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AN EVALUATION OF THE ROACHES 'DUST PARTICLE APPARATUS' DUSTINESS TESTING EQUIPMENT

C P Lyons and D Mark

Warren Spring Laboratory
Stevenage

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This report describes a laboratory evaluation of the Roaches 'Dust Particle Apparatus' (DPA) dustiness tester. The performance of the device was evaluated, in comparison with the Warren Spring Laboratory rotating drum dustiness tester (WSL), whilst measuring the dustiness of 30 powder samples recently employed in the British Occupational Hygiene Society (BOHS) round-robin evaluation of dustiness testers. Generally, the dustiness results from the DPA followed the same trends as those measured by the rotating drum. However, the DPA device collected fewer coarse particles than the WSL and may therefore underestimate the dust dispersed in some material handling processes. Nevertheless, the DPA tester was easy to operate and clean, and with some modifications, may be used successfully to determine the rate of dust released when a material is dropped onto a surface in calm air conditions. The results for the WSL device agree well with those obtained previously at this laboratory during the BOHS round-robin exercise.

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AN EVALUATION OF THE ROACHES 'DUST PARTICLE APPARATUS' DUSTINESS TESTING EQUIPMENT

C.P.Lyons and D.Mark.

SUMMARY

This report describes a laboratory evaluation of the Roaches 'Dust Particle Apparatus' (DPA) - a new device for measuring the dustiness of powders during handling operations. The performance of the device, a version of the single-drop type of dustiness testers, was evaluated whilst measuring the dustiness of the 30 samples recently employed in the BOHS round-robin evaluation of dustiness testers. For comparative purposes, the dustiness of a further 30 samples of the same materials were measured at the same time using the Warren Spring Laboratory rotating drum tester (WSL).

The results showed that generally the dustiness of the material samples, as measured by the DPA dustiness tester, followed the same trends as those measured by the WSL rotating drum. However, the DPA device collected fewer coarse particles than the WSL device, and may therefore underestimate the dust dispersed in some material handling processes. The variability of results obtained with the two testers were usually similar, with coefficients of variation generally between 10 to 30%. However, when insufficient dust was produced the variability was high for both testers, With very dusty materials, sampled particles could fall off the downwards-facing filter of the DPA device. The results for the WSL device agree well with those obtained previously at this laboratory for the same device during the BOHS round-robin exercise.

The DPA tester was easy to use and to clean. It could possibly be of use to determine the rate of dust released when a material is dropped once onto a surface in calm air, provided that certain operational inadequacies are improved.

The broad impressions from the work demonstrate that considerable research and development work is required before a reliable method of measuring the dustiness of a material is realised.

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1. INTRODUCTION

The *dustiness* of a powder is its propensity to emit dust during handling operations. This is a matter of great practical importance due to the hazards to health, and nuisance that can be caused in the workplace when high concentrations of airborne dust are produced during materials handling. There is, at present, no standard method for determining the dustiness of a material. A wide variety of different methods have been used to assess dustiness. A preliminary assessment of some of these methods has been carried out by members of the British Occupational Hygiene Society (BOHS) Technology Working Party on Dustiness Estimation, which was published as BOHS Technical Guide No 4, 1985. Subsequent work by this group has involved a round-robin exercise in which samples of ten different powders were analyzed by a number of different laboratories using their own methods. These methods included the impact, or single drop test, a method incorporating the use of a fluidised bed, and the rotating drum method. The data has not yet been fully analyzed, and so no firm conclusions made as to the validity and reliable of the various methods.

Members of the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry have recently reported a single-drop method for assessing the dustiness of reactive dyestuffs (Berger-Schuun et al, 1989). It is manufactured in Britain by Roaches Engineering Ltd. (Dust Particle Apparatus (DPA)), and is currently being used by six international chemical companies. Unfortunately, this method was reported too late to be included in the BOHS-organised studies. The Health and Safety Executive has, as part of its programme, a requirement to recommend a standard test method for dustiness measurement, and so asked Warren Spring Laboratory (WSL) to carry out an assessment of the performance of the new device. This report describes this assessment.

2. AIMS

The assessment had three main aims. These were:-

1) to determine the dustiness of the 10 test materials involved in the BOHS round-robin exercise, using the Roaches DPA single drop dustiness tester;

2) to carry out similar measurements with the WSL rotating drum method and compare the two sets of results; and,

3) to assess the performance of the DPA, both in terms of its reproducibility and its ability to rank materials for their dustiness, and in terms of the operational aspects such as ease of use and versatility.

3. DESCRIPTION OF THE EQUIPMENT

3.1 Roaches Dust Particle Apparatus (DPA)

The DPA tester is of the impact, or single-drop type of dustiness tester. A schematic diagram of the apparatus is given in Figure 1. It comprises a cylindrical tower 0.6 m long leading to a sealed cylindrical chamber of size 0.2 m high and 0.22 m diameter. This gives a drop height of 0.8 m. A sampling filter holder is fixed to the roof of the chamber, which is mounted onto a baseplate together with a pump and control system. All components in contact with the material under test are constructed from stainless steel.

The apparatus, which is automatically controlled, has the following operating cycle. 10 g of test material are placed in the conical hopper at the top of the tower, which is fitted with a trap door. On pressing the start button, the trap door opens and the material falls to the bottom of the chamber. 5 seconds after the trap door opens the vacuum pump starts and a sample of the dust cloud, which is generated in the chamber, is collected, at a flowrate of 15 l/min, onto a pre-weighed glass fibre filter for a period of 2 minutes. After sampling, the filter is taken out and weighed and the amount of dust collected used as a measure of the dustiness of the material tested. In practice, a dummy run, involving the use of the hopper empty, is carried out to enable the flowrate through the filter to be set to the required value.

3.2 Warren Spring Laboratory Rotating Drum (WSL)

The WSL rotating drum tester was used as a reference tester against which the results from the new DPA tester could be compared. A diagram of the device is given in Figure 2, and a full description can be found both in Taylor (1985) and Higman (1984). It consists of a large drum (300 mm diameter, 460 mm long) with conical ends. It is fitted internally with eight vanes attached to the walls to lift the sample as the drum rotates at 30 rpm. Any dust made airborne during this process is drawn though a modified Andersen size selective sampler using three stages. The preseparator stage, which has a 50% cut point (d_{50}) at an aerodynamic diameter of 10 μm is retained to minimise overloading of the impaction stage which has a d_{50} of 9 μm. The backup filter collects all particles which penetrate the impaction stage. Three measures of material dustiness are therefore obtained; a) for particles <9 μm, b) for particles >9 μm, and c) for all particles.

This apparatus, which is automatically controlled, has the following operating cycle. 100 g of the test material is spread evenly over the bottom of the drum. The system is started and the drum rotates. Five seconds later, the vacuum pump starts drawing air through the sampler (and the drum) at 28.3 lpm (1 cfm) and continues to sample for 1 min. At the end of the test the pump and drum are switched off, and the sampling system is dismantled. The size selecting stages are weighed and the amounts of dust in the three stages calculated. The drum and sampler stages are then cleaned and prepared for the next sample.

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4. THE TEST POWDERS

The test powders were very kindly supplied to us by Dr Bernard Wells of Unilever Environmental Safety Laboratory. They comprised samples of the same materials that were distributed in the BOHS round-robin assessment of dustiness testers. These were initially selected to give a wide range of dustiness values, but with minimum complications in terms of particle size, homogeneity, low toxicity, and cost.They included; calcium carbonate (precipitated, heavy); calcium orthophosphate (precipitated); charcoal (activated, decolorising); charcoal (animal, technical powder); kaolin (light); magnesium oxide (heavy); magnesium oxide (light); sodium chloride (GPR); sulphur (sublimed, flowers); and talc (fine powder). Three samples of the ten different materials were supplied for each tester. Samples of approximately 10 g, and 100 g in weight were supplied for the DPA and the WSL devices respectively. The samples were randomly ordered and sent to us in 60 numbered containers, 30 for the WSL apparatus and 30 for the DPA tester, but to enable direct comparisons of the results of each test, the order of materials in each set was the same. According to Dr Wells, the samples have been tested once already by single drop methods, but he was confident that this should have no effect on the dust yield in further tests. Consequently, it was considered that, besides providing a means of evaluating the performance of the DPA tester, the new results obtained in this project would (subject to HSE's approval) make a useful addition to the BOHS data set. For the purposes of this evaluation it has been assumed that the three samples of each material are identical.

5. EXPERIMENTAL PROCEDURES

In order to minimise additional variability due to variations in temperature and humidity, tests on each sample for both the DPA and the WSL testers were performed (as closely as possible) at the same time . Before testing, the insides of both devices were cleaned thoroughly by a combination of brushing, wiping and vacuum cleaning. Water was not included in the cleaning process to prevent raising the humidity inside the testers. After cleaning, the impaction plate in the WSL tester was greased to minimise particle bounce, as recommended by Vaughan (1989). The filters and impaction plate were then weighed on a 5-place balance, the preseparator on a 3-place balance, and the components inserted into their respective testers. The chosen material samples were weighed in their containers, the sample powder was then emptied into the appropriate test apparatus and the testing cycle started, whilst the empty container was reweighed. This enabled the final values of dustiness to be adjusted for variations in the amount of material actually tested.

With the DPA, at the end of the tests, the filter was removed from the filter holder, taking care to avoid any loss of material from accidentally knocking the filter surface, and the weight of dust collected on the filter determined. This value was then used to calculate the dustiness of the material. For the WSL tester, the sampler complete with the connecting right angle bend were removed from the rotating drum, and any particles deposited in the bend added to those collected in the preseparator stage. The sampler was dismantled and the weights of dust collected on the three stages determined. These values were then used to calculate the dustiness of the material.

During each test measurements of both temperature and relative humidity were made. The tests were carried out without knowledge of which of the samples came from the same material so that subjective bias was eliminated. The information allowing the samples

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to be grouped into ten sets of three samples was supplied by Dr Wells after the measurements had been made, and this was used to compare the results of the two testers for the same materials. Information identifying the composition material of each set of ten results was not supplied.

6. OPERATIONAL ASPECTS

6.1 The DPA tester

Vibration is the main problem with the DPA. The internal pump of the DPA runs continuously throughout the test cycle and a solenoid valve in the line controls the period that dust laden air is drawn through the filter. However, as the pump does not have vibration damping, and is not isolated from the test chamber, the filter is continuously vibrated during the test cycle. Whilst the pump is drawing air through the filter, particle losses due to this vibration should be small. However, when the test is over, air is no longer drawn through the filter, the pump continues to run, and loose particles may be shaken off the downwards-facing filter. With very dusty, non-cohesive materials, losses of this sort could be high, especially if the filter is left in the machine for a long time before the power is switched off. Removal of the filter has to be done with great care as it has a tendency to fall away from the filter holder and again, sampled dust may be lost.

The DPA also loses sample when the trap door snaps open, and with some very light and fine materials substantial clouds of the powder are dispersed into the laboratory atmosphere. How much sample is lost in this way will depend on the material and its condition, but as only 10 g are used in the test, the loss could be important. A simple double-trap system would overcome these problems. The DPA, however, has one major advantage over the WSL device - that of cleaning. The entire cleaning process, including dismantling and cleaning the trap door mechanism, takes 15 min at most.

6.2 The WSL rotating drum

The WSL system, despite being in use for some time, still has a number of operational difficulties which may contribute to the overall variability of results. The major problems are to be found in the size separating system. The wall losses in the pipe to the adapted Andersen sampler have not been calibrated and for very dusty materials these losses can be quite large, although in these tests, powder deposited here was added to the dust collected in the pre-separator. Because of the tare weight of the pre-separator it could only be measured to three decimal places whereas the impactor plate and the filter were measured to five decimal places. So an error in the last digit of the pre-separator will have a large effect on measurements of the total dust given off from the least dusty materials. Also, if the pre-separator becomes swamped, as happens with very dusty materials, there is a risk that powder caught here may be re-entrained, causing a degradation of size separation.

Another problem with the WSL tester occurs when very dusty materials are measured. The grease layer on the impaction plate becomes overloaded with particles and any new particles may bounce off and be re-entrained to be collected by the filter. So for these

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materials the < 9 μm fraction will be overestimated. This problem arises partly from the large amount of material used in the test (100 g) and partly from the small amount of dust that can be held on a grease layer. In research applications this is not a problem as the test can be repeated with less dust until the plate is no longer overloaded but if it is to be used as a standard test method either the total amount of dust used will have to be reduced for all the samples, possibly reducing the sensitivity of the test. One advantage of the larger sample however, is that representative samples of lumpy or agglomerated materials can be tested.

Cleaning the WSL apparatus can be a relatively long job, taking for one material 60 min, but more usually 15 to 30 mins. The nooks and crannies in the drum can become filled with fine sticky particles and these have to be cleaned out to avoid contaminating the next test material. This will need to be improved if the tester is to be used routinely without the risk of contamination from previous test materials. One main operational advantage that the WSL device has over the DPA is that of containment of test sample. No leaks of dust were obvious during the tests.

7. RESULTS

The basic measurements for each sample are given in Table 1, from which it is reassuring to note that the conditions of temperature and relative humidity changed very little during the programme of tests, ranging from 14.9 to 18.4 °C, and from 39.1 to 47 % RH. Dustiness, or rate of dust emission, is expressed as a fraction of the weight of material used, and the sampling time, using units of g kg^{-1} min^{-1}. Plots of this data are given in Figures 3 and 4, where the results from the DPA are plotted on the vertical axis, and the horizontal axis comprises either the < 9 μm results, or the total dustiness results from the WSL tester. The measurements from the three samples of each material are identified by separate symbols, each set being assigned an arbitrarily chosen letter. Lines of equality (1:1) are drawn on each graph together with a simple linear regression analysis. The relationships from the regression are as follows:-

For the WSL < 9 μm results (Figure 3), the correlation coefficient is 0.54, and

$$y = 0.240 x_1 + 1.177 \quad (1)$$

where y, and x_1 are the dustiness results from the DPA and the WSL devices respectively.

For the WSL total results (Figure 4), the correlation coefficient is 0.62, and

$$y = 0.0275 x_2 + 1.174 \quad (2)$$

where y, and x_2 are the dustiness results from the DPA and the WSL devices respectively.

In order to compare the results from the two testers for the same individual materials, the mean values of the three repeat measurements for each material, the associated standard deviation (σ) and coefficient of variation (cv) were calculated and are given in Table 2 for each tester, together with the ranking in order of dustiness from 1 (the most dusty) to 10 (the least dusty). The results are also presented graphically in Figure 5 for the <9 μm WSL results, and in Figure 6 for the total dustiness results. Log axes are used so that the

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characteristics of each material set can be clearly seen. The size of the error bars on each axis of both figures represent +/- 1 σ about the mean value, but it should be remembered that these are also plotted on the log scale and are therefore of unequal linear size on either side of the mean value.

Two further graphs are included in the results to compare the new data obtained with the WSL rotating drum tester with those obtained previously in the BOHS round-robin exercise. The mean values and standard deviations for each material are plotted in Figures 5 and 6 for the < 9μm and the total dustiness, respectively.

Further statistical treatment is beyond the scope of this small project, and as mentioned above, may be carried out by Dr Wells in the BOHS round-robin exercise.

8. DISCUSSION OF THE RESULTS

In a number of previously reported studies (for example, BOHS, 1985, Higman et al, 1984) the position of each material in a ranking order of dustiness has been used to compare the relative performance of dustiness testers. Whilst this may be useful when there are a large number of testers to compare, in this study, with just two machines to compare, more accurate comparisons are gained by considering both the variability of the results as well as the mean values.

The first point that becomes clear from the results, as displayed in Figures 3 and 4, is that the dustiness values obtained with the DPA tester are nearly always larger than the < 9μm values obtained with the WSL tester, but almost always smaller than the WSL total dustiness values. Secondly, it is clear from both the coefficients of the regression (correlation coefficients (r) of 0.54, and 0.62 respectively) and the poor fit of the regression lines to the plotted points, that the relationship between the results from the two testers is non linear. Closer inspection of the two graphs may lead to the conclusion that the regression analyses are biassed to a large extent by the results from material B. However, analyses carried out with these results omitted did not improve the relationships greatly. For the < 9 μm dustiness results, the value of r improves to 0.66, and for the total dustiness results, r drops to 0.48. These findings are to be expected if the mechanisms involved in dust dispersion and sampling in the two testers are compared.

The DPA device relies on a single drop of 0.8 m and impact on a hard surface to disperse dust. In this process some fine particles are stripped from the edge of the stream of material by aerodynamic shear but most of the dust is produced by 'splash' producing a disturbed airflow in the test chamber caused by compaction of bulk material when the fall is arrested. Whilst this latter mechanism may disperse large particles into the air, they may not be sampled because of elutriation before reaching the filter surface in the roof of the chamber. Nevertheless, this method may be useful for determining the quantity of dust dispersed from a given material when it is dropped once onto a surface (e.g. in conveyor transfer points). In the WSL tester, material is continuously lifted and dropped, and so dust is dispersed by both the same mechanisms as the DPA device and also by attrition as the particles mix together. Sampling takes place from the axis of the drum, and so elutriation effects are relatively small. In any case, to allow for this, particles deposited on the internal walls of the connecting pipe between the drum and the sampler are added to the preseparator catch. It is expected therefore, that the WSL device would disperse, and

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collect, more coarse particles than the DPA device.The main exception to this observation is the relationship between the DPA result and the < 9 μm result for material B.

The variability of values produced with the two testers can be discussed by considering the mean values and standard deviations displayed in Table 2 and Figures 5 and 6. The variability of the results from the DPA depends upon the magnitude of the dustiness, and the nature of the material. When testing very dusty materials, such as those of samples B and E, the results sometimes display high variability (cv = 46% for B), and sometimes low variability (cv = 4% for E). This may be possibly due to the 'stickiness' of the material and the amount of deposited dust dislodged from the filter both by the vibration of the pump and by removing the filter for weighing. For most of the other materials tested, cv ranges from 7 to 32%, whilst for material C, with very low dustiness, variability is again high (cv = 67%) due this time to insufficient dust collected for accurate weighing.The variability of repeat tests produced by the WSL tester, both for the <9 μm and the >9 μm results, are generally slightly lower than those with the DPA tester. Values of cv are below 30%, apart from for the low dustiness material C, and the somewhat extraneous results for material J. For the latter material, the range of values for the >9 μm may show evidence of possible sample contamination.

A useful analysis here is to compare the results from the WSL tester with those obtained previously in the BOHS exercise. If it is assumed that the two sets of samples (those tested in 1988 (Upton, 1991), and those tested now) come from the same bulk source, then it is possible to compare directly the results. The mean values and standard deviations for each material are plotted in Figures 7 and 8 for the < 9μm and the total dustiness values respectively. Generally, good agreement can be seen between the two sets of measurements with most points lying close to the 1:1 line. Although there is still considerable variability in the results (cv of the order of 20%), this agreement is reassuring as, not only were the measurements carried out at a two year interval, but they were also carried out by different investigators. One interesting point to emerge from this comparison is that it supports the proposition made above that samples of the material J supplied for the WSL tester were contaminated in some way. The old results for material J show a tightly-grouped set of values close to that obtained from one of the three new samples. Unfortunately, the samples were disposed of after each test and so it is not possible to check the particle size distribution. Nevertheless we have not omitted any results to demonstrate problems that can arise with quality assurance schemes.

9. GENERAL REMARKS

The project was designed to cover as wide a range of materials as possible, and also to involve assessment of the variability of the measurements. As the BOHS Technology Group had recently carried out the extensive round-robin evaluation of dustiness testers, and samples of the powders used were available, we agreed to use these as test materials and also to test, for the purposes of comparison and continuity, the WSL tester. In this respect we have achieved our objective and the results should be a useful addition to the BOHS round-robin data set. In hindsight however, a more reliable evaluation of the DPA device would have been achieved by limiting the number of materials tested and increasing the numbers of repeat measurements for each material. The influence of the anomalous results that have biased the variability would then have been reduced, and the reasons for the differences in performance investigated in more depth. This could be a useful subject

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for future work.

An important lesson from this small project is that the process of designing a dustiness tester should involve consideration of the way dust is both *dispersed* and *sampled* inside the tester. Failure to do so may lead to inappropriate and variable results. Neither of the devices tested were entirely suitable for their allotted tasks and improvements are required before valid and reproducible results are obtained. This is an urgent requirement if the concept of dustiness is to fulfil its promise as being a very useful tool for the designers of material handling systems and dust control equipment. Whilst, because of its mechanism of dust dispersal, the WSL rotating drum tester appears to be more versatile than the DPA single drop method, in terms of the material handling processes that it represents and the range of materials it can handle, the DPA tester does have application if the rate of dust dispersed from a single drop of a given material is required.

10. CONCLUSIONS

The following conclusions can be made from the work:-

1) Generally, the dustiness of material samples, as measured by the DPA dustiness tester, followed the same trends as those measured by the WSL rotating drum. However, in detail the correlation between the two testers is poor.

2) The DPA device collects fewer coarse particles than the WSL rotating drum and may therefore underestimate the dust dispersed in some more energetic materials handling processes.

3) The variability in the dustiness measured with the DPA device depends upon the magnitude of dustiness and hence upon the material.

4) The DPA device may suffer from particle losses due to excessive vibration transmitted from the pump, difficulties in removing the dust laden filter from the downwards-pointing filter holder, and due to losses to the atmosphere when the trap door at the top of the tower is opened.

5) The DPA device is easy to operate and, for most materials, takes only 10-15 minutes to clean. Though also fairly easy to operate, the WSL rotating drum can take longer to clean out (up to 60 minutes) in its present form.

6) The DPA device should produce results that indicate the amount of dust that is produced by a falling stream of material in calm air, but may not give valid indications of the dust dispersed from other material handling processes.

11. ACKNOWLEDGEMENTS

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Table 1. Dustiness data for the 30 samples tested.

Sample	Mass tested (gm)		Temp (°C)	RH (%)	Normalised Dustiness (gm kg⁻¹ min⁻¹)			
					WSL			DPA
	WSL	DPA			<9μm	>9μm	Total	
1	101.6	11.6	15.7	45.7	0.16	0.65	0.81	0.27
2	101.8	11.7	15.9	45.9	12.20	97.86	110.06	5.00
3	108.7	11.1	15.9	46.4	0.02	0.03	0.05	0.005
4	100.1	11.2	15.9	46.9	0.053	2.00	2.05	0.11
5	103.0	11.2	16.2	47.0	0.75	7.16	7.91	3.65
6	102.5	11.5	16.6	46.5	1.29	21.70	22.99	2.64
7	102.3	15.0	16.3	46.3	0.87	10.10	10.97	3.47
8	103.7	11.3	15.6	46.7	0.13	0.21	0.34	1.73
9	103.5	11.1	15.7	46.8	0.37	0.56	0.93	0.33
10	101.2	11.4	18.0	48.2	12.35	101.61	113.96	1.41
11	103.5	12.0	18.2	48.2	1.72	8.70	10.42	1.67
12	103.4	10.6	17.7	48.2	0.22	30.70	30.92	0.92
13	100.9	12.3	18.2	48.2	0.16	0.36	0.52	1.61
14	106.3	11.5	18.3	48.0	0.02	0.03	0.05	0.003
15	100.5	11.9	16.9	39.1	14.97	54.85	69.82	5.56

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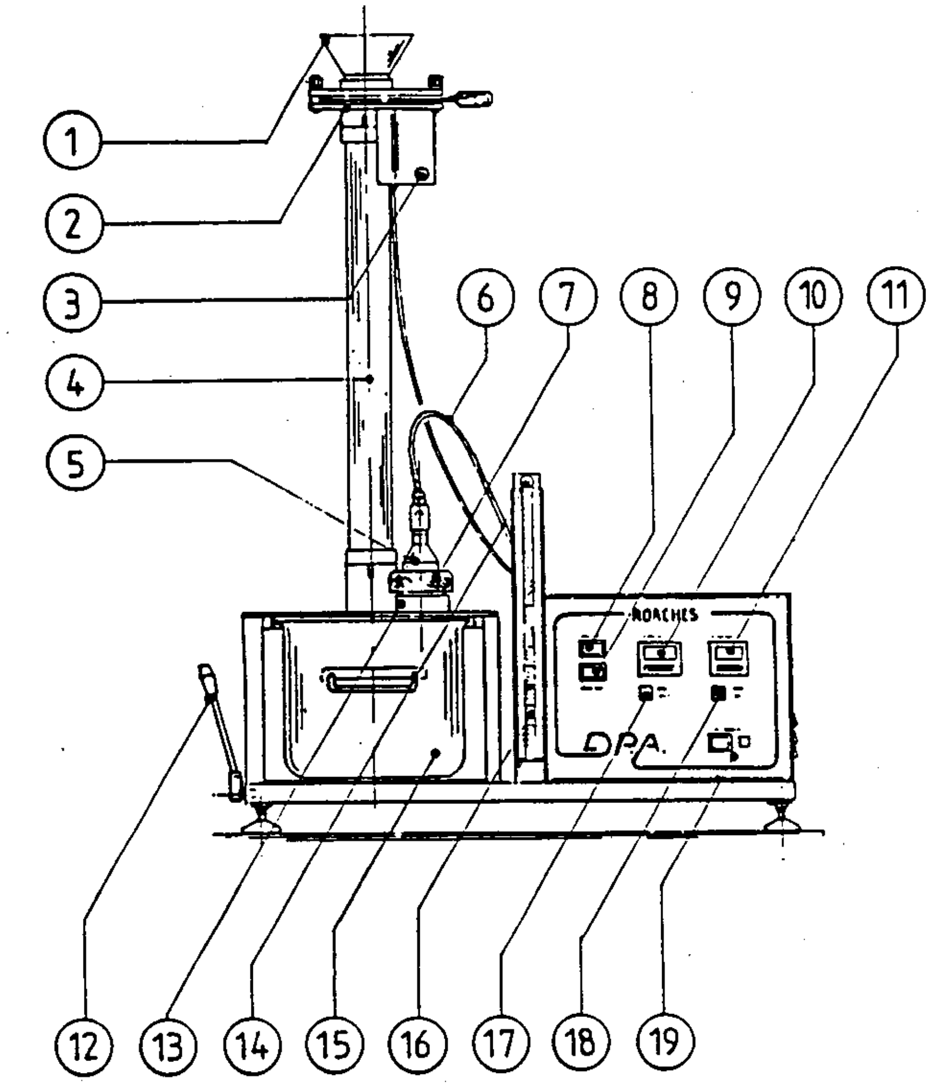
Table 1 (cont).

Sample No	Mass tested (gm)		Temp (°C)	RH (%)	Normalised Dustiness ($gm\ kg^{-1}\ min^{-1}$)			
					WSL			DPA
	WSL	DPA			<9μm	>9μm	Total	
16	102.2	13.1	18.5	41.1	0.21	1.70	1.91	1.26
17	103.8	11.8	18.4	41.0	1.45	8.90	10.35	3.84
18	102.5	11.8	17.8	39.4	0.62	1.30	1.92	0.78
19	102.1	10.5	15.3	40.1	0.16	0.82	0.98	0.28
20	102.8	10.8	16.6	40.0	1.57	8.10	9.67	1.62
21	101.6	11.5	16.2	40.5	0.58	1.27	1.85	0.74
22	101.2	10.6	16.7	39.4	0.03	1.21	1.24	0.12
23	104.5	10.3	15.5	38.9	1.68	7.70	9.38	2.90
24	103.8	12.2	16.3	39.9	0.17	0.69	0.86	0.31
25	100.9	11.5	16.2	42.4	1.28	22.65	23.93	1.46
26	101.0	9.4	16.2	43.0	0.16	0.32	0.48	2.27
27	103.8	11.5	16.1	42.6	0.04	0.08	0.12	0.001
28	103.0	11.9	14.9	42.9	0.18	10.17	10.35	1.85
29	101.5	10.6	16.0	42.3	1.33	24.93	26.26	2.58
30	98.0	11.6	15.7	42.5	0.06	1.50	1.56	0.10

Table 2. Mean and standard deviations for the dustiness of each material tested along with the coefficients of variation and ranking in order from the most to the least dusty.

Material (Sample Nos)	WSL dustiness values and ratings (gm kg^{-1} min^{-1})												DPA dustiness values and rank (gm kg^{-1} min^{-1})			
	<9μm				>9μm				Total							
	Mean	s.d.	c of v (%)	Rank	Mean	s.d.	c of v (%)	Rank	Mean	s.d.	c of v (%)	Rank	Mean	s.d.	c of v (%)	Rank
A 1,19,24	0.16	0.02	13	7	0.72	0.07	10	8	0.88	0.02	2	8	0.29	0.02	7	8
B 2,10,15	13.17	1.27	10	1	84.77	21.21	25	1	97.94	19.95	20	1	3.99	1.84	46	1
C 3,14,27	0.03	0.01	33	10	0.04	0.03	75	10	0.07	0.03	43	10	0.003	0.002	67	10
D 4,22,30	0.05	0.01	20	9	1.57	0.32	20	6	1.62	0.33	20	6	0.11	0.01	9	9
E 5,7,17	1.02	0.31	30	4	8.72	1.23	14	4	9.74	1.32	14	5	3.65	0.15	4	2
F 6,25,29	1.30	0.02	2	3	23.09	1.36	6	2	24.39	1.37	6	2	2.23	0.54	24	3
G 8,13,26	0.15	0.02	13	8	0.30	0.07	23	9	0.44	0.12	27	9	1.87	0.29	16	5
H 9,18,21	0.52	0.1	19	5	1.04	0.34	33	7	1.57	0.46	29	7	0.62	0.20	32	7
I 11,20,23	1.66	0.06	4	2	8.17	0.41	5	5	9.95	0.37	4	4	2.06	0.59	28	4
J 12,16,28	0.20	0.02	10	6	14.19	12.18	86	3	14.39	12.18	85	3	1.34	0.38	28	6

Contents



KEY TO REFERENCE NUMBERS

1	DROP FUNNEL	8	START SWITCH	15	DUST RECIEVER.
2	SLIDE VALVE	9	RESET SWITCH	16	FLOW METER.
3	SLIDE OPEN LIGHT	10	SLIDE VALVE TIMER	17	SLIDE OPEN LIGHT
4	FALL TUBE	11	SUCTION VALVE TIMER	18	ON LINE LIGHT
5	SUCTION FUNNEL	12	CLAMP LEVER	19	POWER SWITCH
6	AIR LINE	13	FILTER STAGE		
7	LOCKING COLLAR	14	ADJUSTING SCREW.		

Figure 1. The Roaches Dust Particle Apparatus (DPA)
The total drop height is 0.8 m and the sampling filter is 0.2 m above the base.

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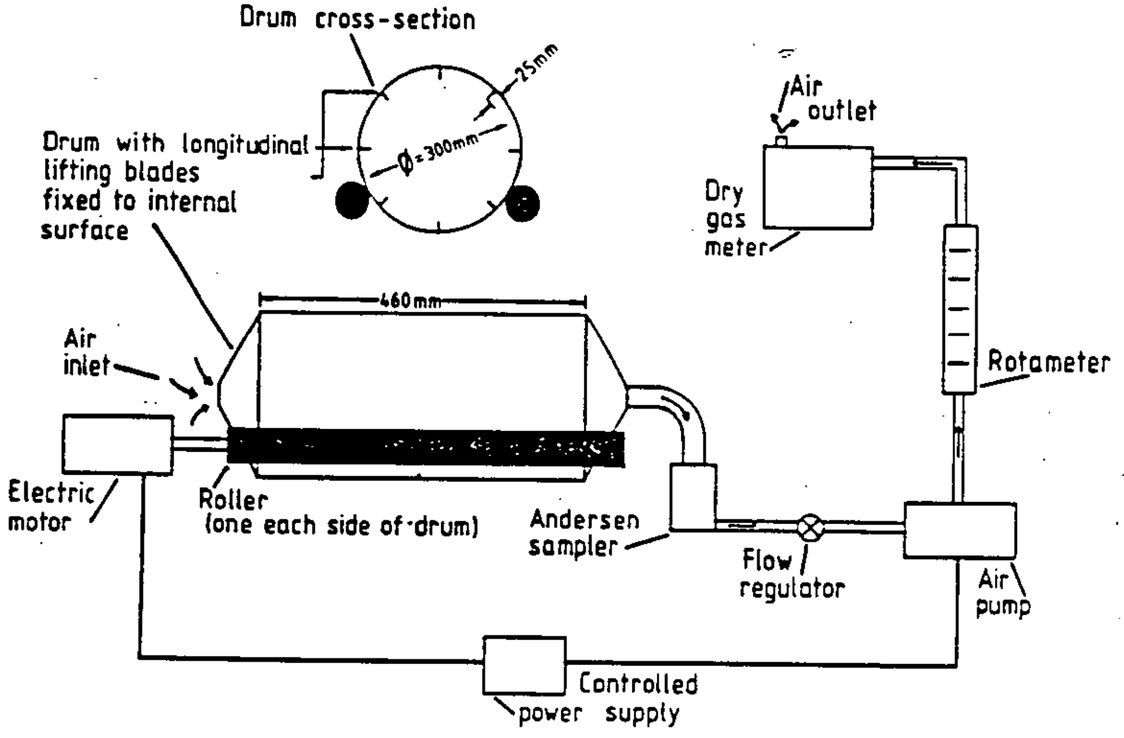

Figure 2. The Warren Spring Laboratory Rotating Drum Tester (WSL)

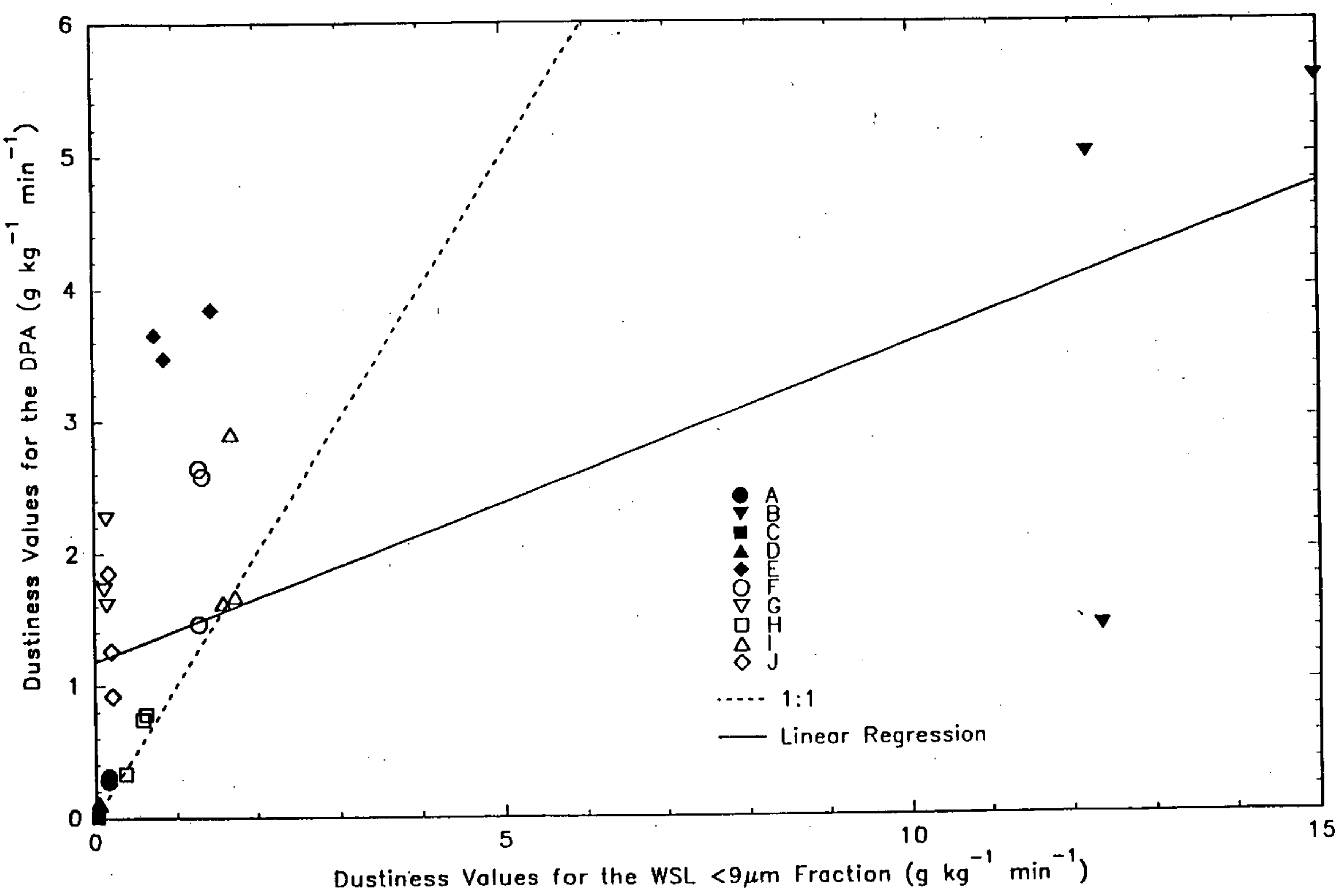

Figure 3. Graph showing the values of dustiness of all the samples measured for the <9 μm fraction on the WSL apparatus plotted against the results from the DPA. The dotted line shows the 1:1 correlation line and the full line shows the result of a linear regression analysis of the results.

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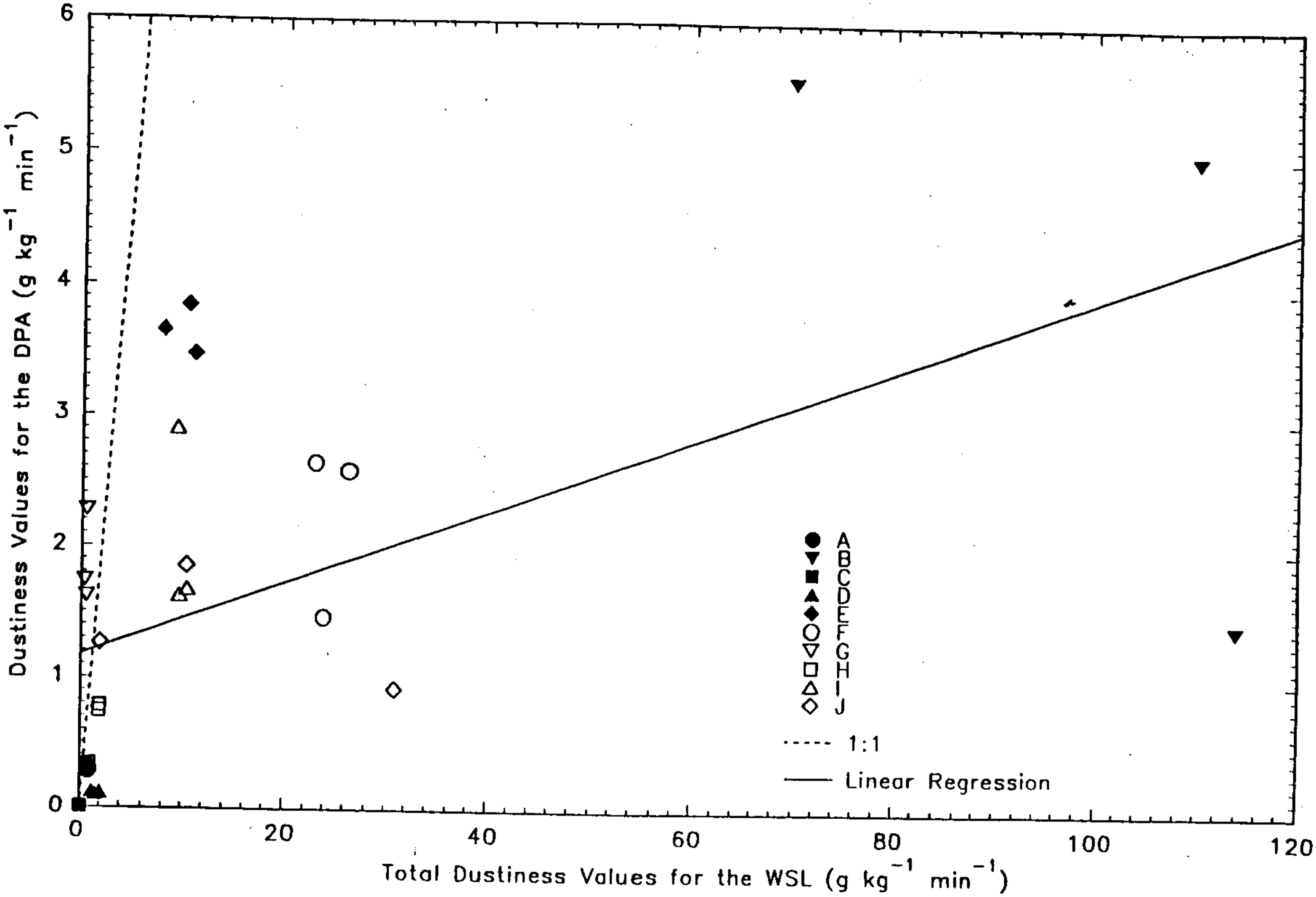

Figure 4. Graph showing all the values of dustiness of total dustiness of the samples measured on the WSL apparatus plotted against the results from the DPA. The dotted line shows the 1:1 correlation line and the full line shows the result of a linear regression analysis of the results.

Contents

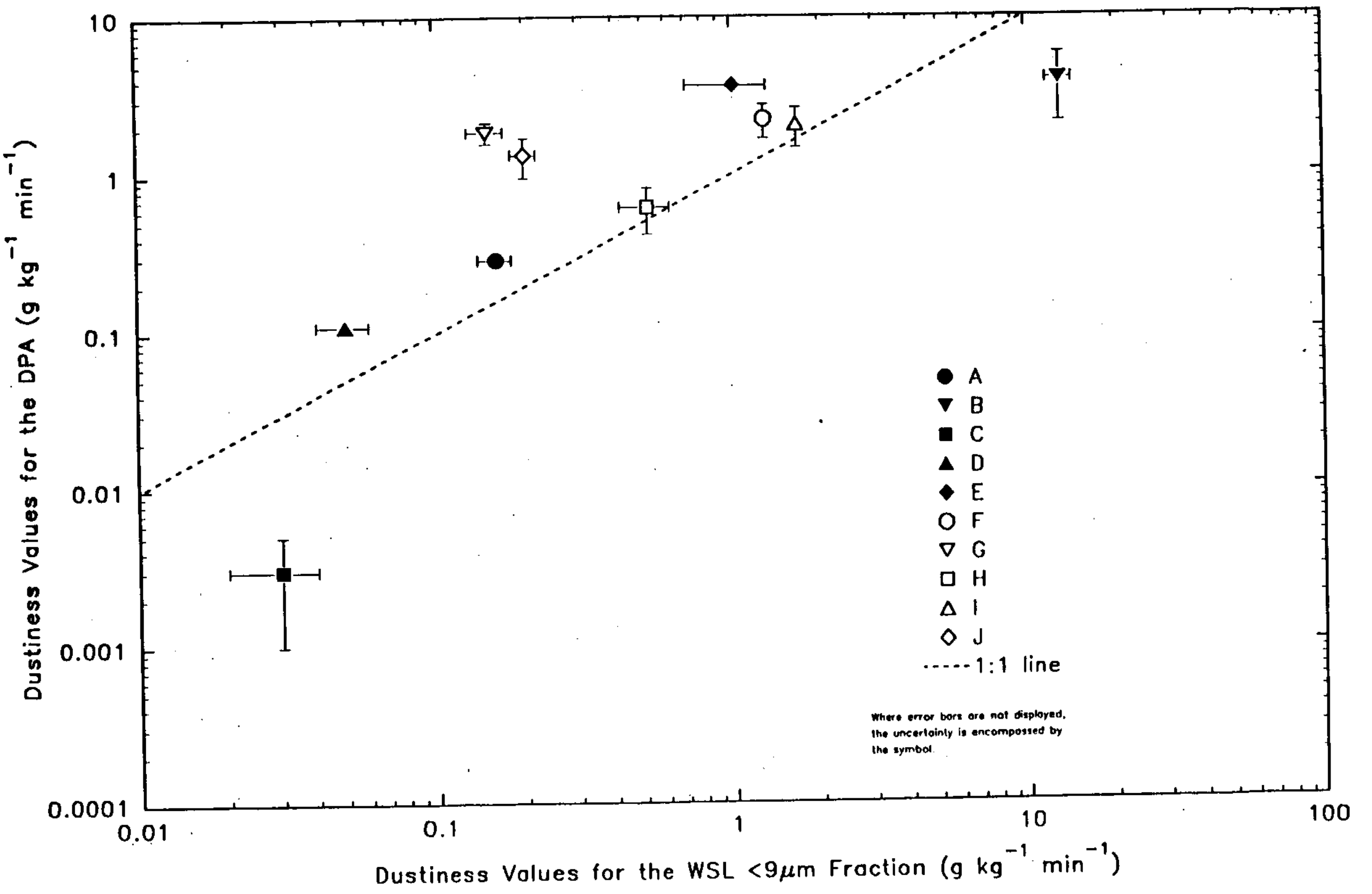

Figure 5. Graph showing the mean dustiness of each material measured using the DPA compared with the mean <9 μm WSL size fraction of each material. The error bars show the standard deviation on each measurement and the straight line corresponds to a 1:1 relation between the two measurements.

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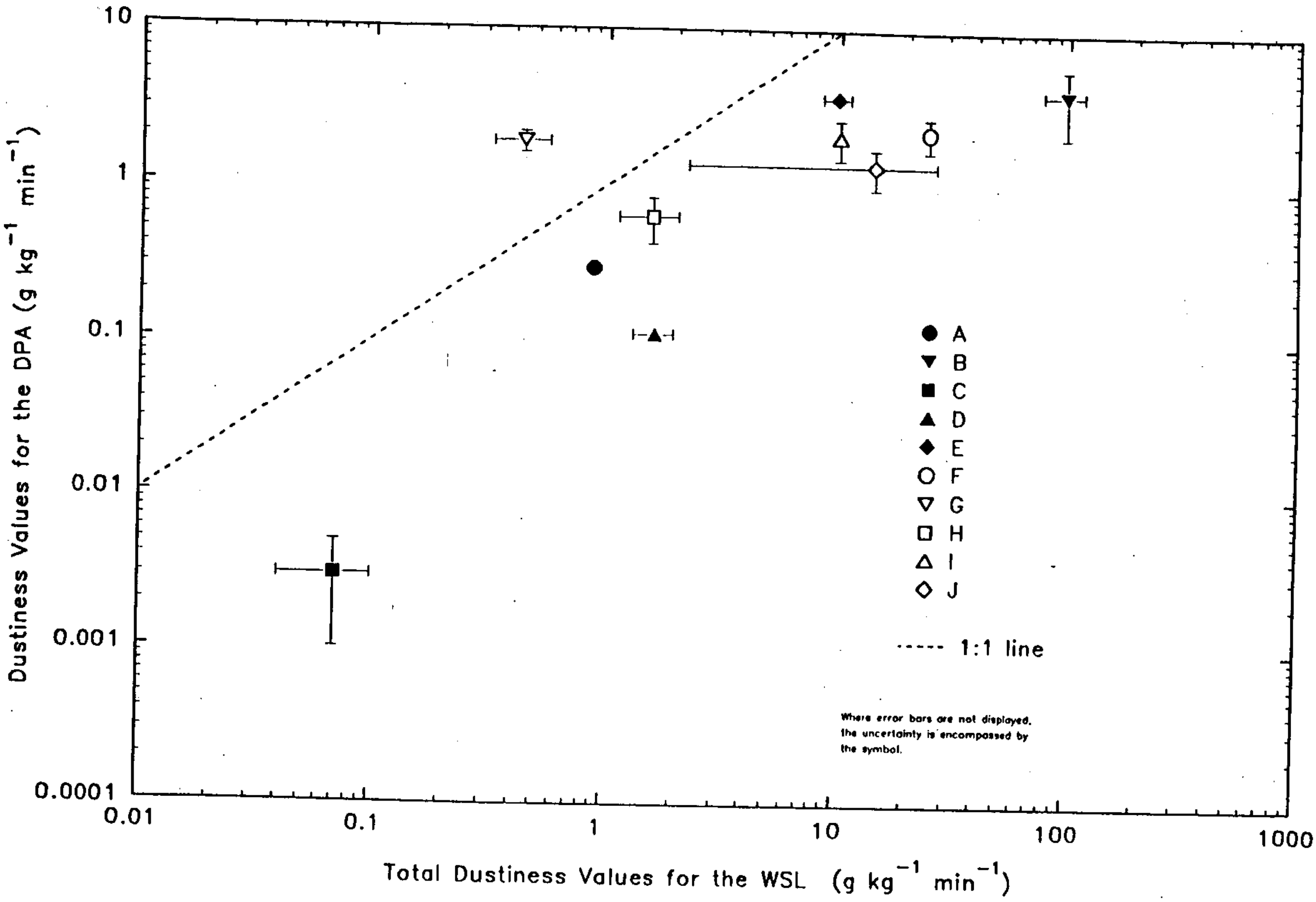

Figure 6. Graph showing the mean dustiness of each material measured using the DPA compared with the mean total WSL dustiness of each material. The error bars show the standard deviation on each measurement and the straight line corresponds to a 1·1 relation between the two measurements.

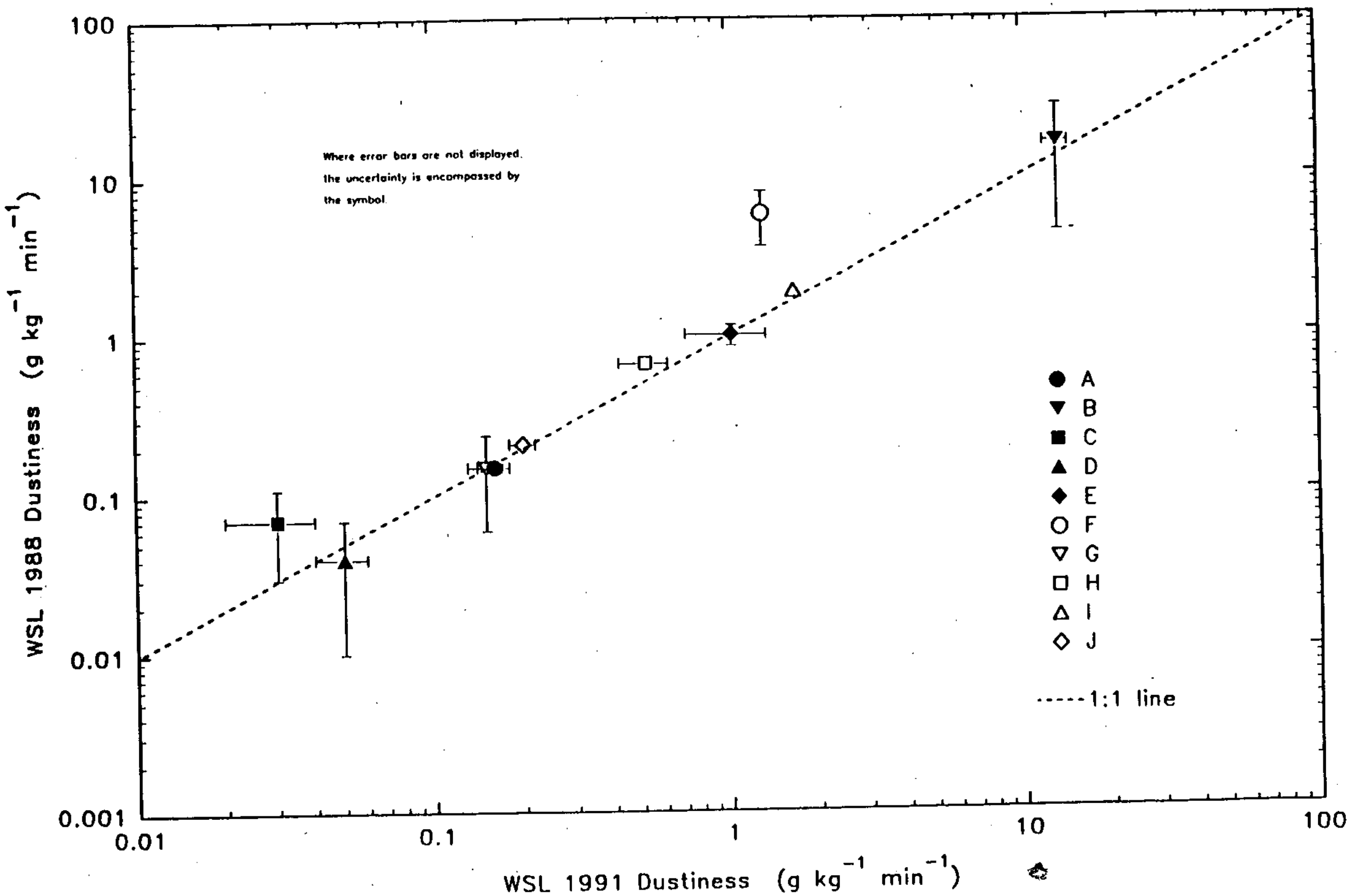

Figure 7. Graph showing the mean <9 μm fraction for each material measured using the WSL in 1988 compared with the present values. The error bars show the standard deviation on each measurement and the straight line corresponds to a 1:1 relation between the two measurements.

Contents

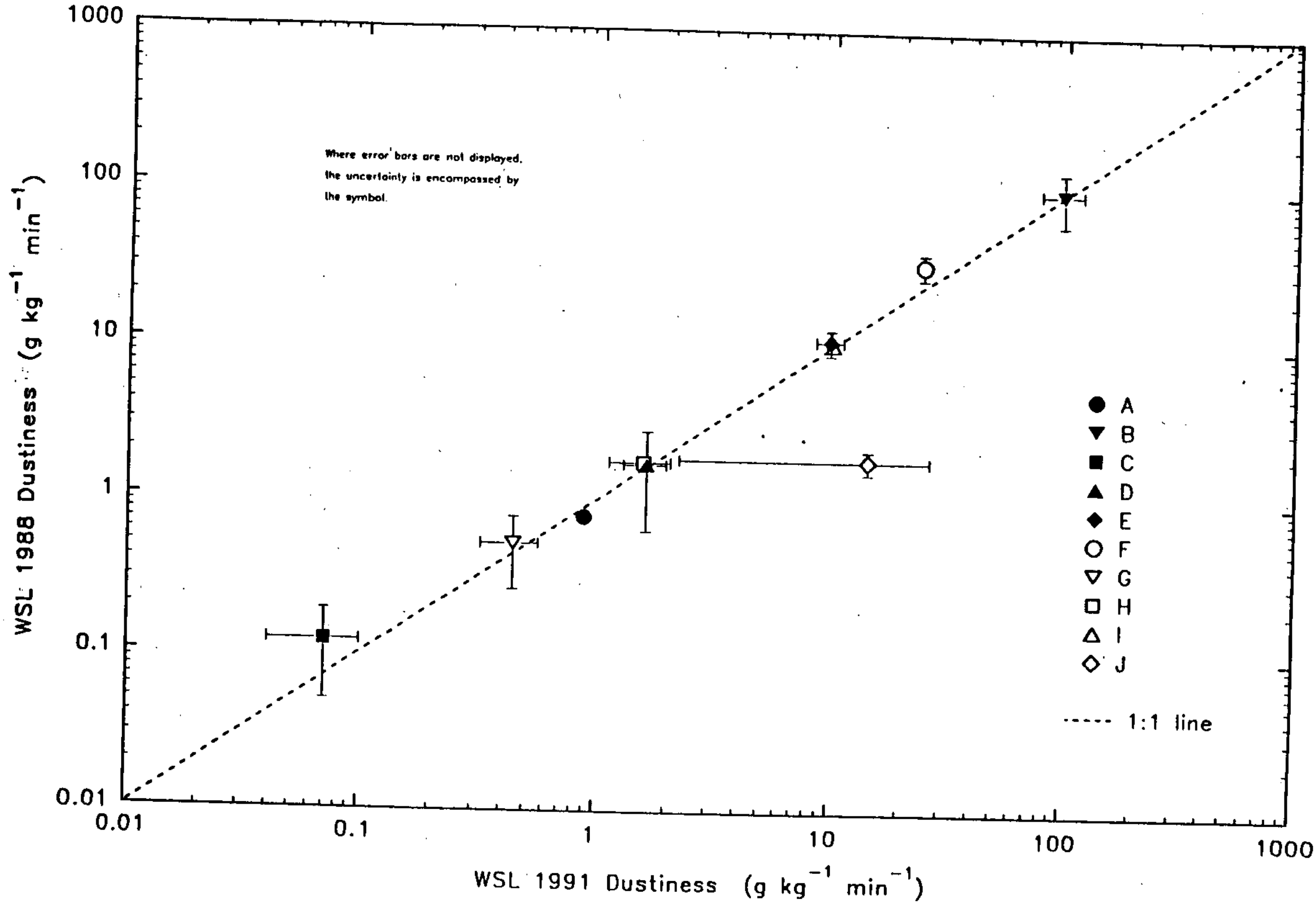

Figure 8. Graph showing the mean total dustiness of each material measured using the WSL in 1988 compared with the present values. The error bars show the standard deviation on each measurement and the straight line corresponds to a 1:1 relation between the two measurements.

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