Part 1 - An Introduction to Air Stripping for VOC Removal

Dave Fischer

QED Environmental Systems Inc.

Ann Arbor, MI / San Leandro, CA

Topics Overview

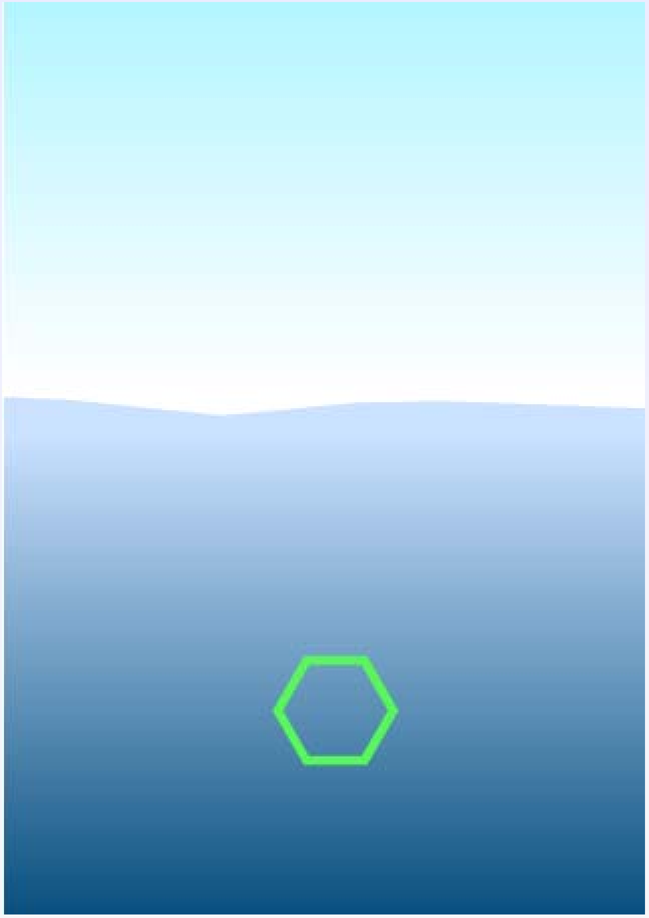
- Description of the Air Stripping process
- Methods of Air Stripping
- Comparison to other VOC removal options
- Air stripping for fouling conditions
- Predicting and managing fouling
- E-Z Tray product features/benefits
- Case Studies

QED Environmental Systems

Air Stripping

A process that removes or "strips" volatile organic compounds from contaminated water by contacting clean air with contaminated water across a high surface area, causing the volatile compounds to move from the water into the air.

Process is governed by Henry's Law.

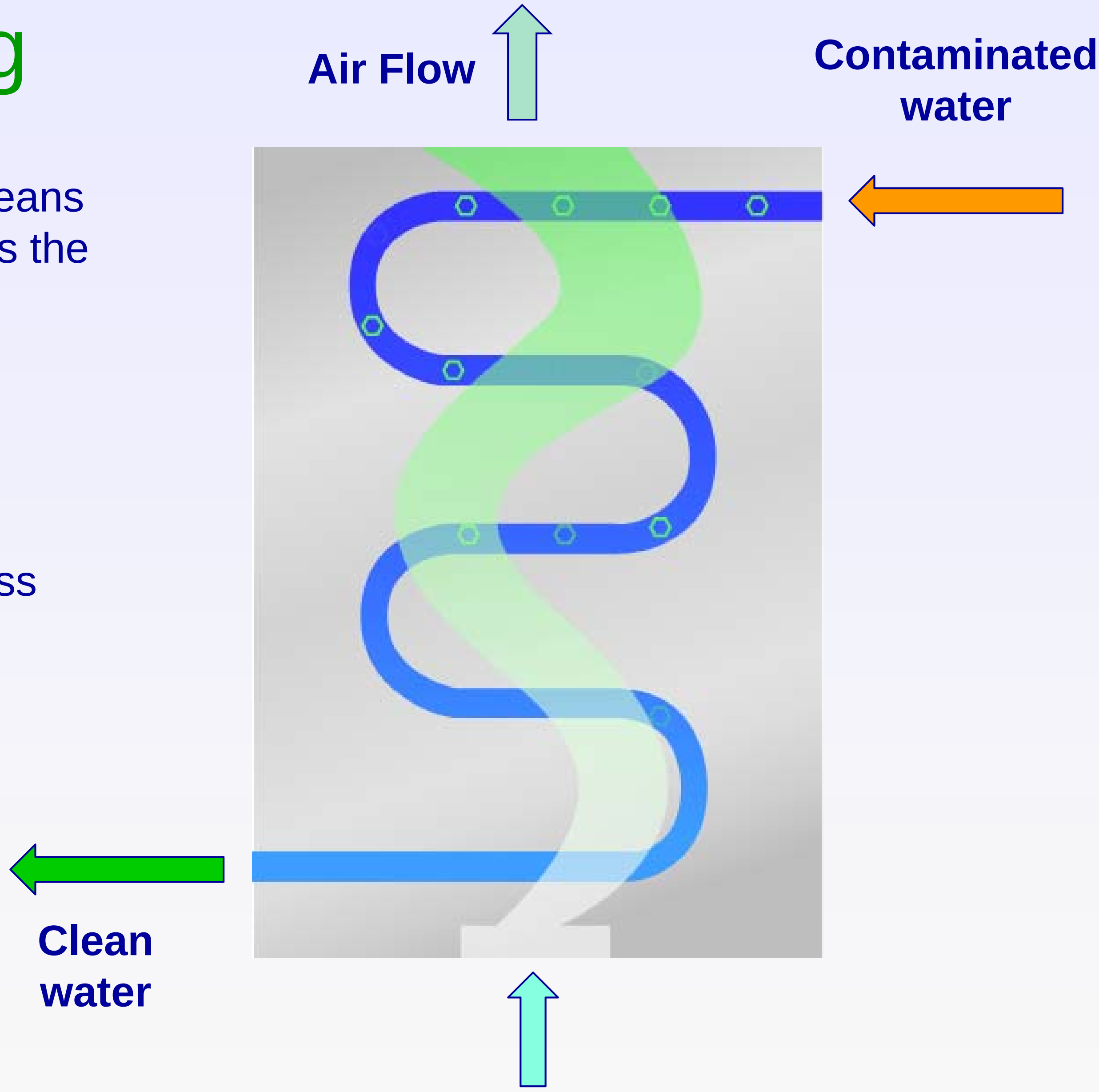


Driving dissolved volatile organic contaminants from water into air.

Air Stripping

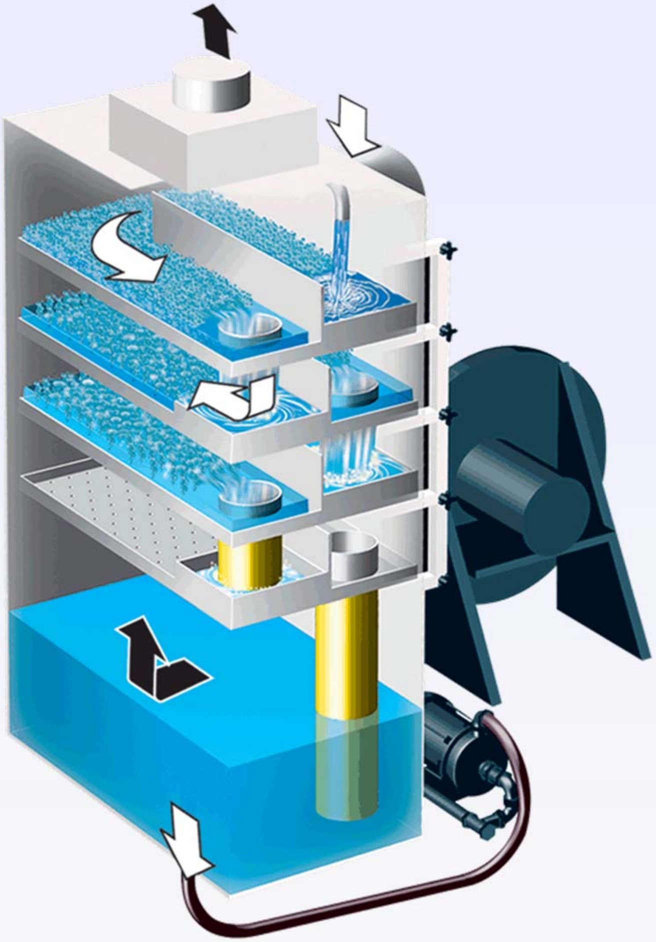
Counter-current flow means the cleanest air contacts the cleanest water. This ensures efficient *mass transfer* throughout the entire flow path

Contaminants are not destroyed during process



Air Stripping

The froth in action.



Air Stripping – Technology Overview

Contaminants defined by Henry’s law constant

Higher Henry’s law constant = more volatile contaminant

Henry’s law constant is temperature dependent (increase with increasing temp).

Increasing air to water ratio (A/W) improves removal efficiency for marginally volatile contaminants.

Some contaminants will not respond to air stripping (1,4 dioxane, methanol, tert-butyl alcohol)

Easiest to strip

Dissolved gases (methane, carbon dioxide)

Chlorinated solvents

Light hydrocarbons (BTEX)

Heavy hydrocarbons (DRO, naphthalene)

MTBE

Ammonia

Hardest to strip

QED Environmental Systems

Air Stripping

Some physical elements

- Temperature affects the process – higher temperature = better stripping
- Process temperature is roughly equal to water temperature; air temperature not a big factor
- Freezing is not a concern for continuous operation
- Discharged air is saturated (high humidity) at the process temperature, so consider condensation and thermal impacts if air treatment is planned

QED Environmental Systems

Methods - Tower Stripper

Method

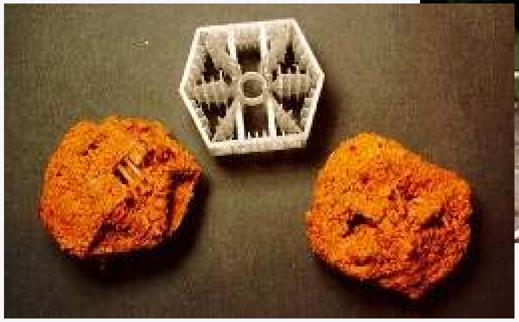
Thin film of water flows over a high surface area packing

Advantages

- Lower energy use in the air mover, due to lower overall pressure drop

Disadvantages

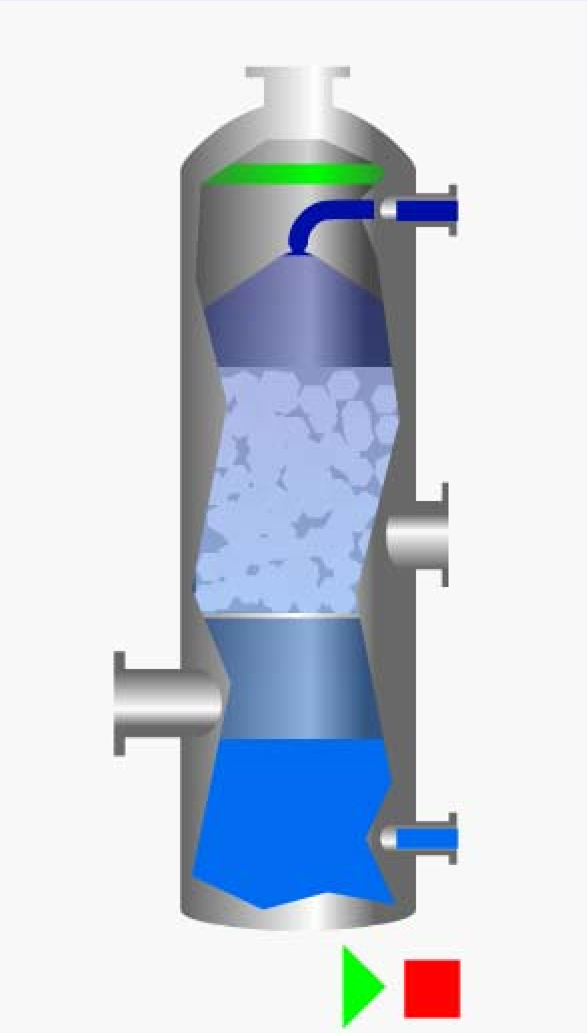
- Flow turn-down difficult
- Difficult to clean
- Tall structure
- Short circuiting



QED Environmental Systems

Tower Stripper

If fouling conditions develop, the tower can quickly loose mass transfer area. Small local areas of deposition can produce flow short circuiting that further limits available contact area.



E-Z Tray® vs. Tower O&M Example

- Site in Sturgis, MI treating 250 GPM water containing:

  1,1,1-trichloroethane
  c-1,2-dichloroethylene
  hexachlorobutadiene
  methylene chloride
  naphthalene
  tetrachloroethylene (PERC,PCE)
  trichloroethylene (TCE)

- Oversized tower replaced with a 500 GPM E-Z Tray
- Historical tower cleaning with acid cost about $54,000/year
- Pressure washing the E-Z Tray every 40-50 days estimated at $8,000/year

QED Environmental Systems

Methods - Stacking Tray Stripper

- Stacking trays strippers are a series of stacked rectangular boxes with bottom perforations
- Trays layers are sealed with gaskets and fastened together with clamps around outer edges
- Cleaning requires lifting trays and breaking pipe connections, often requires two or more people or overhead crane
- Requires access to all sides for installation and maintenance

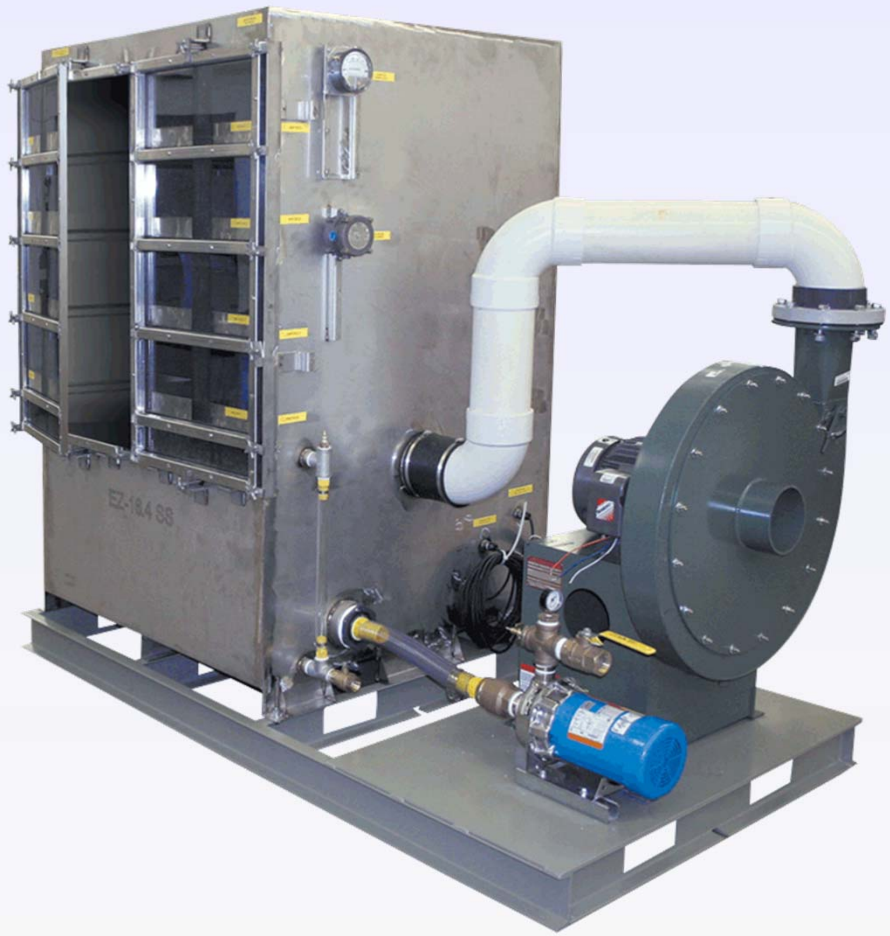
Stacking Tray Design

QED
Environmental Systems

Methods - Sliding Tray Type Stripper

Method

Air bubbles - froth and turbulent mixing creates mass transfer surface area



Advantages

- Easy access
- Less prone to fouling
- Less intrusive at site
- Wide flow turn-down

Disadvantage

- Requires higher pressure blower (HP)

QED Environmental Systems

E-Z Tray® Advantages … Cleaning

E-Z Tray Air Strippers	Tower Air Strippers	Stacking Tray Air Strippers
• Single person cleaning	• Packing access and removal is difficult	• Major disassembly and multi person crew needed

QED Environmental Systems

E-Z Tray® Advantages … Footprint

E-Z Tray Air Strippers	**Tower Air Strippers**	**Stacking Tray Air Strippers**
• Reduced footprint for installation and maintenance	• Small footprint but very tall structure often required	• Lots of space needed for disassembly, lifting from all sides, pipe disconnection and tray stage stacking

QED Environmental Systems

E-Z Tray® Advantages … Monitoring

E-Z Tray Air Strippers	**Tower Air Strippers**	**Stacking Tray Air Strippers**
• Easy process monitoring and inspection, even while in operation	• Condition of packing and air flow distribution are very difficult to observe	• Difficult or impossible to observe air and liquid flow distribution during operation

QED Environmental Systems

E-Z Tray® Advantages … Modeling

QED Air Stripper Model ver. 2.01 8/31/2009

Site Data

Name: Ms. Cleanup
Project: Project Site
Units: English
Air Temp: 55 F
Water Temp: 55 F
Stripper: EZ-Tray 12.x - Click for details
Stripper Max Flow: 120 gpm

e-mail: cleanup@qedenv.com
Altitude: 200 ft
Flow: 100 gpm
Stripper Air Flow: 600 cfm

Water Results

Contaminant	Influent (ppb)	Target (ppb)	4-Tray Results (ppb)	4-Tray %Removal	6-Tray Results (ppb)	6-Tray %Removal
naphthalene	1258	0	742.0	41.017	712.7	43.347
1,1-dichloroethylene	875	0	< 1	100.000	< 1	100.000
vinyl chloride (chloroethylene)	6890	0	2.9	99.958	< 1	100.000
trichloroethylene (TCE)	15878	0	37.4	99.764	1.9	99.988

Air Results

Contaminant	4-Tray (ppmV)	4-Tray (lb/hr)	6-Tray (ppmV)	6-Tray (lb/hr)
naphthalene	2.1044	0.02584	2.2238	0.02730
1,1-dichloroethylene	4.7159	0.04379	4.7180	0.04381
vinyl chloride (chloroethylene)	57.6022	0.34485	57.6259	0.34499
trichloroethylene (TCE)	63.0215	0.79318	63.1624	0.79495

Notes

PH-> 1-800-624-2026 or 1-734-995-2547, FX-> 1-734-995-1170. E-mail->info@qedenv.com. WEB->www.qedenv.com.

The QED modeler estimates unit performance for the listed contaminants. ***Results assume -***

1. *dissolved-phase contaminant within a water matrix*
2. *clean stripper air*

E-Z Tray Air Strippers

- Easily modeled online by customer to help process evaluation

Tower Air Strippers

- More complex design process due to structural aspects, assistance normally required

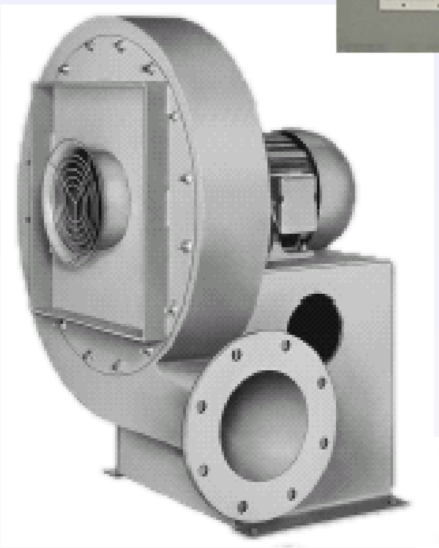
Stacking Tray Air Strippers

- Online modeler not offered

QED Environmental Systems

Ancillary Equipment

- Skid
- Blower
- Infeed Pump
- Discharge Pump
- Gravity Drain
- Control Panel
- Level Switches
- Pressure Switch
- Liquid Flow Meter
- Air Flow Meter
- Bag Filters
- Solenoid Valve
- Tank



QED E-Z Tray Air Strippers

E-Z Tray Model 6.4 (65 gpm max)

E-Z Tray Model 16.4 (150 gpm max)

E-Z Tray Model 24.4 (250 gpm max)

E-Z Tray Model 96.6 (1000 gpm max)

QED Environmental Systems

MODELER Modeling the Process

Web based Model
http://www.qedenv.com/modeler

$$\frac{x_{\text{in}} - x_{\text{out}}}{x_{\text{in}} - (y_{\text{in}}/K_H)} = \frac{S - S^{(N_{TH}+1)}}{1 - S^{(N_{TH}+1)}},$$

$$S = \frac{G \cdot K_H}{L}$$

Xin = aqueous concentration entering the air stripper
Xout = aqueous concentration exiting the air stripper
Yin = gas concentration entering the air stripper
Nth = number of theoretical trays in the air stripper
S = stripping factor
Kh = Henry's Law constant
L = liquid flow rate
G = gas flow rate

QED Air Stripper Model ver. 2.01 8/31/2009

Site Data

Name: Mr. Cleanup
e-mail: cleanup@qedenv.com
Project: Project Site
Units: English
Altitude: 200 ft
Air Temp: 55 F
Flow: 100 gpm
Water Temp: 55 F
Stripper: EZ-Tray 12.x - Click for details
Stripper Air Flow: 400 cfm
Stripper Max Flow: 120 gpm

Water Results

Contaminant	Influent (ppb)	Target (ppb)	4-Tray Results (ppb)	4-Tray %Removal	6-Tray Results (ppb)	6-Tray %Removal
naphthalene	1258	0	742.0	41.017	712.7	43.347
1,1-dichloroethylene	875	0	< 1	100.000	< 1	100.000
vinyl chloride (chloroethylene)	6890	0	2.9	99.958	< 1	100.000
trichloroethylene (TCE)	15878	0	37.4	99.764	1.9	99.988

Air Results

Contaminant	4-Tray (ppmV)	4-Tray (lb/hr)	6-Tray (ppmV)	6-Tray (lb/hr)
naphthalene	2.1044	0.02584	2.2238	0.02730
1,1-dichloroethylene	4.7159	0.04379	4.7180	0.04381
vinyl chloride (chloroethylene)	57.6022	0.34485	57.6259	0.34499
trichloroethylene (TCE)	63.0215	0.79318	63.1626	0.79495

Notes

Copyright -- QED Treatment Equipment, PO Box 3726, Ann Arbor, MI 48106.

PH-> 1-800-624-2026 or 1-734-995-2547, FX-> 1-734-995-1170. E-mail->info@qedenv.com. WEB->www.qedenv.com.

The QED modeler estimates unit performance for the listed contaminants. ***Results assume -***

1. *dissolved-phase contaminant within a water matrix*
2. *clean stripper air*

The performance modeler is based on the design procedure discussed in -- Kibbey, T. C. G., K. F. Hayes and Pennell, K.D., "Application of Sieve-Tray Air Strippers to the Treatment of Surfactant-Containing Wastewaters", AIChE Journal, Vol. 47, No. 6, June 2001. Also -- Perry, R. H., and D. W. Green, *Perry's Chemical Engineer's Handbook*, 7th ed., McGraw-Hill, New York 1997.

QED Environmental Systems

MODELER

Ease of Stripping

Max	High	Med	Low	Min

Most Frequently Modeled Contaminants

Note: these contaminants also appear in the tables below, if you select a contaminant in both places it will appear twice on the data entry grid.

☑ -- benzene	☐ -- toluene	☐ -- p-xylene
☐ -- ethylbenzene	☐ -- trichloroethylene (TCE)	☐ -- methyl-t-Butyl ether (MTBE)
☐ -- tetrachloroethylene (PERC,PCE)	☐ -- naphthalene	☐ -- c-1,2-dichloroethylene
☐ -- 1,1-dichloroethylene	☑ -- vinyl chloride (chloroethylene)	☐ -- 1,1,1-trichloroethane
☐ -- 1,1-dichloroethane	☐ -- BTEX (as benzene)	☐ -- t-1,2-dichloroethylene
☐ -- 1,2-dichloroethane	☐ -- TPH (as benzene)	☐ -- methylene chloride
☐ -- chloroform (trichloromethane)	☐ -- acetone	

Henry's Constant (H)

Larger H = more easily stripped (atm/mol-frac)

- vinyl chloride - 1245
- TCE – 648
- benzene - 309
- MTBE - 32
- acetone - 2.4

QED
Environmental Systems

MODELER

QED Air Stripper Model ver. 2.01	8/31/2009

Site Data

Name: Your Name
e-mail: dfischer@qedenv.com
Project: Project Identifier
Units: Metric
Altitude: 0 m
Air Temp: 12 C
Flow: 55 lpm
Water Temp: 12 C
Stripper: EZ-Stacker 2.xp - Click for details
Stripper Air Flow: 3.96 m3/min
Stripper Max Flow: 94.6 lpm

Water Results

Contaminant	Influent (ppb)	Target (ppb)	4-Tray Results (ppb)	4-Tray %Removal	6-Tray Results (ppb)	6-Tray %Removal
benzene	100000	0	517.1	99.483	39.5	99.960
methyl-t-Butyl ether (MTBE)	100000	0	30011.2	69.989	22563.2	77.437
tetrachloroethylene (PERC,PCE)	100000	0	14.0	99.986	< 1	100.000
vinyl chloride (chloroethylene)	100000	0	14.8	99.985	< 1	100.000
methylene chloride	100000	0	3475.6	96.524	751.8	99.248
acetone	100000	0	93104.8	6.895	93096.9	6.903
trichloroethylene (TCE)	100000	0	85.7	99.914	2.6	99.997

Air Results

Contaminant	4-Tray (ppmV)	4-Tray (lb/hr)	6-Tray (ppmV)	6-Tray (lb/hr)
benzene	413.4638	0.72384	415.4487	0.72731
methyl-t-Butyl ether (MTBE)	257.7620	0.50924	285.1920	0.56343
tetrachloroethylene (PERC,PCE)	195.7392	0.72750	195.7663	0.72760
vinyl chloride (chloroethylene)	519.3675	0.72749	519.4436	0.72760
methylene chloride	368.9546	0.70231	379.3662	0.72213
acetone	38.5419	0.05017	38.5862	0.05023
trichloroethylene (TCE)	246.8772	0.72698	247.0825	0.72758

Warnings

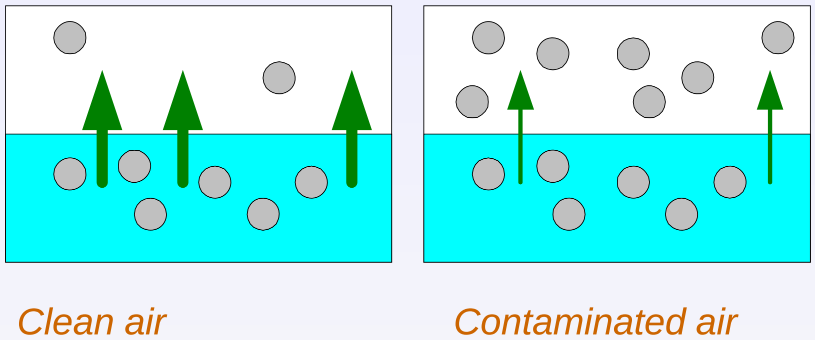
Warning: tetrachloroethylene (PERC,PCE) concentration is > 25% of solubility -- see disclaimer. Typical water solubility is 150000 ppb.

(URL listed to allow easy remodeling)

QED Environmental Systems

Successful Process Requirements

- Dissolved volatile organics in a water matrix
- No free-phase organics
- Clean air (concentration gradient driven)
- High surface area of contact between air and water
- High air to water ratio
- Sufficient contact time
- No surfactants or other H lowering factors (dissolved polar organics)
- Stripper is level



Impact of dirty air – less "driving force" for mass transfer

Process Economics for high efficiency VOC removal

- Sliding Tray Stripper – \$0.10-\$0.35/Kgal
- Tower Stripper – \$0.48/Kgal
- Activated Carbon (GAC) – \$0.95-\$1.57/Kgal
- Oxidation process – \$0.88 – \$2.42 /Kgal

Considering 10 year project life & equivalent removal efficiency – equipment cost, install cost, operating / maintenance cost (energy, GAC replenishment), and annual flow treated (x / 1000 gallons). Legacy & lifecycle costs are becoming a major design requirement.

QED Environmental Systems

Air Stripper Performance Impacts

- Air flow restrictions
- Liquid flow issues
- Major water/air temperature changes
- Free phase product or other sorptive compounds that decrease stripping
- Surfactants or other polar organic chemicals that can lower H for target organics

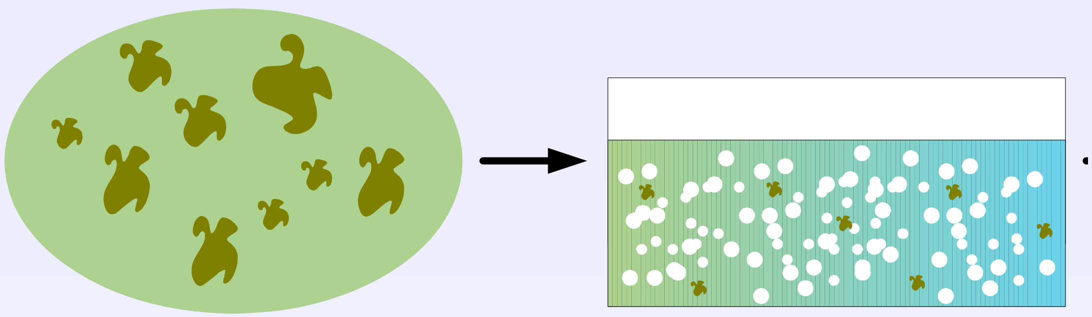
QED Environmental Systems

Surfactants Example

Normal froth

Surfactant impacted froth

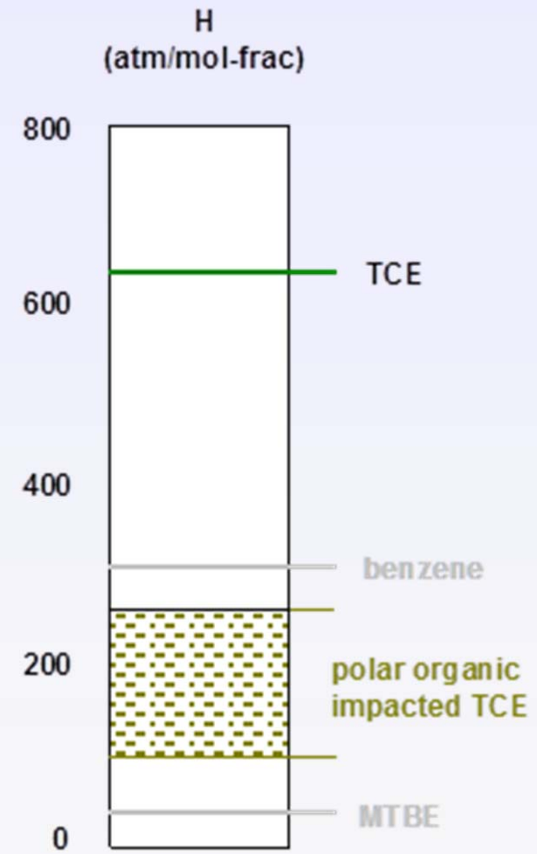
Free-phase Organics Example



Contaminant in equilibrium with oil, water, & air phases

Stripping removes dissolved portion of contaminants in water.

Some organics partition into the free-phase organic component and re-equilibrate after stripping.



Types of Tray Air Stripper Fouling

- Metal oxides - iron
- Hardness (scale)
- Suspended solids
- Bio solids & slimes
- Oils & Greases
- Free phase non-aqueous phase liquids (NAPL)

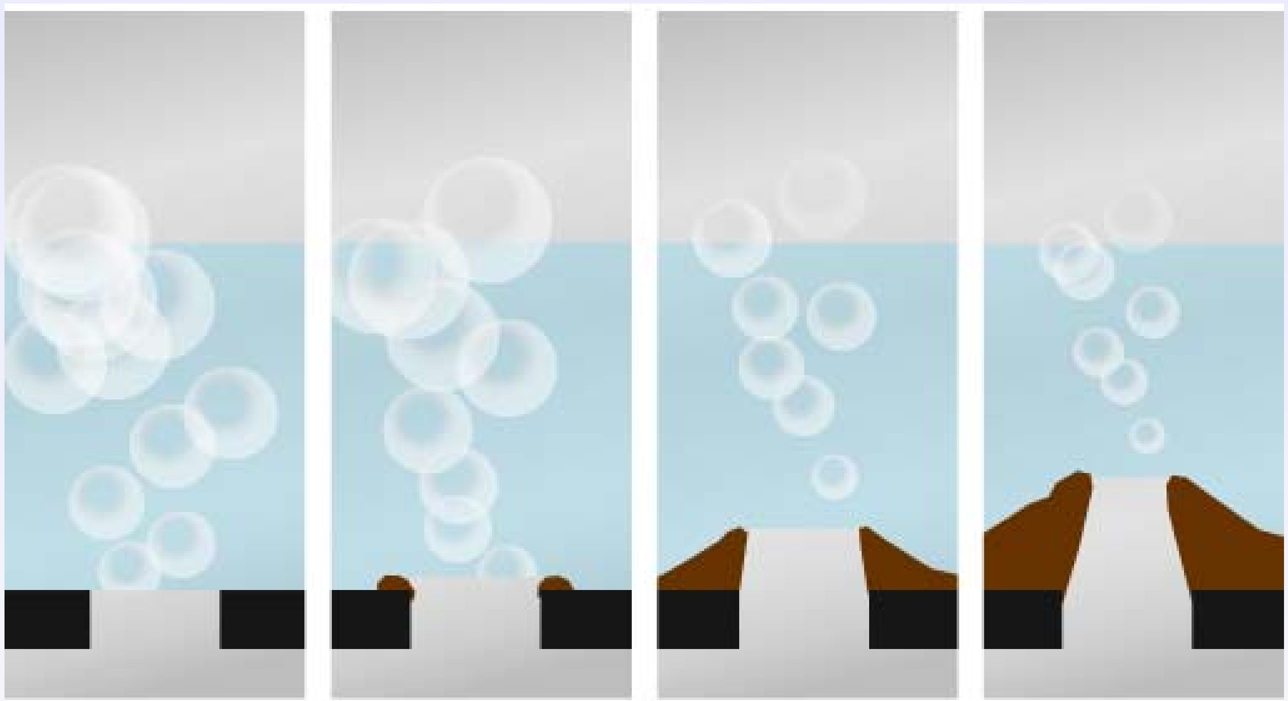
QED Environmental Systems

Insoluble Metal Oxides

CO2 stripping causes a slight pH increase, leading to insoluble metal oxide formation. The resulting solids can increase blower back pressure and reduce stripper efficiency (from lower air-water ratio).

QED Environmental Systems

Tray Fouling – Knowing When to Clean



Normal stripper sump pressure = 4-6 inch H2O / tray stage

Stripper Fouling Rules of Thumb

Iron	<0.1ppm	low fouling potential
	0.1-1ppm	modest fouling potential (not bio)
	1-5ppm	significant fouling potential (optimum for bio)
	5-20ppm	serious fouling potential, heavy O&M (manageable)
	>20ppm	extreme, control options required

Langelier Saturation Index (LSI*)

<1	no scale forming, corrosive potential
0	neutral
>1	scale forming potential

Microbial – Biological Activity Test (BART – Hach kit)

> 1000	cfu/ml – concern for bio-fouling
>10,000	cfu/ml – expect serious bio-fouling

*(*calculate LSI with calcium hardness, total alkalinity, pH and water temperature)*

QED Environmental Systems

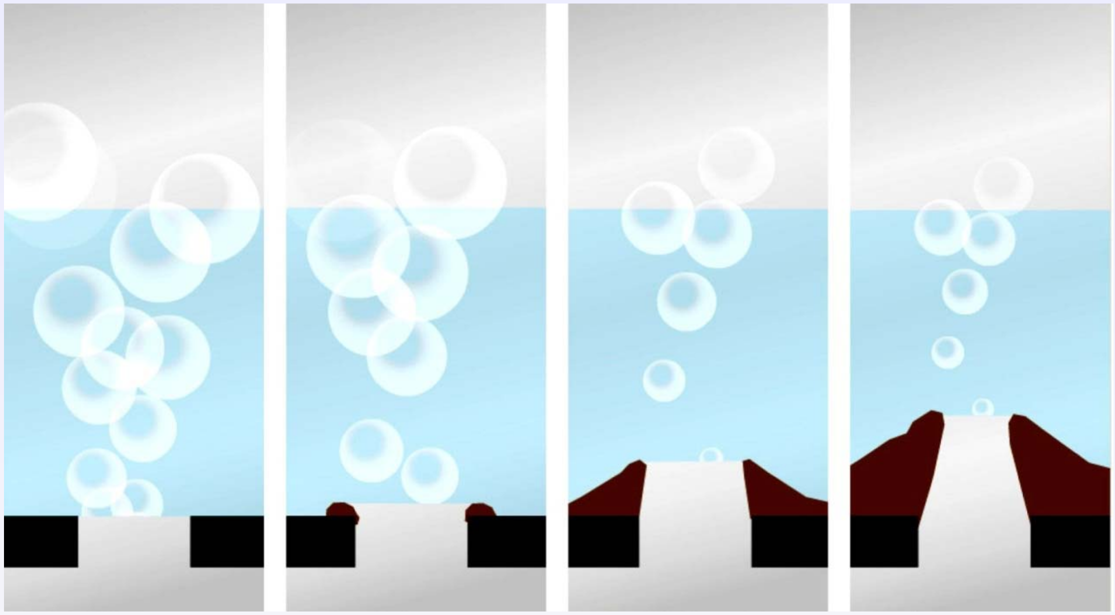
Stripper Cleaning

- Cleaning frequency and effort is highly site-specific
- *Example* -
  - 0.03 ppm iron, high hardness scales - stripper requires cleaning every 3 weeks
- Cleaning time for an E-Z Tray stripper
  - Two 1000gpm, E-Z Tray 96.6 units (8 doors, 48 trays) takes 8-10 minutes/tray to fully remove, pressure wash and reinstall all the trays in this system (about 1/2 day per stripper)

QED Environmental Systems

Tray Fouling - Preventative Measures

- Clean trays
  - Backup tray set
- Sequestering agents (decrease cleaning frequency)
  - inorganic polyphosphates
- Bio-fouling
  - Ozone, etc.
- pH adjustment
  - In/out
- Pre-stripper oxidation and filtration for severe cases



QED Environmental Systems

Pilot Testing

- Prepackaged, just add electricity
- Rental
- Used for scale-up design and fouling studies
- Allows H correction from results when NAPLs, surfactants, etc. are known to be present

Rental skids available from QED and some equipment contractors – contact us for more information.

QED Environmental Systems

Additional Site Information for Design

- Site history of DNAPL and/or LNAPL
- Parameters that are hard to strip (DRO, etc.)
- Is O&G above detection limit (is O&G MDL low enough)
- Is there air contamination near the blower inlet
- Does stable foam form if target water is shaken in a jar
- Is there an offset between TOC and the sum of the target organics
- Is there a site history of surfactant use
- Are high shear pumps used to capture the water (stable emulsions of NAPL)

QED Environmental Systems

Case Study 1 - NY

- Gasoline spill in high value residential area
- Space for process equipment limited
- Need for low profile - sound and appearance
- Strippers housed in metal shipping containers

QED
Environmental Systems

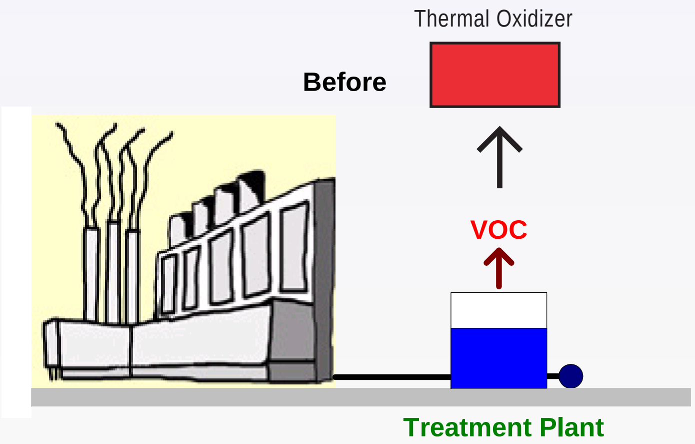
Case Study 2 - Alaska

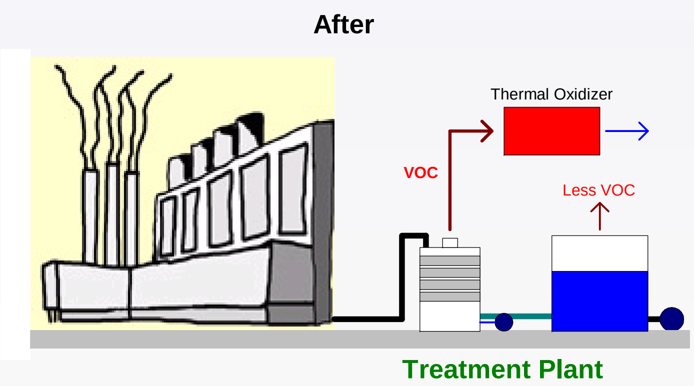
- VOC treatment of tanker ballast water
- Strippers replaced an aging activated sludge treatment process that was unable to handle changes in flow and concentration
- Process string includes free-phase removal and air treatment
- Pilot testing used prior to design

QED Environmental Systems

Case Study 3 – Puerto Rico

- VOC reduction prior to aerobic bio-reactor treatment of pharmaceutical wastewater
- Stripper air flow rate much lower than flow from bio treatment unit
- Pre-stripping with E-Z Tray = a much smaller air treatment unit





QED Environmental Systems

Case Study 4 – Cheyenne, WY

- Abandoned Atlas Missile sites contaminated city wells with chlorinated solvent
- US Army Corps is QED's customer
- Strippers treat city water during high demand, summer months (4000gpm capacity)
- Excellent equipment reliability required to ensure continuous water treatment
- System started June 2011

QED Environmental Systems

Case Study 5 – Cedarburg, WI

- Landfill near a 700gpm supply well causing low level vinyl chloride hits
- System modeling based on a long list of possible future contaminants, based on LF monitoring data
- City operates an older tower stripper on another well treating an unrelated TCE issue – in operation 18 years
- Sequestering agent used for tower and E-Z Tray
- E-Z Tray footprint helped to keep project costs low

QED Environmental Systems

E-Z Tray Advantage - Safer by design

Live Safer.®

QED's sliding tray air stripper (E-Z Tray) is the first self-container air stripper to achieve certification from NSF International to **NSF/ANSI Standard 61: *Drinking Water System Components – Health Effects***

Nationally recognized health effects standard for all products that come in contact with drinking water

All water contacting materials in the E-Z Tray units are safe for drinking water systems use

QED
Environmental Systems

Summary

- Air strippers are effective at removing dissolved volatile organic compounds from water
- The primary process factor is air to water ratio
- The process can be modeled using QED's on-line computer tool - *http://www.qedenv.com/modeler*
- Air stripping equipment needs to be maintained to ensure continued design removals

QED Environmental Systems

Survey + Questions?

David Fischer
QED Environmental Systems, Inc.

Tel: 800-624-2026
E-mails: dfischer@qedenv.com

WEB:
www.qedenv.com