Compost Air Emissions:

Managing Compost Air Emissions Through Process Control

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Introduction –
A Basis for Changing the Regulatory Paradigm

Concerns around air emissions continue to be an impediment to siting and permitting large-scale composting facilities in the USA. These concerns encompass the interrelated emission of nuisance odors, generalized Volatile Organic Compounds (VOCs), and specific chemicals that are identified as Hazardous Air Pollutants (HAPs). Often, air quality enforcement agencies' first inclination is to require the addition of an enclosure to capture these emissions and control devices to scrub the air exhausted from those enclosures. In many cases this approach is neither effective nor economically viable. Fortunately, research has shown that a "root-cause" approach to managing air emissions can meet air quality goals, encourage process efficiency, and provide an economically viable alternative to mechanical capture and control pollution control measures.

Getting this message out, understood and adopted has been impeded in part by a lack of full-scale example facilities using semi-optimized process conditions to minimize the generation of VOCs. This paper will compare the process conditions and resulting VOC Emission Factor (EF: lb VOC/ton compost) generated by three distinct levels of process control. These data show that as process conditions improve from Poor to Modest, and from Modest to Semi-Optimized, that VOC generation is reduced by roughly a factor of 10 at each quanta. Further, Semi-Optimized process conditions produce EFs significantly lower than the default values traditionally used by California AQMDs.

Background – BMP's Control Process Conditions

Research has established that the rate of VOC generation during composting is determined by the thermal, biological and chemical conditions within the pile. These conditions are primarily controlled by the quality of the initial mix and of the design and operation of the active phase composting system. The application of Best Management Practices (BMPs) to both the structural design and operation of a composting facility can reliably maintain process conditions during active composting in the semi-optimized conditions shown here:

	BMP Range
Initial Mix Properties	Density <950 lb/cy; Moisture 50 – 60%; C/N 25
Active Composting Process Conditions	pH >6.5 within 3 days; Film-layer Oxygen > 3ppm; Temperature < 150°F

TABLE 1

Background – Conditions Control Emissions

Oxygen availability and pH are primarily determined by pile temperature, which in turn is actively controlled by aeration rate. Sundberg(1,2) showed aeration rates that provide measureable cooling will necessarily provide excess oxygen. Sauer(3) showed how the oxygen solubility in liquid film layer of a composting particle decreases with increasing temperature and recommended that film oxygen concentration be kept above 3 ppm to avoid process inhibitions an minimize odors. Sundberg demonstrated that combination of pH below 6.5 and temperatures over 113F strongly inhibit bio-oxidation and generate elevated emissions. These findings demonstrated that several days of moderate temperatures are required raise the pH of food waste rich feedstocks (acidic) above this threshold. Keener(4) has shown that temperatures over 160F inhibit bio-oxidation regardless of pH. These findings argue that moderated temperatures and elevated pore-space oxygen levels are key process indicators of semi-optimized composting conditions.

To sustain semi-optimized conditions most of the time in most of the pile (composting does not require perfection) the design of an aeration system needs to provide adequate airflow to limit the temperature rise of the specific feedstocks. To be globally effective, the airflow also needs to be relatively uniformly distributed and adaptively controlled to follow the highly variable heat production rates common in composting.

Data:
Comparison of Three Different Processes

Three levels process conditions and resulting VOC EFs are drawn from two facilities. Two historical data sets were generated at Jepson Prairie Organics in Dixon CA. The first in 2008 (5) and the second, after conversion from a static pile to a negatively Aerated Static Pile (ASP) method, is the average of two source tests conducted in 2014 and 2016 (6). The third data set was generated in 2020 at the City of Napa's positive ASP facility (7).

The process condition data are shown in Table 2. The process quality rating at the top of each column is based on the author's judgement as to the extent that key process indicators in Table 2 conform to the BMP process conditions recommended in Table 1.

JPO ASP 2015

Napa ASP 2020

Data: Process Conditions

Process Quality	Poor	Medium	Semi-Optimized
Facility	JPO 2008	JPO 2014 - 2016	Napa 2020
Average Peak Aeration Capability & %Mal-distribution	Unaerated static pile	0.5 cfm/cy (A): ±50%	4.9 cfm/cy (A): ±5%
Feedstock Mix	50/50 Green & Food	80/20 Green & Food	80/20 Green & Food
Average Initial Mix Density & Moisture	1,300 lb/cy 65% MC (B)	1,100 lb/cy, 60% MC	908 lb/cy, 56% MC
Typical Process Conditions	Pore Oxygen: <1%, Temperature: (B)	Oxygen: 4%, Temperature 159°F	Oxygen: 20%, Temperature 129°F
Typical Film Oxygen Saturation (C)	< 0.3 ppm	< 1 ppm	> 4.5 ppm
Average pH After Active Composting	4	Not recorded	7.8

TABLE 2

A. Average zone aeration rates with 100% open dampers, manual measurements with hot-wire anemometer. JPO average of 35 readings, Napa average of 16 readings.

B. Limited process data if available from the 2008 operations of the unaerated static piles at JPO. The estimated mix density and moisture content is based on measurement made in 2010 with feedstocks from the same sources. The estimates of pore oxygen and pH are based measurements made by the author on other active composting piles without aeration.

C. The film oxygen level is deduced from applying the temperature and oxygen levels to the Sauer's chart (2), see slide #10

Data: VOC Generation

Process Quality	Poor	Medium	Semi-Optimized
Source Test EF (a)	27.6	3.24	0.17
Active Composting Flux Surface	Top of Piles	Top/Bottom Piles	Top of Piles
EF from Other Surfaces (b)	0.41	0.08	0.1
Top of Pile EF	27.2	0.33	0.07
Bio-Layer Scrubbing Effect (c)	30%	30%	30%
Calculated VOC EF to Bio-Layer	38.8	0.47	0.10
Bottom of Pile EF (d)	n/a	2.83	n/a
Calculated VOC Generation in Pile	38.84	3.30	0.10

TABLE 3

Notes:

(a) Total facility EFs in pounds VOC per initial wet ton of feedstocks. All source test used SCAQMD 25.3 method.

(b) Emissions from surfaces other than active composting (curing, stockpiles, mixing, etc.).

(c) CIWMB (8) and others have demonstrated a range of bio-layer VOC scrubbing effects; 30% is at the low end of this range and applied equally to all three sources analyzed.

(d) The Medium quality process used negative aeration such that 90% of emissions measured in the duct drawing air from the bottom of the pile. This air was scrubbed through a biofilter, but this control was erroneously not measured/included in the total facility EF analysis. It likely would have reduced emissions by 80-90%.

Discussion & Conclusions

When evaluating the impact of process conditions on VOC generation, the scrubbing effects of a biolayer or a biofilter need to be accounted for separately. Capture and biofiltration of exhaust air from non-BMP active composting can produce EFs similar to those of a positive CASP designed and operated in compliance with BMP standards; EFs from subsequent stages will be higher since the compost will be less stable.

While the data sets compared here do not provide rigorous parametric analysis (not all key process indicators were measured and several are varied between each set), the magnitude change, and the positive correlation between the quality of the process conditions and VOC emission is very strong.

The VOC emissions averaged from Napa's three source test results call into question the baseline compost EF's currently used by regulatory agencies (Table 4).

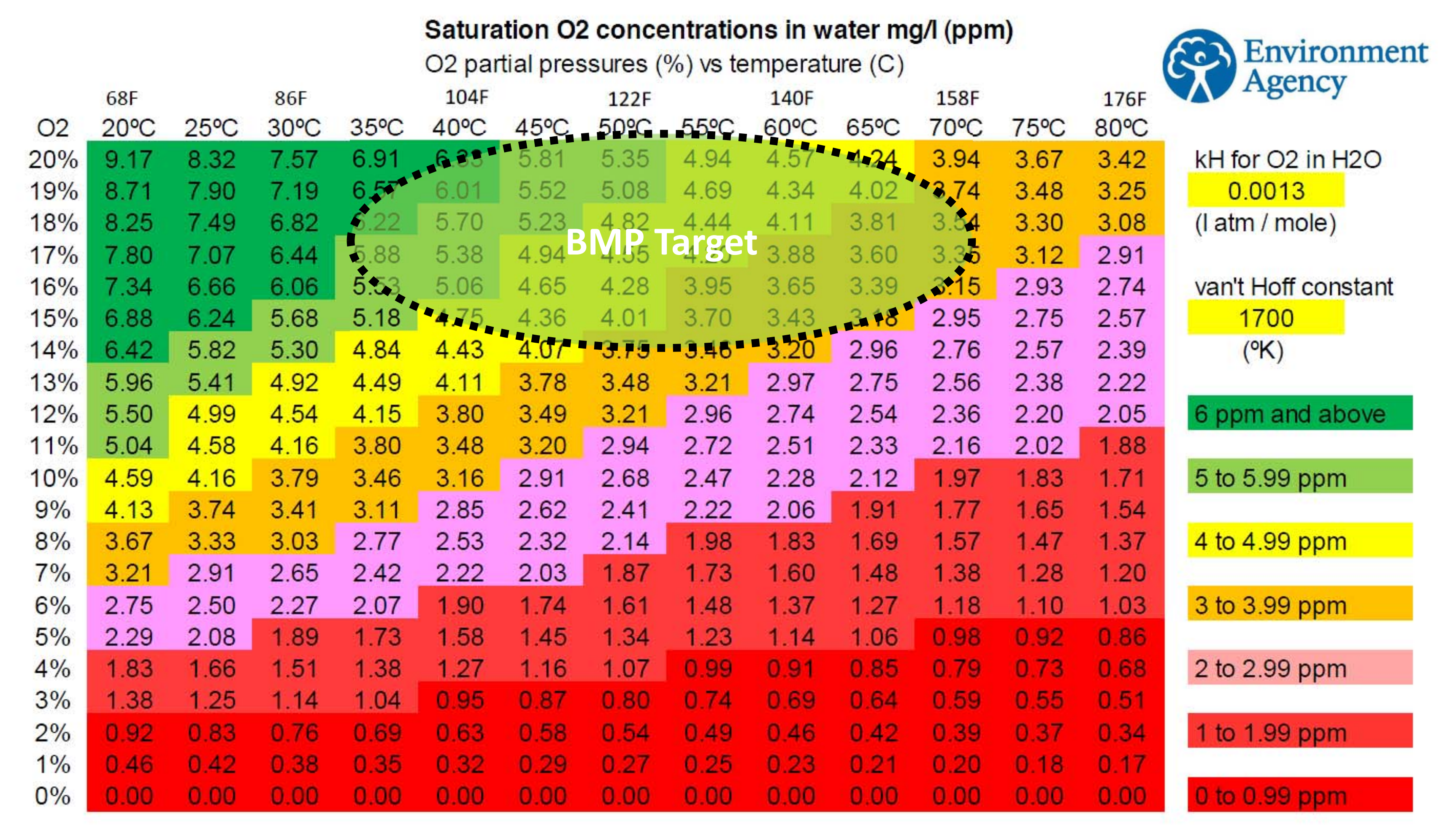
Regulatory Agency	Baseline VOC EF (lb/ton)	% of Baseline
CARB	3.58	4.7%
SJVAPCD	5.71	3.0%
SCAQMD	4.68	3.6%

TABLE 4

References:

1. Sundberg C., "Effects of pH and Microbial Composition on Odour in Foodwaste Composting", Waste Management 33 (2013) 204-211
2. Sundberg C., "Higher pH and Faster Decomposition of Biowaste Composting by Increased Aeration", Waste Management 28 (2008) 518-526
3. Sauer N., "Odour Technical Guide 3, Oxygen Solubility in Compost" UK Environment Agency (2012) 2. Capelli et. al. Sensors 2013, 13, 938-955 (See next page)
4. Keener, H. & Ekinci, Kamil & Michel, Frederick. (2007). Composting Process Optimization – Using On/Off Controls. Compost Science & Utilization. 13.
5. SJVAPCD Compost VOC EF Report 9-15-10 page 56-57
6. Yolo-Solano Air Quality Management District, COMPOST SYSTEM EMISSION TEST REPORT JEPSON PRAIRIE ORGANICS VACAVILLE, CALIFORNIA (2016)
7. Compliance Test Results per Application No. 27180 at plant No. 17403 issued by Bay Area Air Quality Management District (2020)
8. CIWMB, Comprehensive Compost Odor Response Project (2007)

Combined Effect of Temperature & Pore O_2% on Film Layer O_2 Concentration (Ref 3)



Saturation O2 concentrations in water mg/l (ppm)

O2 partial pressures (%) vs temperature (C)

Environment Agency

	68F		86F		104F		122F		140F		158F		176F
O2	20ºC	25ºC	30ºC	35ºC	40ºC	45ºC	50ºC	55ºC	60ºC	65ºC	70ºC	75ºC	80ºC
20%	9.17	8.32	7.57	6.91	6.33	5.81	5.35	4.94	4.57	4.24	3.94	3.67	3.42
19%	8.71	7.90	7.19	6.57	6.01	5.52	5.08	4.69	4.34	4.02	3.74	3.48	3.25
18%	8.25	7.49	6.82	6.22	5.70	5.23	4.82	4.44	4.11	3.81	3.54	3.30	3.08
17%	7.80	7.07	6.44	5.88	5.38	4.94	4.55	4.20	3.88	3.60	3.35	3.12	2.91
16%	7.34	6.66	6.06	5.53	5.06	4.65	4.28	3.95	3.65	3.39	3.15	2.93	2.74
15%	6.88	6.24	5.68	5.18	4.75	4.36	4.01	3.70	3.43	3.18	2.95	2.75	2.57
14%	6.42	5.82	5.30	4.84	4.43	4.07	3.75	3.46	3.20	2.96	2.76	2.57	2.39
13%	5.96	5.41	4.92	4.49	4.11	3.78	3.48	3.21	2.97	2.75	2.56	2.38	2.22
12%	5.50	4.99	4.54	4.15	3.80	3.49	3.21	2.96	2.74	2.54	2.36	2.20	2.05
11%	5.04	4.58	4.16	3.80	3.48	3.20	2.94	2.72	2.51	2.33	2.16	2.02	1.88
10%	4.59	4.16	3.79	3.46	3.16	2.91	2.68	2.47	2.28	2.12	1.97	1.83	1.71
9%	4.13	3.74	3.41	3.11	2.85	2.62	2.41	2.22	2.06	1.91	1.77	1.65	1.54
8%	3.67	3.33	3.03	2.77	2.53	2.32	2.14	1.98	1.83	1.69	1.57	1.47	1.37
7%	3.21	2.91	2.65	2.42	2.22	2.03	1.87	1.73	1.60	1.48	1.38	1.28	1.20
6%	2.75	2.50	2.27	2.07	1.90	1.74	1.61	1.48	1.37	1.27	1.18	1.10	1.03
5%	2.29	2.08	1.89	1.73	1.58	1.45	1.34	1.23	1.14	1.06	0.98	0.92	0.86
4%	1.83	1.66	1.51	1.38	1.27	1.16	1.07	0.99	0.91	0.85	0.79	0.73	0.68
3%	1.38	1.25	1.14	1.04	0.95	0.87	0.80	0.74	0.69	0.64	0.59	0.55	0.51
2%	0.92	0.83	0.76	0.69	0.63	0.58	0.54	0.49	0.46	0.42	0.39	0.37	0.34
1%	0.46	0.42	0.38	0.35	0.32	0.29	0.27	0.25	0.23	0.21	0.20	0.18	0.17
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BMP Target

kH for O2 in H2O

0.0013

(l atm / mole)

van't Hoff constant

1700

(ºK)

6 ppm and above

5 to 5.99 ppm

4 to 4.99 ppm

3 to 3.99 ppm

2 to 2.99 ppm

1 to 1.99 ppm

0 to 0.99 ppm

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