THE REMOVAL OF CARCINOGENIC VOCS AT THE SUB-MICRON LEVEL WITH LOW PROFILE AIR STRIPPING

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BACKGROUND

- The U.S. EPA drinking water strategy (DWS).
- The strategy will regulate contaminants as groups rather than individually.
- The first group consists of **16 carcinogenic VOCs** (cVOCs)
- Little information is available about the effectiveness of aeration technologies, such as low profile aeration, in the removal of cVOCs in **sub ug/L** level.

Multistage low profile air stripping height and fouling

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OBJECTIVE

- The objective of this project is to determine the effectiveness of tray aeration technology for removing 13 focus carcinogenic volatile organic compounds (cVOCs) to the sub µg/L concentration range.

Research Team:

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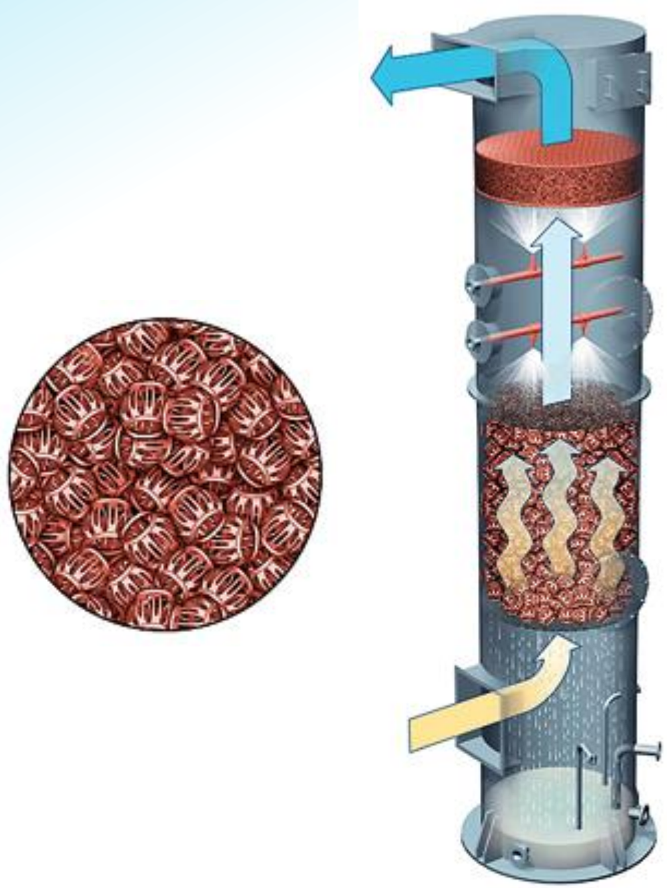
PACKED TOWER AIR STRIPPING

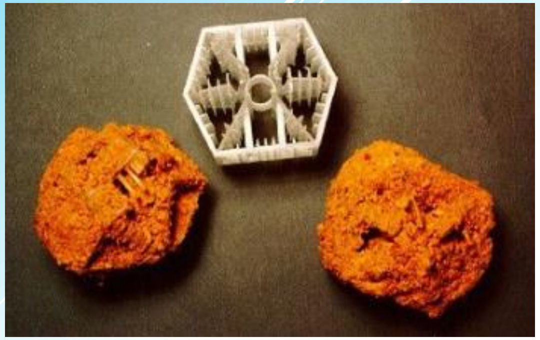
- The most commonly used technology for removing VOCs from drinking and ground water
- Utilizes engineered or random media to provide the interface required for mass
- Design parameters: Specific surface area, column diameter, column height, and air/water ratio
- A wealth of VOCs removal data with various types of media are readily available



PACKED TOWER AIR STRIPPING

- Require significantly less air flow rate for the same treatment objective, therefore their operational power requirements are lower.
- More appropriate if the water has tendency to foam.
- Susceptible to inorganic fouling
- Requires very tall towers and very often operated in series for this reason

encyclopedia.che.engin.umich.edu



LOW PROFILE AIR STRIPPERS

- Also called tray strippers and tray aerators
- Utilizes a multistage treatment scheme
- Water is introduced in a step-wise manner to a series of perforated trays
- The water flows by gravity from
- The top tray downward while the air in introduced counter-currently from the bottom of the unit upward through the holes in each tray

Carbonair STAT15
0.5-15 gpm, 80 CFM

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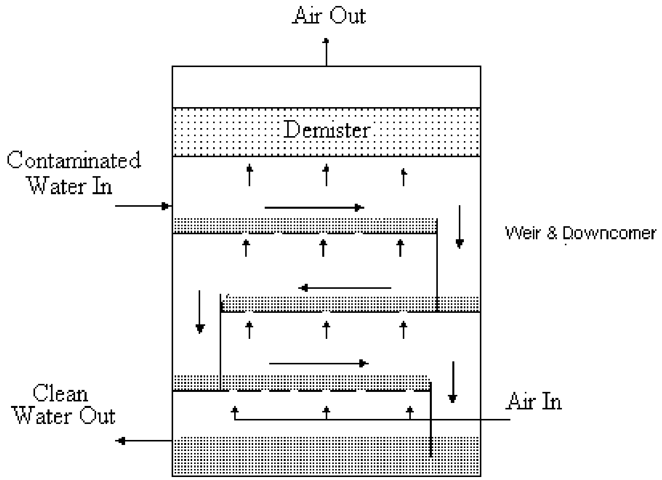
LOW PROFILE AIR STRIPPERS

- Much smaller and more compact
- water flows horizontally in the trays
- It doesn't utilize packing media
- Less susceptible to inorganics fouling
- Requires less and easier maintenance
- Easy to assemble, add on, and disassemble

Carbonair.com



DESIGN OF LPAS

- Analytical equations: Crittenden et al. 2012
- McCabe–Thiele graphical method: Crittenden et al. 2012
- Manufacturer-supplied software: Such as Carbonair Env. Systems Inc.; North East Env. Products Inc.
- USACE design manual

$$N_{th} = \frac{\ln\left[1 + \left(\frac{C_o}{C_{TO}}\right) \times (S - 1)\right]}{\ln S} - 1$$

N_{th} = number of theoretical trays
S = stripping factor, dimensionless
C_o = influent liquid-phase concentration
C_{TO} = treatment objective concentration

$$S = H_c \times \frac{Q_a}{Q_w}$$

H_c = the dimensionless Henry's law constant
Q_a = air flow rate
Q_w = water flow rate

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RESEARCH APPROACH

- The VOCs' removal efficiencies were studied by collecting operational data from pilot plant operations, under:
  - Various air-to-water ratios (53 – 652),
  - Three different temperatures (4, 12, and 20°C),
  - 1 to 6 trays in series.
- WRF specified 13 cVOCs of interest for this study:

Focus carcinogenic VOCs, Henry's constant (20°C), analytical method limits (MDLs) and lowest concentration minimum reporting levels (LCMRLs)

No.	VOC	Henry's Constant (dimensionless)*	MDL (ng/L)	LCMRL (ng/L)
1	Vinyl chloride	0.869	3.2	11
2	1,3-butadiene	2.235	16	43
3	Dichloromethane	0.081	11	116
4	1,1-dichloroethane	0.19	16	23
5	Carbon tetrachloride	0.969	21	21
6	Benzene	0.171	23	24
7	1,2-dichloroethane	0.0397	7.9	20
8	Trichloroethylene	0.289	10	17
9	1,2-dichloropropane	0.088	16	25
10	Tetrachloroethylene	0.530	30	30
11	1,1,1,2-tetrachloroethane	0.077	16	16
12	1,1,2,2-tetrachloroethane	0.014	7.1	30
13	1,2,3-trichloropropane	0.0096	20	37

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RESULTS

- Operating Condition

The operating conditions covered wide range of conditions as illustrated in the table below:

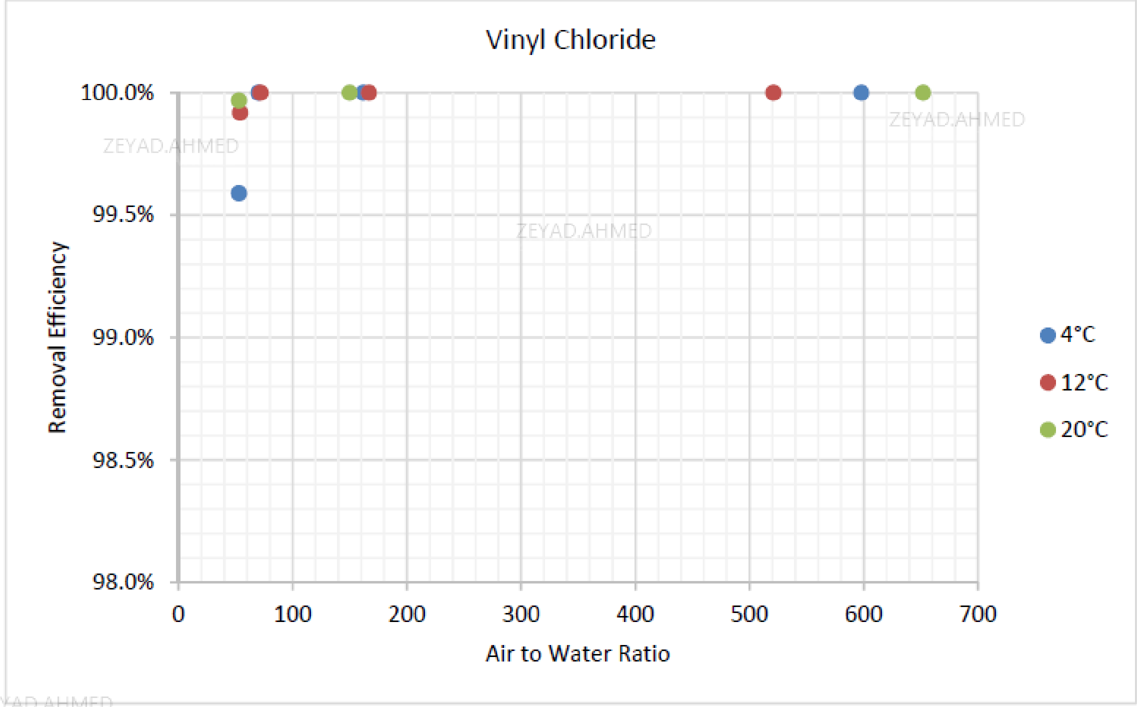
The results of the highest, lowest and medium Henry's constants cVOCs Will be presented, full information and performance data for the 13 VOC is available in the project report

Pilot plant testing conditions for the 13 focus VOCs

Test ID	Temperature °C (°F)	A/W 1		A/W 2		A/W 3		A/W 4	
		Q_w (gpm)	A/W	Q_w (gpm)	A/W	Q_w (gpm)	A/W	Q_w (gpm)	A/W
T1	4 (39.2)	1	598	3.7	162	8.5	70	11.35	53
T2	20 (68)	0.92	652	3.98	150	11.28	53		
T3	12 (53.6)	1.15	521	3.59	167	8.26	72	11.09	54

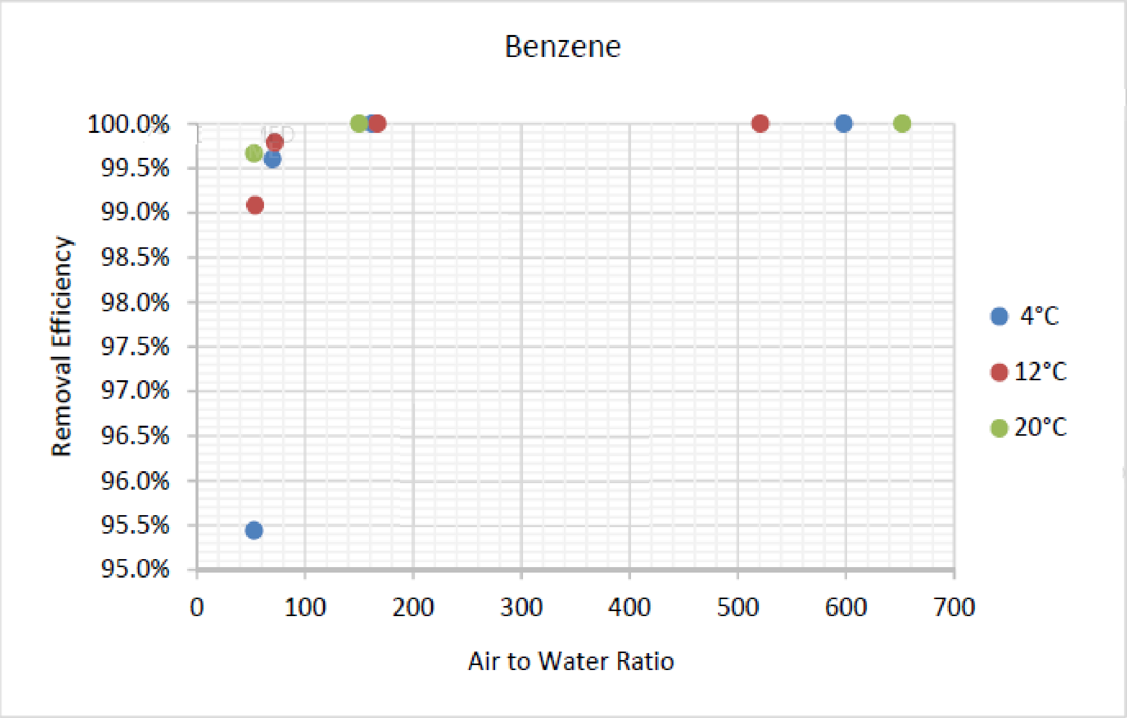
VINYL CHLORIDE

- Vinyl chloride is characterized with high Henry's law constant(0.869 dimensionless air/water at 20°C).
- Low profile air stripping is very effective for vinyl chloride removal even at low temperatures and low air to water ratios (below 100).
- Vinyl chloride was completely removed in most of the tested scenarios
- Very high removal efficiency (99.6%) at the lowest temperature (4°C) and lowest air to water ratio (53) which is the worst case examined.



BENZENE

- Benzene is characterized with a moderate Henry's law constant (0.171 dimensionless air/water at 20°C).
- Low profile air stripping is very effective for benzene removal even at low temperatures and low air to water ratios (below 100)
- 100% removal at the three temperatures and air to water ratio of about 150.
- At the low air to water ratio of 53, a lowest removal efficiency of 95.3% was achieved at the worst case scenario of 4°C.



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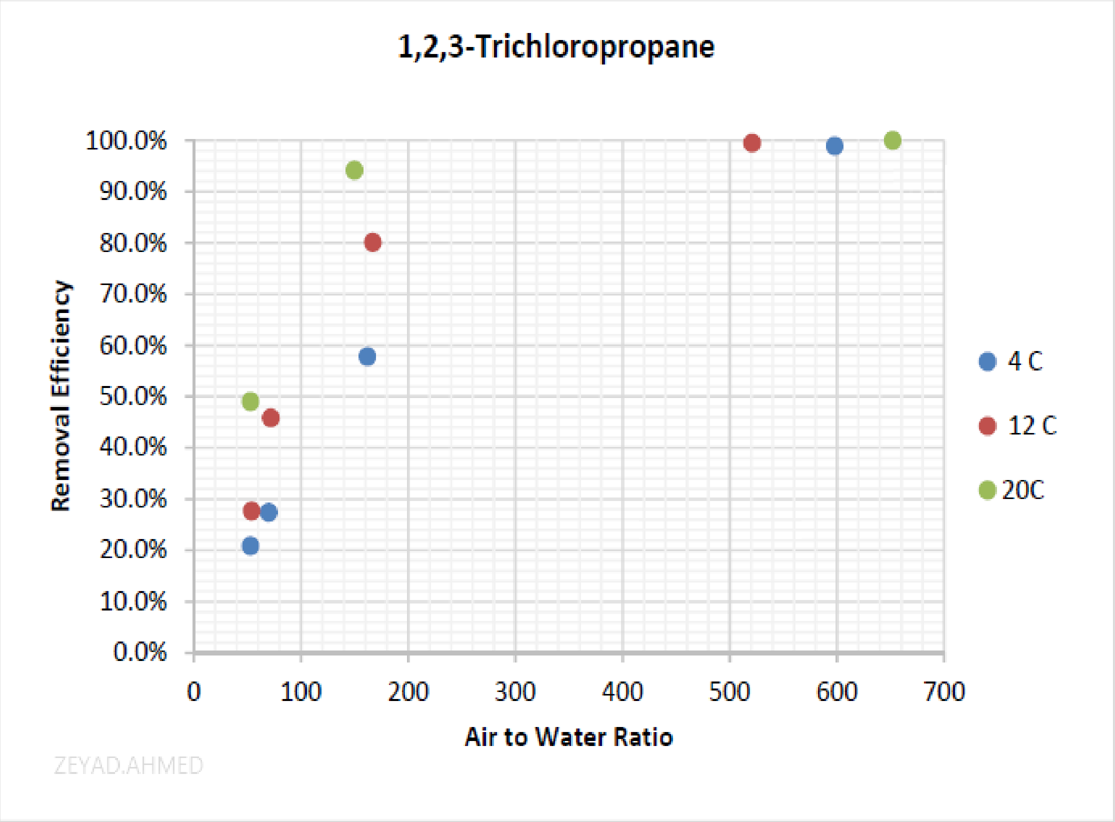
1,2,3-TRICHLOROPROPANE

- 1,2,3-trichloropropane is characterized with a low Henry's law constant (0.0096 dimensionless air/water), which is the lowest among the 13 focus VOCs.
- Low profile air stripping is effective for 1,2,3-trichloropropane removal at high air to water ratios, and at high temperatures at moderate air to water ratios.
- 1,2,3-trichloropropane was almost completely removed at the three temperatures and air to water ratio of above 500.
- Lower removal efficiencies (94.2%, 80.1% and 57.8%) were observed at lower air to water ratios (150, 167 and 162), sub ug/L effluent was not achieved at 12°C and 4°C,
- The temperature change effect was significant at this range of air to water ratios.
- At the low air to water ratio of about 53, the removal efficiency dropped to between 50% and 20%, at temperatures between 20°C and 4°C, and no sub ug/L effluent was achieved.



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DIFFUSED AIR VS LPAS

- Significant difference between the diffused air model and the data collected from the pilot plant operation.
- Diffused air model underestimated the removal efficiency.
- The mass transfer mechanism is fundamentally different from bubble aeration

High air flow rate causes the formation of very small bubbles or **frothing** to form upon contact with the water

Results of low profile air stripper and ASAP diffused air model for 10 VOCs under identical conditions (same initial concentrations at 12°C and air to water of 54).

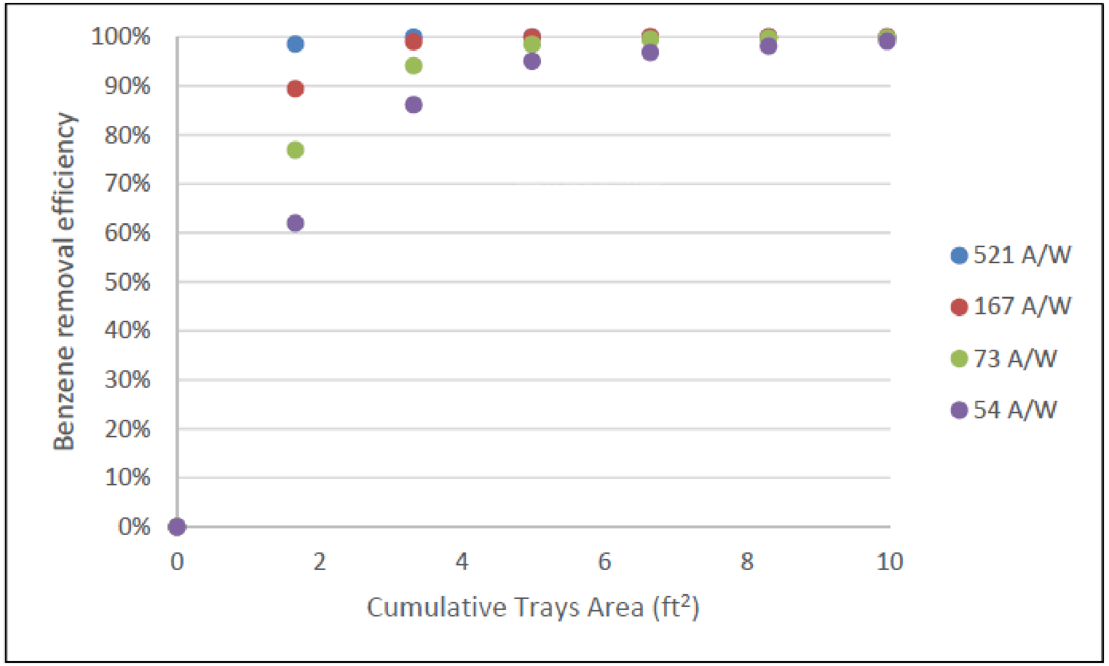
	Vinyl Chloride	1,3-Butadiene	Dichloromethane	1,1-Dichloroethane	Carbon Tetrachloride	Benzene	1,2-Dichloroethane	Trichloroethylene	1,2-Dichloropropane	Tetrachloroethylene
Influent, ng/L	8035	4092	6383	6109	6494	7026	6441	6952	6400	5864
Effluent Data , ng/L	7	ND	206	56	9	64	1090	964	273	19
Dif. Air model, ng/L	4470	2370	3730	3650	3920	4270	4090	4210	4070	3620
Efficiency, data	99.9%	100.0%	96.8%	99.1%	99.9%	99.1%	83.1%	86.1%	95.7%	99.7%
Efficiency, Dif. Air Model	44.4%	42.1%	41.6%	40.3%	39.6%	39.2%	36.5%	39.4%	36.4%	38.3%

TRAYS EFFICIENCY

- Trays in any low profile air stripper are most likely identical and operate under similar conditions
- Trays have similar removal efficiencies
- overall removal efficiency for trays can then be calculated from the tanks in series formula

$$RE_n = \left(1 - \left[\frac{RE_t}{100}\right]^n\right) \times 100$$

RE_n = The removal efficiency after the n^{th} tray (%)
RE_t = The removal efficiency of a single tray
n = Number of trays



The correlation between the removal efficiency and the cumulative surface area of trays 1-6 in the STAT15 low profile air stripper for benzene at 12°C and four air to water ratios

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CONCLUSIONS

- Low profile air stripping is a very effective technology for the removal of the 13 focus VOCs examined by this study.
- High removal efficiencies for many VOCs were achieved at air-to-water ratios as low as 53, which challenges the common assumption that low profile air stripping requires much higher air-to-water ratios.
- It is possible to achieve high removal rates at high air-to-water ratios (521-652) for all VOCs at a wide range of temperatures (4-20°C).
- The temperature effect becomes more significant at low air-to water ratios, especially for VOCs such as 1,2,3-trichloropropane, which have low Henry's Law constants.

THANK YOU


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Removal of Volatile Organic Contaminants via Low Profile Aeration Technology

Web Report #4439

Subject Area: Water Quality

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VOCS CONCENTRATIONS MEASUREMENTS

The VOCs analysis was conducted by the EPA in Cincinnati, OH using EPA Method 524.3 (EPA 2009). The method was modified to use heated headspace analysis instead of purge and trap for VOCs that are liquid or solid at room temperature. For VOCs that are gaseous at room temperature (vinyl chloride and 1,3-butadiene), the method used solid phase microextraction (SPME) analysis. In addition, the method used an MS detector in the single ion mode (SIM) instead of full scan mode to obtain lower detection limits. Samples were collected in 40 ml vials, packed with ice, and shipped overnight to the EPA in Cincinnati. The lowest concentration minimum reporting levels (LCMRLs) for the VOCs of interest were determined in distilled deionized water. The LCMRLs were determined to be between 10 – 50 ng/L, with the exception of dichloromethane (116 ng/L). The method detection limits (MDLs) and the LCMRLs are shown in Table 2.1.

A stock solution of the 13 VOCs was prepared at the EPA laboratory in Cincinnati. Target concentrations were tested and verified before the stock solution was used in the field testing phase.