ODOR PARAMETERS

St. Croix Sensory specializes in quantification of perceived odors of air samples and commercial products and materials. Odors are the sensory perception caused by odorants (chemicals) stimulating olfactory receptors in the nose.

Odors can be quantified by five parameters that profile the human response. These parameters include: odor thresholds, odor intensity, odor persistency, hedonic tone, and odor characterization.

The following is a brief explanation of these parameters of the odor evaluation services provided by St. Croix Sensory. For environmental odor samples, an odorous air sample collected in a Tedlar air sample bag is evaluated. For product and material testing, the sample may also be from a Tedlar air sample bag or it may be a direct observation of a headspace developed around the sample or from an environmental test chamber.

Odor Thresholds

The most common measure of odors is the odor threshold value (OTV), also referred to as the odor concentration or odor strength. Odor strength is quantified by determining the amount of dilution needed to bring the odorous air sample to its threshold. The higher the threshold value, the more dilution is needed to bring the odor to threshold, thus the stronger the odor.

The odor threshold is determined by trained human assessors observing presentations of the odorous air sample dynamically diluted with an olfactometer. The testing procedures follow ASTM International E679-04, *Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits*, and EN13725:2003, *Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*. EN13725, the official standard of all European Union countries, exceeds the requirements of ASTM E679-04. The standardization organizations of Australia and New Zealand have also adopted an identical standard (AS/NZ 4323.3-2001).

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These testing standards utilize a presentation method called "3-alternative forced-choice" (3-AFC) or "triangular forced-choice (TFC). Each assessor performs the odor evaluation task by sniffing diluted odorous air from the olfactometer. The assessor sniffs three sample presentations; one contains the diluted odor while the other two are "blanks" (odor-free air). They must then select the one of the three that is "different" from the other two. The assessor is required (forced) to choose one of the three and acknowledge their response as a "guess", "detection", or "recognition", as defined by ASTM E679-04.

After the first set of presentations, the assessor is then presented with the next dilution level. At this next level, the assessor is again presented with three sample choices, one of which is the diluted odor sample. However, this next dilution level presents the odor at a higher concentration (i.e. two times higher). This is one-half the dilution ratio (fewer number of dilutions = higher concentration). The first dilution level presented to the assessors is below the odor threshold (subthreshold). The assessor proceeds to higher levels of sample presentation following these methods until the odor concentration is above the recognition threshold. This statistical approach is called "ascending concentration series."

Results are computed for each assessor based on the dilution levels where correct "detection" or "recognition" responses are recorded. The responses of all assessors are averaged to determine the sample's detection and recognition thresholds.

The dynamic dilution of an odorous emission is the physical process that occurs in the atmosphere down-wind of the odor source. An individual, or citizen from the community, observes the diluted odor. The dilution ratio is an estimate of the number of dilutions needed to make the actual odor emission just detectable. This is known as the Detection Threshold (DT). The Recognition Threshold (RT) is the dilution ratio at which the assessor first detects the odor's character ("smells like…"). The recognition threshold value is always lower than the detection threshold value. It takes more dilution to bring an odor to its detection threshold (no odor present) compared to its recognition threshold (odor is not recognizable).

The odor threshold is reported as a dimensionless dilution ratio; however, often the pseudo-dimensions of "Odor Units' (O.U.) are used. Units of "Odor Units per cubic meter" (O.U./m^3) are also commonly applied in order to calculate odor emission rates.

For this testing, St. Croix Sensory utilizes an AC'SCENT® International Olfactometer, a dynamic dilution triangle olfactometer, operating at 20-LPM with 5 assessors, who complete the threshold determination a minimum of two times (EN13725:2003). Final results are retrospectively screened in order to evaluate and identify assessors who may have a specific hypersensitivity or anosmia to the odor sample presented.

The assessors are tested and "certified" with a standard odorant (n-butanol) and are required to meet specific sensitivity criteria outlined in the European testing standard, EN13725. These assessors are required to have an average n-butanol detection threshold between 20-80 ppb based on their last 20 evaluations. Assessors also must maintain a

defined standard deviation of n-butanol threshold measurements in order to satisfy repeatability requirements of the standard.

St. Croix Sensory may utilize more assessors when necessary for a specific project. Furthermore, the AC'SCENT International Olfactometer is capable of operating from 3-LPM to 20-LPM if the client requires a specific flow rate that deviates from the EN13725 standard requirements.

Odor Intensity

Odor intensity is the relative strength of the odor above the Recognition Threshold (suprathreshold). The intensity of an odor is referenced on the ASTM Odor Referencing Scale described in ASTM E544-99, *Standard Practice for Referencing Suprathreshold Odor Intensity*. The IITRI Dynamic Dilution Binary Olfactometer (Butanol Wheel) is the dynamic presentation method St. Croix Sensory utilizes for the procedure of odor intensity referencing.

The odor referencing is accomplished by comparison of the odor intensity of the odor sample to the odor intensity of a series of concentrations of the reference odorant n-butanol. The Butanol Wheel olfactometer delivers the butanol in air to 8 glass sniffing ports that make-up a series of increasing concentrations of the butanol. The series starts at 12-ppm butanol and has an increasing concentration ratio of 2 (binary scale).

Each assessor observes the odorous air sample and determines the odor intensity. The average value of the panel of assessors is the reported intensity for the odor sample, expressed in units of parts per million (PPM) butanol equivalent. A larger value of butanol concentration means a stronger odor, but not in a simple numerical proportion, i.e. twice the butanol concentration does not mean twice the perceived odor intensity.

The Odor Intensity Referencing Scale serves as a standard method to quantify the intensity of odors for documentation and comparison purposes.

Odor Persistency ("Dose Response"):

Odor is a psychophysical phenomenon; the perceived odor intensity changes with concentration. Odor persistency is a term used to describe the rate at which the perceived intensity decreases as the odor is diluted, i.e. in the atmosphere down-wind from the odor source. The rate of change in intensity versus odor concentration is not the same for all odors.

The odor intensity is related to the odor concentration by the following equation (Steven's Law),

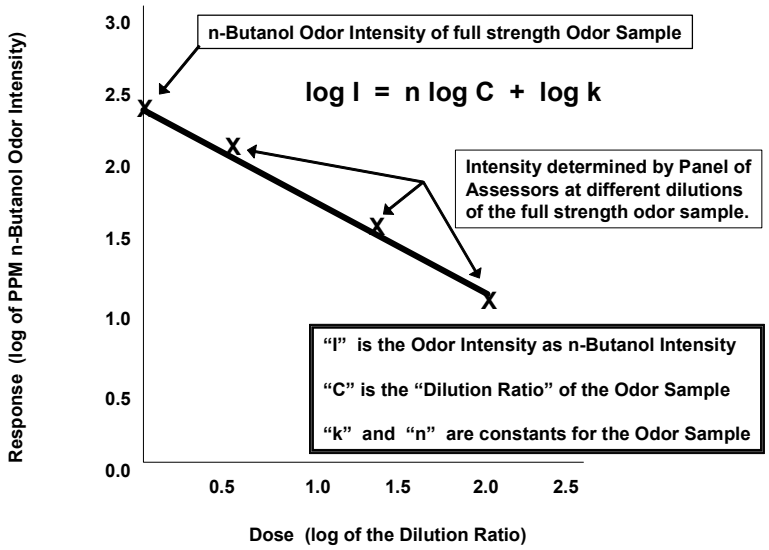
$I = k\,(C)^n$

Where:
I is the odor intensity expressed in ppm n-butanol,
C is the odor concentration expressed in number of dilutions (dilution ratio), and
k and n are constants that are different for every specific odorant or mixture of odorants.

This odor persistency relationship is a "Dose-Response" function (a psychophysical power function), which is linear on a log-log scale with the following equation:

Log I = n Log C + log k

The "Dose-Response" function is determined from intensity measurements of an odor at a minimum of three dilutions and possibly at the full strength concentration, utilizing ASTM E544, *Standard Practice for Referencing Suprathreshold Odor Intensity*. The plotted logarithmic values of the odor intensities and the odor dilution ratios (concentrations) create the "Dose-Response" function of the odor sample. The resultant straight line of the log-log plot is specific for each odor, with the slope of the line, n, representing relative persistency and the y-axis intercept, k, representing the full strength intensity. A flatter slope of an odorant mixture represents a more persistent odor.



This "Dose-Response", persistency, graph can be converted to a Power Law graph showing how the intensity changes with the odor concentration, represented in "Odor Units." This conversion is completed by taking the recognition threshold of the odorous air sample, the full strength odor concentration, into consideration.

The number of odor units presented at each diluted odor presentation can be determined by dividing the Recognition Threshold (RT) by the Dose-Response dilution ratio test points. For example, if the RT (full strength odor concentration) is 2000 O.U. and the

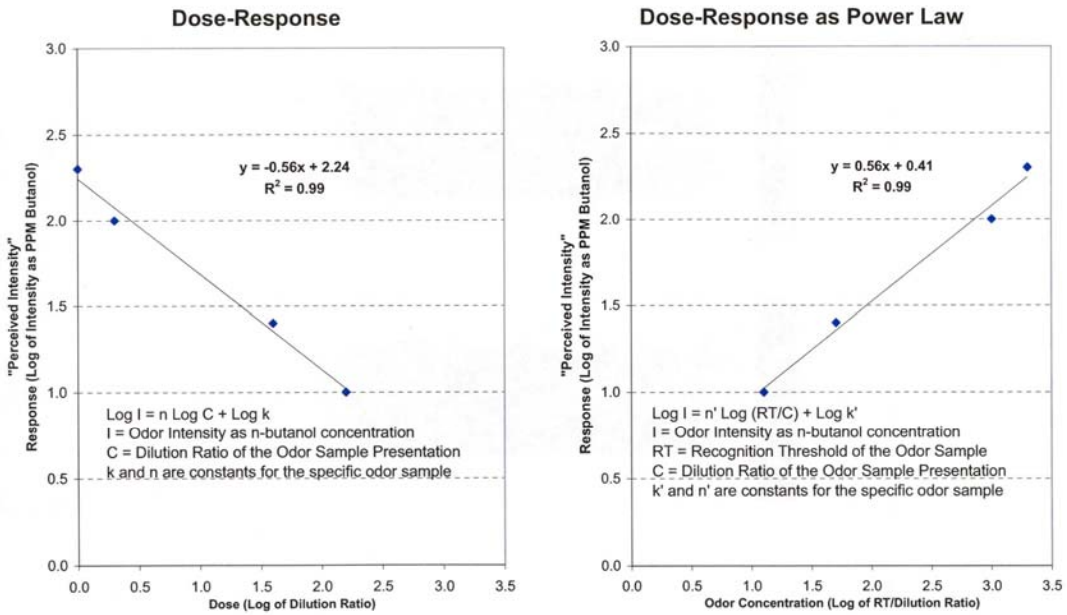
assessor is presented with this odor at 40 dilutions, then the assessor was presented with an odor that is equivalent to 50 O.U. The power law relationship can then be represented as:

Log I = n' Log (RT/C) + Log k'

This equation will have a positive slope. The slopes of the two curves are related by:

n = - n'

The following pair of graphs illustrates the example of an odor that has a recognition threshold of 2000 O.U. The assessors were presented with this odor sample at full strength and at dilutions of 2, 40, and 160.



The positive slope of the Power Law graph illustrates that the odor intensity of odorants increase as the mass concentration increases. The slope of the Dose-Response and Power Law graphs is less than one for most odors since it takes larger and larger increases in concentration to maintain a constant increase in perceived intensity.

Hedonic Tone HT

Hedonic Tone (HT) is a measure of the pleasantness or unpleasantness of an odor sample. An arbitrary but common scale for ranking odor by hedonic tone is the use of a 21 point scale:

+10	Pleasant
0	Neutral
-10	Unpleasant

The assigning of a hedonic tone value to an odor sample by an assessor is "subjective" to the assessor. An assessor uses her/his personal experiences and memories of odors as a referencing scale. The assessor, during training, becomes aware of their individual odor experience and memory referencing.

The average value of all assessors is the reported hedonic tone (HT) for the odor sample.

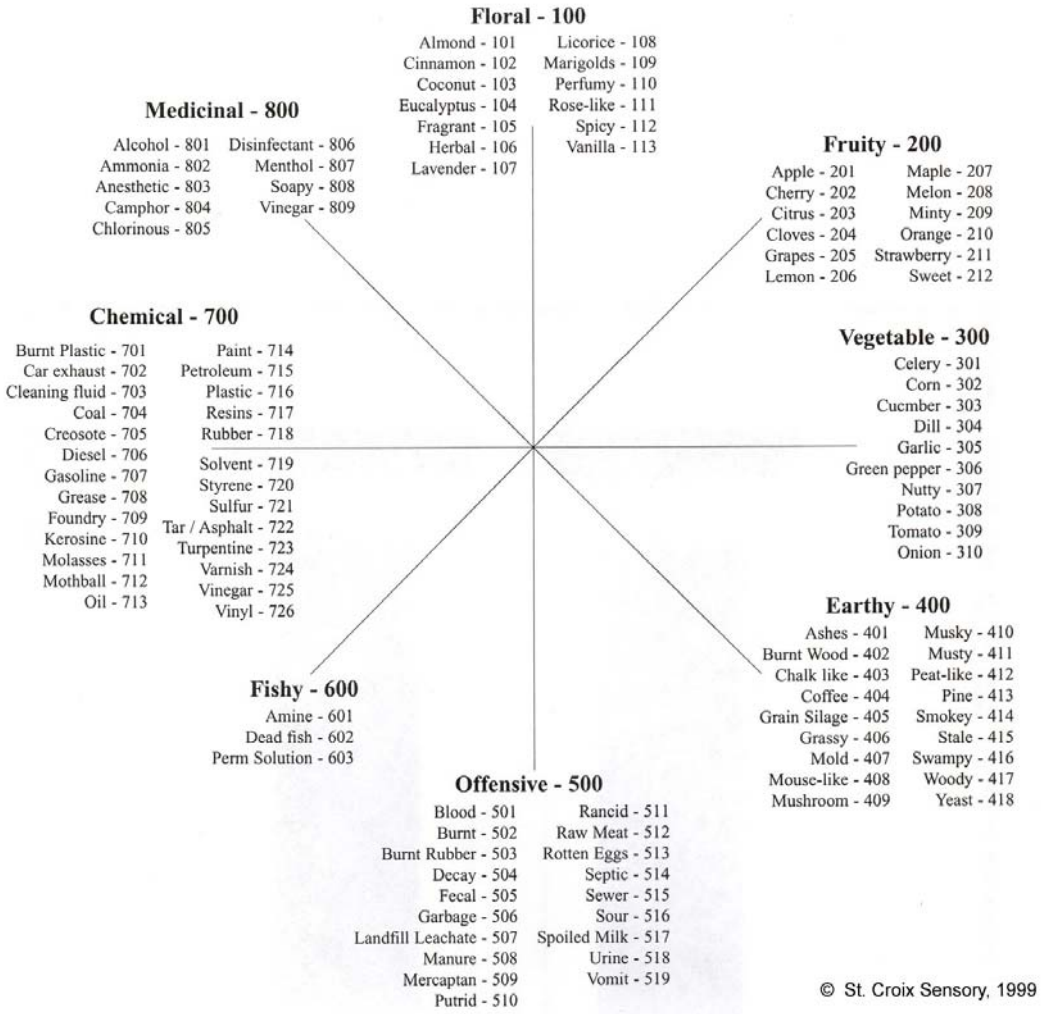
It is important to note that the hedonic tone values provided by the trained assessors should not be considered to represent the opinions of the general population. The values should be used for relative comparison of the pleasantness between samples within one test session since they would be observed by the same panel of assessors.

Odor Characterization

The character of an odor, also referred to as "odor quality," is reported using standard descriptor lists. Assessors report both what the odor "smells like" (e.g. sewer, banana, etc.) and what the odor "feels like" (e.g. burning, cooling, etc.) Assessors also report relative strengths of the different characters identified.

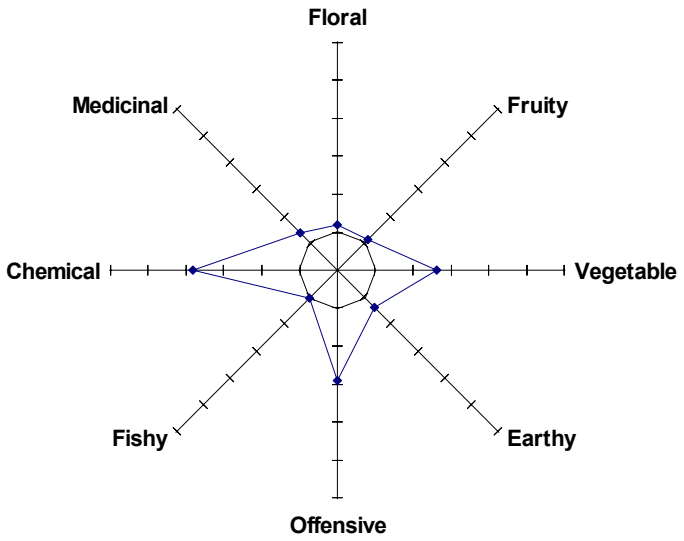
Odor Descriptors

Numerous "standard" *odor* descriptor lists are available to use as a referencing vocabulary. Eight (8) recognized odor descriptor categories, including **Vegetable, Fruity, Floral, Medicinal, Chemical, Fishy, Offensive, and Earthy,** are illustrated as an "odor wheel". Specific descriptors within each of these odor categories are presented in the subsequent diagram.



Each assessor rates these eight main odor descriptor categories on a relative strength scale of zero to five, where zero is “not present”, 1 = faint, 3 = moderate, and 5 = strong. The average results of the panel of assessors are plotted on a spider graph (polar plot). The axis on the spider graph, for example in the direction of Offensive, is the average relative strength on the 0 to 5 scale.

Odor Descriptor Graph

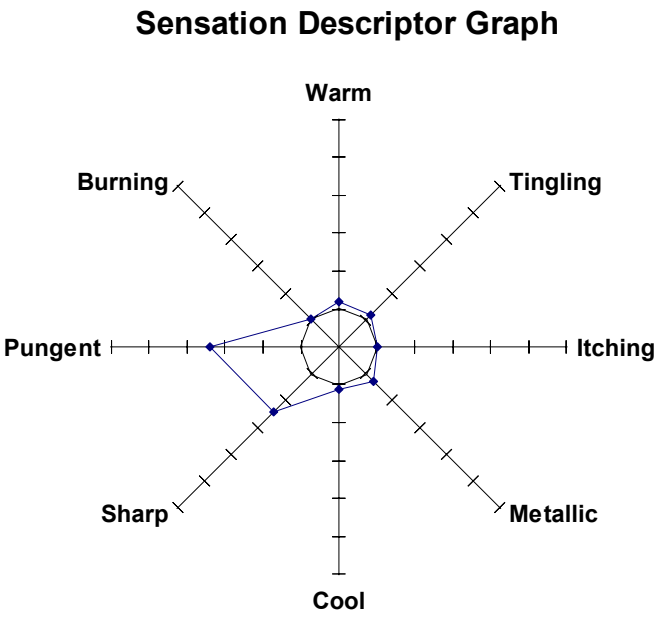


Each assessor also reports the specific Odor Descriptors observed. A histogram presents the percentage of assessors in the panel that assigned specific descriptors to the odor sample.

% of Assessors	|**********|**********|**********|**********| 100%
Vegetable	**********
Garlic	**********
Onion	**********
Lemon	*****
Floral	*****
Medicinal	**********
Menthol	*****
Chemical	**********
Petroleum	**********
Turpentine	*****
Solvent	*****
Gasoline	*****
Sulfur	**********
Offensive	**********
Sewer	*****
Garbage	*****
Rotten eggs	**********
Decay	*****
Putrid	*****
Earthy	*****
Musty	*****

Sensation Descriptors

The Trigeminal Nerves (Fifth Cranial Nerve), located throughout the nasal cavity and in the upper palate, and the other nerves in these areas sense the presence of some odors (i.e. "feels like…" rather than "smells like…"). Eight (8) common *sensation descriptors* that can be reported include: **Itching, Tingling, Warm, Burning, Pungent, Sharp, Cool, and Metallic**. Each assessor rates each of these sensations on a relative strength scale of zero to five, where zero is "not present", 1 = faint, 3 = moderate, and 5 = strong. The average results of the panel of assessors are plotted on a spider graph (polar plot). The axis on the spider graph, for example in the direction of **Burning**, is the relative strength scale.



St. Croix Sensory technical staff works closely with our clients to discuss the specific odor evaluation needs of each project to provide valuable results.