Odor as an air pollutant

Prof. Tim Larson

CEE 357

Some states have ambient air odor standards based on hydrogen sulfide concentrations,…

Location	Compound	Ambient Odor Standard
California	Hydrogen sulfide	30 ppbv* (1-hour average)
Connecticut	Hydrogen sulfide Methyl mercaptan	6.3 ug/m^3 2.2 ug/m^3
Idaho	Hydrogen sulfide	10 ppbv (24 hour average) 30 ppbv (30 min. average)
Minnesota	Hydrogen sulfide	30 ppbv (30 minute average)** 50 ppbv (30 minute average)***
Nebraska	Total reduced sulfur	100 ppb (30 minute average)
New Mexico	Hydrogen sulfide	10 ppbv (1 hour avg.) or 30 - 100 ppbv (30 minute avg.)
New York State	Hydrogen sulfide	10 ppbv (14 ug/m^3) 1-hour average
New York City	Hydrogen sulfide	1 ppbv (for wastewater plants)
North Dakota	Hydrogen sulfide	50 ppbv (instantaneous, two readings 15 min. apart)
Pennsylvania	Hydrogen sulfide	100 ppbv (1 hour average) 5 ppbv (24 hour average)
Texas	Hydrogen sulfide	80 ppbv (30 minute avg.) - residential/commercial & 120 ppbv - industrial, vacant or range lands

* - parts per billion by volume
** - not to be exceeded more than 2 days in a 5-day period
*** - not to be exceeded more than 2 times per year

…but there are other odorous compounds besides H_2S.

http://www.env.go.jp/en/lar/odor_measure/02_1_4.pdf

Other odor standards are based on “dilutions-to-threshold” (D/T)

Table 2 Examples of OU/m3 (D/T) Limits Used *from Mahin (1)*

Location	Off-site standard or guideline	Averaging times
Allegheny County Wastewater Treatment Plant (WWTP)	4 D/T (design goal)	2-minutes
San Francisco Bay Area Air Quality District	5 D/T	Applied after at least 10 complaints within 90-days
State of Colorado	7 D/T (Scentometer)	
State of Connecticut	7 D/T	
State of Massachusetts	5 D/T*	
State of New Jersey	5 D/T **	5-minutes or less
State of North Dakota	2 D/T (Scentometer)	
State of Oregon	1 to 2 D/T	15-minutes
City of Oakland, CA	50 D/T	3-minute
City of San Diego WWTP	5 D/T	5-minutes
City of Seattle WWTP	5 D/T	5-minutes

* draft policy and guidance for composting facilities

** for biosolids/sludge handling and treatment facilities

http://www.env.go.jp/en/lar/odor_measure/02_1_4.pdf

Dilutions-to-threshold (D/T)

Dilutions-to-threshold is defined as the amount of dilution where 50% of the population will perceive an odor. This amount of dilution is determined by:
1) obtaining an air sample at the source
2) diluting it a known amount with clean air
3) having the diluted sample sniffed by a panel of people
4) repeating the dilution until the perception threshold is reached.

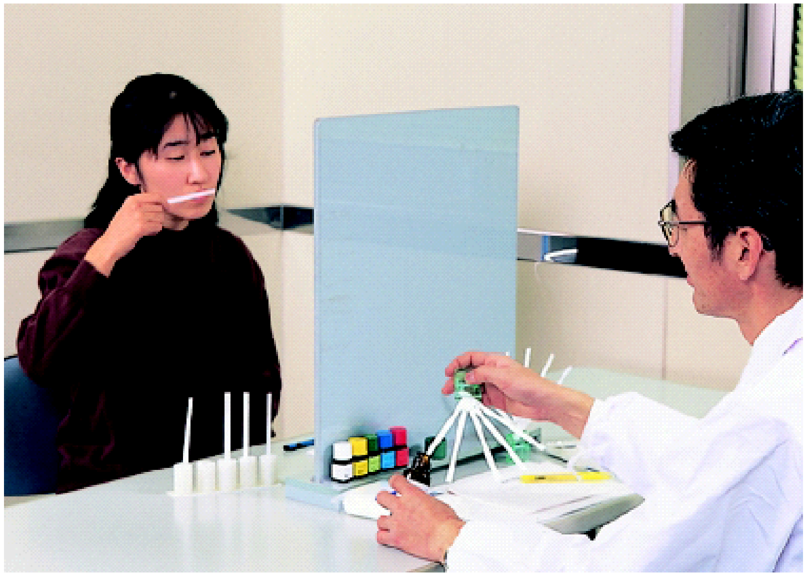
D/T = 10,000   original air sample is smelly

D/T = 5 original air sample is difficult to smell

Triangle Odor Bag Method

(1) Selection of panel (group of persons who judge the presence of odor with their olfaction)

An aptitude test is conducted using five standard odorants to choose a group of persons without olfaction abnormalities as the panel. To measure the odor intensity precisely and fairly, the panel must be in good health, both physically and mentally. It is important to take panel members' health condition into account and confirm that their olfactory sense is not affected by cold or other illness.



Aptitude Test using Five Standard Odorants:
testees identify two test strips with odor out of five strips of test papers.

Standard Odorants for Aptitude Test:
There are five standard odors used in the aptitude test including odor "smells like flowers" and odor "smells like sweaty socks."

Office of Odor, Noise and Vibration
Environmental Management Bureau
Ministry of the Environment
Government of Japan

Triangle Odor Bag Method

Preparing the bags

Fill a bag with odor-free air (filtered through activated charcoal).

When panel members detect intensive odors, their olfaction weakens (olfactory fatigue). Therefore, the test is started with a moderately diluted concentration.

Office of Odor, Noise and Vibration
Environmental Management Bureau
Ministry of the Environment
Government of Japan

Triangle Odor Bag Method

(3) Performance of sensory test

The sensory test is conducted by at least 6 members of the panel. Each panel is given 3 bags; 1 with a sample in it and 2 without sample (odor-free air) and asked to choose the odorous bag.

If the panel can tell the correct bag, the odor is then diluted and the test is continued until it becomes impossible to identify the bag with odor.

In order to ensure the accuracy of the measurement, it is important to take psychological influences of panel members and olfactory fatigue into account.

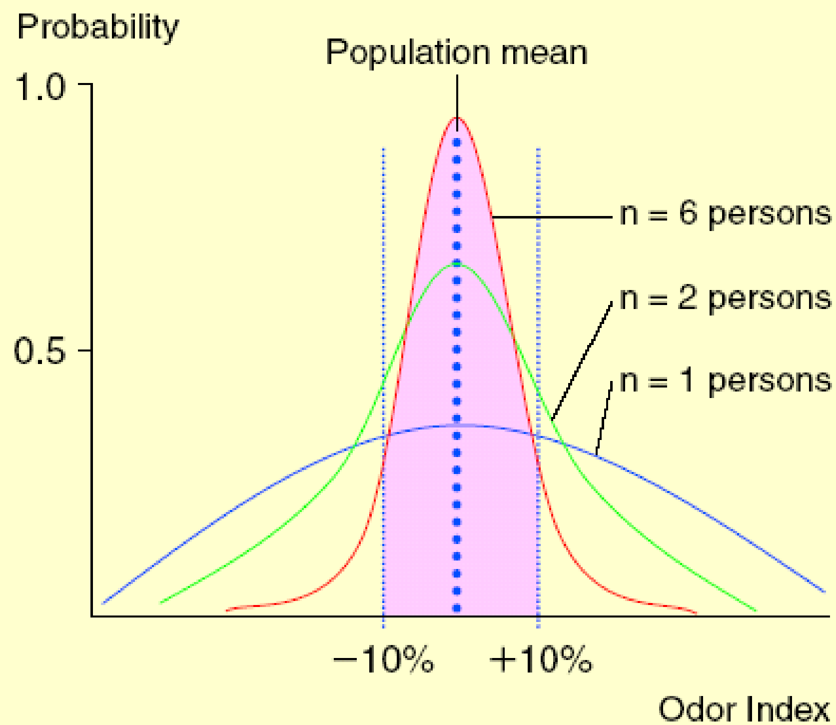
Panel members are to identify the bag with odor among 3 bags in a composed environment without odor where they can concentrate on the test.

Sample vs Population

Why are at least 6 members necessary for the panel ?

The indivisual sensitivity to smell differs even among those who passed the aptitude test. To examine the variation of test results, a series of sensory tests was conducted by changing the number of panel members. Sensory tests performed by 6 panel members yielded test results (odor index) which ranged within ±10% of the population mean with a probability of 94%. When calculated with 4 members excluding maximum and minimum values, the probability of results being in a ±10% range of the population mean was 91%, revealing a high reliability of results.

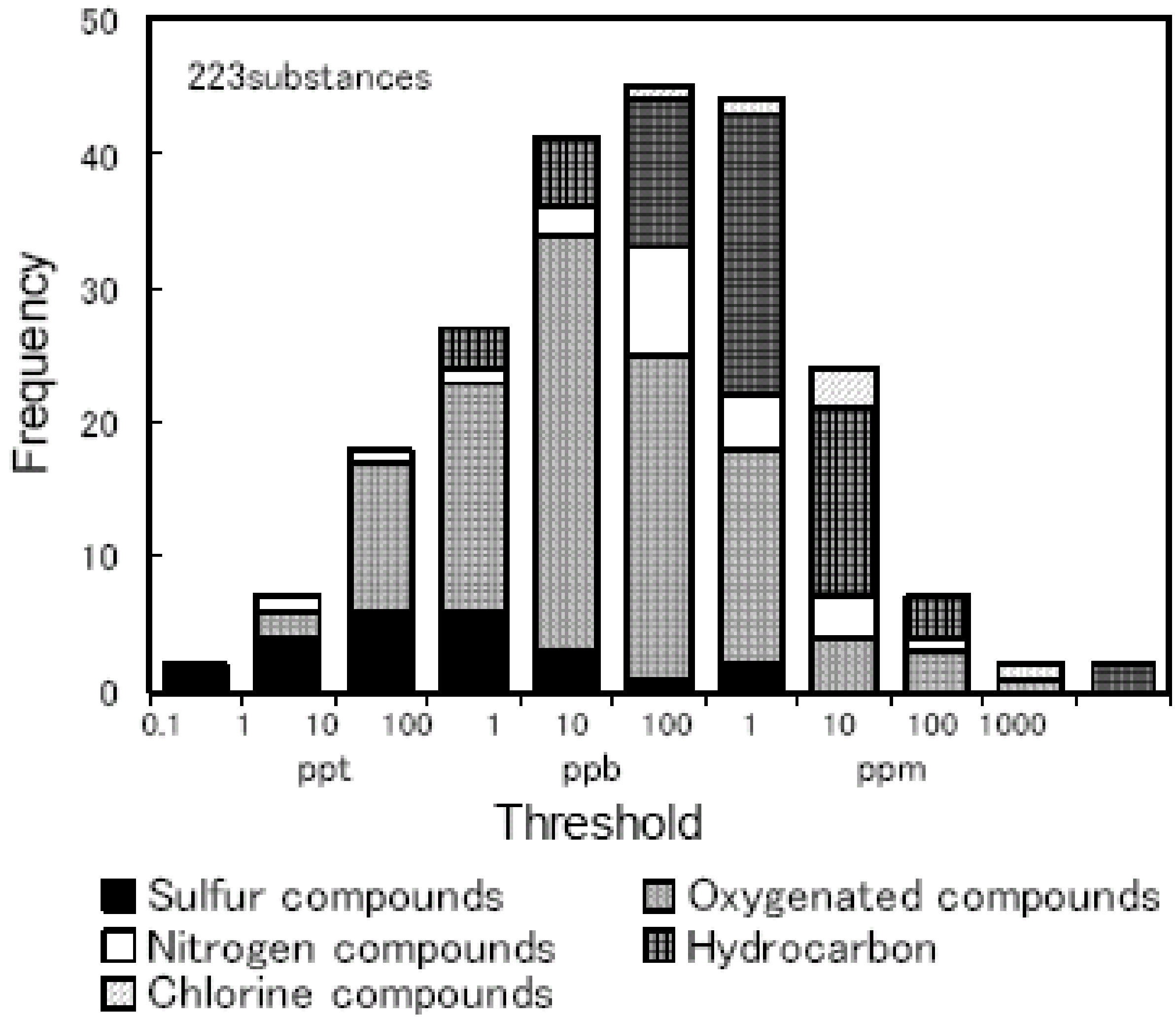
Therefore, the panel for the olfactory measurement should include 6 or more members. Moreover, in order to eliminate the influence of outliers, maximum and minimum values should be excluded.



Probability distribution of test results

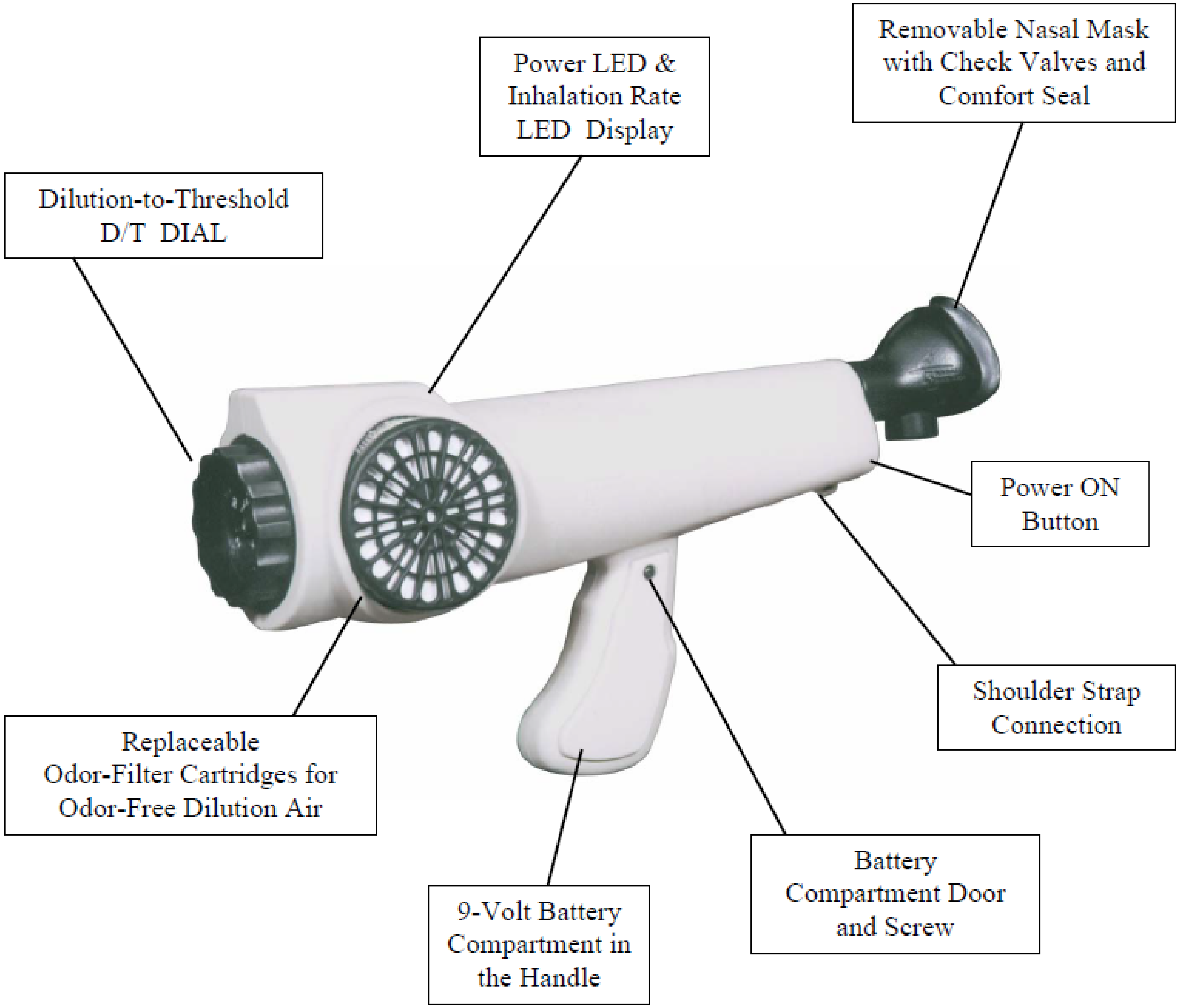
Office of Odor, Noise and Vibration
Environmental Management Bureau
Ministry of the Environment
Government of Japan

Odor Thresholds

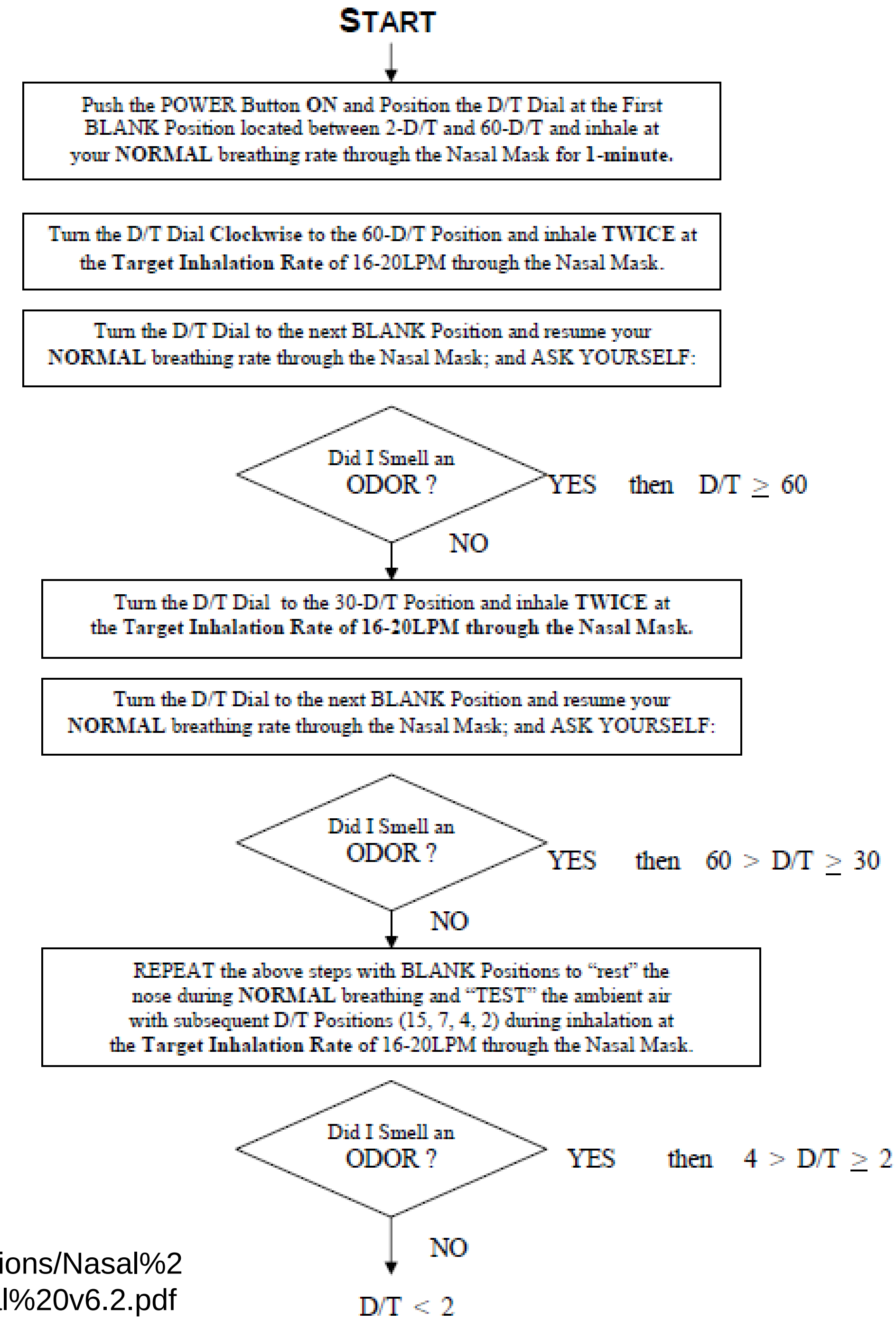


Odor measurement in the field

The “nasal ranger” field olfactometer



http://www.nasalranger.com/Operations/Nasal%20Ranger%20Operations%20Manual%20v6.2.pdf



http://www.nasalranger.com/Operations/Nasal%20Ranger%20Operations%20Manual%20v6.2.pdf

Odor Regulations

A field olfactometer device ("scentometer") is referenced in a number of existing state odor regulations. The "Dilution to Threshold" (D/T) terminology and the method of calculating the D/T are also referenced.

The criteria of an odor regulation often defines compliance as

"…ambient air that is less than 7 D/T" (7 used for exemplary purpose only).

The exact wording in a regulation is important and may be stated in two ways:

Compliance criteria: "…compliance if…less than 7 D/T."

Nuisance criteria: "nuisance if…equal to or greater than 7 D/T."

In these two examples, if an air pollution inspector observed "odor" with the field olfactometer set at a 7 D/T

The "odor" would meet the criteria for nuisance or

The ambient air would be "non-compliant".

Odor regulations that utilize field olfactometry and a calibrated field olfactometer, e.g. Nasal Ranger Field Olfactometer, also define the number of observations needed and the time frame of the observations.

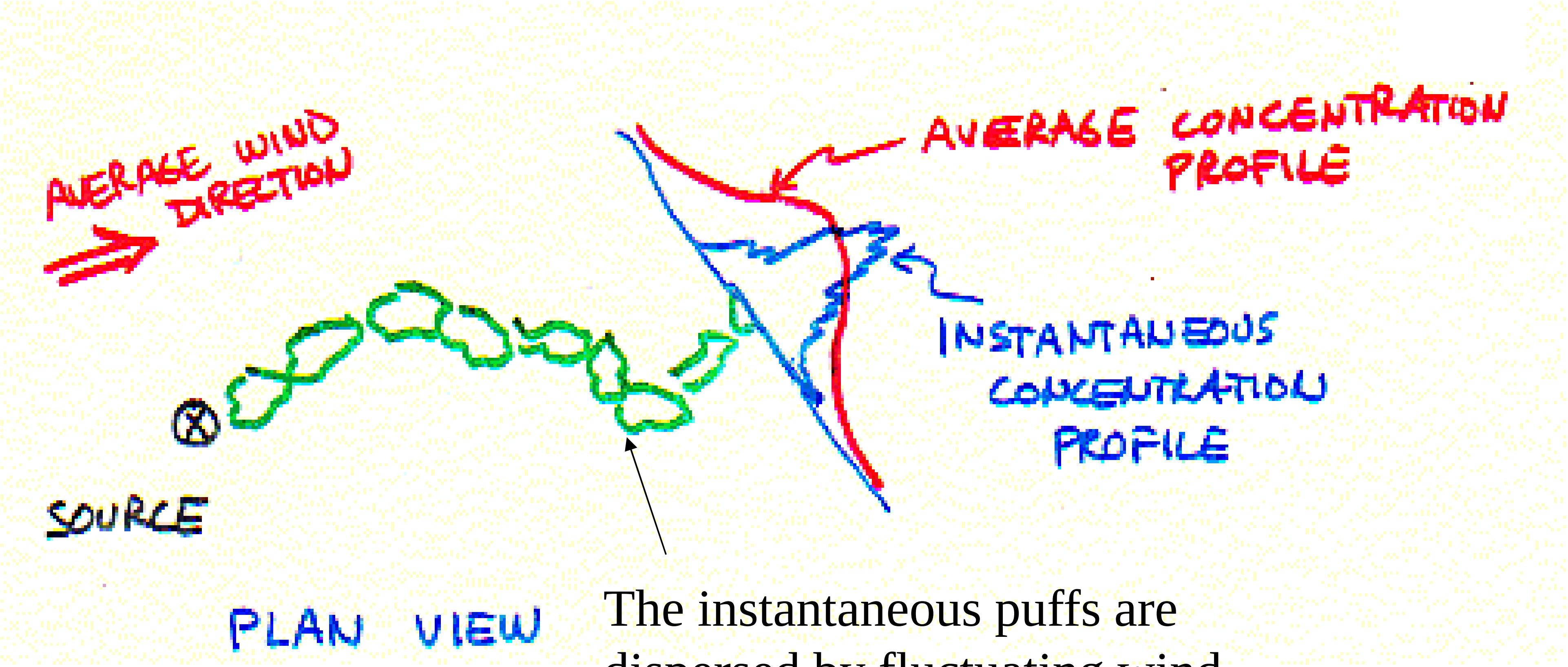
For example, a regulation may read:

"…Two field olfactometer observations in a one-hour period separated by 15 minutes each…" OR

"…Two field olfactometer observations not less than 15 minutes apart within a 1-hour period…"

http://www.nasalranger.com/Operations/Nasal%20Ranger%20Operations%20Manual%20v6.2.pdf

Our nose detects the instantaneous concentrations, not the long term average values



The instantaneous puffs are dispersed by fluctuating wind directions.

Odor Models

Ratio of 1 hr to 5 min average concentration increases with increasing stability at a given downwind location

Therefore the inverse ratio decreases with increasing stability

This inverse ratio is called the “peak to mean” ratio

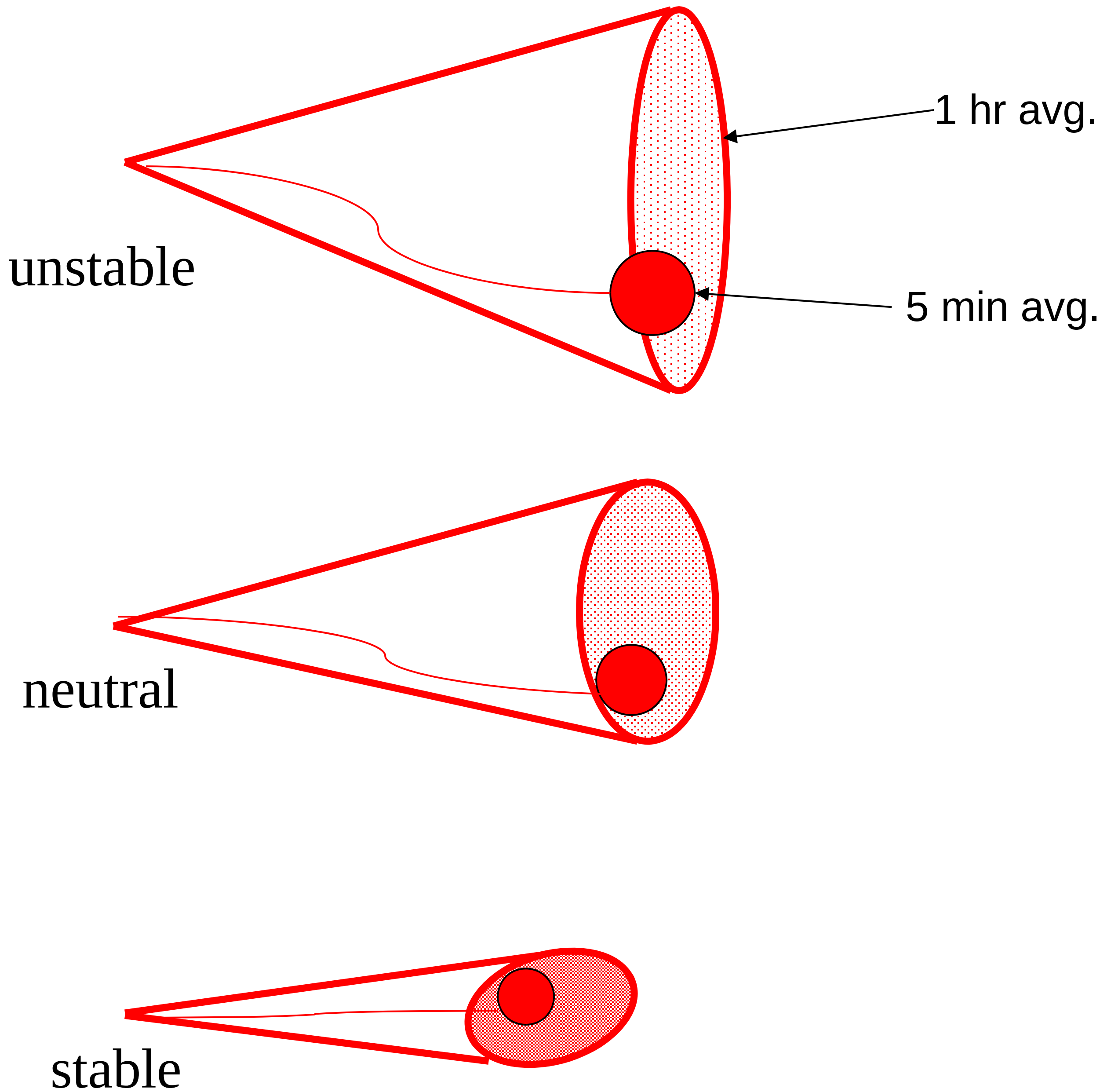


TABLE G-1. Conversion Factors for Peak-To-Mean Ratio

Distance (m)	B Stability: Wind Speed: 2 m/s (4.5 mi/hr)	D Stability: Wind Speed: 6 m/s (13.4 mi/hr)	E Stability: Wind Speed: 2 m/s (4.5 mi/hr)
Case I: Point Source Plume Height = 40 Meters			
100	45.0	6.0	8.3
200	38.5	7.3	8.3
300	23.2	8.5	10.1
400	16.1	10.2	10.9
600	12.8	12.4	12.7
800	12.6	13.3	13.1
1,000 (0.62 mi)	12.4	10.2	15.6
Case II: Point Source Plume Height = 20 Meters			
100	36.0	6.0	5.6
200	14.7	9.7	7.8
300	11.6	12.6	10.9
400	11.0	10.3	12.6
600	10.8	7.4	10.9
800	10.6	6.7	8.4
1,000 (0.62 mi)	10.4	6.6	7.3

$$C_{5min} = (C_{1hr}) * (\text{Peak to mean ratio})$$

Once short-term pollutant concentrations have been calculated, they must be compared to odor detection and complaint levels. Odor delectability, or the odor threshold, is usually defined as the point at which 50 percent of a given population will perceive an odor. Table 2 lists some of the published odor detection levels of pollutants that often cause odor problems. Odor complaint levels are usually 2 to 3 times higher than the odor threshold levels. The Connecticut DEP odor limits given in Table 2 are considered nuisance levels. Applicable odor detection and complaint levels for odor producing emissions from a proposed source should be discussed in the modeling protocol.

Table 2 Odor thresholds measured by the triangle odor bag method (ppm,v/v)

Substance	Odor Threshold	Substance	Odor Threshold
Formaldehyde	0.50	Hydrogen sulfide	0.00041
Acetaldehyde	0.0015	Dimethyl sulfide	0.0030
Propionaldehyde	0.0010	Methyl allyl sulfide	0.00014
n-Butylaldehyde	0.00067	Diethyl sulfide	0.000033
Isobutylaldehyde	0.00035	Allyl sulfide	0.00022
n-Valeraldehyde	0.00041	Carbon disulfide	0.21
I sovaleraldehyde	0.00010	Dimethyl disulfide	0.0022
n-Hexylaldehyde	0.00028	Diethyl disulfide	0 0020
n-Heptylaldehyde	0.00018	Diallyl disulfide	0.00022
n-Octylaldehyde	0.000010	Methyl mercaptane	0.000070
n-Nonylaldehyde	0.00034	Ethyl mercaptane	0.0000087
n-Decylaldehyde	0.00040	n-Propyl mercaptane	0.000013
Acrolein	0.0036	Isopropyl mercaptane	0.0000060
Methacrolein	0.0085	n-Butyl mercaptane	0.0000028
Crotonaldehyde	0.023	Isobutyl mercaptane	0.0000068
Methanol	33	sec. Butyl mercaptane	0.000030
Ethanol	0.52	tert. Butyl mercaptane	0.000029
n-Propanol	0.094	n-Amyl mercaptane	0.00000078
I sopropanol	26	Isoamyl mercaptane	0.00000077
n-Butanol	0.038	n-Hexyl mercaptane	0.000015
I sobutanol	0.011	Thiophene	0.00056
sec.Butanol	0.22	Tetrahydrothiophene	0.00062
tert.Butanol	4.5	Nitrogen dioxide	0.12
n-Pentanol	0.10	Ammonia	1.5

Sensitive Receptor:

A sensitive receptor shall include, but shall not be limited to:

a) Residents of occupied homes and residential areas
b) Employees and customers at industrial, commercial or government establishments
c) Visitors at a recreational public place such as a park or playground.
d) Schools and hospitals

Wastewater Treatment Equipment:

For the purposes of this document, wastewater handling and/or treatment equipment shall include, but shall not be limited to, screening and grit removal equipment, primary and secondary clarifiers, dewatering/thickening equipment, biological treatment equipment and advanced treatment equipment.

A source emits odors from a stack. The concentration of odor in the air inside the stack is 10,000 odor units/m^3 (OU/m^3). The volumetric flow rate of air from the stack is 10 cubic meters per second. The effective stack height is 20 meters above the ground. The wind speed of 6 meters per second is measured over rough terrain at a reference height of 10 meters above the ground. For an overcast night, find the D/T at ground level at point 500 meters directly downwind.

First compute the one-hour average concentration using the standard Gaussian model and then adjust this value using the appropriate peak to mean ratio.

Stability Class "D", p = 0.25 for rough terrain

$$\sigma_z = cx^d + f = 33.2(0.5)^{0.725} - 1.7 = 18.4 \text{ meters}$$

$$\sigma_y = ax^b = 68(0.5)^{0.894} = 36.6 \text{ meters}$$

$$u_{50} = u_{10}\left(\frac{20}{10}\right)^{0.25} = 6(2)^{0.25} = 7.1 \text{ m/s}$$

Odor mass emission rate from the stack:

Q = (10,000 OU/m^3)* (10 m^3/sec) = 100,000 OU/sec

TABLE G-1. Conversion Factors for Peak-To-Mean Ratio

Distance (m)	**B Stability: Wind Speed: 2 m/s (4.5 mi/hr)**	**D Stability: Wind Speed: 6 m/s (13.4 mi/hr)**	**E Stability: Wind Speed: 2 m/s (4.5 mi/hr)**
Case I: Point Source Plume Height = 40 Meters			
100	45.0	6.0	8.3
200	38.5	7.3	8.3
300	23.2	8.5	10.1
400	16.1	10.2	10.9
600	12.8	12.4	12.7
800	12.6	13.3	13.1
1,000 (0.62 mi)	12.4	10.2	15.6
Case II: Point Source Plume Height = 20 Meters			
100	36.0	6.0	5.6
200	14.7	9.7	7.8
300	11.6	12.6	10.9
400	11.0	10.3	12.6
600	10.8	7.4	10.9
800	10.6	6.7	8.4
1,000 (0.62 mi)	10.4	6.6	7.3

The peak-to-mean ratio for this case is found by interpolation between the 400 m and 600 m downwind cases shown for “D” stability:

Peak-to-mean ratio = $\{10.3 + 7.4\}/2 = 8.8$

The 5-minute average odor concentration is described by the standard Gaussian model prediction (one hour average) multiplied by the appropriate peak to mean ratio (note that for this problem, y = 0 (directly downwind) and z = 0 (ground level) and therefore the Gaussian plume equation takes a slightly different form in this special case).

$C(x,0,0) = \{\text{peak-to-mean ratio}\}\{Q / (\pi u\ \sigma_y\ \sigma_z)\}\ \exp\{-h^2 / (2\ \sigma_z)^2\}$
$C(500,0,0) = \{8.8\}\{100{,}000/ [\pi(7.1)(36.6)(18.4)]\}\ \exp\{-(20)^2 / [2\ (18.4)]^2\}$
$C(500,0,0) = 43.6\ OU/m^3 = 43.6\ D/T$

Therefore, if the air quality regulations dictate that the D/T be less than 5 at the property fenceline, then the stack gas odor concentration needs to be reduced to (10,000 OU/m^3)*(5/43.6) = 1150 OU/m^3 (an approximate odor emission reduction of 90%).

Odor Descriptors

Floral - 100

- Almond - 101
- Cinnamon - 102
- Coconut - 103
- Eucalyptus - 104
- Fragrant - 105
- Herbal - 106
- Lavender - 107
- Licorice - 108
- Marigolds - 109
- Perfumy - 110
- Rose-like - 111
- Spicy - 112
- Vanilla - 113

Fruity - 200

- Apple - 201
- Cherry - 202
- Citrus - 203
- Cloves - 204
- Grapes - 205
- Lemon - 206
- Maple - 207
- Melon - 208
- Minty - 209
- Orange - 210
- Strawberry - 211
- Sweet - 212

Vegetable - 300

- Celery - 301
- Corn - 302
- Cucmber - 303
- Dill - 304
- Garlic - 305
- Green pepper - 306
- Nutty - 307
- Potato - 308
- Tomato - 309
- Onion - 310

Earthy - 400

- Ashes - 401
- Burnt Wood - 402
- Chalk like - 403
- Coffee - 404
- Grain Silage - 405
- Grassy - 406
- Mold - 407
- Mouse-like - 408
- Mushroom - 409
- Musky - 410
- Musty - 411
- Peat-like - 412
- Pine - 413
- Smokey - 414
- Stale - 415
- Swampy - 416
- Woody - 417
- Yeast - 418

Offensive - 500

- Blood - 501
- Burnt - 502
- Burnt Rubber - 503
- Decay - 504
- Fecal - 505
- Garbage - 506
- Landfill Leachate - 507
- Manure - 508
- Mercaptan - 509
- Putrid - 510
- Rancid - 511
- Raw Meat - 512
- Rotten Eggs - 513
- Septic - 514
- Sewer - 515
- Sour - 516
- Spoiled Milk - 517
- Urine - 518
- Vomit - 519

Fishy - 600

- Amine - 601
- Dead fish - 602
- Perm Solution - 603

Chemical - 700

- Burnt Plastic - 701
- Car exhaust - 702
- Cleaning fluid - 703
- Coal - 704
- Creosote - 705
- Diesel - 706
- Gasoline - 707
- Grease - 708
- Foundry - 709
- Kerosine - 710
- Molasses - 711
- Mothball - 712
- Oil - 713
- Paint - 714
- Petroleum - 715
- Plastic - 716
- Resins - 717
- Rubber - 718
- Solvent - 719
- Styrene - 720
- Sulfur - 721
- Tar / Asphalt - 722
- Turpentine - 723
- Varnish - 724
- Vinegar - 725
- Vinyl - 726

Medicinal - 800

- Alcohol - 801
- Ammonia - 802
- Anesthetic - 803
- Camphor - 804
- Chlorinou- 805
- Disinfectant - 806
- Menthol - 807
- Soapy - 808
- Vinegar - 809

http://www.nasalranger.com/Operations/Nasal%20Ranger%20Operations%20Manual%20v6.2.pdf

County Environmental Dept.

Date: 1/4/08

Time	Location	D/T 60	30	15	7	4	2	<2	Descriptors	Comments
7:05 AM	1 - Industrial Park							x		
7:10 AM	2 - " "						x		718	FACTORY
7:15 AM	3 - " "							x		
7:20 AM	4 - " "				x				718, 723	FACTORY
7:25 AM	5 - Intersection					x			705	FACTORY
7:30 AM	6 - Intersection							x		
7:35 AM	7 - Co. RD. 20		x						718, 723, 515	FACTORY & WWTP
7:40 AM	8 - Intersection			x					718, 723	FACTORY
7:45 AM	9 - Junction Rd.				x				718, 723, 515	FACTORY & WWTP
7:50 AM	10 - Co. Rd. 28			x					718, 515, 601	FACTORY & WWTP
7:55 AM	11 - Division Ave.					x			718, 601	FACTORY & WWTP
8:00 AM	12 - Intersection							x		
8:05 AM	13 - Parking Lot					x			104, 304	VEGETATION
8:10 AM	14 - Intersection						x		707	HIGHWAY
8:15 AM	15 - Intersection							x		
8:20 AM	16 - Intersection							x		
8:25 AM	17 - Housing Devel.						x		201	APPLE TREES
8:30 AM	18 - 3rd & Oak					x			706, 404	COFFEE SHOP

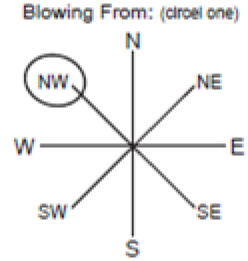
Weather Conditions

- [ ] Sunny
- [ ] Partly Cloudy
- [ ] Mostly Cloudy
- [x] Overcast
- [ ] Hazy

Precipitation:

- [ ] None
- [x] Fog
- [ ] Rain
- [ ] Sleet
- [ ] Snow

Wind Direction Blowing From: (circle one)

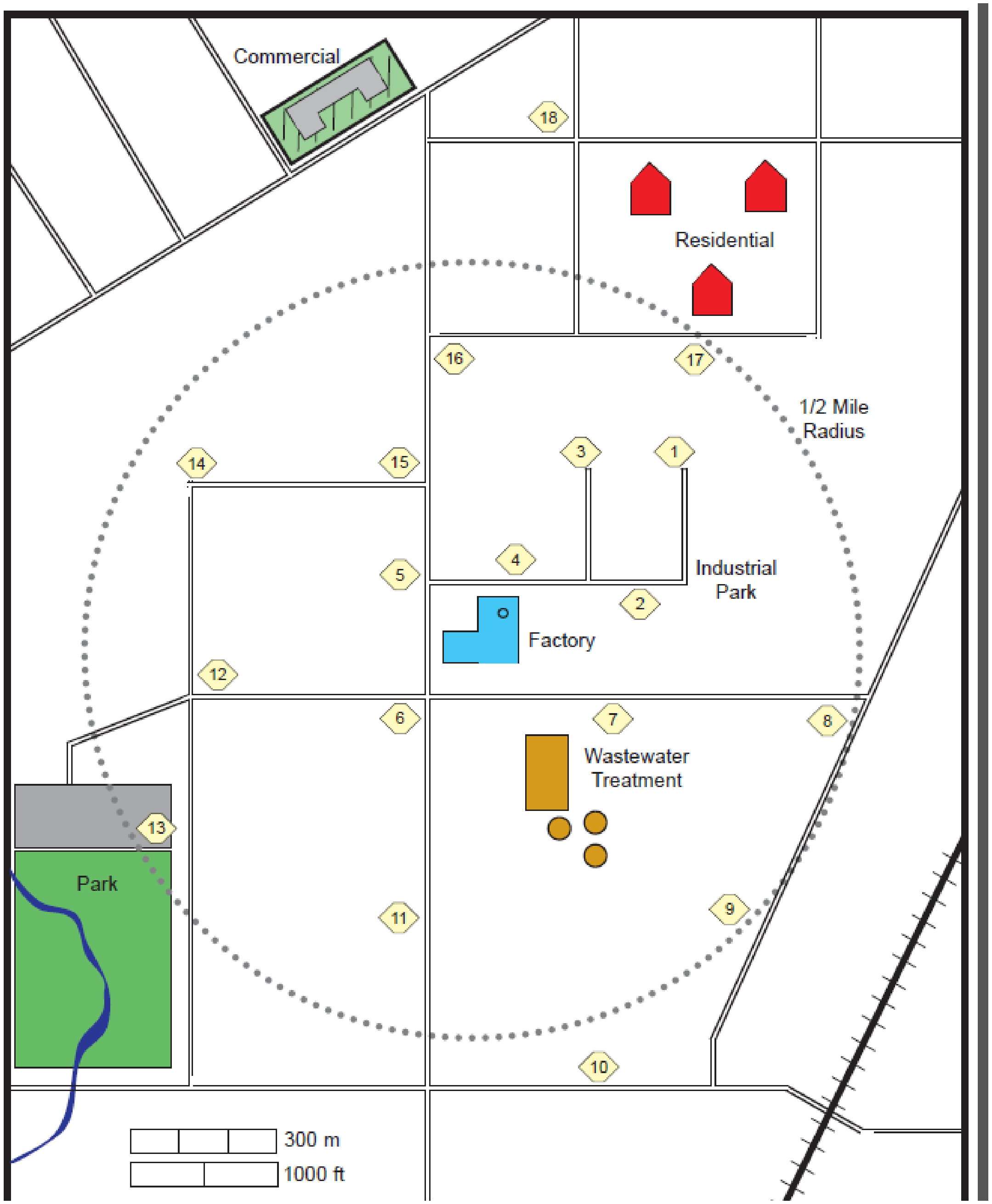


Wind Speed:

- [ ] Calm
- [x] Light Breeze (1-5 mph)
- [ ] Moderate Wind (5-15 mph)
- [ ] Strong Winds (15 or higher mph)

Temperature: 55 °F/°C   Relative Humidity: 60 %   Barometric Pressure: 30.1

Comments: ______

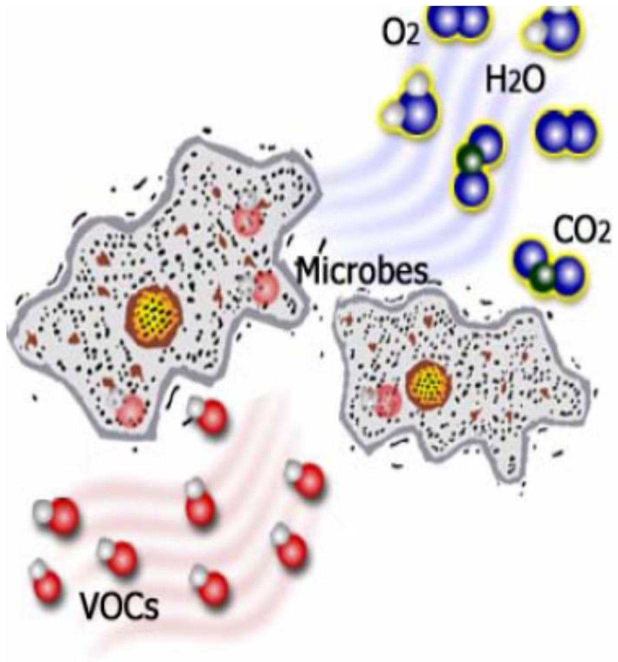


Commercial
18
Residential
16
17
1/2 Mile
Radius
14
15
3
1
4
5
Industrial
Park
2
Factory
12
6
7
8
Wastewater
Treatment
13
Park
11
9
10
300 m
1000 ft

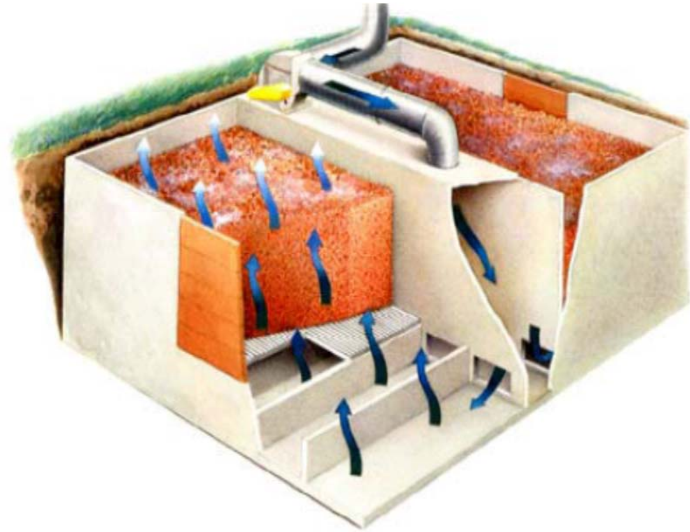
Odor Control Technology

Biofiltration uses microorganisms attached to a substrate to degrade contaminants

- Pollutants pass by diffusion and advection from the gas to a liquid biofilm
- Microorganisms oxidize organic compounds to CO_2, H_2O and new cell material
- Removal of odors and sulfides are aerobic process with sulfur and sulfate as final electron acceptors



Traditional biofilters are large and relatively inefficient



- Very Large Footprint
- Bed Compaction & Replacement
- Limited Surge Loading Capability/Efficiency
- Limited Upper VOC Concentration Capability (<5,000 ppm)

Media height is limited to prevent uneven drying of media; this results in very large cross-sectional areas

Typical size for 85,000 m^3/hr stream is 25 m x 30 m

Larger size material needed in traditional biofilter to provide porosity

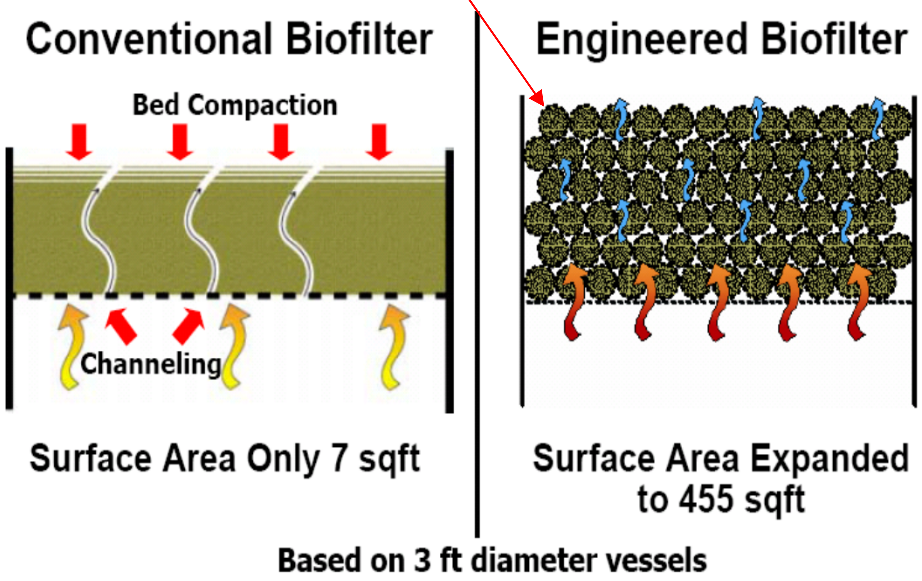
Source: City of Brownsville

Source: City of Brownsville

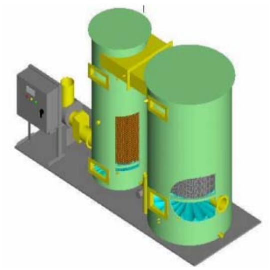
Sewer Lift Station

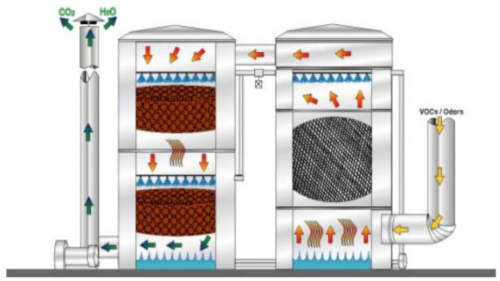
Newer biofilters have solid phase support to provide porosity; they are more efficient (and smaller)

Compost inside 1.5 inch plastic spheres ~900/ft^3

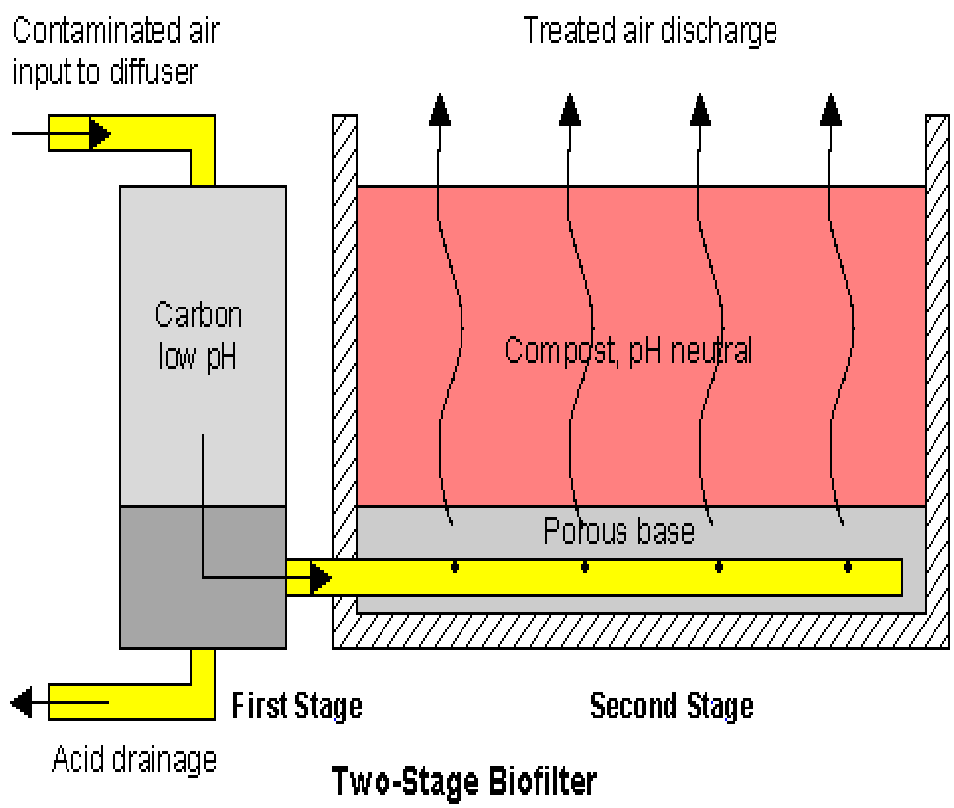


Two Stage biofilters are useful for odor control where both VOCs and reduced sulfur compounds are present

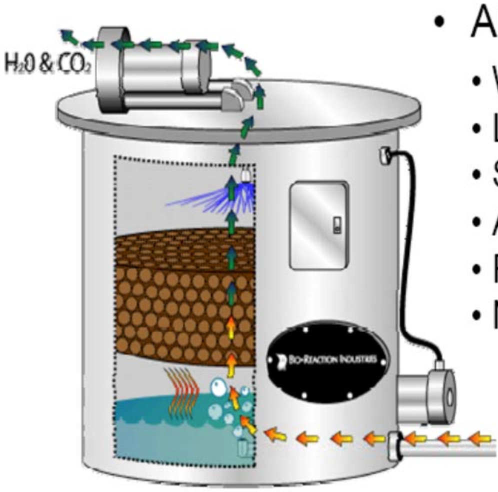




- Usually involves a carbon bed in series with biofilter
- Eliminates pH problems by flushing acidic material
- Biofilter + biofilter (different microbial communities)
- Bioscrubber (for H2S) + biofilter



ODOR CONTROL



- APPLICATIONS
  - Wastewater Treatment Facilities
  - Lift Stations
  - Sewer Gas Vents
  - Animal Processing
  - Food Processing
  - Non-regulated VOC sources

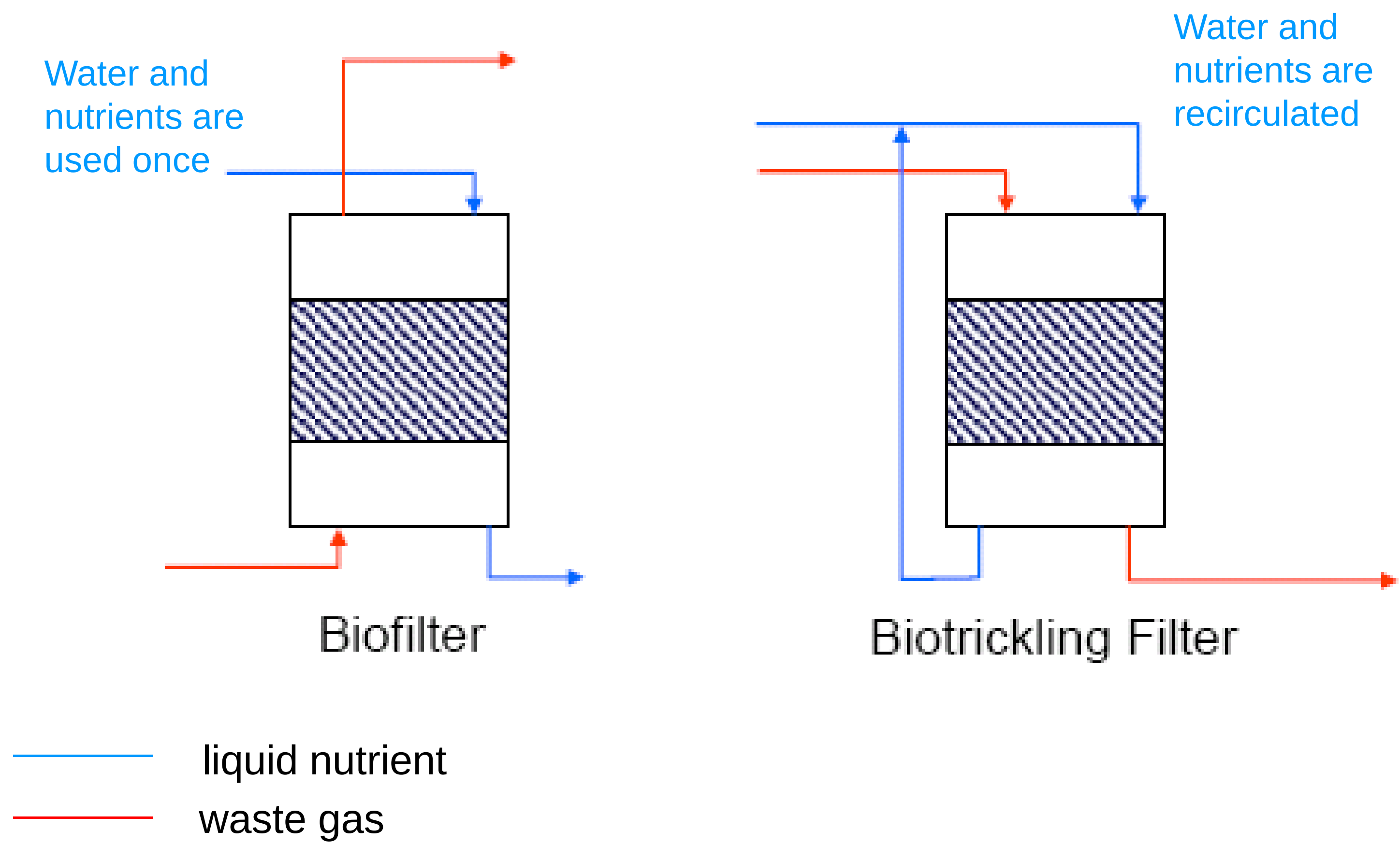
Lift Station – Odor Control

- 200cfm airflow from lift station – located in elite housing area.
- H2S/mixed odor compounds pulled from plumes & oversized wet well for community compliance
- Second system requested by customer

Wastewater Treatment Facility

- Grit removal storage bin
- Residential area nearby
- Complete removal of odors
- Small footprint
- Long media lifecycle
- Low O&M

Biotrickling filters are the latest technology



Biotrickling filters have potential advantages over traditional biofilters

- Excess biomass growth controlled by sloughing
- Humidification of inlet gases is unnecessary
- Nutrients and buffers (pH control) are supplied externally
- High Void Fraction (> 80%)
- High Surface Area per Unit Volume (> 30 ft^2/ft^3)
- Low Gas-Phase Pressure Drop

Biotrickling filter solid supports have high specific surface area but are hard to clog

Plastic Lattice Support

Material:	Polypropylene
Specific Surface Area:	132 ft^2/ft^3 (effective biomass up to 300 ft^2/ft^3)
Drip Points:	75,000/ft^3
Bulk Density:	7.5 lb/ft^3
Void Fraction:	87.8 %
Smallest Grid Opening:	0.16"× 0.16"
Standard Module Size:	12"× 12"× 12"

Installing packing

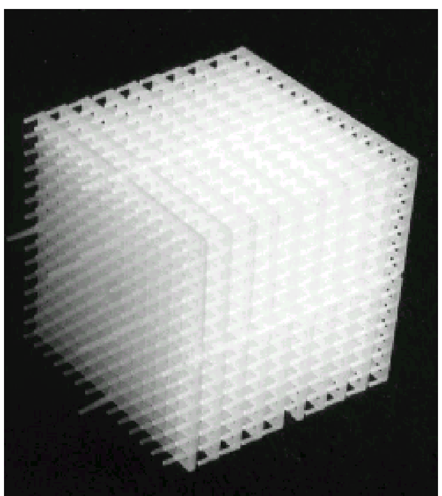
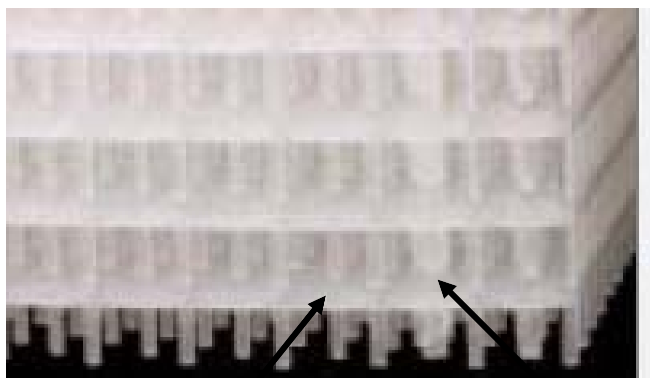


Figure 3. HD Q-PAC®



Gap between rod and grid promotes coalescing drops

Vertical support bar provides for spacing between grids

Biotrickling Filter at Sewage Treatment Plant (Plastic Lattice Supports)

In addition to controlling the pH, the 360 gallons of make-up water added each day provided micronutrients needed for growth of the biofilm. (*Thiobacillus thiooxidans* is autotrophic; it uses atmospheric CO_2 as its carbon source.)

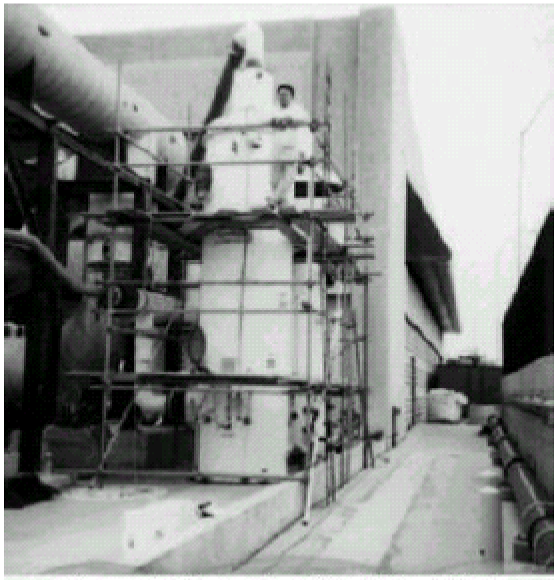


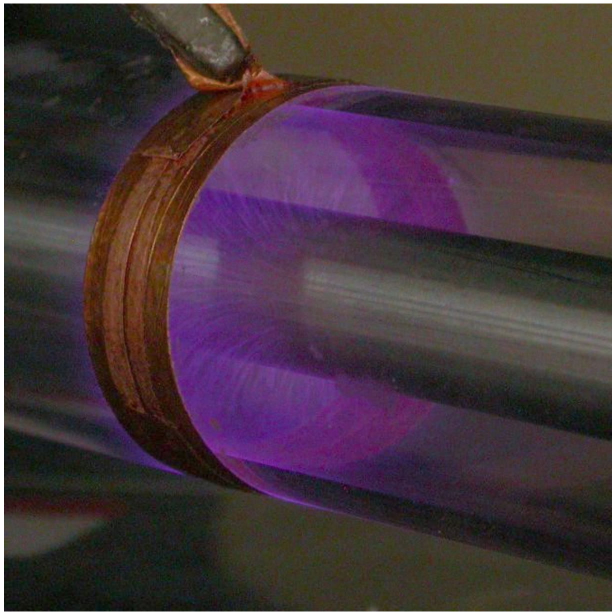
Figure 5. Hyperion Plant Test Unit

The H_2S concentrations in the inlet and outlet air streams were measured daily using an Interscan Voltammetric Sensor.

The removal efficiency of H_2S increased steadily for the first few days of operation, reaching 90% within 10 days.

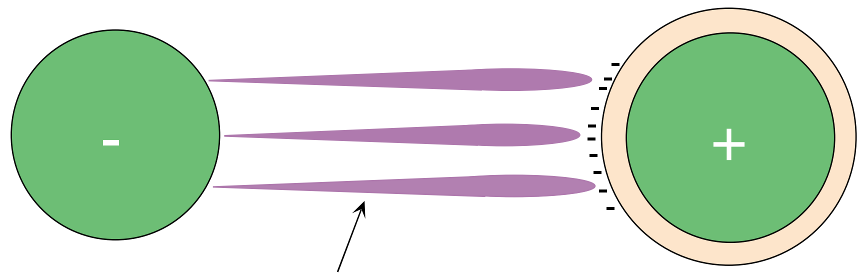
Ever since then, the removal efficiency has remained between 90% and 95%, with higher efficiencies recorded occasionally. Since the initial start-up period, the H_2S removal efficiency has never fallen below 90%.[5] This is in a small trickling biofilter with less than 10 seconds of residence time.

Non-Thermal Plasma Destruction of VOCs

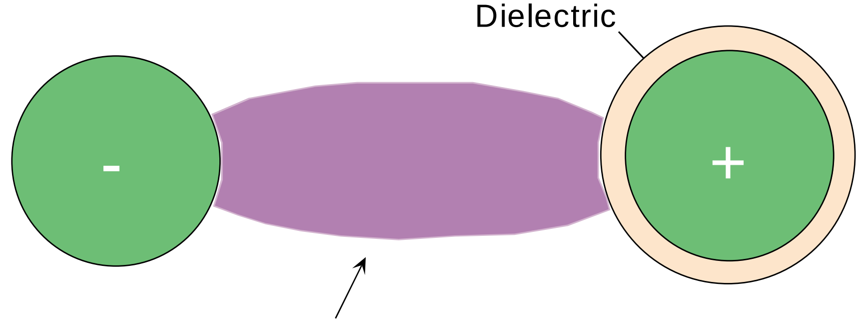


Non-Thermal Plasma: Dielectric Barrier Discharge

- Only electrons are 'hot'.
- Gas can be passed through discharge resulting in treatment.
- Gas remains relatively cool, hence the common term of 'cold plasma'. Similar to a neon sign.
- Active species for oxidation include N_2^+, O_2^+, N•, O•, •OH, •O_2H, and O_3.



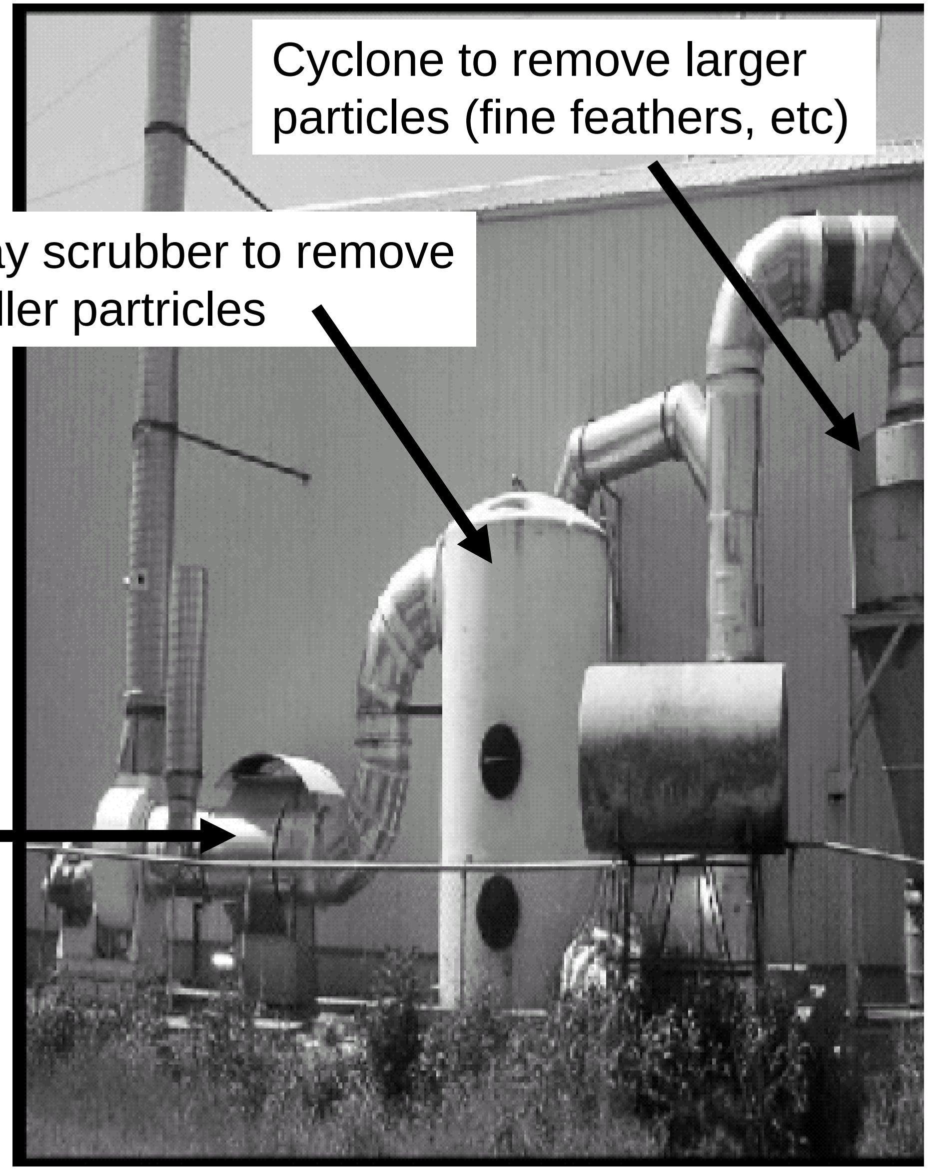
Electron Avalanches Charge Dielectric Surface
(No Conduction Path Due to Dielectric)



Individual Micro-Arcs Are Quenched
(Non-Thermal Plasma)

Rendering Plant

12,000 acfm odorous air



Hybrid System to treat VOCs

- 500 ppm Acetonitrile in Air with Pt/Pd catalyst in NTP at room temp.
- Drawback of NTP is that very high degree of organic destruction is prohibitive due to high energy cost.
- Energy cost for 80-90% contaminant destruction is manageable.
- Solution is to integrate plasma with carbon sorbent.