard-like particles contain much more carbon than do the lumpy, smoother particles. Based on optical microscopy, the angular, shard-like particles appear to be chunks of unconverted or partially converted coal. Most of the carbon is contained in these poorly converted coal particles, which have more internal porosity and more surface area than the fully converted particles of gasification ash. Since the partially converted coal particles also have irregular shapes that offer more flow resistance, it is not surprising that drag and surface area increase with increasing carbon content.

CONCLUSIONS

For the three different coal types studied, drag increases as the residual carbon content of the gasification ash increases. The effect of carbon on drag appears to be related to the difference in particle morphology and surface area. Most of the residual carbon appears to be present in the form of shard-like, angular particles of partially converted coal. These angular particles offer more resistance to flow than the smoother, lumpy particles of gasification ash. Thus, it is not surprising that drag would increase with increasing carbon content.

In the KBR Transport Gasifier, carbon conversion is strongly influenced by the collection efficiency of the recycle cyclone. If the cyclone collection efficiency is degraded, less carbon will be recycled to the gasifier loop, resulting in lower carbon conversion and increased drag. These factors must be carefully considered when the gasifier and hot-gas filter systems are scaled up for commercial application.

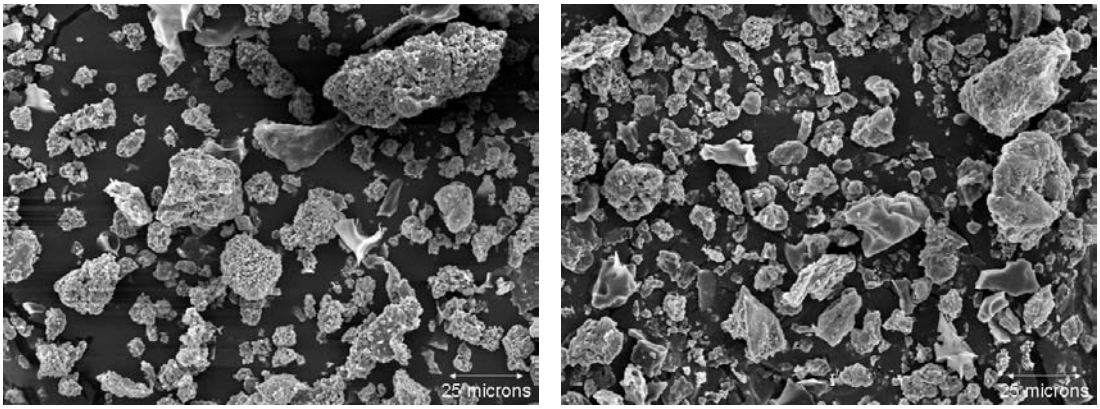

Figure 7. SEM Photographs of Low- and High-Drag Samples from Falkirk Lignite
(Low-drag sample on left -- 3 wt percent carbon and 19 m^2/g surface area;
High-drag sample on right -- 34 wt percent carbon and 99 m^2/g surface area).

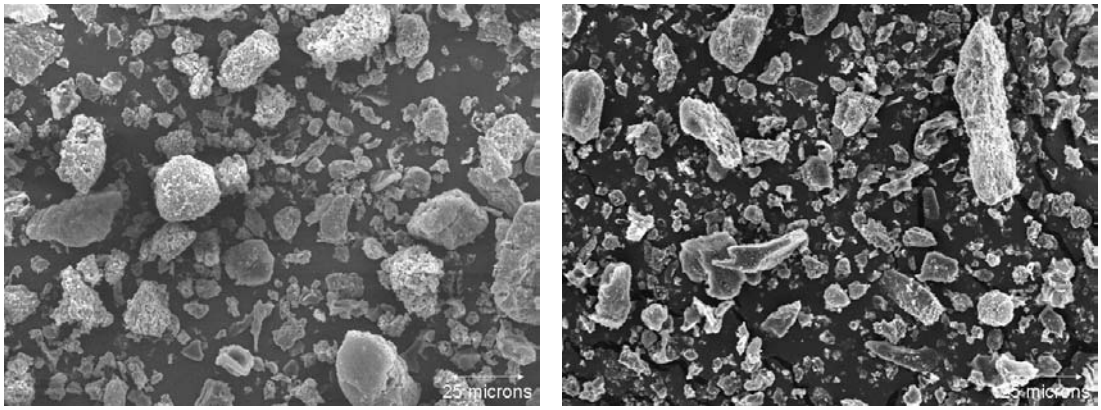

Figure 8. SEM Photographs of Low- and High-Drag Samples from PRB Coal
(Low-drag sample on left -- 13 wt percent carbon and 74 m^2/g surface area;
High-drag sample on right -- 43 wt percent carbon and 185 m^2/g surface area).

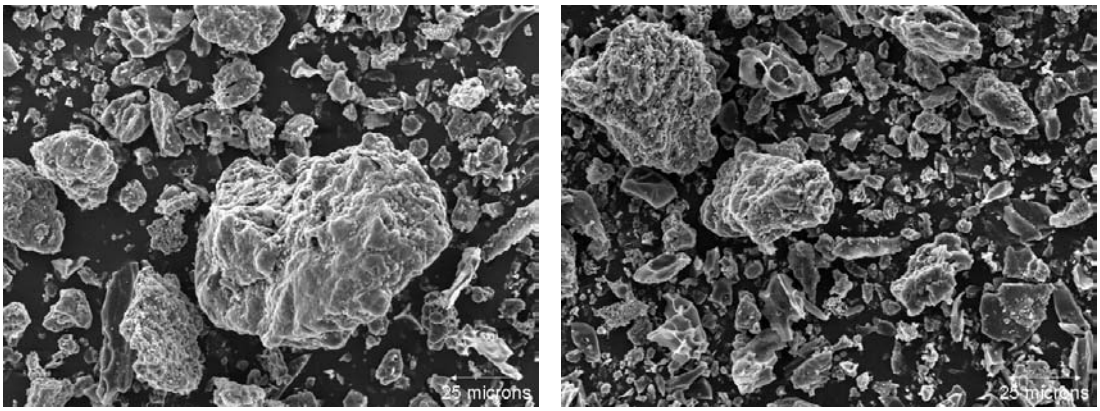

Figure 9. SEM Photographs of Low- and High-Drag Samples from Freedom Lignite
(Low-drag sample on left -- 18 wt percent carbon and 12 m^2/g surface area;
High-drag sample on right -- 57 wt percent carbon and 75 m^2/g surface area).

NOMENCLATURE

b: Intercept of linear regression fit of log(R) versus log(D) [dimensionless]
D: Mean particle diameter [μm]
ΔP_d: Pressure drop across dustcake [mbar or inwc]
L_a: Areal loading of dustcake [g/cm^2 or lb/ft^2]
m: Slope of linear regression fit of log(R) versus log(D) [dimensionless]
R: Normalized drag of dustcake [mbar/(g/cm^2)/(cm/sec) or inwc/(lb/ft^2)/(ft/min)]
V_f: Filter face velocity [cm/sec or ft/min]

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