AWMA- MLC Meeting
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Methane/VOC Flux Testing at Landfills and Compost Facilities Using the USEPA Flux Chamber Technology (and beyond!)

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Purpose of the Discussion.....

- Present the approach used for area source emission assessment including municipal landfills, compost sites, and more!
- Present the USEPA flux chamber technology and assessment protocol
- Show photos of application of the technology to landfills and compost sites in particular
- Discuss the advantages of this assessment approach.

What's A Flux Chamber?

- A flux chamber is a device used for measuring the flux (mass transfer) of gas species (organic or inorganic compounds, or olfactory odor) from area sources

- There are a variety of 'flux chambers'- static and dynamic; most are not 'qualified' or 'documented'; most are not used following an accepted operating protocol

- USEPA Recommended Technology is a mixed tank reactor operated at atmospheric pressure following the USEPA Guidance Document published by EPA/EMSL

Four Groups of Area Source Assessment Technologies

- Direct Measurement
- Indirect Measurement
- Predictive Modeling
- Fence line Measurement and Dispersion Modeling

- Documented in the Air/Superfund National Technical Guidance Series, Volume II- Estimation of Baseline Air Emissions at Superfund Sites. January 1989

So Why Use The Flux Chamber Technology Over the Others?

- Assessment does not involve predictive modeling
- All parameters of the measurement technology are controlled and an estimate of accuracy and precision is made per application
- Very cost-effective assessment technology
- Can differentiate between sources of emissions at a complex-source facility
- Very sensitive and method selective assessment

Theory of Operation

- Mixed tank reactor- CSTR
- Clean sweep air is added to the chamber
- Chamber is operated for 5 residence times
- Chamber contents come to equilibrium
- Gas sample is collected for study compounds (grab or integrated sample collection)
- Flux is calculated knowing sweep air flow rate, surface area, and concentration

Calculation of Flux

$$\text{Flux} = \frac{(\text{concentration})(\text{sweep air flow rate})}{(\text{surface area})}$$

$$\text{Flux} = \frac{(\text{ug/m}^3)(0.005\ \text{m}^3/\text{min})}{(0.13\ \text{m}^2)} = \text{ug/m}^2\text{-min}$$

$$\text{Flux} = \frac{(\text{DT})(0.005\ \text{m}^3/\text{min})}{(0.13\ \text{m}^2)} = (\text{DT})/\text{m}^2\text{-min}$$

Goal of the Assessment Using the USEPA Flux Chamber

- Measure the compound (or odor) flux from the area source without disturbing the flux process and without predictive modeling
- Provide a data set that represents the area source emissions (flux x surface area = emission rate, mass/time)
- Report the range, average, and maximum compound flux as a function of the area source (i.e., spatial, process, chemical/physical source changes as a function of time)
- Data use includes engineering evaluation, compliance, and litigation support

Advantages of Using the Direct Measurement/Flux Chamber

- The USEPA flux chamber is the only recommended in-depth assessment technology applicable for most area sources including landfills
- Known accuracy and precision per test
- Very low sensitivity using appropriate sample collection and analysis
- The technology can be used cost-effectively by using knowledge of the source or process, and taking advantage of any an all screening data and related process data

So… How Do You Assess Methane/VOC Emissions from a Huge Landfill with an Itty Bitty Flux Chamber?

- The technical approach uses methane screening data from the CARB methane monitoring requirements
- Integrated methane data from several recent reports are used to rank the grid cells into three groups:
  high/medium/low
- The median cell per category is selected for study: one high, one medium plus a repeat cell, and one low cell
- Cells are re-screened and real-time concentration points are 'flagged' in different categories: <25, 25-100, etc.
- Locations are then selected for flux testing by more screening of cells

Screening Data Collected and Used

- California Air Resources Board protocol **Implementation Guidance Document For The Regulation To Reduce Methane Emissions From Municipal Solid Waste Landfills**
- Site is divide up into 50,000 sq ft grid cells
- Grid cells are routinely surveyed for methane emission monitored by concentration on the surface
- Serpentine path is walked over the grid collecting monitoring methane concentration collecting an integrated sample. Mitigation criteria is 25 ppmv methane for remedial activity

Closed Landfill Screening for Methane

Use of the Screening Data

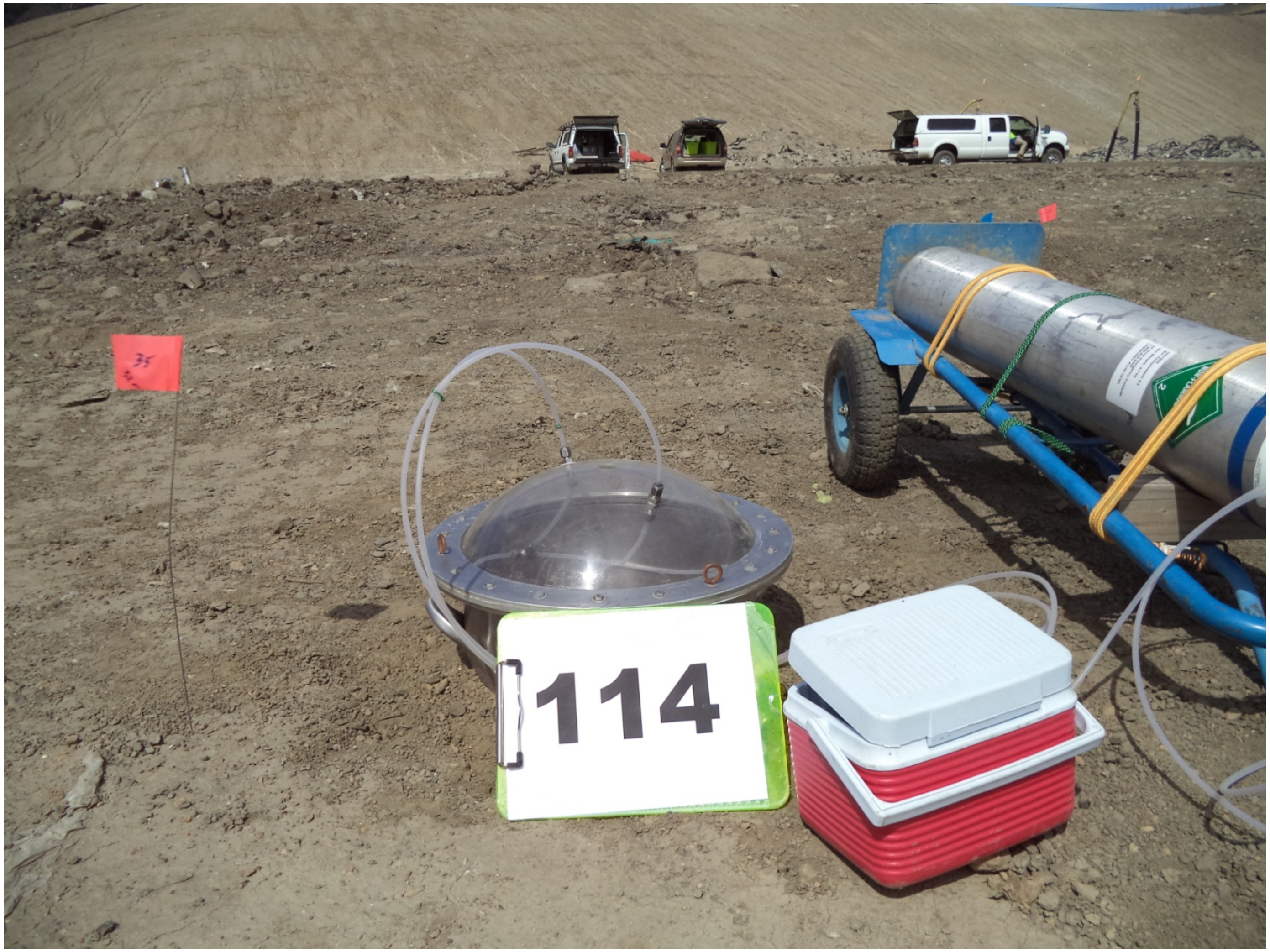
- Grid cell data (integrated methane concentration) are averaged over several monitoring events
- All grid cells are ranked by average, integrated methane concentration
- Cells are grouped and the median-ranked cells per each group is selected
- Selected cells are studied point-by-point using the screening approach and real-time methane data
- Real-time concentration data are used to identify high, medium and low ranges of potential emissions

Grid	Count	Integrated Methane Concentration Average	StdDev		Cumulative Average	Cumulative Percent of Total
105	4	28.48	12.99		28.48	4%
201	3	25.67	7.15		54.14	7%
174	1	22.40			76.54	9%
140	1	17.40			93.94	12%
65	4	16.90	6.04		110.84	14%
177	4	16.88	1.37		127.72	16%
94	4	16.78	4.06		144.49	18%
135	4	16.15	6.54		160.64	20%
188	1	15.90			176.54	22%
47	4	15.40	8.24		191.94	24%
156	4	15.23	6.76		207.17	26%
84	4	14.38	5.57		221.54	27%
50	4	14.35	6.97		235.89	29%
153	4	14.03	15.14		249.92	31%
161	3	13.83	14.01		263.75	33%
34	4	13.70	5.44		277.45	34%
181	4	13.33	1.96		290.78	36%
21	2	13.20	16.26		303.98	38%
133	1	12.80			316.78	39%
24	4	12.73	4.61		329.50	41%
73	3	12.07	3.61		341.57	42%
185	4	11.50	3.62		353.07	44%
175	4	11.45	3.50		364.52	45%
54	4	11.30	5.49		375.82	46%
36	2	11.10	5.23		386.92	48%
19	4	10.83	2.70		397.74	49%
56	1	10.80			408.54	50%
32	4	10.53	7.58		419.07	52%
66	4	10.53	7.77		429.59	53%
114	4	10.13	4.09		439.72	54%
134	1	9.90			449.62	55%
213	4	9.73	5.81		459.34	57%
49	4	9.13	3.98		468.47	58%
51	4	9.10	6.47		477.57	59%
71	4	9.05	4.79		486.62	60%
29	4	9.00	7.24		495.62	61%
79	4	8.65	2.38		504.27	62%
78	1	8.60			512.87	63%
20	4	8.58	8.25		521.44	64%
142	2	8.55	1.48		529.99	65%
59	2	8.00	3.11		537.99	66%
69	4	7.90	3.33		545.89	67%
48	1	7.70			553.59	68%
33	4	7.48	4.01		561.07	69%
39	4	7.25	3.18		568.32	70%
244	4	7.13	6.09		575.44	71%
23	4	7.10	3.34		582.54	72%
15	4	7.05	3.83		589.59	73%
40	4	6.98	0.85		596.57	74%
206	4	6.75	3.25		603.32	74%
196	4	6.70	4.15		610.02	75%
60	4	6.13	3.47		616.14	76%
62	4	5.80	6.08		621.94	77%
63	4	5.80	5.60		627.74	77%
118	2	5.80	8.20		633.54	78%
9	4	5.60	3.75		639.14	79%
3	4	5.53	1.69		644.67	80%
92	4	5.43	0.85		650.09	80%
25	4	5.35	4.53		655.44	81%
168	3	5.23	2.36		660.68	82%
162	4	5.20	3.34		665.88	82%
150	2	5.10	7.21		670.98	83%
57	4	4.93	2.65		675.90	83%
72	4	4.88	5.07		680.78	84%
154	4	4.48	3.68		685.25	85%
22	4	4.38	2.46		689.63	85%

Flux Chamber Testing per Grids

- Flux chamber testing is performed over the range of locations per cell selected based on the real-time screening data from selected landfill cells
- Replicate measurements are performed
- High, medium, and low screening locations are selected along with the highest emitting location detected from pre-screening
- Flux data are used for the assessment of study compounds

Testing at a Selected Location



Landfill Emission Estimate

- Average emissions of study compounds are calculated per each group of grid cell (high, medium, low emitters)
- Area source (sq ft) for each group of cells is determined by summing the number of cells and multiplying out the area
- Confirmation is obtained by studying the repeat mid-range group data
- Site emissions for study compounds or odor is calculated by adding emissions per group for the landfill surface area

So…. What About Compost Sites?

- There is no comprehensive emission screening data for compost sites like landfills, but we do have process data!
- Further, there are many compost technologies out there, including windrow, negative flow aerated static pile (ASP) with biofilter, positive ASP with a micropore membrane cover, and positive ASP with a biofilter layer
- There is screening data (compost temperature) and all compost technologies have different stages of operation, and each has a life-cycle metabolic process
- Each stage or component can be studied, emissions estimated based on mass, and summed for site emissions

Presentation Outline

- Composting Technology Overview
- How to simulate full-cycle emissions from compost operations
- Examples of full-cycle simulations for
  - Odor
  - VOC
  - Ammonia
  - Greenhouse Gases
- TAP Results; +ASP/BFL (or CASP technology)

Compost Science

- Micro-organisms consume organic material and produce:
  - Heat
  - Carbon Dioxide
  - Methane (This normally suggests a problem)
  - A little bit of Nitrous Oxide
  - Ammonia
  - Odorous Compounds (Organic Reduced Sulfur, Organic acids)
- A 'stable' organic product is produced in 21 to 120 days depending on technology
- The technology is conceptually simple, but can be very complicated in actual practice

Compost Science

- Primary Process Control Parameters
  - Moisture
  - Porosity
  - Oxygen levels
  - Temperature
- Changing any one of these parameters, normally has significant effect on the others and air emissions
- Optimization is challenging, particularly in extreme climates (rain, extreme temperatures).

Common Compost Substrates

- Green Waste
  - Highly variable as a function of location and sources
- Biosolids (Wastewater Treatment Residual Solids)
- Food Waste
  - Highly variable as a function of location and sources
- Manure
- Livestock Carcasses
- Mixtures of the above ‘bulked’ with wood chips

Compost Technologies

- Windrow
- Aerated Static Piles
  - Positive ventilated (Air is blown into the pile)
    - Uncontrolled
    - Controlled with Biofilter layer (excellent approach- see TAP research)
    - Controlled with a Cover Technology
  - Negatively ventilated (Air is pulled out of the pile)
    - Uncontrolled- no filtration of exhaust
    - Controlled with Biofilter (Normally shredded wood media)
- Mechanical
  - Enclosed devices normally with automatic turning and filtration or scrubbing

Windrow Composting

Windrow Composting

- Oldest Large Scale Commercial Technology
- Windrow 4’-to- 8’ tall and 40’ to over 100’ long
- Composting takes 45 to 120 days to complete
- Only control parameters are:
  - Mixing
  - Moisture levels
  - Amendment (wood chips)/porosity
  - Windrow size

Mechanical Turning

Aerated Static Piles (ASP)

- ASP technology has been around for 40 years.
- More compact and there are more effective control options than windrow composting.
- Initially, the only air emissions control option was a negative ASP with a biofilter.
- Positive ASP technology did not have a viable air emission control technology until Gore® Produced the first Cover for Positive ASP. Now finish compost can be used as a cover.
- Active Composting (meeting pathogen/parasite kill objectives) occurs in a nominal 21 day period.
- Curing is another 20 to 40 days for complete stabilization
  - Degree of stabilization required is a function of local regulations and intended final market

Negative ASP w/Shredded Wood Biofilter

Negative ASPs

- First Large Scale ASP Technology used was negative aeration
- First Used with Biofilter for Compliance with Criteria Pollutants in 2009.
  - Biofilters have been used for odor control since 1990
  - Biofilters have wide range of performance
  - Can reliably control non-methane hydrocarbon and ammonia by 80% when built and operated correctly
    - Most biofilters used for odor control do not achieve this
    - Higher performance (over 90% ammonia removal) can be achieved, but not reliably.
    - High performance biofilters normally last a maximum of 2 years and then must be replaced.
  - Positive ASPs are Replacing this Technology when Air Emissions Control is Important

Positive ASP w/Cover

Positive ASP w/Cover

- Gore® Introduced the First Micro Pore Cover for Odor/Moisture Control in 2000.
- There are other producers of Micro Pore and other Cover Technologies.
- Covers can be very expensive
- They can provide high levels of Non-methane hydrocarbon and Ammonia control.
- Performance mechanisms are not completely understood.
- A GORE® system has passed an 80% emissions control test (TNMHC and NH_3) in SCAQMD and higher in other locations.

Positive ASP w/Biolayer

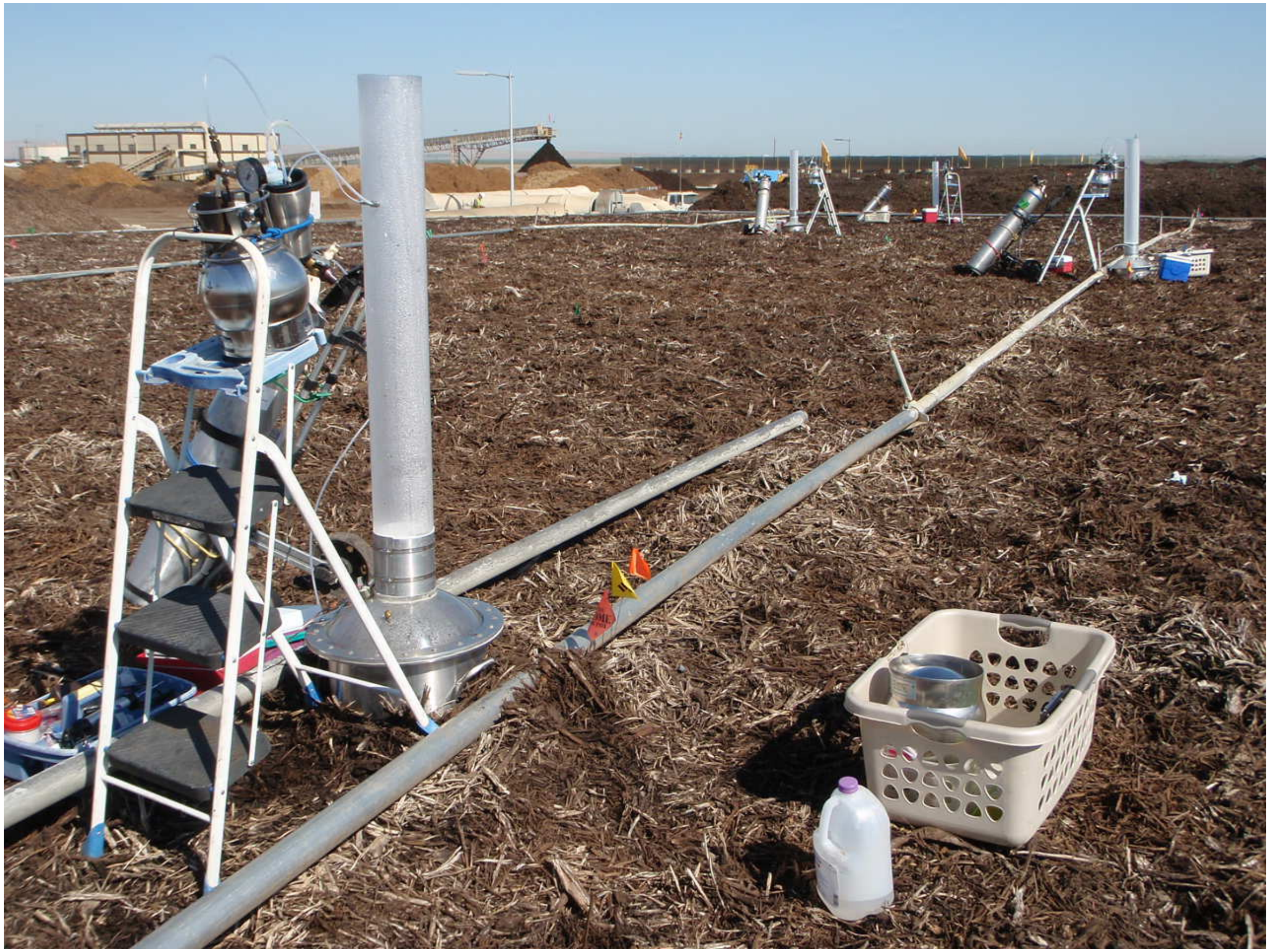
Positive ASP w/Biofilter Layer

- Technology was Developed by Creative Compost Operators
- Was Demonstrated Effective in 2014 by SJVAPCD
- Can Achieve Very High Levels (>95%) of Control for TNMHC and Ammonia
- Biofilter layers vary from 0.5 to 2 feet thick
  - Normally consists of finished compost (screened, unscreened, or both)
  - Cover moisture levels critical
    - Many installations have external sprinklers
  - Well made covers can perform well as thin as 0.5 feet.

Measuring Emissions

- SCAQMD and Card/Schmidt developed a modified USEPA Flux Chamber Method to Measure Compost/Biofilter Emissions for SCAQMD Rule 1133.3 (Attachment A)
  - Uses Trace Gas, normally Helium, to accurately Measure Flow Rates
  - Has interchangeable stacks to handle flow rates up to 100 times (600 liters per minute) the original flux chamber design, while maintaining minimum flow rates to manage back mixing from the atmosphere.
  - Has enhanced mixing gas inlet manifold to assure complete mixing in a short residence time
  - Has a mechanical impeller to assure high mixing levels in chamber.
  - Has sample port in stack meeting USEPA Method 1,2 requirements.

USEPA Flux Chamber, Modified for Rule 1133.3 Compliance Testing



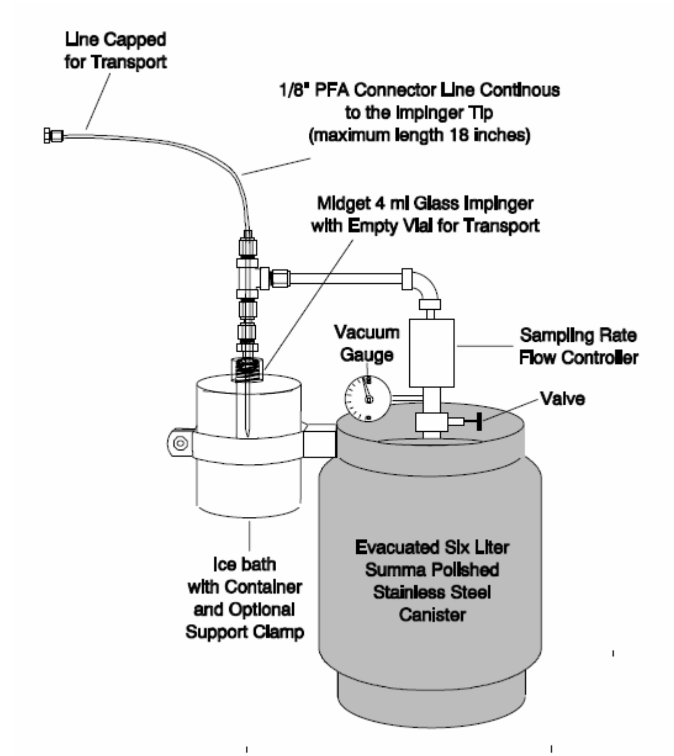
Test Methods Typically Used

- Precursor Organic Compounds
- Ammonia
- Greenhouse Gases (methane and carbon dioxide)
- Odor

Precursor Organic Compounds

- Many jurisdictions use Total Non-methane Non-Ethane Carbon (TNMNEOC reported as methane)
- Most academic research for composting air emissions uses GC/FID detector or equivalent methods (USEPA TO-12)
  - Some research just sums detected compounds using GC/MS (USEPA TO-15); not recommended
- SCAQMD and SJVAPCD have rules based on SCAQMD Method 25.3 and therefore use Method 25.3 for compliance.
- If your rule or inventory is based on academic research values TO-12 is recommended (GC/FID).
- Methods give different values, so the method used for rule development/inventory should be used for compliance as well.

SCAQMD Method 25.3 Apparatus



Ammonia Emissions

- Most use acid bath midget impingers
  - i.e. SCAQMD Method 207.1
- We use colorimetric tubes to assure accurate results by managing sample volume.
  - Target 10 to 100 x liquid phase MDL
  - No breakthrough risk at these levels, so single impinger is used
  - Backup impingers are used when sample time exceeds 60 minutes and ammonia exceeds 1,000 ppmv.
- Personal sampling pumps are used.
  - Pumps are traceable standard calibrated immediately before and after use.

Ammonia Emissions

- Ammonia is measured Using a Micro-Impinger per SCAQMD Method 207.1.

Simulating Full Cycle Compost Emissions

- Why simulate?
  - Compost cycles range from 21 to 120 days.
  - The compost emissions are different for every process day.
  - It can cost up to $10,000 to test a single process day.
  - There is a substantial cost savings to pick key process days and then interpolate the emissions for the days not tested.

How do you Simulate Emissions?

- Select the Key Process Days
  - Not as easy as it seems (details later)
- Test the Key Process Day
  - Raw data is concentration
  - Needs to be translated to flux units (mg/m2-min)
- Calculate the Process Area
- Calculate the Daily Emissions
- Interpolate the Daily Emissions for the Days not tested.
- Sum the Daily Emissions over the entire cycle length
- Divide the total Emissions Mass by the initial Mass taken at the gate for the Process on an annual basis
- The result is reported in pounds of emission per ton of initial mix.

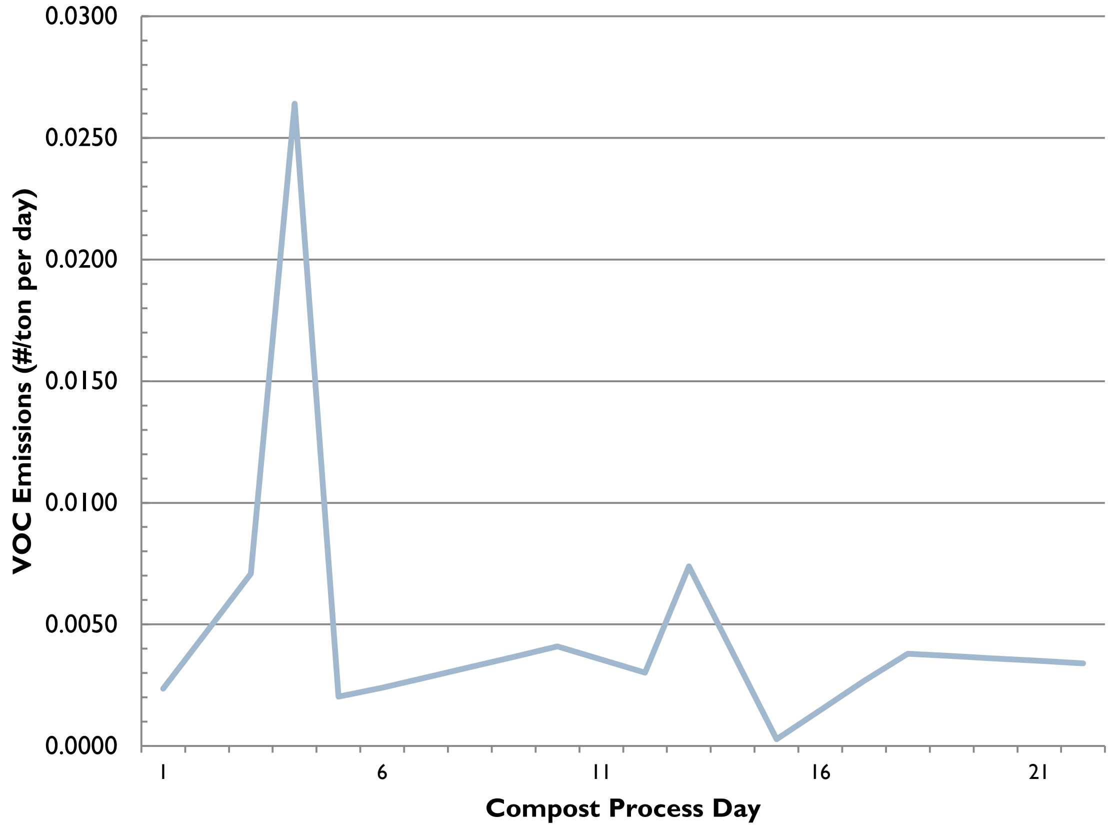
Tabular Data (flux units)

These are days that were tested

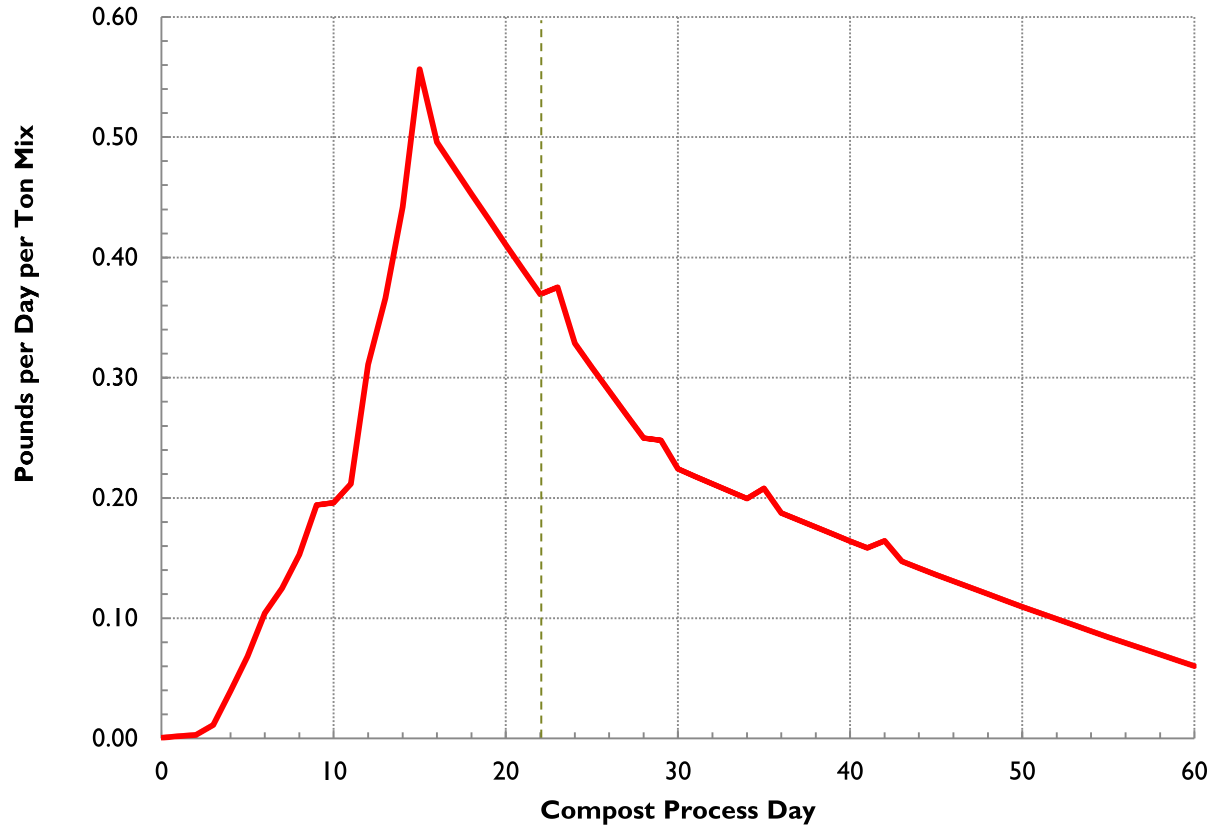
These are days that were interpolated

Day	CH4	CO2	NH3 T	NH3 L	VOC	N2O
0	0	0	0.00	0.00	0.00	0.00
1	1	714	0.32	0.15	0.66	0.07
2	2	1,427	0.64	0.29	1.32	0.13
3	3	2,141	0.96	0.44	1.98	0.20
4	6	3,069	0.90	0.12	7.37	0.05
5	5	2,434	0.13	0.03	0.57	0.08
6	3	2,308	0.09	0.04	0.67	0.01
7	47	2,452	0.15	0.04	0.79	0.02
8	90	2,596	0.21	0.04	0.91	0.02
9	133	2,740	0.28	0.04	1.02	0.02
10	176	2,884	0.34	0.04	1.14	0.02
11	187	3,062	0.19	0.04	0.99	0.05
12	198	3,240	0.04	0.04	0.84	0.08
13	248	5,634	0.03	0.08	2.06	0.02
14	129	3,270	0.06	0.05	1.07	0.08
15	10	907	0.09	0.02	0.08	0.13
16	38	1,944	0.07	0.03	0.41	0.21
17	66	2,982	0.05	0.03	0.75	0.29
18	20	3,013	0.00	0.10	1.06	0.15
19	17	2,867	0.01	0.08	1.03	0.22
20	14	2,721	0.02	0.06	1.00	0.29
21	10	2,576	0.03	0.05	0.98	0.36
22	7	2,430	0.04	0.03	0.95	0.43
23	4	2,284	0.05	0.01	0.92	0.50

Final Graph- VOCs



Methane Emission Profiles Windrow



TAP +ASP w/Biofilter Layer Performance
(pounds per ton mix/% Reduction from Control)

		NH3		Greenhouse Gas			
Cycle Length	**VOC**	**Field**	**Lab**	**CO2**	**CH4**	**N2O**	**CO2e**
22 Day	0.10	0.02	0.01	206	5.1	0.01	315
30 Day	0.13	0.02	0.01	271	5.2	0.02	387
60 Day	0.22	0.02	0.01	517	5.6	0.08	658

		NH3		Greenhouse Gas			
Cycle Length	**VOC**	**NH3 Field**	**NH3 Lab**	**CO2**	**CH4**	**N2O**	**CO2e**
22 Day	99%	83%	53%	72%	13%	89%	64%
30 Day	99%	91%	84%	74%	36%	83%	69%
60 Day	99%	94%	92%	72%	55%	70%	70%

Conclusions

- Measuring Air Emissions from Composting is Complicated and Expensive
- If the Process is Well Understood, there can be Cost Savings
- Different Compounds can Emit at very different times on the same Composting Process
- Covering the Process Normally has a Dramatic Effect on Emissions
- The TAP Biofilter layer ASP Performed very Well.

Development of the Flux Chamber

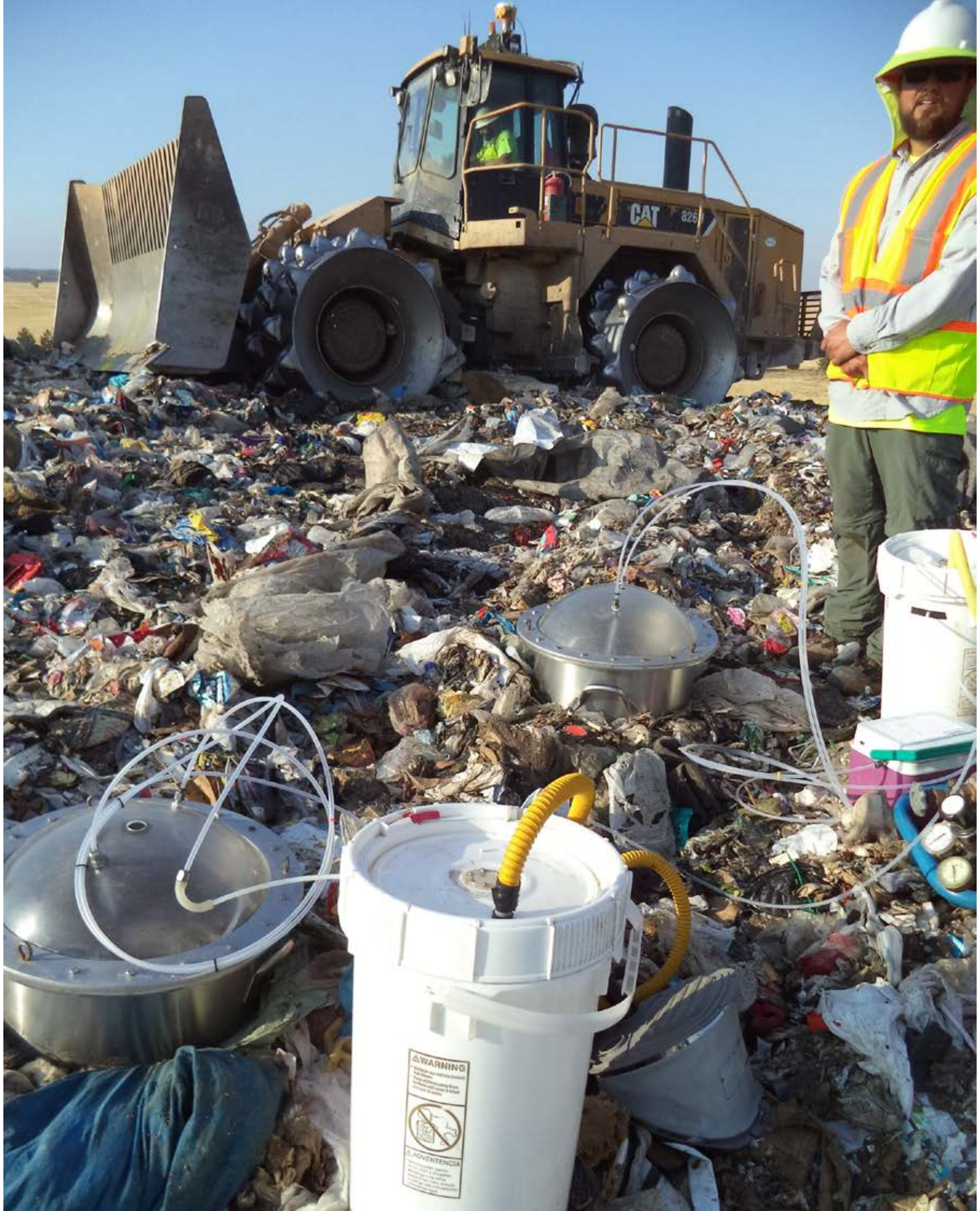
- Specifications of the technology
  - Qualifies as a mixed tank reactor (CSTR)
  - No significant effect on the flux event
  - Acceptable accuracy, precision, background levels
  - Inert material; non reactive
  - Portable and easy to clean
  - Size/shape applicable to many sources
  - Volume/flow rate specified for reasonable residence time
  - Flow rate affords reasonable sample duration

Development Work

- Designed, built, and tested five chamber designs
- EPA selected the current design as 'best compromise'
- Recovery tests (103% recovery)
- Mixing tests (CO tracer study; 97% mixed at 5 residence times: 30 liters/5 lpm = 6 minutes)
- Precision tests (typically <20%)
- Accuracy tests (typically >90%)
- Comparison to other area source assessment technologies was conducted
- Selected by EMSL as cost effective

Parametric Studies

- Sweep air flow rate
- Evaluated 0.5 to >10 lpm sweep air flow rates
- Selected 5.0 lpm in the mid-range of flow rate having little to no effect on flux
- Sample collection methods
- Variability studies: spatial, temporal, seasonal (control tests at Superfund or RCRA sites)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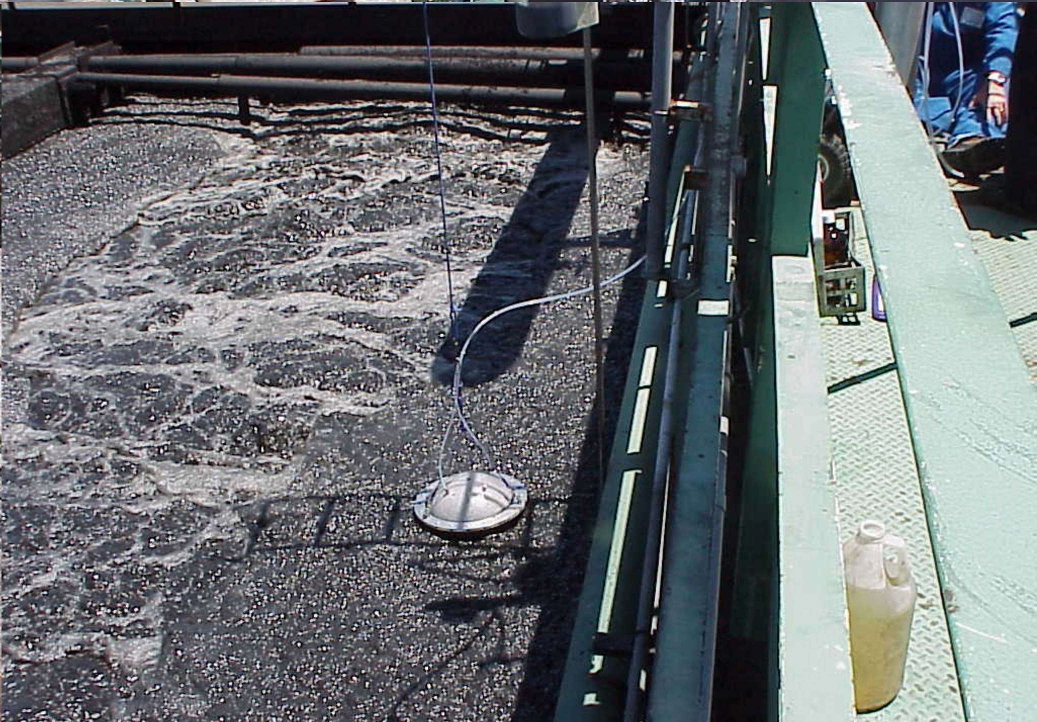
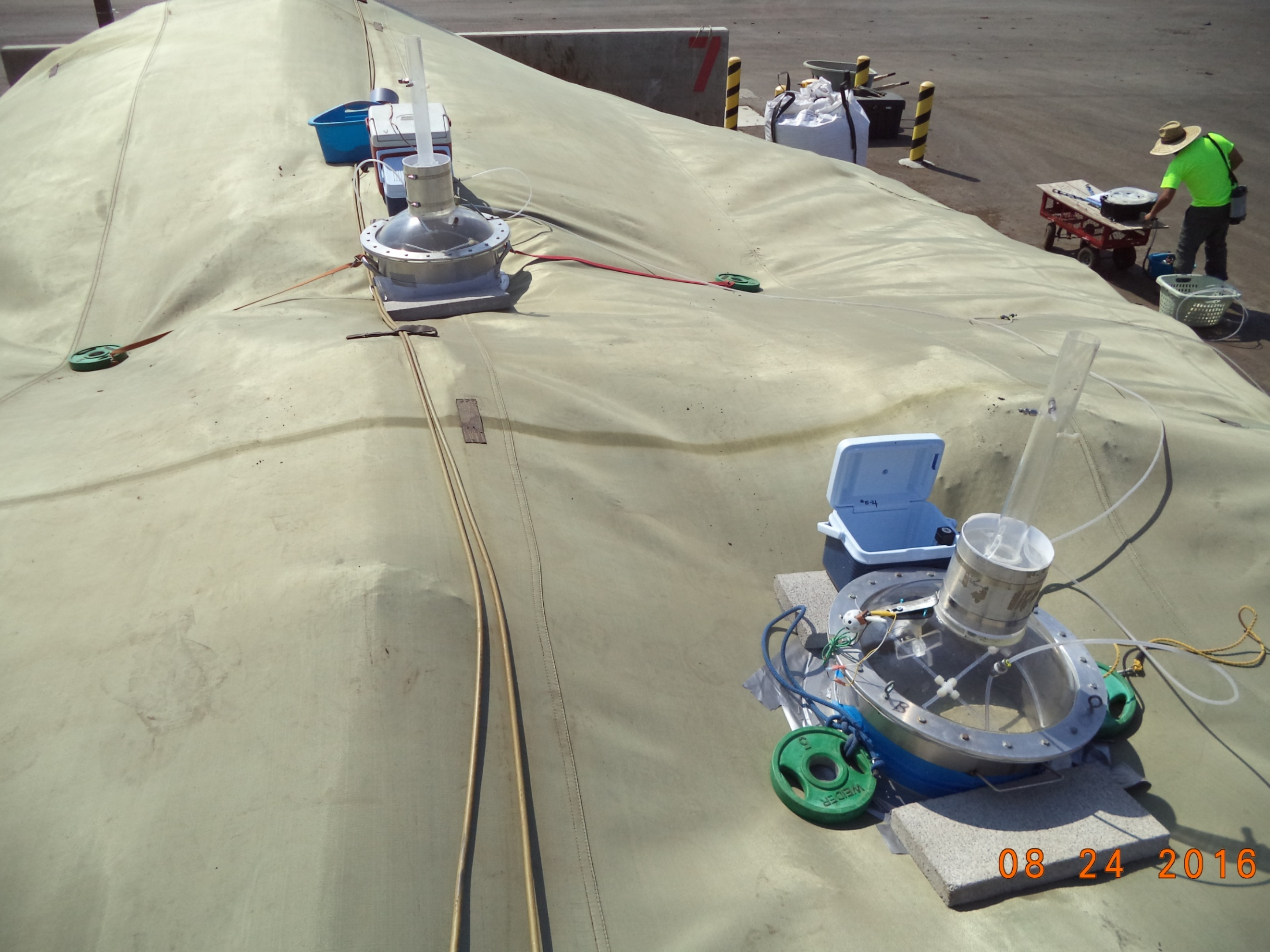



Gladiator


Dielectric
DryCal
DC-Lite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