LETTER TO THE EDITOR

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Comment on Comparison of Powder Dustiness Methods

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We have read with interest the recent work by the University of Wuppertal group (Bach et al., 2013) on dustiness determination using the University of North Carolina (UNC) Dustiness Testing Device (Boundy et al., 2006). We have referred to the UNC device as the ‘Venturi’ device (Evans et al., 2013), as that describes the underlying dispersal mechanism; we continue with this terminology. The Wuppertal paper is presented in two parts. In Part 1, the dustiness of nine industrial powders was measured with the Venturi device, and results compared with their earlier measurements (Bach and Schmidt, 2008) using macroscopic techniques: EN 1505 standardized continuous drop (CEN 2006, 2013) and the commercial Heubach rotating drum and commercial Palas single drop. In Part 2, dustiness values for 11 pharmaceutical powders were determined solely with the Venturi device. We would like to comment on these Wuppertal results, especially in light of our previous and extensive use of the Venturi device for fine and nanoscale powders (Evans et al., 2013).

Unfortunately, insufficient detail is provided on the provenance of the Wuppertal powders (Bach and Schmidt, 2008; Bach et al., 2013), to allow an inter-laboratory comparison with identical materials. (By contrast, our measurements (Evans et al., 2013) for Holland lactose of $D_{\text{tot}} = 5.2 (0.4)\%$ and $D_{\text{resp}} = 0.9 (0.1)\%$ are fully consistent with those of the UNC group (Boundy et al., 2006), with $D_{\text{tot}} = 5.1 (0.9)\%$ and $D_{\text{resp}} = 1.3 (0.5)\%$ for the same material.) In the technique comparison, Part 1, of the Wuppertal study, only three Venturi measurements were made for each powder, and no ranges or statistics were reported. In the pharmaceutical, Part 2, of their study, five Venturi measurements were made for each powder, and standard deviations were reported, permitting some analysis of possible error. Finally, we observed an empirical
correlation between respirable and total dustiness, as measured with the Venturi device, to hold for a wide range of powders (Evans et al., 2013). It is informative to test that empirical correlation with these additional Wuppertal results.

With the Venturi device, we measured total and respirable dustiness for 27 materials (Evans et al., 2013), primarily focusing on fine and nanoscale powders, but also included are several materials with micrometer-sized primary particles, the presumed size of the Wuppertal Industrial powders; their Al$_2$O$_3$ can be traced to Aloxite F-1200, with mean volume diameter $d \sim 3.6$ μm (Mark et al., 1985). The relative standard deviation (RSD), $D_{tot}/D_{tot}$, of the total dustiness is plotted (Fig. 1) as a function of the measurement value, $D_{tot}$. The National Institute for Occupational Safety & Health (NIOSH) RSDs (typically, $n \geq 6$, with minor exceptions, see Evans et al., 2013) are all small, except for one extremely low dusty material (Kemira TiO$_2$); the RSDs ($n = 9$) for the five materials tested in the original UNC study (Boundy et al., 2006) are similarly small. By contrast, the RSDs ($n = 5$) for the Wuppertal pharmaceutical measurements (Wupp-Pharm) are systematically higher and become increasingly poor at lower dustiness values.

Similar higher RSDs obtain for the Wuppertal measurements of the respirable fraction (Fig. 2) and these, again, become increasingly poor at the lower dustiness values.

We have found (Evans et al., 2013) that particular care must be taken when gravimetrically measuring the less dusty powders; indeed, the least dusty powders are the most problematic for the Wuppertal group. We believe that this is the source of the ‘negative’ total dustiness that they report for Al(OH)$_3$ and also for their having obtained physically unreasonable higher respirable than total dustiness values for erythromycin, metronidazole and tetracycline hydrochloride. We disagree with their statement ‘that the device is error-prone’; we and the UNC group have demonstrated that, with sufficient care, reproducible, physically reasonable results are obtainable with the device for a wide variety of powders. The UNC group also report impressive inter-instrument consistency with the device (Boundy et al., 2006).

In our earlier work (Evans et al., 2013), we found an unexpected, linear correlation between the respirable and total dustiness, as measured with the Venturi device. We have plotted (Fig. 3) the Wuppertal data, both for their industrial (‘Wupp-Ind’) and pharmaceutical (‘Wupp-Pharm’) powders, together with our earlier fine and nanoscale powders (‘NIOSH’) and the original UNC data (‘UNC’). The linear correlation is obeyed, with the exception of the very low dustiness values.

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1 Relative standard deviation, $D_{tot}/D_{tot}$, of total dustiness as a function of total dustiness, $D_{tot}$. NIOSH (Evans et al., 2013), UNC (Boundy et al., 2006), Wupp-Pharm (Bach et al., 2013). All data derived from the Venturi device.
2 Relative standard deviation, $\frac{\sigma_{D_{\text{resp}}}}{D_{\text{resp}}}$, of respirable dustiness as a function of respirable dustiness, $D_{\text{resp}}$. NIOSH (Evans et al., 2013), UNC (Boundy et al., 2006), Wupp-Pharm (Bach et al., 2013). All data derived from the Venturi device.

3 Scaling of respirable dustiness, $D_{\text{resp}}$, versus total dustiness, $D_{\text{tot}}$. Linear best fit to the earlier NIOSH fine and nanoscale powder data (Evans et al., 2013). No error bars are plotted for the Wuppertal industrial powder data (Wupp-Ind) due to a lack of reported statistics. UNC (Boundy et al., 2006), Wupp-Ind and Wupp-Pharm (Bach et al., 2013). All data derived from the Venturi device.
Wuppertal materials: Al(OH)$_3$, BaSO$_4$, code B, metronidazole, erythromycin, lidocaine hydrochloride, and tetracycline hydrochloride.

Finally, we commend the attempt to correlate these four different dustiness methods. As we previously discussed (Evans et al., 2013), the Venturi device disperses the powders at significantly higher Reynolds numbers than do the gravity-driven rotating drum or falling powder techniques and has unique value in simulating high energy dust dispersion operations in the workplace. Using the Wuppertal Venturi data (Bach et al., 2013) and earlier data with gentler gravity driven techniques (Bach and Schmidt, 2008), we construct the following correlation tables ($r = \sqrt{R^2}$, simple linear regressions are calculated for $n = 9$ materials, using MS Excel) for the paired dustiness techniques.

**Table 1. Correlation coefficients for total (inhalable) dustiness, measured by four dustiness techniques for nine industrial powders (Venturi measured in Bach et al., 2013 and Heubach rotating drum, EN 15051 continuous drop and Palas single drop all measured in Bach et al., 2008).**

| Device                              | Venturi | Heubach rotating drum | EN 15051 continuous drop | Palas single drop |
|-------------------------------------|---------|-----------------------|--------------------------|-------------------|
| Venturi                             | 1.00    | 0.84                  | 0.11                     | 0.77              |
| Heubach rotating drum               | 1.00    | 0.34                  | 1.00                     | 0.79              |
| EN 15051 continuous drop            |         |                       | 1.00                     | 0.61              |
| Palas single drop                   |         |                       |                          | 1.00              |

**Table 2. Correlation coefficients for respirable dustiness, measured by four dustiness techniques for nine industrial powders (UNC Venturi measured in Bach et al., 2013 and Heubach rotating drum, EN 15051 continuous drop and Palas single drop all measured in Bach et al., 2008).**

| Device                              | Venturi | Heubach rotating drum | EN 15051 continuous drop | Palas single drop |
|-------------------------------------|---------|-----------------------|--------------------------|-------------------|
| Venturi                             | 1.00    | 0.72                  | 0.80                     | 0.91              |
| Heubach rotating drum               | 1.00    | 0.28                  | 1.00                     | 0.46              |
| EN 15051 continuous drop            |         |                       | 1.00                     | 0.96              |
| Palas single drop                   |         |                       |                          | 1.00              |

DISCLAIMERS
The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of product or company name does not constitute endorsement by the Centers for Disease Control and Prevention.
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