Olfactometry Precision and Real World Decision Making

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ABSTRACT

Odour sampling and testing is often conducted at facilities such as wastewater treatment plants to understand the impact of odorous emissions and for confirming performance of odour control systems. Olfactometry is a precise testing method; however, this precision depends on the quality assurance/quality control (QA/QC) statistics associated with the odour laboratory (ASTM E679 & EN13273). The European odour testing standard, EN13725:2003, describes a standard method, using n-butanol, for monitoring the performance of the odour panel members (assessors), the odour laboratory, and the odour test results.

This paper describes olfactometry QA/QC methods and how they define the statistical parameters of accuracy and precision of odour test results. This statistical knowledge will be used to present case study scenarios as examples of how odour control performance test standards can be written and how testing data should be evaluated. This paper will provide important information for engineers and facility stakeholders to prepare appropriate odour control specifications and for suppliers to evaluate the odour sources and design the control systems. Ultimately, if the statistics of olfactometry are more clearly understood and interpretation of results are more clearly defined, facility stakeholders and odour control system suppliers will enter a contract with less ambiguity of the performance requirement.

Keywords

olfactometry, EN13725, ASTM E679, odour control, performance testing, stakeholders

INTRODUCTION

Odour Control systems are designed to reduce odour emissions and thereby mitigate odour in the surrounding community. System designers will ask one or two questions such as: 1) “How much odour mitigation is needed?” or 2) “What percentage of odour reduction is required?”

Odour in the community is measureable using field olfactometry at various times and locations. The data collected during an odour monitoring program can be combined with meteorological data and analyzed with citizen odour complaint records to approximate the base line odour level in the community. Odour strength and offensiveness data coupled with episode frequency and duration data provide a good “picture” of a community’s odour issues, where stakeholders will now consider how much odour reduction is necessary, 75%, 90%, 95%?

Air dispersion modelling, using odour emission data, provides additional insight into the community odour issues. Air dispersion modelling calculates the transport and dispersion of the odour emissions from a source into the community. This information assists the stakeholders to consider how much odour reduction is necessary or if there is an odour emission “target” from a specific source, such as 50, 200, or 500 odour units per cubic meter (OU_E/m^3).

The answers, sought by the community and the facility owners, are not “black and white” answers, nor are the odour reduction percentages or odour emission targets “bright line” values. Nevertheless, the community and other stakeholders will search for an odour reduction goal or a maximum odour outlet “target” (maximum outlet concentration).

If an odour control system is needed to reduce source odour, then a performance standard for that odour control system is required. Vendors/suppliers of odour control systems depend on a well-written odour control system performance standard. A quality performance standard will take into consideration the known precision and accuracy of odour testing as well as stability of the process and control system to address the number of samples to be tested and the statistical data review of results.

PERFORMANCE STANDARDS

The policies of setting community ambient odour standards are not well established. A few U.S. states have set ambient odour limits; Missouri and Colorado routinely enforce their respective ambient odour limits. However, in most cases throughout the U.S., each community decides if an ambient odour limit is needed.

Odour control system performance standards by other names are “performance guarantees”. Engineers and owners prepare system specifications with performance requirements. The contractors and vendors guarantee their control systems will comply with the performance standards.

For odour control systems, performance standards are well established in the engineering and vendor industries. Two common forms of standards are 1) percent odour reduction, and 2) maximum odour concentration at the outlet.

Percent odour reduction

Percent odour reduction requirements may first appear to be what is needed to guarantee less odour in the community. However, percent odour reduction requirements (guarantees) may be problematic in some cases.

If a source has a relatively high odour concentration (e.g. 100,000 OU_E/m^3) that needs to be reduced to mitigate odour in a community, a percent removal requirement of 95% may not be adequate to satisfy the community. In this example, 95% removal of 100,000 OU_E/m^3 yields 5,000 OU_E/m^3, still a relatively strong odour emission. Even if 99% removal is specified, the outlet concentration would be 1,000 OU_E/m^3. Both of these example calculations illustrate how a community might be disappointed, even when a “high efficiency” odour control system is installed.

Conversely, if a source has a relatively low odour concentration (e.g. 1,000 OU_E/m^3) that needs to be reduced, a percent removal of 95% may be “too much” for a control system to achieve. In this case, 95% removal of 1,000 OU_E/m^3 yields 50 OU_E/m^3, and that may be impractical (too low) for many odour control system types, i.e. scrubbers, biofilters, etc (McGinley, 2008). A variation of this case example is the situation where a source odour at the time of system start-up is not at “full strength”, e.g. 500 OU_E/m^3, and 95% removal of 500 OU_E/m^3 yields 25 OU_E/m^3, which may be too low for even the “best” odour control system type, i.e. carbon adsorber. Both of these example calculations illustrate how a contractor and vendor might “fail to perform” even when the odour control system has a very low outlet, but falling short of the specified percent removal level.

Maximum odour concentration

Performance standards that set maximum odour concentration at the outlet address the conundrum of the percent removal performance standard approach. The community will expect reduced odour from the baseline odour. The engineer and owner will study and calculate (i.e. field testing, pilot testing, air/odour dispersion modelling) the maximum odour concentration “target” of the source to achieve the community expectations. The subsequent performance standard will specify the odour concentration maximum required of the odour control system. The contractor and vendor will study, design, respond, bid, and provide the odour control system in accordance with the specifications as written or negotiated.

If stakeholders (community, owners, engineers, contractors, vendors) discuss and collaborate on the development of the odour control system performance standards, odour outcomes will be improved.

Development of performance standards will include the following elements for discussion (Cizek, 2001):

Is the performance standard a product (outcome) of policy making?

- Is the standard making process open to collaboration (input) by all stakeholders?
- Is the standard transparent; is the standard open for review by auditors?
- Is the standard valid; can the validity of the standard be "tested"?
- Is the standard referenced to an industry or regulatory standard?
- Is the standard based on achievable performance?

If the performance standard is a product of policy making, does the standard contain the following key elements?

- Does the standard specify a sharp "cut-score" (bright line) for acceptance/rejection?
- Does the standard describe the score scale and continuous range of scale values?
- Does the standard recognize the cut-score is "arbitrary", selected from the scale of values?
- Does the standard guard against extreme outcomes?
- Does the standard incorporate analysis of probable error?
- Does the standard acknowledge bias in sampling?
- Does the standard include variance for the precision and accuracy of testing?
- Does the standard provide for reasonable consequences for failing to achieve?
- Does the standard provide for reasonable remedies?

These elements require the stakeholders to explore the underlying **policy making** of the performance standard. Fundamental standard setting involves development of a policy for the performance standard (Cizek, 2001). When the policy is transparent, policy implementation through testing becomes successful for all the stakeholders.

STANDARD METHODS OF ODOUR TESTING

Olfactometry and log transformations

Odour testing is defined by the ASTM International standard practice E679-04 (ASTM, 2011) and the European standard method EN13725:2003 (CEN, 2003). EN13725 provides a standardized framework for the performance of odour assessors and odour panels. Documentation of assessor and panel performance allows a laboratory to clearly define precision of odour results, accomplished through testing with the standard odorant 1-butanol (n-butanol).

It is first important to understand that the human perception of odours is a logarithmic phenomenon of the brain (Stevens, 1960, 1962). An understanding of the logarithm scale of odours provides a basis for understanding the precision of odour testing.

Odour testing involves presenting a sample to assessors in an ascending series of concentrations, a geometric progression, where each dilution level is twice the concentration (one half the dilution ratio) as the previous level. The odour testing scale does not have equal spacing between the dilution levels (i.e. 8, 16, 32, 64, 128, etc.) Therefore, there is the need for the use of logarithm (base 10) transformations for statistical review of odour evaluation data (Dravnieks 1968; Stevens 1962).

Logarithms are used to make the spacing between dilution levels uniform. In the case of olfactometry, this leads to a uniform logarithm dilution level spacing of approximately 0.3, and the data then shows symmetry around the panel average. Therefore, all statistical calculations for odour results are conducted with logarithm values (Stevens, 1962).

Odour Laboratory QA/QC

The EN13725 odour-testing standard contains detailed quality assurance and quality control requirements for determining the performance of an odour testing laboratory. The performance requirements are based on the n-butanol standard odorant. The assumption is made that the odour laboratory's precision and accuracy performance to the standard odorant, n-butanol, can be transferred to all environmental odour samples tested by the laboratory. Since environmental odour samples do not have a known actual or true value, accuracy can only be defined with standard odorants, i.e. n-butanol. A concept not unusual to environmental testing as it has been used for decades in testing of biochemical oxygen demand, BOD (WEF, 2012; McGinley, 2012).

When determining an odour laboratory's performance, four tests (called variance tests) are considered:

1. Specific panel variance: This is the variance between the results of the individual assessors in one test session. This is usually expressed as the standard deviation of the logarithms of the individual threshold values. When conducting odour panels following EN13725, this standard deviation usually ranges between 0.00 and 0.30. However, this is not an appropriate value to define the variance of the threshold result. The final threshold value result (detection or recognition threshold) can only be defined by the average of the group's individual thresholds, thus any measure of precision of olfactometry must compare the variance of multiple determinations of this group average and not the variance among the assessors.

2. Within panel variance: This is the variance that defines the repeatability of one panel of assessors evaluating the same sample multiple times on the same test day. This value is usually the smallest test variance since the variability associated with different assessors and different test periods are removed.

3. Inter-panel variance: This variance defines the reproducibility of one sample tested in one laboratory during different lab sessions with potentially different panels of assessors. This value is determined for a laboratory by using n-butanol as a standard test odorant. A test sample of n-butanol is evaluated on a regular basis. The laboratory's inter-panel average n-butanol threshold and variance of this result can be determined (see EN13725, Section 5.3.2). This variance for n-butanol is used to estimate the inter-panel variance for all other environmental odour testing results. EN13725 requires the standard deviation between tests (inter-panel variance) to be less than 0.172 (CEN, 2003).

4. Inter-laboratory variance: This is the variance of one sample (usually a standard odorant) evaluated by multiple laboratories. This variance may be much higher since it will take into account all components of variability between laboratories, i.e. assessors, olfactometers, quality control procedures, etc. It is not uncommon for the inter-lab standard deviation to be as high as

0.30 of the threshold log values (van Harreveld, 1997; Bardsley, 2003; Oxbol, 2004; Maxeiner, 2003, 2006).

An example odour laboratory (St. Croix Sensory, Inc.) evaluated a test sample of n-butanol during every odour test session in accordance with Section 5.3 of EN13725 (McGinley, 2006). The n-butanol threshold of the test panel is recorded in a quality assurance database. The panel result is confirmed to range between 20-80 ppb as specified in EN13725. The n-butanol testing determined the laboratory's inter-panel variance to be a standard deviation of 0.10 (n=50, rolling average). The n-butanol testing also yielded a measure of accuracy, as defined by EN13725, to be 0.08 (Section 5.3.2). These values for the laboratory are lower than (better than) the EN13725 allowable maximum variance of 0.172 and maximum accuracy value of 0.217.

As part of a comprehensive quality assurance and quality control (QA/QC) program, an odour laboratory should periodically test random environmental odour samples multiple times with the same panel of assessors and multiple times with different panels of assessors.

The example odour laboratory reported testing 27 environmental odour samples 2-5 times with the same panel of assessors during the same testing session (McGinley, 2006). The average detection threshold values of all samples ranged from 60 to 5,000. The standard deviations of all samples ranged from 0.00 to 0.11 with an average standard deviation of 0.05 for the within panel testing.

One sample of 5-ppm hydrogen sulphide was evaluated four times as part of this testing program. The average detection threshold was 5,100 OU_E/m^3 (0.98ppb) with a log standard deviation of 0.064.

The same odour laboratory tested 25 environmental odour air samples with two different panels of assessors on the same day following EN13725 (McGinley, 2006). The detection thresholds of the 25 test samples ranged from 60 to 5,000. The log standard deviation of the paired tests ranged from 0.010 to 0.176 with an average of 0.060 for the inter-panel testing. These results are consistent with the estimated inter-panel standard deviation of 0.10 determined through daily testing with n-butanol.

This information about a laboratory's quality parameters allow for proper analysis of olfactometery results for making decisions regarding setting and then testing odour performance test standards.

A 95% confidence interval can be determined for any odour testing result. As shown in EN13725:2003 Annex G, "Example of the calculation used to determine the number of odour concentration measurements required to achieve a defined precision", the 95% confidence interval can be calculated with the variability information of the odour laboratory. Annex G shows the confidence intervals for an example laboratory that "just meets" the minimum precision criterion, which is a standard deviation of 0.172 determined from testing with n-butanol. This example shows how samples collected in triplicate have an average odour threshold value of 1,000 with a lower confidence limit (LCL) of 633 and an upper confidence limit (UCL) of 1580 (95% confidence interval).

If one were to consider the inter-panel variability of a specific laboratory, defined with a standard deviation of 0.10 instead of the maximum allowable 0.172, this confidence interval becomes smaller. The triplicate sample with an average of 1,000 would have an LCL of 767 and a UCL of 1305 (95% confidence interval).

The 95% confidence interval is narrower still when using the odour laboratory's actual within panel variability, defined by the standard deviation of 0.05. The triplicate samples with an average of 1,000 would now have an LCL of 876 and a UCL of 1142 (95% confidence interval).

Other variability in odour testing

It is important to realize that the laboratory variability, no matter what level, is not the only source of uncertainty in odour testing results. Selection of a proper lab is important to achieving a credible result; however, other variability cannot be ignored.

The emission process to be tested can have significant variability. Processes throughout a WWTP can vary through the day based on flow and operational characteristics. There may be certain times of day to test a worst-case scenario, or a sampling protocol may be designed to capture the range of conditions.

Depending on the complexity of odour sampling protocols, levels of variance of the sampling process itself also exist. Some factors influencing this are proper sampling equipment and experience of the sample technician.

RESULTS AND DISCUSSION

Performance standards for odour control systems are well established in the engineering and vendor industries. As previously reviewed, two forms of odour performance standards are most common: percent odour reduction (system efficiency) and maximum odour (target) concentration at the outlet.

Percent odour reduction

Consider an example of a field technician/engineer collecting multiple samples from a source at "exactly" the same time or over a relatively short period of time from a source with confirmed stable conditions. Sets of inlet and outlet samples of the control system would be collected for determination of the odour reduction efficiency.

EN13725:2003 Annex H, "Example of the calculation used to determine the number of odour concentration measurements required to detect a difference between two means", presents statistical background and the calculation of the 95% confidence interval for removal efficiency of a biofilter example odour control system with required removal efficiency of 90%.

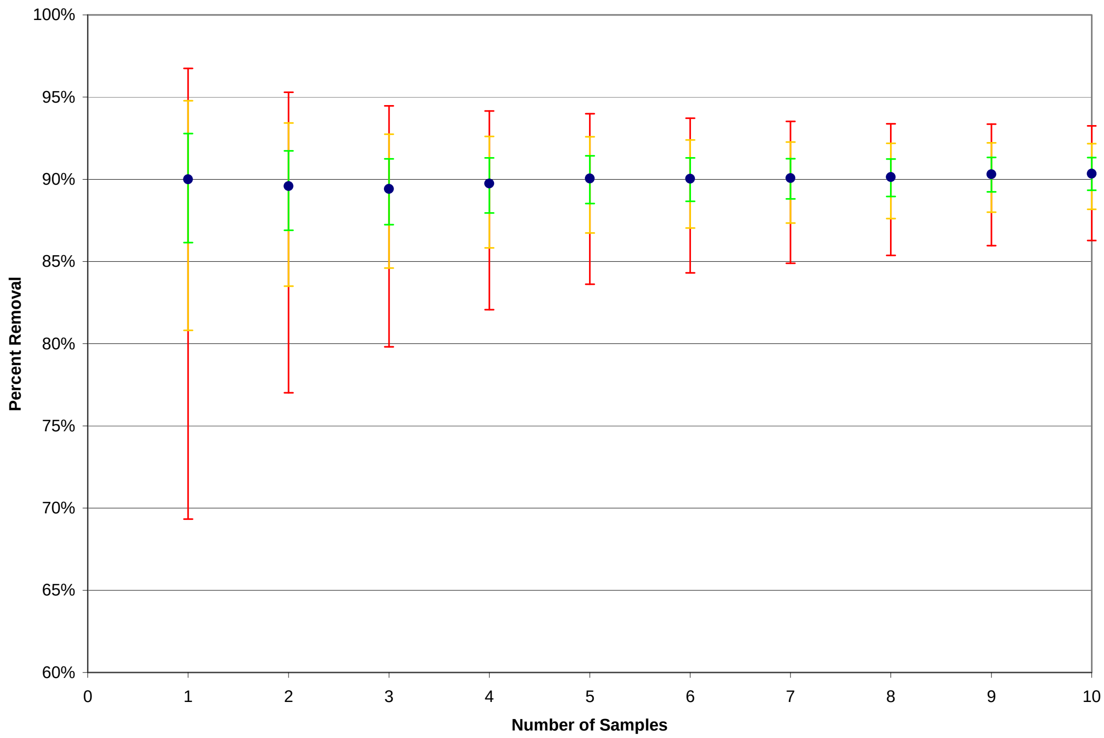
Figure 1 provides a summary of calculations shown in EN13725 Annex H for the 95% confidence interval as the number of paired samples increases. The results of three different precision levels are displayed: minimum precision criteria of EN13725 (std. dev. = 0.172) in red (Annex H), an example of inter-panel precision (std. dev. = 0.10) in yellow, and an example of within panel precision (std. dev. = 0.05) in green. The 95% confidence interval for the calculated efficiency is reduced if the odour laboratory's precision (inter-panel variance) is better than the EN13725 criteria. The 95% confidence interval is even narrower if conditions allow for the use of the odour laboratory's within panel variance. It is shown in the figure how three samples reduces the confidence interval as n increases; however, this reduction has a diminishing return beyond 4 or more samples.

Figure 1 shows how at some points the 90% odour reduction limit is not met; however the 95% confidence interval includes the 90% reduction requirement. For example, with three paired samples, the average odour reduction efficiency is only 89.4%, but the 95% confidence interval includes the 90% limit, which means that a calculated 90% efficiency would not be considered statistically different.

One must consider the ultimate use of the testing results when determining which type of variability (inter-panel or within panel) correctly reflects the precision of the olfactometry data (Oxbol, 2004).

For example, if the testing specification required three sets (triplicate) of inlet and outlet samples to be evaluated by one odour panel of assessors, then the within panel precision variance would be used. The test specification would further clarify that the 95% confidence interval would be used as a measure of test acceptance. For the example previously discussed and shown in Figure 1, for three paired inlets and outlets, the 95% confidence interval for this defined level of precision (std. dev. = 0.05 for the laboratory used) would provide a range of 87.2% to 91.2%. The result would be that the performance test would be given a "PASS" for having an equivalent 90% odour reduction level.

Figure 1. Comparison of 95% confidence intervals for replicate samples of an odour control (biofilter) performance test. The red bands (widest) represent the 95% confidence interval based on the EN13725 criteria for precision (S_r=0.172). The yellow bands (middle) represent the 95% confidence interval based on common inter-panel precision (S_r=0.10). The green bands (narrow) represent the 95% confidence interval based on common within panel precision (S_r=0.05).



Maximum odour concentration (target outlet)

A second common measure of performance is a maximum odour concentration at the outlet. Consider an example odour performance requirement of an outlet concentration not to exceed 200 OU_E/m^3. A performance specification should provide much more detail than just this limit. Is it one sample collected to prove performance? Is it three samples collected through the course of the day? Or is it triplicate samples collected at essentially one time period?

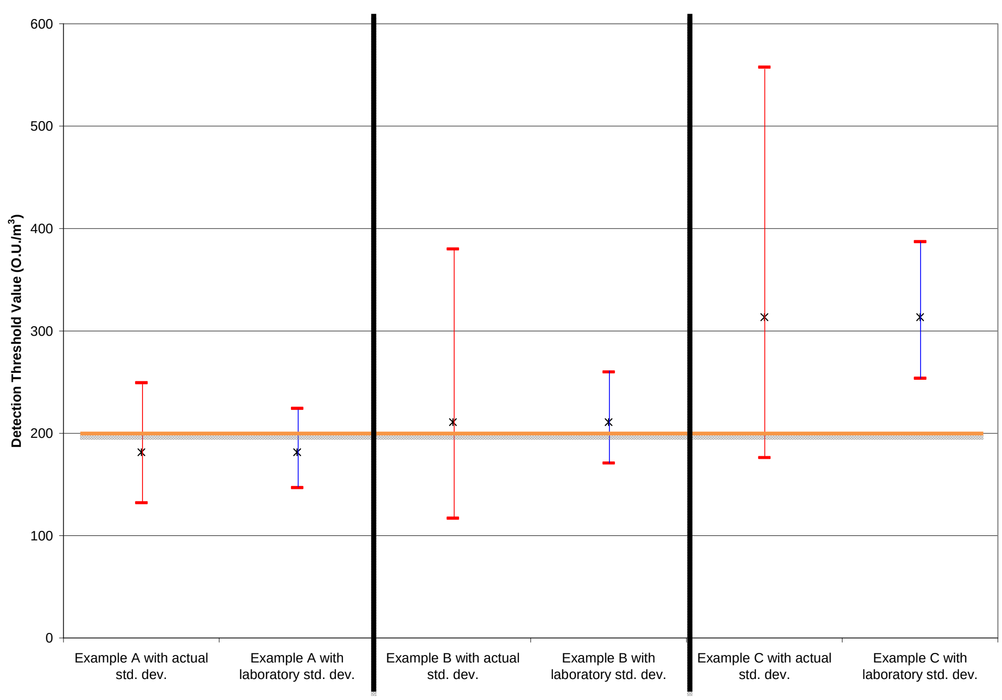
EN13725:2003 Annex G, "Example of the calculation used to determine the number of odour concentration measurements required to achieve a defined precision", presents the statistical background and the calculation for the 95% interval for odour measurements based on the precision and accuracy of a given odour laboratory. Annex G shows the results for a laboratory that "just meets" the minimum precision criterion, which is a standard deviation of 0.172, determined by the laboratory through a QA/QC program including testing with standard odorant n-butanol.

In some cases, it may be possible for a facility or engineering firm hired by the facility to set a bright-line performance specification. For example, air dispersion modelling may show that any emission over 200 OU_E/m^3 has the potential to cause a nuisance at the nearest receptor, so the facility has agreed that no odour higher than 200 OU_E/m^3 can be allowed. The specification would be written that no odour test result could exceed the 200 OU_E/m^3 bright-line requirement.

In other situations, a bright-line is not necessary and may be unreasonable. For these situations, the stakeholders must consider and understand testing variability and provide a specification that takes this into consideration and provides a measure of performance.

Consider three example cases of results collected in triplicate from an odour source. In Example A, the triplicate samples yielded results of 210, 150, and 190 OU_E/m^3. While one of the three samples exceeded 200 OU_E/m^3, the geometric mean of the test was 182 OU_E/m^3. Figure 2 shows this example graphically displayed with the geometric mean and the upper and lower bounds of the 95% confidence interval. The confidence interval is shown two different ways. The first is the confidence interval based on the actual standard deviation of the three results, 0.075, which had a lower bound at 132 OU_E/m^3 and an upper bound at 249 OU_E/m^3. The second confidence interval is based on the laboratory within panel standard deviation, for this lab a standard deviation of 0.05, which leads to a narrower range from 147 to 224 OU_E/m^3. In this Example A, the use of either standard deviation gives essentially the same conclusion: the System PASSED the test.

Figure 2. Examples of geometric means and 95% confidence intervals for three scenarios considering triplicate samples evaluated to compare to a performance criterion maximum odour emission concentration of 200 OU_E/m^3. Ranges in red are 95% confidence intervals calculated with actual calculated standard deviations. Ranges in blue are 95% confidence intervals calculated with the laboratory's within panel standard deviation.



Example B is a second example with triplicate samples that yielded results of 195, 300, and 100 OU_E/m^3. In this case, the geometric mean of 210 OU_E/m^3 is just above the 200 OU_E/m^3 requirement. If one ignored statistics, the conclusion would be that the System FAILED. However, while the one result of 300 OU_E/m^3 leads to a much wider confidence interval when the actual standard deviation is used versus when the lab within panel standard deviation is used, both statistical reviews show the 95% confidence interval overlaps the 200 OU_E/m^3 requirement value. In this Example B, the use of either standard deviation value gives the same conclusion: the System PASSED the test.

A final example shows how it is important that the calculation of the performance measure is clearly defined. Example C has triplicate samples with results of 220, 400, and 350 OU_E/m^3. All the samples were higher than the 200 OU_E/m^3 requirement. Further, the geometric mean of the three samples was 313 OU_E/m^3. Figure 2 shows the 95% confidence intervals for these results under the two conditions. When the actual standard deviation of the three samples is considered, the confidence interval ranges from 176 to 558 OU_E/m^3. This interval includes the requirement value of 200 OU_E/m^3, suggesting this test would PASS. However, if the lab within panel standard deviation is utilized for the data review, the confidence interval is narrower with a range of 254 to 387 OU_E/m^3, which does not include the requirement value of 200 OU_E/m^3. This shows how an argument of statistics could ensue unless the statistical procedure is clearly defined ahead of time.

Example C also shows a situation where the performance standard could possibly have a secondary criterion. For example, maybe the performance measure is based on the actual standard deviation of the three results having a confidence interval that included the outlet requirement of 200 OU_E/m^3, but also includes a secondary criterion that no one measure may be greater than 350 OU_E/m^3.

CONCLUSIONS

Odour control system performance is measured by testing odour samples collected from system outlets and sometimes with paired inlet samples as well.

Odour testing is a precise testing method that depends on the quality assurance/quality control (QA/QC) statistics associated with the odour laboratory. The European odour testing standard, EN13725:2003, describes a standard method using n-butanol for monitoring the performance of the odour panel members (assessors), the odour laboratory, and the odour test results (CEN, 2003).

If an odour control system is needed to reduce source odour, then a performance standard for that odour control system is required. Vendors/suppliers of odour control systems depend on well-written odour control system performance standards. If stakeholders (community, owners, engineers, contractors, vendors) discuss and collaborate on the development of the odour control system performance standards, odour outcomes will be improved.

Odour control system performance standards by other names are “performance guarantees.” Engineers and source owners prepare system specifications with performance requirements. Contractors and vendors guarantee their odour control systems to comply with the performance standard (guarantees).

These performance standards for odour control systems are well established in the engineering and vendor industries. Two common forms of standards are: percent odour reduction and maximum odour (target) concentration at the outlet.

Following EPA protocols as well as shown in statistical examples from EN13725 Annex H, triplicate samples of a system outlet or inlet/outlet paired samples should be collected for the time period of interest. This allows for a practical balance of the number of samples to achieve reduced variability in the final calculated result. If multiple time periods through the day are necessary to document continued performance with variable process conditions or continued performance with a variable control system, then triplicate samples at each time period should be tested.

For either performance measure criteria, a statistical review of the results is critical to understanding the true meaning of the results. Understanding the facility, the specific process, and the community will help to determine if the standard should be a bright-line criterion that cannot be exceeded or if a value within a specified range is acceptable. For the statistical review of the results, it is important to consider which standard deviation (measure of variability) should be used. A specification should outline this procedure in order to avoid a post-hoc battle of statistics.

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