ANALYSIS OF DATA OBTAINED FROM AN HISTORIC ASH RESIDUE LEACHING INVESTIGATION

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Having received a flattering acceptance of my comments during the review process, perhaps a few additional thoughts will be appreciated that contribute to the content and appropriate use of this paper.

I am not sure that it is possible to establish distribution characteristics from plots like Fig. 4. Usually, the analyst replaces the accumulative "% of Samples with Concentration <X" on the vertical axis by the corresponding number of standard deviations (Z) the accumulative percentage is located from the center of the normal distribution. This is a quantile-quantile plot and is the same as a probability plot except that the vertical scale is normal deviates rather than percentage points. When a correct distribution type has been identified by transforming the X axis, the data will plot as a reasonably straight line. If the data are lognormal, for example, the horizontal axis will be logs of the data; normally distributed data can be plotted as is. A nice thing about these plots is that the average is found at $Z = 0$ and the standard deviation is the slope of the line.

Having recognized that the data used in the example on page 113 is lognormally distributed, the upper confidence limit (UCL) should be calculated using the average and standard deviation of the *logarithms* of the data (0.4538 and 1.2124, respectively). These yield a UCL of 0.6813 ln (mg/l). This equals 1.98 mg/l when the UCL is expressed in original units. Transforming the data before calculating the UCL of lognormally distributed data obviously changes the specifics of Table 2 and Figs. 18 and 19.

For completeness, SW-646 recommends comparing the transformed UCL to a similarly transformed regulatory limit (for example 5 mg/l becomes 1.61 ln(mg/l). But, I find it easier to simply re-express the transformed data UCL in original units. Both approaches produce the same conclusion since they are mathematically equivalent. Original units seem to be easier for most people to understand.

Regarding the purpose of using the UCL, my understanding is that all data are inherently noisy. This results from undetectable sampling, analytic and data reduction errors, as well as inherent source variability. Since the purpose of ash testing is to characterize this waste stream, the average is the most appropriate single measure. However, the result from any test series is highly unlikely to represent exactly all the waste if the characterization test is repeated a large number of times. The true average is likely to be bounded by the confidence limit. Hence, comparing the UCL to the regulatory limit provides assurance that the waste stream does not trip RCRA requirements. That is, that the residue's characteristic does not qualify it as a RCRA hazardous waste.

The possibility that boiler tube rapping affects residue metal concentrations is intriguing and plausible. However, Fig. 9 and the data in Table 1 do not support the conclusion. First, the saw-tooth seems to have a 4-hr cycle, while the text says rapping is done once a shift. Second, if the data are taken as a whole, it plots as a straight line on log probability paper. If there was a periodic rapping effect, I would expect to see a "hockey stick" type plot indicating two mechanisms. To be environmentally significant, rapping and non-rapping residues have to come from different distributions. Two separate distributions will plot as two different line segments on a normal probability graph. Third, there are advanced statistical techniques that can be used to separate periodic effects from random noise. When the data in Table 1 is so analyzed, the only statistically significant period is an 11-hr cycle, and that one is negative. While the hypothesis may be true for other facilities and data sets, the author's data provides the counter-example needed to reject it. Rapping had no effect on the residue lead and cadmium concentrations observed at this plant.

The author's discussion of Fig. 17 suggests that lead migrates through ash piles. An alternate explanation is that chemical reactions within the ash stabilize that lead over time and the increase of around 20 ft may be due to a combination of the waste being burned, combustor conditions, and how the waste was deposited on the pile during that time period. Leachate from ash monofills typically has below-detection-limit lead and cadmium concentrations. Hence, the wash-out hypothesis is inconsistent with this additional piece of often verified information. Some other explanation consistent with all the available information is needed.

AUTHOR'S REPLY

Dr. Rigo correctly point out that log-normally distributed data often plots as a straight line on probability paper, especially if the data reflects purely random chance.

When plotting evenly-spaced data on log coordinates, I fint that it falls on a straight line up to about 80–90% of the scale, then tilts away. The same data on probability plots continue to fall on a straight line, as can be seen on Fig. A, based on the data in my paper. Since this is so, we can do further interpretation of the data to find the several populations represented in the data.

I have generally found that when the standard deviation is more than about 50% of the mean, that there may be more than one population present. Looking at the data, it is often possible to discern these populations. In Fig. A, three populations can be seen, each set falling on a straight line, unraveling the kinky line which stretches broadly across the plot.

In my interpretation of this graph, the high group of four represents the high-metal content flyash component, with an average of about 8 mg/l of lead in the EP extract. The 14 intermediate samaples have an average of about 2 mg/l of lead, whereas the lower group of four or six averages 0.2 to 0.3 mg/l. The intermediate group of 2 mg/l has the same mean as the segregated bottom ash of June, shown in Fig. 10.

The point I wish to make here is that using statistics blindly, albeit expertly, may cover over important information which may have great significance to the operator. My guru on statistics, the late Dr. Ellis Blade, gave me this advice, which I have found to be fruitful: "Look at the data itself: it may tell you something important; don't just use the numbers the computer comes up with."

Dr. Rigo notes that the "cycle" of tube rapping appears to be 4 hr, not 8 hr, as I incorrectly stated in the paper. I agree with this interpretation, but point out that Fig. 19 shows a low point at the fifth hour, and a clear peak at the eighth hour. This indicates that "once per shift" was actually somwhere in the middle of the shift.

One purpose in presenting this data at this time was to use it to illustrate the problems in establishing valid methods for determining the average EP concentrations over time, to represent the true average of the ash stream leaving the facility.

Another purpose was to show that the flyash, with higher concentrations of lead and cadmium, could contaminate the bottom ash in strange and irregular ways. Up to a certain extent, this contamination would not cause the bottom ash to fail the EP test. However, surges, poor mixing, variations in combustion characteristics, or the waste itself, can cause high readings to appear in the data set.

It should not be forgotten that the Saugus data was from a facility with an ESP, without acid gas controls. The addition of caustic reagents results in totally different flyash and mixed bottom ash characteristics. Also, once the bottom ash and flyash become wet, and given sufficient time, many reactions can take place, most of which tend to reduce the solubility of the metals.

Finally, Dr. Rigo points out that a proper procedure to use with log-normal data is to transform it to log form, calculate the mean and standard deviation, and convert them both back to the original form. I find that if the data is from one major population, that the results before and after conversion are not very different. However, with widely dispersed data, such as the Saugus data, the mean and standard deviation are not as accurate predictors of the true mean as the transformed data.

The reader is invited to play with this data set and become familiar with the statistical principles raised here.

FIG. A RESCO MSW