

4.3 Waste Water Collection, Treatment And Storage

4.3.1 General

Many different industries generate waste water streams that contain organic compounds. Nearly all of these streams undergo collection, contaminant treatment, and/or storage operations before they are finally discharged into either a receiving body of water or a municipal treatment plant for further treatment. During some of these operations, the waste water is open to the atmosphere, and volatile organic compounds (VOC) may be emitted from the waste water into the air.

Industrial waste water operations can range from pretreatment to full-scale treatment processes. In a typical pretreatment facility, process and/or sanitary waste water and/or storm water runoff is collected, equalized, and/or neutralized and then discharged to a municipal waste water plant, also known as a publicly owned treatment works (POTWs), where it is then typically treated further by biodegradation.

In a full-scale treatment operation, the waste water must meet Federal and/or state quality standards before it is finally discharged into a receiving body of water. Figure 4.3-1 shows a generic example of collection, equalization, neutralization, and biotreatment of process waste water in a full-scale industrial treatment facility. If required, chlorine is added as a disinfectant. A storage basin contains the treated water until the winter months (usually January to May), when the facility is allowed to discharge to the receiving body of water. In the illustration, the receiving body of water is a slow-flowing stream. The facility is allowed to discharge in the rainy season when the facility waste water is diluted.

Figure 4.3-1 also presents a typical treatment system at a POTW waste water facility. Industrial waste water sent to POTWs may be treated or untreated. POTWs may also treat waste water from residential, institutional, and commercial facilities; from infiltration (water that enters the sewer system from the ground); and/or storm water runoff. These types of waste water generally do not contain VOCs. A POTW usually consists of a collection system, primary settling, biotreatment, secondary settling, and disinfection.

Collection, treatment, and storage systems are facility-specific. All facilities have some type of collection system, but the complexity will depend on the number and volume of waste water streams generated. As mentioned above, treatment and/or storage operations also vary in size and degree of treatment. The size and degree of treatment of waste water streams will depend on the volume and degree of contamination of the waste water and on the extent of contaminant removal desired.

4.3.1.1 Collection Systems -

There are many types of waste water collection systems. In general, a collection system is located at or near the point of waste water generation and is designed to receive 1 or more waste water streams and then to direct these streams to treatment and/or storage systems.

A typical industrial collection system may include drains, manholes, trenches, junction boxes, sumps, lift stations, and/or weirs. Waste water streams from different points throughout the industrial facility normally enter the collection system through individual drains or trenches connected to a main sewer line. The drains and trenches are usually open to the atmosphere. Junction boxes, sumps,

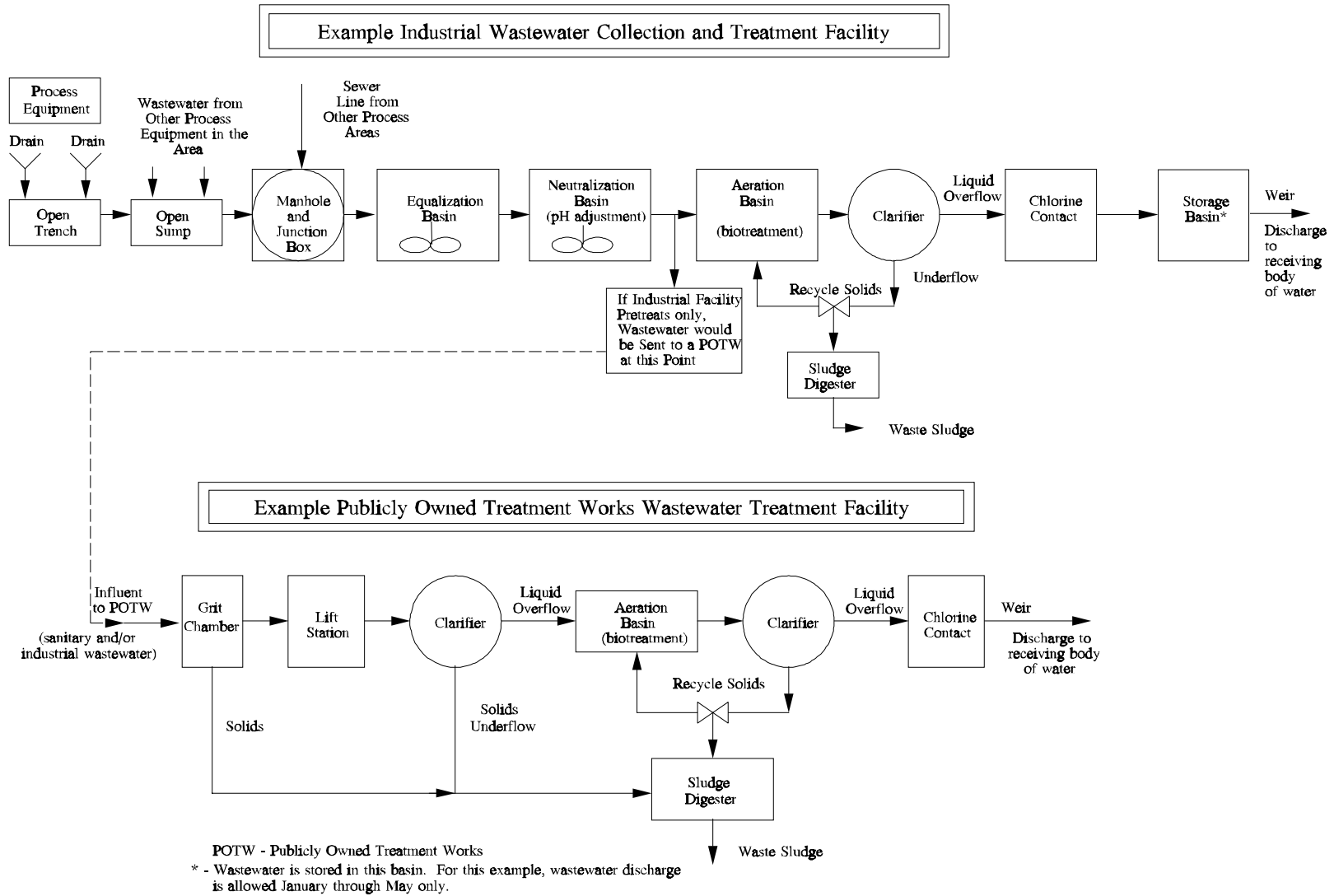


Figure 4.3.1. Typical waste water collection and treatment systems for industrial and municipal facilities.

trenches, lift stations, and weirs will be located at points requiring waste water transport from 1 area or treatment process to another.

A typical POTW facility collection system will contain a lift station, trenches, junction boxes, and manholes. Waste water is received into the POTW collection system through open sewer lines from all sources of influent waste water. As mentioned previously, these sources may convey sanitary, pretreated or untreated industrial, and/or storm water runoff waste water.

The following paragraphs briefly describe some of the most common types of waste water collection system components found in industrial and POTW facilities. Because the arrangement of collection system components is facility-specific, the order in which the collection system descriptions are presented is somewhat arbitrary.

Waste water streams normally are introduced into the collection system through individual or area drains, which can be open to the atmosphere or sealed to prevent waste water contact with the atmosphere. In industry, individual drains may be dedicated to a single source or piece of equipment. Area drains will serve several sources and are located centrally among the sources or pieces of equipment that they serve.

Manholes into sewer lines permit service, inspection, and cleaning of a line. They may be located where sewer lines intersect or where there is a significant change in direction, grade, or sewer line diameter.

Trenches can be used to transport industrial waste water from point of generation to collection units such as junction boxes and lift station, from 1 process area of an industrial facility to another, or from 1 treatment unit to another. POTWs also use trenches to transport waste water from 1 treatment unit to another. Trenches are likely to be either open or covered with a safety grating.

Junction boxes typically serve several process sewer lines, which meet at the junction box to combine multiple waste water streams into 1. Junction boxes normally are sized to suit the total flow rate of the entering streams.

Sumps are used typically for collection and equalization of waste water flow from trenches or sewer lines before treatment or storage. They are usually quiescent and open to the atmosphere.

Lift stations are usually the last collection unit before the treatment system, accepting waste water from 1 or several sewer lines. Their main function is to lift the collected waste water to a treatment and/or storage system, usually by pumping or by use of a hydraulic lift, such as a screw.

Weirs can act as open channel dams, or they can be used to discharge cleaner effluent from a settling basin, such as a clarifier. When used as a dam, the weir's face is normally aligned perpendicular to the bed and walls of the channel. Water from the channel usually flows over the weir and falls to the receiving body of water. In some cases, the water may pass through a notch or opening in the weir face. With this type of weir, flow rate through the channel can be measured. Weir height, generally the distance the water falls, is usually no more than 2 meters (6 feet). A typical clarifier weir is designed to allow settled waste water to overflow to the next treatment process. The weir is generally placed around the perimeter of the settling basin, but it can also be towards the middle. Clarifier weir height is usually only about 0.1 meters (4 inches).

4.3.1.2 Treatment And/Or Storage Systems -

These systems are designed to hold liquid wastes or waste water for treatment, storage, or disposal. They are usually composed of various types of earthen and/or concrete-lined basins, known as surface impoundments. Storage systems are used typically for accumulating waste water before its ultimate disposal, or for temporarily holding batch (intermittent) streams before treatment.

Treatment systems are divided into 3 categories: primary, secondary, or tertiary, depending on their design, operation, and application. In primary treatment systems, physical operations remove floatable and settleable solids. In secondary treatment systems, biological and chemical processes remove most of the organic matter in the waste water. In tertiary treatment systems, additional processes remove constituents not taken out by secondary treatment.

Examples of primary treatment include oil/water separators, primary clarification, equalization basins, and primary treatment tanks. The first process in an industrial waste water treatment plant is often the removal of heavier solids and lighter oils by means of oil/water separators. Oils are usually removed continuously with a skimming device, while solids can be removed with a sludge removal system.

In primary treatment, clarifiers are usually located near the beginning of the treatment process and are used to settle and remove settleable or suspended solids contained in the influent waste water. Figure 4.3-2 presents an example design of a clarifier. Clarifiers are generally cylindrical and are sized according to both the settling rate of the suspended solids and the thickening characteristics of the sludge. Floating scum is generally skimmed continuously from the top of the clarifier, while sludge is typically removed continuously from the bottom of the clarifier.

Equalization basins are used to reduce fluctuations in the waste water flow rate and organic content before the waste is sent to downstream treatment processes. Flow rate equalization results in a more uniform effluent quality in downstream settling units such as clarifiers. Biological treatment performance can also benefit from the damping of concentration and flow fluctuations, protecting biological processes from upset or failure from shock loadings of toxic or treatment-inhibiting compounds.

In primary treatment, tanks are generally used to alter the chemical or physical properties of the waste water by, for example, neutralization and the addition and dispersion of chemical nutrients. Neutralization can control the pH of the waste water by adding an acid or a base. It usually precedes biotreatment, so that the system is not upset by high or low pH values. Similarly, chemical nutrient addition/dispersion precedes biotreatment, to ensure that the biological organisms have sufficient nutrients.

An example of a secondary treatment process is biodegradation. Biological waste treatment usually is accomplished by aeration in basins with mechanical surface aerators or with a diffused air system. Mechanical surface aerators float on the water surface and rapidly mix the water. Aeration of the water is accomplished through splashing. Diffused air systems, on the other hand, aerate the water by bubbling oxygen through the water from the bottom of the tank or device. Figure 4.3-3 presents an example design of a mechanically aerated biological treatment basin. This type of basin is usually an earthen or concrete-lined pond and is used to treat large flow rates of waste water. Waste waters with high pollutant concentrations, and in particular high-flow sanitary waste waters, are typically treated using an activated sludge system where biotreatment is followed by secondary clarification. In this system, settled solids containing biomass are recycled from clarifier sludge to the biotreatment system. This creates a high biomass concentration and therefore allows biodegradation to occur over a shorter residence time. An example of a tertiary treatment process is nutrient

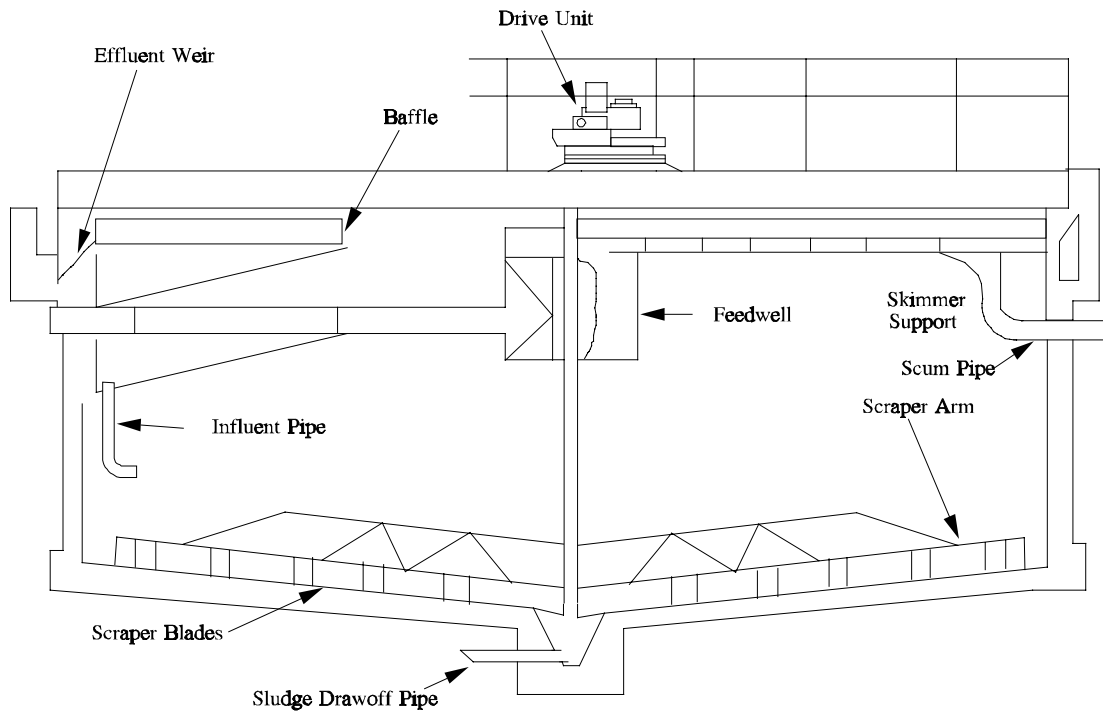


Figure 4.3-2. Example clarifier configuration.

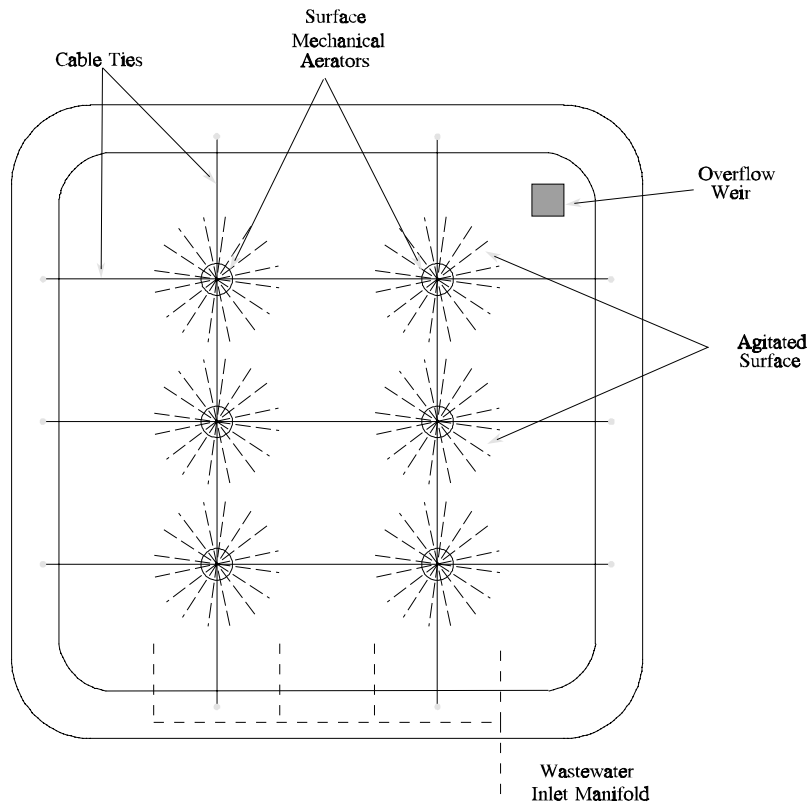


Figure 4.3-3. Example aerated biological treatment basin.

removal. Nitrogen and phosphorus are removed after biodegradation as a final treatment step before waste water is discharged to a receiving body of water.

4.3.1.3 Applications -

As previously mentioned, waste water collection, treatment, and storage are common in many industrial categories and in POTW. Most industrial facilities and POTW collect, contain, and treat waste water. However, some industries do not treat their waste water, but use storage systems for temporary waste water storage or for accumulation of waste water for ultimate disposal. For example, the Agricultural Industry does little waste water treatment but needs waste water storage systems, while the Oil and Gas Industry also has a need for waste water disposal systems.

The following are waste water treatment and storage applications identified by type of industry:

1. Mining And Milling Operations - Storage of various waste waters such as acid mine water, solvent wastes from solution mining, and leachate from disposed mining wastes. Treatment operations include settling, separation, washing, sorting of mineral products from tailings, and recovery of valuable minerals by precipitation.
2. Oil And Gas Industry - One of the largest sources of waste water. Operations treat brine produced during oil extraction and deep-well pressurizing operations, oil-water mixtures, gaseous fluids to be separated or stored during emergency conditions, and drill cuttings and drilling muds.
3. Textile And Leather Industry - Treatment and sludge disposal. Organic species treated or disposed of include dye carriers such as halogenated hydrocarbons and phenols. Heavy metals treated or disposed of include chromium, zinc, and copper. Tanning and finishing wastes may contain sulfides and nitrogenous compounds.
4. Chemical And Allied Products Industry - Process waste water treatment and storage, and sludge disposal. Waste constituents are process-specific and include organics and organic phosphates, fluoride, nitrogen compounds, and assorted trace metals.
5. Other Industries - Treatment and storage operations are found at petroleum refining, primary metals production, wood treating, and metal finishing facilities. Various industries store and/or treat air pollution scrubber sludge and dredging spoils sludge (i. e., settled solids removed from the floor of a surface impoundment).

4.3.2 Emissions

VOCs are emitted from waste water collection, treatment, and storage systems through volatilization of organic compounds at the liquid surface. Emissions can occur by diffusive or convective mechanisms, or both. Diffusion occurs when organic concentrations at the water surface are much higher than ambient concentrations. The organics volatilize, or diffuse into the air, in an attempt to reach equilibrium between aqueous and vapor phases. Convection occurs when air flows over the water surface, sweeping organic vapors from the water surface into the air. The rate of volatilization relates directly to the speed of the air flow over the water surface.

Other factors that can affect the rate of volatilization include waste water surface area, temperature, and turbulence; waste water retention time in the system(s); the depth of the waste water in the system(s); the concentration of organic compounds in the waste water and their physical

properties, such as volatility and diffusivity in water; the presence of a mechanism that inhibits volatilization, such as an oil film; or a competing mechanism, such as biodegradation.

The rate of volatilization can be determined by using mass transfer theory. Individual gas phase and liquid phase mass transfer coefficients (k_g and k_l , respectively) are used to estimate overall mass transfer coefficients (K , K_{oil} , and K_D) for each VOC.¹⁻² Figure 4.3-4 presents a flow diagram to assist in determining the appropriate emissions model for estimating VOC emissions from various types of waste water treatment, storage, and collection systems. Tables 4.3-1 and 4.3-2, respectively, present the emission model equations and definitions.

VOCs vary in their degree of volatility. The emission models presented in this section can be used for high-, medium-, and low-volatility organic compounds. The Henry's law constant (HLC) is often used as a measure of a compound's volatility, or the diffusion of organics into the air relative to diffusion through liquids. High-volatility VOCs are $HLC > 10^{-3} \text{ atm}\cdot\text{m}^3/\text{gmol}$; medium-volatility VOCs are $10^{-3} < HLC < 10^{-5} \text{ atm}\cdot\text{m}^3/\text{gmol}$; and low-volatility VOCs are $HLC < 10^{-5} \text{ atm}\cdot\text{m}^3/\text{gmol}$.¹

The design and arrangement of collection, treatment, and storage systems are facility-specific; therefore the most accurate waste water emissions estimate will come from actual tests of a facility (i. e., tracer studies or direct measurement of emissions from openings). If actual data are unavailable, the emission models provided in this section can be used.

Emission models should be given site-specific information whenever it is available. The most extensive characterization of an actual system will produce the most accurate estimates from an emissions model. In addition, when addressing systems involving biodegradation, the accuracy of the predicted rate of biodegradation is improved when site-specific compound biorates are input. Reference 3 contains information on a test method for measuring site-specific biorates, and Table 4.3-4 presents estimated biorates for approximately 150 compounds.

To estimate an emissions rate (N), the first step is to calculate individual gas phase and liquid phase mass transfer coefficients k_g and k_l . These individual coefficients are then used to calculate the overall mass transfer coefficient, \bar{K} . Exceptions to this procedure are the calculation of overall mass transfer coefficients in the oil phase, K_{oil} , and the overall mass transfer coefficient for a weir, K_D . K_{oil} requires only k_g , and K_D does not require any individual mass transfer coefficients. The overall mass transfer coefficient is then used to calculate the emissions rates. The following discussion describes how to use Figure 4.3-4 to determine an emission rate. An example calculation is presented in Part 4.3.2.1 below.

Figure 4.3-4 is divided into 2 sections: waste water treatment and storage systems, and waste water collection systems. Waste water treatment and storage systems are further segmented into aerated/nonaerated systems, biologically active systems, oil film layer systems, and surface impoundment flowthrough or disposal. In flowthrough systems, waste water is treated and discharged to a POTW or a receiving body of water, such as a river or stream. All waste water collection systems are by definition flowthrough. Disposal systems, on the other hand, do not discharge any waste water.

Figure 4.3-4 includes information needed to estimate air emissions from junction boxes, lift stations, sumps, weirs, and clarifier weirs. Sumps are considered quiescent, but junction boxes, lift stations, and weirs are turbulent in nature. Junction boxes and lift stations are turbulent because incoming flow is normally above the water level in the component, which creates some splashing.

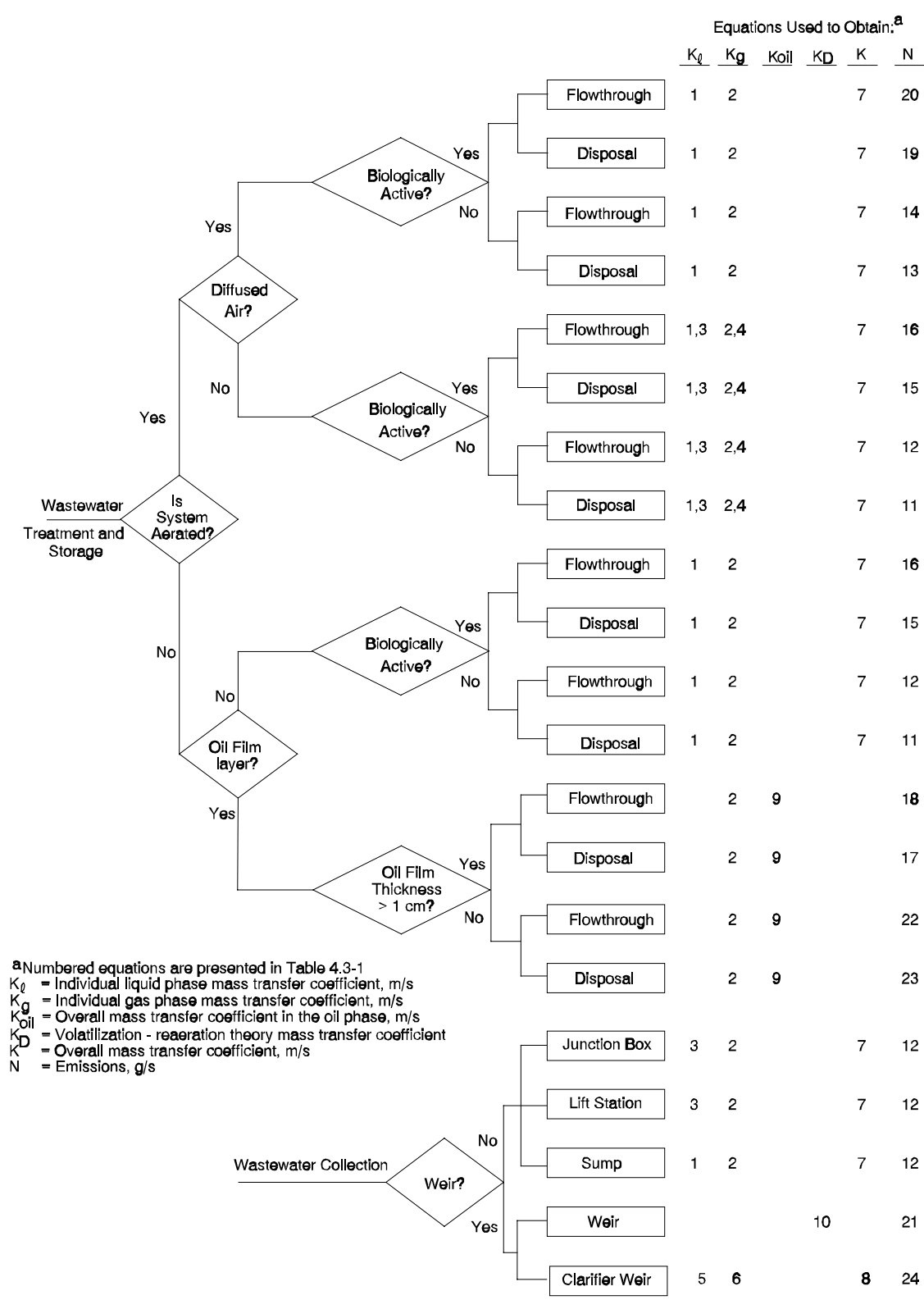


Figure 4.3.4. Flow diagram for estimating VOC emissions from waste water collection, treatment, and storage systems.

Table 4.3-1. MASS TRANSFER CORRELATIONS AND EMISSIONS EQUATIONS^a

Equation No.	Equation
<u>Individual liquid (k_l) and gas (k_g) phase mass transfer coefficients</u>	
1	$k_l \text{ (m/s)} = (2.78 \times 10^{-6})(D_w/D_{\text{ether}})^{2/3}$ <p>For: $0 < U_{10} < 3.25$ m/s and all F/D ratios</p> $k_l \text{ (m/s)} = [(2.605 \times 10^{-9})(F/D) + (1.277 \times 10^{-7})](U_{10})^2(D_w/D_{\text{ether}})^{2/3}$ <p>For: $U_{10} > 3.25$ m/s and $14 < F/D < 51.2$</p> $k_l \text{ (m/s)} = (2.61 \times 10^{-7})(U_{10})^2(D_w/D_{\text{ether}})^{2/3}$ <p>For: $U_{10} > 3.25$ m/s and $F/D > 51.2$</p> $k_l \text{ (m/s)} = 1.0 \times 10^{-6} + 144 \times 10^{-4} (U^*)^{2.2} (Sc_L)^{-0.5}; U^* < 0.3$ $k_l \text{ (m/s)} = 1.0 \times 10^{-6} + 34.1 \times 10^{-4} U^* (Sc_L)^{-0.5}; U^* > 0.3$ <p>For: $U_{10} > 3.25$ m/s and $F/D < 14$</p> <p>where:</p> $U^* \text{ (m/s)} = (0.01)(U_{10})(6.1 + 0.63(U_{10}))^{0.5}$ $Sc_L = \mu_L/(\rho_L D_w)$ $F/D = 2(A/\pi)^{0.5}$
2	$k_g \text{ (m/s)} = (4.82 \times 10^{-3})(U_{10})^{0.78} (Sc_G)^{-0.67} (d_e)^{-0.11}$ <p>where:</p> $Sc_G = \mu_a/(\rho_a D_a)$ $d_e \text{ (m)} = 2(A/\pi)^{0.5}$
3	$k_l \text{ (m/s)} = [(8.22 \times 10^{-9})(J)(POWR)(1.024)^{(T-20)}(O_t)(10^6) * (MW_L)/(V a_v \rho_L)](D_w/D_{O_2,w})^{0.5}$ <p>where:</p> <p>POWR (hp) = (total power to aerators)(V)</p> <p>$V a_v$ (ft²) = (fraction of area agitated)(A)</p>
4	$k_g \text{ (m/s)} = (1.35 \times 10^{-7})(Re)^{1.42} (P)^{0.4} (Sc_G)^{0.5} (Fr)^{-0.21} (D_a MW_a/d)$ <p>where:</p> $Re = d^2 w \rho_a/\mu_a$ $P = [(0.85)(POWR)(550 \text{ ft-lb}_f/\text{s-hp})/N_t] g_c/(\rho_L(d^*)^5 w^3)$ $Sc_G = \mu_a/(\rho_a D_a)$ $Fr = (d^*)w^2/g_c$
5	$k_l \text{ (m/s)} = (f_{\text{air},l})(Q)/[3600 \text{ s/min} (h_c)(\pi d_c)]$ <p>where:</p> $f_{\text{air},l} = 1 - 1/r$ $r = \exp [0.77(h_c)^{0.623}(Q/\pi d_c)^{0.66}(D_w/D_{O_2,w})^{0.66}]$
6	$k_g \text{ (m/s)} = 0.001 + (0.0462(U^{**}))(Sc_G)^{-0.67}$ <p>where:</p> $U^{**} \text{ (m/s)} = [6.1 + (0.63)(U_{10})]^{0.5}(U_{10}/100)$ $Sc_G = \mu_a/(\rho_a D_a)$

Table 4.3-1 (cont.).

Equation No.	Equation
<u>Overall mass transfer coefficients for water (K) and oil (K_{oil}) phases and for weirs (K_D)</u>	
7	$K = (k_l \text{ Keq } k_g) / (K \text{ eq } k_g + k_l)$ where: $K \text{ eq} = H / (RT)$
8	$K \text{ (m/s)} = \left[\frac{[MW_L / (k_l \rho_L * (100 \text{ cm/m})] + [MW_a / (k_g \rho_a H * 55,555 (100 \text{ cm/m}))]}{MW_L / [(100 \text{ cm/m}) \rho_L]} \right]^{-1} MW_L / [(100 \text{ cm/m}) \rho_L]$
9	$K_{oil} = k_g K \text{ eq}_{oil}$ where: $K \text{ eq}_{oil} = P^* \rho_a MW_{oil} / (\rho_{oil} MW_a P_o)$
10	$K_D = 0.16h (D_w / D_{O2,w})^{0.75}$
<u>Air emissions (N)</u>	
11	$N(g/s) = (1 - Ct/Co) V Co/t$ where: $Ct/Co = \exp[-K A t/V]$
12	$N(g/s) = K C_L A$ where: $C_L(g/m^3) = Q Co / (KA + Q)$
13	$N(g/s) = (1 - Ct/Co) V Co/t$ where: $Ct/Co = \exp[-(KA + K \text{ eq}_a)t/V]$
14	$N(g/s) = (KA + Q_a K \text{ eq}) C_L$ where: $C_L(g/m^3) = Q Co / (KA + Q + Q_a K \text{ eq})$
15	$N(g/s) = (1 - Ct/Co) KA / (KA + K_{max} b_i V / K_s) V Co/t$ where: $Ct/Co = \exp[-K_{max} b_i t / K_s - K A t/V]$
16	$N(g/s) = K C_L A$ where: $C_L(g/m^3) = [-b + (b^2 - 4ac)^{0.5}] / (2a)$ and: $a = KA/Q + 1$ $b = K_s(KA/Q + 1) + K_{max} b_i V/Q - Co$ $c = -K_s Co$

Table 4.3-1 (cont.).

Equation No.	Equation
17	$N(g/s) = (1 - C_{t_{oil}}/C_{o_{oil}})V_{oil}C_{o_{oil}}/t$ <p>where:</p> $C_{t_{oil}}/C_{o_{oil}} = \exp[-K_{oil} t/D_{oil}]$ <p>and:</p> $C_{o_{oil}} = Kow Co/[1 - FO + FO(Kow)]$ $V_{oil} = (FO)(V)$ $D_{oil} = (FO)(V)/A$
18	$N(g/s) = K_{oil}C_{L,oil}A$ <p>where:</p> $C_{L,oil}(g/m^3) = Q_{oil}C_{o_{oil}}/(K_{oil}A + Q_{oil})$ <p>and:</p> $C_{o_{oil}} = Kow Co/[1 - FO + FO(Kow)]$ $Q_{oil} = (FO)(Q)$
19	$N(g/s) = (1 - Ct/Co)(KA + Q_aKeq)/(KA + Q_aKeq + Kmax b_i V/K_s) V Co/t$ <p>where:</p> $Ct/Co = \exp[-(KA + KeqQ_a)t/V - Kmax b_i t/K_s]$
20	$N(g/s) = (KA + Q_aKeq)C_L$ <p>where:</p> $C_L(g/m^3) = [-b + (b^2 - 4ac)^{0.5}]/(2a)$ <p>and:</p> $a = (KA + Q_aKeq)/Q + 1$ $b = K_s[(KA + Q_aKeq)/Q + 1] + Kmax b_i V/Q - Co$ $c = -K_sCo$
21	$N(g/s) = (1 - \exp[-K_D])Q Co$
22	$N(g/s) = K_{oil}C_{L,oil}A$ <p>where:</p> $C_{L,oil}(g/m^3) = Q_{oil}(C_{o_{oil}}^*)/(K_{oil}A + Q_{oil})$ <p>and:</p> $C_{o_{oil}}^* = Co/FO$ $Q_{oil} = (FO)(Q)$
23	$N(g/s) = (1 - C_{t_{oil}}/C_{o_{oil}}^*)(V_{oil})(C_{o_{oil}}^*)/t$ <p>where:</p> $C_{t_{oil}}/C_{o_{oil}}^* = \exp[-K_{oil} t/D_{oil}]$ <p>and:</p> $C_{o_{oil}}^* = Co/FO$ $V_{oil} = (FO)(V)$ $D_{oil} = (FO)(V)/A$
24	$N(g/s) = (1 - \exp[-K \pi d_c h_c/Q])Q Co$

^a All parameters in numbered equations are defined in Table 4.3-2.

Table 4.3-2. PARAMETER DEFINITIONS FOR MASS TRANSFER CORRELATIONS AND EMISSIONS EQUATIONS

Parameter	Definition	Units	Code ^a
A	Waste water surface area	m ² or ft ²	A
b _i	Biomass concentration (total biological solids)	g/m ³	B
C _L	Concentration of constituent in the liquid phase	g/m ³	D
C _{L,oil}	Concentration of constituent in the oil phase	g/m ³	D
Co	Initial concentration of constituent in the liquid phase	g/m ³	A
Co _{oil}	Initial concentration of constituent in the oil phase considering mass transfer resistance between water and oil phases	g/m ³	D
Co _{oil} [*]	Initial concentration of constituent in the oil phase considering no mass transfer resistance between water and oil phases	g/m ³	D
Ct	Concentration of constituent in the liquid phase at time = t	g/m ³	D
Ct _{oil}	Concentration of constituent in the oil phase at time = t	g/m ³	D
d	Impeller diameter	cm	B
D	Waste water depth	m or ft	A,B
d [*]	Impeller diameter	ft	B
D _a	Diffusivity of constituent in air	cm ² /s	C
d _c	Clarifier diameter	m	B
d _e	Effective diameter	m	D
D _{ether}	Diffusivity of ether in water	cm ² /s	(8.5x10 ⁻⁶) ^b
D _{O₂,w}	Diffusivity of oxygen in water	cm ² /s	(2.4x10 ⁻⁵) ^b
D _{oil}	Oil film thickness	m	B
D _w	Diffusivity of constituent in water	cm ² /s	C
f _{air,ℓ}	Fraction of constituent emitted to the air, considering zero gas resistance	dimensionless	D
F/D	Fetch to depth ratio, d _e /D	dimensionless	D
FO	Fraction of volume which is oil	dimensionless	B
Fr	Froude number	dimensionless	D
g _c	Gravitation constant (a conversion factor)	lb _m -ft/s ² -lb _f	32.17

Table 4.3-2 (cont.).

Parameter	Definition	Units	Code ^a
h	Weir height (distance from the waste water overflow to the receiving body of water)	ft	B
h_c	Clarifier weir height	m	B
H	Henry's law constant of constituent	atm-m ³ /gmol	C
J	Oxygen transfer rating of surface aerator	lb O ₂ /(hr-hp)	B
K	Overall mass transfer coefficient for transfer of constituent from liquid phase to gas phase	m/s	D
K_D	Volatilization-re-aeration theory mass transfer coefficient	dimensionless	D
K_{eq}	Equilibrium constant or partition coefficient (concentration in gas phase/concentration in liquid phase)	dimensionless	D
$K_{eq_{oil}}$	Equilibrium constant or partition coefficient (concentration in gas phase/concentration in oil phase)	dimensionless	D
k_g	Gas phase mass transfer coefficient	m/s	D
k_l	Liquid phase mass transfer coefficient	m/s	D
K_{max}	Maximum biorate constant	g/s-g biomass	A,C
K_{oil}	Overall mass transfer coefficient for transfer of constituent from oil phase to gas phase	m/s	D
K_{ow}	Octanol-water partition coefficient	dimensionless	C
K_s	Half saturation biorate constant	g/m ³	A,C
MW_a	Molecular weight of air	g/gmol	29
MW_{oil}	Molecular weight of oil	g/gmol	B
MW_L	Molecular weight of water	g/gmol	18
N	Emissions	g/s	D
N_I	Number of aerators	dimensionless	A,B
O_t	Oxygen transfer correction factor	dimensionless	B
P	Power number	dimensionless	D
P^*	Vapor pressure of the constituent	atm	C
P_o	Total pressure	atm	A
POWR	Total power to aerators	hp	B
Q	Volumetric flow rate	m ³ /s	A

Table 4.3-2 (cont.).

Parameter	Definition	Units	Code ^a
Q_a	Diffused air flow rate	m^3/s	B
Q_{oil}	Volumetric flow rate of oil	m^3/s	B
r	Deficit ratio (ratio of the difference between the constituent concentration at solubility and actual constituent concentration in the upstream and the downstream)	dimensionless	D
R	Universal gas constant	$atm \cdot m^3/gmol \cdot K$	8.21×10^{-5}
Re	Reynolds number	dimensionless	D
Sc_G	Schmidt number on gas side	dimensionless	D
Sc_L	Schmidt number on liquid side	dimensionless	D
T	Temperature of water	$^{\circ}C$ or Kelvin (K)	A
t	Residence time of disposal	s	A
U^*	Friction velocity	m/s	D
U^{**}	Friction velocity	m/s	D
U_{10}	Wind speed at 10 m above the liquid surface	m/s	B
V	Waste water volume	m^3 or ft^3	A
V_{a_v}	Turbulent surface area	ft^2	B
V_{oil}	Volume of oil	m^3	B
w	Rotational speed of impeller	rad/s	B
ρ_a	Density of air	g/cm^3	$(1.2 \times 10^{-3})^b$
ρ_L	Density of water	g/cm^3 or lb/ft^3	1^b or 62.4^b
ρ_{oil}	Density of oil	g/m^3	B
μ_a	Viscosity of air	$g/cm \cdot s$	$(1.81 \times 10^{-4})^b$
μ_L	Viscosity of water	$g/cm \cdot s$	$(8.93 \times 10^{-3})^b$

^a Code:

A = Site-specific parameter.

B = Site-specific parameter. For default values, see Table 4.3-3.

C = Parameter can be obtained from literature. See Attachment 1 for a list of ~150 compound chemical properties at $T = 25^{\circ}C$ ($298^{\circ}K$).

D = Calculated value.

^b Reported values at $25^{\circ}C$ ($298^{\circ}K$).

Table 4.3-3. SITE-SPECIFIC DEFAULT PARAMETERS^a

Default Parameter ^b	Definition	Default Value
General		
T	Temperature of water	298°K
U ₁₀	Windspeed	4.47 m/s
Biotreatment Systems		
b _i	Biomass concentration (for biologically active systems)	
	Quiescent treatment systems	50 g/m ³
	Aerated treatment systems	300 g/m ³
	Activated sludge units	4000 g/m ³
POWR	Total power to aerators (for aerated treatment systems) (for activated sludge)	0.75 hp/1000 ft ³ (V) 2 hp/1000 ft ³ (V)
W	Rotational speed of impeller (for aerated treatment systems)	126 rad/s (1200 rpm)
d(d [*])	Impeller diameter (for aerated treatment systems)	61 cm (2 ft)
Va _v	Turbulent surface area (for aerated treatment systems)	0.24 (A)
	(for activated sludge)	0.52 (A)
J	Oxygen transfer rating to surface aerator (for aerated treatment systems)	3 lb O ₂ /hp•hr
O _t	Oxygen transfer correction factor (for aerated treatment systems)	0.83
N _I	Number of aerators	POWR/75
Diffused Air Systems		
Q _a	Diffused air volumetric flow rate	0.0004(V) m ³ /s
Oil Film Layers		
MW _{oil}	Molecular weight of oil	282 g/gmol
D _{oil}	Depth of oil layer	0.001 (V/A) m
V _{oil}	Volume of oil	0.001 (V) m ³
Q _{oil}	Volumetric flow rate of oil	0.001 (Q) m ³ /s
ρ _{oil}	Density of oil	0.92 g/cm ³

Table 4.3-3 (cont.).

Default Parameter ^b	Definition	Default Value
FO	Fraction of volume which is oil ^c	0.001
Junction Boxes		
D	Depth of Junction Box	0.9 m
N _I	Number of aerators	1
Lift Station		
D	Depth of Lift Station	1.5 m
N _I	Number of aerators	1
Sump		
D	Depth of sump	5.9 m
Weirs		
d _c	Clarifier weir diameter ^d	28.5 m
h	Weir height	1.8 m
h _c	Clarifier weir height ^e	0.1 m

^a Reference 1.

^b As defined in Table 4.3-2.

^c Reference 4.

^d Reference 2.

^e Reference 5.

Waste water falls or overflows from weirs and creates splashing in the receiving body of water (both weir and clarifier weir models). Waste water from weirs can be aerated by directing it to fall over steps, usually only the weir model.

Assessing VOC emissions from drains, manholes, and trenches is also important in determining the total waste water facility emissions. As these sources can be open to the atmosphere and closest to the point of waste water generation (i. e., where water temperatures and pollutant concentrations are greatest), emissions can be significant. Currently, there are no well-established emission models for these collection system types. However, work is being performed to address this need.

Preliminary models of VOC emissions from waste collection system units have been developed.⁴ The emission equations presented in Reference 4 are used with standard collection system parameters to estimate the fraction of the constituents released as the waste water flows through each unit. The fractions released from several units are estimated for high-, medium-, and low-volatility compounds. The units used in the estimated fractions included open drains, manhole covers, open trench drains, and covered sumps.

The numbers in Figure 4.3-4 under the columns for k_l , k_g , K_{oil} , K_D , K , and N refer to the appropriate equations in Table 4.3-1.^a Definitions for all parameters in these equations are given in Table 4.3-2. Table 4.3-2 also supplies the units that must be used for each parameter, with codes to help locate input values. If the parameter is coded with the letter A, a site-specific value is required. Code B also requires a site-specific parameter, but defaults are available. These defaults are typical or average values and are presented by specific system in Table 4.3-3.

Code C means the parameter can be obtained from literature data. Table 4.3-4 contains a list of approximately 150 chemicals and their physical properties needed to calculate emissions from waste water, using the correlations presented in Table 4.3-1. All properties are at 25°C (77°F). A more extensive chemical properties data base is contained in Appendix C of Reference 1.) Parameters coded D are calculated values.

Calculating air emissions from waste water collection, treatment, and storage systems is a complex procedure, especially if several systems are present. Performing the calculations by hand may result in errors and will be time consuming. A personal computer program called the Surface Impoundment Modeling System (SIMS) is now available for estimating air emissions. The program is menu driven and can estimate air emissions from all surface impoundment models presented in Figure 4.3-4, individually or in series. The program requires for each collection, treatment, or storage system component, at a minimum, the waste water flow rate and component surface area. All other inputs are provided as default values. Any available site-specific information should be entered in place of these defaults, as the most fully characterized system will provide the most accurate emissions estimate.

The SIMS program with user's manual and background technical document can be obtained through state air pollution control agencies and through the U. S. Environmental Protection Agency's Control Technology Center in Research Triangle Park, NC, telephone (919) 541-0800. The user's manual and background technical document should be followed to produce meaningful results.

The SIMS program and user's manual also can be downloaded from EPA's Clearinghouse For Inventories and Emission Factors (CHIEF) electronic bulletin board (BB). The CHIEF BB is open to all persons involved in air emission inventories. To access this BB, one needs a computer, modem, and communication package capable of communicating at up to 14,400 baud, 8 data bits, 1 stop bit, and no parity (8-N-1). This BB is part of EPA's OAQPS Technology Transfer Network system and its telephone number is (919) 541-5742. First-time users must register before access is allowed.

Emissions estimates from SIMS are based on mass transfer models developed by Emissions Standards Division (ESD) during evaluations of TSDFs and VOC emissions from industrial waste water. As a part of the TSDF project, a Lotus[®] spreadsheet program called CHEMDAT7 was developed for estimating VOC emissions from waste water land treatment systems, open landfills, closed landfills, and waste storage piles, as well as from various types of surface impoundments. For more information about CHEMDAT7, contact the ESD's Chemicals And Petroleum Branch (MD 13), US EPA, Research Triangle Park, NC 27711.

^aAll emission model systems presented in Figure 4.3-4 imply a completely mixed or uniform waste water concentration system. Emission models for a plug flow system, or system in which there is no axial, or horizontal mixing, are too extensive to be covered in this document. (An example of plug flow might be a high waste water flow in a narrow channel.) For information on emission models of this type, see Reference 1.

4.3.2.1 Example Calculation -

An example industrial facility operates a flowthrough, mechanically aerated biological treatment impoundment that receives waste water contaminated with benzene at a concentration of 10.29 g/m^3 .

The following format is used for calculating benzene emissions from the treatment process:

- I. Determine which emission model to use
- II. User-supplied information
- III. Defaults
- IV. Pollutant physical property data and water, air, and other properties
- V. Calculate individual mass transfer coefficient
- VI. Calculate the overall mass transfer coefficients
- VII. Calculate VOC emissions

- I. Determine Which Emission Model To Use — Following the flow diagram in Figure 4.3-4, the emission model for a treatment system that is aerated, but not by diffused air, is biologically active, and is a flowthrough system, contains the following equations:

Parameter	Definition	Equation Nos. from Table 4.3-1
K	Overall mass transfer coefficient, m/s	7
k_l	Individual liquid phase mass transfer coefficient, m/s	1,3
k_g	Individual gas phase mass transfer coefficient, m/s	2,4
N	VOC emissions, g/s	16

- II. User-supplied Information — Once the correct emission model is determined, some site-specific parameters are required. As a minimum for this model, site-specific flow rate, waste water surface area and depth, and pollutant concentration should be provided. For this example, these parameters have the following values:

$$Q = \text{Volumetric flow rate} = 0.0623 \text{ m}^3/\text{s}$$

$$D = \text{Waste water depth} = 1.97 \text{ m}$$

$$A = \text{Waste water surface area} = 17,652 \text{ m}^2$$

$$C_o = \text{Initial benzene concentration in the liquid phase} = 10.29 \text{ g/m}^3$$

- III. Defaults — Defaults for some emission model parameters are presented in Table 4.3-3. Generally, site-specific values should be used when available. For this facility, all available general and biotreatment system defaults from Table 4.3-3 were used:

$$U_{10} = \text{Wind speed at 10 m above the liquid surface} = e = 4.47 \text{ m/s}$$

$$T = \text{Temperature of water} = 25^\circ\text{C} \text{ (298}^\circ\text{K)}$$

$$b_1 = \text{Biomass concentration for aerated treatment systems} = 300 \text{ g/m}^3$$

$$J = \text{Oxygen transfer rating to surface aerator} = 3 \text{ lb O}_2/\text{hp-hr}$$

$$\text{POWR} = \text{Total power to aerators} = 0.75 \text{ hp/1,000 ft}^3 \text{ (V)}$$

$$O_t = \text{Oxygen transfer correction factor} = 0.83$$

$$V_{a_v} = \text{Turbulent surface area} = 0.24 \text{ (A)}$$

$$d = \text{Impeller diameter} = 61 \text{ cm}$$

$$d^* = \text{Impeller diameter} = 2 \text{ ft}$$

$$w = \text{Rotational speed of impeller} = 126 \text{ rad/s}$$

$$N_I = \text{Number of aerators} = \text{POWR}/75 \text{ hp}$$

IV. Pollutant Physical Property Data, And Water, Air and Other Properties — For each pollutant, the specific physical properties needed by this model are listed in Table 4.3-4. Water, air, and other property values are given in Table 4.3-2.

A. Benzene (from Table 4.3-4)

$$D_{w,\text{benzene}} = \text{Diffusivity of benzene in water} = 9.8 \times 10^{-6} \text{ cm}^2/\text{s}$$

$$D_{a,\text{benzene}} = \text{Diffusivity of benzene in air} = 0.088 \text{ cm}^2/\text{s}$$

$$H_{\text{benzene}} = \text{Henry's law constant for benzene} = 0.0055 \text{ atm} \cdot \text{m}^3/\text{gmol}$$

$$K_{\text{max},\text{benzene}} = \text{Maximum biorate constant for benzene} = 5.28 \times 10^{-6} \text{ g/g-s}$$

$$K_{s,\text{benzene}} = \text{Half saturation biorate constant for benzene} = 13.6 \text{ g/m}^3$$

B. Water, Air, and Other Properties (from Table 4.3-3)

$$\rho_a = \text{Density of air} = 1.2 \times 10^{-3} \text{ g/cm}^3$$

$$\rho_L = \text{Density of water} = 1 \text{ g/cm}^3 \text{ (62.4 lb}_m/\text{ft}^3)$$

$$\mu_a = \text{Viscosity of air} = 1.81 \times 10^{-4} \text{ g/cm-s}$$

$$D_{O_2,w} = \text{Diffusivity of oxygen in water} = 2.4 \times 10^{-5} \text{ cm}^2/\text{s}$$

$$D_{\text{ether}} = \text{Diffusivity of ether in water} = 8.5 \times 10^{-6} \text{ cm}^2/\text{s}$$

$$MW_L = \text{Molecular weight of water} = 18 \text{ g/gmol}$$

$$MW_a = \text{Molecular weight of air} = 29 \text{ g/gmol}$$

$$g_c = \text{Gravitation constant} = 32.17 \text{ lb}_m\text{-ft/lb}_f\text{-s}^2$$

$$R = \text{Universal gas constant} = 8.21 \times 10^{-5} \text{ atm}\cdot\text{m}^3/\text{gmol}$$

V. Calculate Individual Mass Transfer Coefficients — Because part of the impoundment is turbulent and part is quiescent, individual mass transfer coefficients are determined for both turbulent and quiescent areas of the surface impoundment.

Turbulent area of impoundment — Equations 3 and 4 from Table 4.3-1.

A. Calculate the individual liquid mass transfer coefficient, k_l :

$$k_l(\text{m/s}) = [(8.22 \times 10^{-9})(J)(\text{POWR})(1.024)^{(T-20)} * \\ (O_t)(10^6)MW_L/(V_a v \rho_L)](D_w/D_{O_2,w})^{0.5}$$

The total power to the aerators, POWR, and the turbulent surface area, $V_a v$, are calculated separately [Note: some conversions are necessary.]:

1. Calculate total power to aerators, POWR (Default presented in III):

$$\text{POWR (hp)} = 0.75 \text{ hp}/1,000 \text{ ft}^3 (V)$$

$$V = \text{waste water volume, m}^3$$

$$V (\text{m}^3) = (A)(D) = (17,652 \text{ m}^2)(1.97 \text{ m})$$

$$V = 34,774 \text{ m}^3$$

$$\text{POWR} = (0.75 \text{ hp}/1,000 \text{ ft}^3)(\text{ft}^3/0.028317 \text{ m}^3)(34,774 \text{ m}^3)$$

$$= 921 \text{ hp}$$

2. Calculate turbulent surface area, $V_a v$ (default presented in III):

$$V_a v (\text{ft}^2) = 0.24 (A)$$

$$= 0.24(17,652 \text{ m}^2)(10.758 \text{ ft}^2/\text{m}^2)$$

$$= 45,576 \text{ ft}^2$$

Now, calculate k_l , using the above calculations and information from II, III, and IV:

$$\begin{aligned} k_l \text{ (m/s)} &= [(8.22 \times 10^{-9})(3 \text{ lb O}_2/\text{hp-hr})(921 \text{ hp}) * \\ &\quad (1.024)^{(25-20)}(0.83)(10^6)(18 \text{ g/gmol})/ \\ &\quad ((45,576 \text{ ft}^2)(1 \text{ g/cm}^3))] * \\ &\quad [(9.8 \times 10^{-6} \text{ cm}^2/\text{s})/(2.4 \times 10^{-5} \text{ cm}^2/\text{s})]^{0.5} \\ &= (0.00838)(0.639) \\ k_l &= 5.35 \times 10^{-3} \text{ m/s} \end{aligned}$$

B. Calculate the individual gas phase mass transfer coefficient, k_g :

$$k_g \text{ (m/s)} = (1.35 \times 10^{-7})(\text{Re})^{1.42}(\text{P})^{0.4}(\text{Sc}_G)^{0.5}(\text{Fr})^{-0.21}(\text{D}_a \text{ MW}_a/d)$$

The Reynolds number, Re, power number, P, Schmidt number on the gas side, Sc_G , and Froude's number Fr, are calculated separately:

1. Calculate Reynolds number, Re:

$$\begin{aligned} \text{Re} &= d^2 w \rho_a / \mu_a \\ &= (61 \text{ cm})^2 (126 \text{ rad/s})(1.2 \times 10^{-3} \text{ g/cm}^3) / (1.81 \times 10^{-4} \text{ g/cm-s}) \\ &= 3.1 \times 10^6 \end{aligned}$$

2. Calculate power number, P:

$$\begin{aligned} \text{P} &= [(0.85)(\text{POWR})(550 \text{ ft-lb}_f/\text{s-hp})/N_I] g_c / (\rho_L (d^*)^5 w^3) \\ N_I &= \text{POWR}/75 \text{ hp (default presented in III)} \\ \text{P} &= (0.85)(75 \text{ hp})(\text{POWR}/\text{POWR})(550 \text{ ft-lb}_f/\text{s-hp}) * \\ &\quad (32.17 \text{ lb}_m\text{-ft}/\text{lb}_f\text{-s}^2) / [(62.4 \text{ lb}_m/\text{ft}^3)(2 \text{ ft})^5 (126 \text{ rad/s})^3] \\ &= 2.8 \times 10^{-4} \end{aligned}$$

3. Calculate Schmidt number on the gas side, Sc_G :

$$\begin{aligned} \text{Sc}_G &= \mu_a / (\rho_a \text{D}_a) \\ &= (1.81 \times 10^{-4} \text{ g/cm-s}) / [(1.2 \times 10^{-3} \text{ g/cm}^3)(0.088 \text{ cm}^2/\text{s})] \\ &= 1.71 \end{aligned}$$

4. Calculate Froude number, Fr:

$$\begin{aligned} \text{Fr} &= (d^*)w^2/g_c \\ &= (2 \text{ ft})(126 \text{ rad/s})^2 / (32.17 \text{ lb}_m\text{-ft}/\text{lb}_f\text{-s}^2) \\ &= 990 \end{aligned}$$

Now, calculate k_g using the above calculations and information from II, III, and IV:

$$\begin{aligned} k_g \text{ (m/s)} &= (1.35 \times 10^{-7})(3.1 \times 10^6)^{1.42}(2.8 \times 10^{-4})^{0.4}(1.71)^{0.5} * \\ &\quad (990)^{-0.21}(0.088 \text{ cm}^2/\text{s})(29 \text{ g/gmol})/(61 \text{ cm}) \\ &= 0.109 \text{ m/s} \end{aligned}$$

Quiescent surface area of impoundment — Equations 1 and 2 from Table 4.3-1

A. Calculate the individual liquid phase mass transfer coefficient, k_l :

$$\begin{aligned} F/D &= 2(A/\pi)^{0.5}/D \\ &= 2(17,652 \text{ m}^2/\pi)^{0.5}/(1.97 \text{ m}) \\ &= 76.1 \\ U_{10} &= 4.47 \text{ m/s} \end{aligned}$$

For $U_{10} > 3.25$ m/s and $F/D > 51.2$ use the following:

$$\begin{aligned} k_l \text{ (m/s)} &= (2.61 \times 10^{-7})(U_{10})^2(D_w/D_{\text{ether}})^{2/3} \\ &= (2.61 \times 10^{-7})(4.47 \text{ m/s})^2[(9.8 \times 10^{-6} \text{ cm}^2/\text{s})/ \\ &\quad (8.5 \times 10^{-6} \text{ cm}^2/\text{s})]^{2/3} \\ &= 5.74 \times 10^{-6} \text{ m/s} \end{aligned}$$

B. Calculate the individual gas phase mass transfer coefficient, k_g :

$$k_g = (4.82 \times 10^{-3})(U_{10})^{0.78}(Sc_G)^{-0.67}(d_e)^{-0.11}$$

The Schmidt number on the gas side, Sc_G , and the effective diameter, d_e , are calculated separately:

1. Calculate the Schmidt number on the gas side, Sc_G :

$$Sc_G = \mu_a/(\rho_a D_a) = 1.71 \text{ (same as for turbulent impoundments)}$$

2. Calculate the effective diameter, d_e :

$$\begin{aligned} d_e \text{ (m)} &= 2(A/\pi)^{0.5} \\ &= 2(17,652 \text{ m}^2/\pi)^{0.5} \\ &= 149.9 \text{ m} \\ k_g \text{ (m/s)} &= (4.82 \times 10^{-3})(4.47 \text{ m/s})^{0.78} (1.71)^{-0.67} (149.9 \text{ m})^{-0.11} \\ &= 6.24 \times 10^{-3} \text{ m/s} \end{aligned}$$

VI. Calculate The Overall Mass Transfer Coefficient — Because part of the impoundment is turbulent and part is quiescent, the overall mass transfer coefficient is determined as an area-weighted average of the turbulent and quiescent overall mass transfer coefficients. (Equation 7 from Table 4.3-1).

Overall mass transfer coefficient for the turbulent surface area of impoundment, K_T

$$\begin{aligned} K_T \text{ (m/s)} &= (k_l Keq k_g)/(Keq k_g + k_l) \\ Keq &= H/RT \\ &= (0.0055 \text{ atm}\cdot\text{m}^3/\text{gmol})/[(8.21 \times 10^{-5} \text{ atm}\cdot\text{m}^3/\text{gmol}\cdot^\circ\text{K})(298^\circ\text{K})] \\ &= 0.225 \\ K_T \text{ (m/s)} &= (5.35 \times 10^{-3} \text{ m/s})(0.225)(0.109)/[(0.109 \text{ m/s})(0.225) + \\ &\quad (5.35 \times 10^{-6} \text{ m/s})] \\ K_T &= 4.39 \times 10^{-3} \text{ m/s} \end{aligned}$$

Overall mass transfer coefficient for the quiescent surface area of impoundment, K_Q

$$\begin{aligned} K_Q \text{ (m/s)} &= (k_l Keq k_g)/(Keq k_g + k_l) \\ &= (5.74 \times 10^{-6} \text{ m/s})(0.225)(6.24 \times 10^{-3} \text{ m/s})/ \\ &\quad [(6.24 \times 10^{-3} \text{ m/s})(0.225) + (5.74 \times 10^{-6} \text{ m/s})] \\ &= 5.72 \times 10^{-6} \text{ m/s} \end{aligned}$$

Overall mass transfer coefficient, K , weighted by turbulent and quiescent surface areas, A_T and A_Q

$$\begin{aligned} K \text{ (m/s)} &= (K_T A_T + K_Q A_Q)/A \\ A_T &= 0.24(A) \text{ (Default value presented in III: } A_T = Va_v) \\ A_Q &= (1 - 0.24)A \\ K \text{ (m/s)} &= [(4.39 \times 10^{-3} \text{ m/s})(0.24 A) + (5.72 \times 10^{-6} \text{ m/s})(1 - 0.24)A]/A \\ &= 1.06 \times 10^{-3} \text{ m/s} \end{aligned}$$

VII. Calculate VOC Emissions For An Aerated Biological Flowthrough Impoundment — Equation 16 from Table 4.3-1:

$$N \text{ (g/s)} = K C_L A$$

where:

$$C_L \text{ (g/m}^3\text{)} = [-b + (b^2 - 4ac)^{0.5}]/(2a)$$

and:

$$\begin{aligned} a &= KA/Q + 1 \\ b &= K_s(KA/Q + 1) + K_{max} b_i V/Q - C_o \\ c &= -K_s C_o \end{aligned}$$

Calculate a, b, c, and the concentration of benzene in the liquid phase, C_L , separately:

1. Calculate a:

$$\begin{aligned} a &= (KA/Q + 1) = [(1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)/(0.0623 \text{ m}^3/\text{s})] + 1 \\ &= 301.3 \end{aligned}$$

2. Calculate b ($V = 34,774 \text{ m}^3$ from IV):

$$\begin{aligned} b &= K_s (KA/Q + 1) + K_{max} b_i V/Q - C_o \\ &= (13.6 \text{ g/m}^3)[(1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)/(0.0623 \text{ m}^3/\text{s})] + \\ &\quad [(5.28 \times 10^{-6} \text{ g/g-s})(300 \text{ g/m}^3)(34,774 \text{ m}^3)/(0.0623 \text{ m}^3/\text{s})] - 10.29 \text{ g/m}^3 \\ &= 4,084.6 + 884.1 - 10.29 \\ &= 4,958.46 \text{ g/m}^3 \end{aligned}$$

3. Calculate c:

$$\begin{aligned} c &= -K_s C_o \\ &= -(13.6 \text{ g/m}^3)(10.29 \text{ g/m}^3) \\ &= -139.94 \end{aligned}$$

4. Calculate the concentration of benzene in the liquid phase, C_L , from a, b, and c above:

$$\begin{aligned} C_L \text{ (g/m}^3\text{)} &= [-b + (b^2 - 4ac)^{0.5}]/(2a) \\ &= [(4,958.46 \text{ g/m}^3) + [(4,958.46 \text{ g/m}^3)^2 - \\ &\quad [4(301.3)(-139.94)]]^{0.5}]/(2(301.3)) \\ &= 0.0282 \text{ g/m}^3 \end{aligned}$$

Now calculate N with the above calculations and information from II and V:

$$\begin{aligned} N \text{ (g/s)} &= K A C_L \\ &= (1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)(0.0282 \text{ g/m}^3) \\ &= 0.52 \text{ g/s} \end{aligned}$$

4.3.3 Controls

The types of control technology generally used in reducing VOC emissions from waste water include: steam stripping or air stripping, carbon adsorption (liquid phase), chemical oxidation, membrane separation, liquid-liquid extraction, and biotreatment (aerobic or anaerobic). For efficient control, all control elements should be placed as close as possible to the point of waste water generation, with all collection, treatment, and storage systems ahead of the control technology being covered to suppress emissions. Tightly covered, well-maintained collection systems can suppress

emissions by 95 to 99 percent. However, if there is explosion potential, the components should be vented to a control device such as an incinerator or carbon adsorber.

The following are brief descriptions of the control technology listed above and of any secondary controls that may need to be considered for fugitive air emissions.

Steam stripping is the fractional distillation of waste water to remove volatile organic constituents, with the basic operating principle being the direct contact of steam with waste water. The steam provides the heat of vaporization for the more volatile organic constituents. Removal efficiencies vary with volatility and solubility of the organic impurities. For highly volatile compounds (HLC greater than 10^{-3} atm-m³/gmol), average VOC removal ranges from 95 to 99 percent. For medium-volatility compounds (HLC between 10^{-5} and 10^{-3} atm-m³/gmol), average removal ranges from 90 to 95 percent. For low-volatility compounds (HLC $<10^{-5}$ atm-m³/gmol), average removal ranges from less than 50 to 90 percent.

Air stripping involves the contact of waste water and air to strip out volatile organic constituents. By forcing large volumes of air through contaminated water, the surface area of water in contact with air is greatly increased, resulting in an increase in the transfer rate of the organic compounds into the vapor phase. Removal efficiencies vary with volatility and solubility of organic impurities. For highly volatile compounds, average removal ranges from 90 to 99 percent; for medium- to low-volatility compounds, removal ranges from less than 50 to 90 percent.

Steam stripping and air stripping controls most often are vented to a secondary control, such as a combustion device or gas phase carbon adsorber. Combustion devices may include incinerators, boilers, and flares. Vent gases of high fuel value can be used as an alternate fuel. Typically, vent gas is combined with other fuels such as natural gas and fuel oil. If the fuel value is very low, vent gases can be heated and combined with combustion air. It is important to note that organics such as chlorinated hydrocarbons can emit toxic pollutants when combusted.

Secondary control by gas phase carbon adsorption processes takes advantage of compound affinities for activated carbon. The types of gas phase carbon adsorption systems most commonly used to control VOC are fixed-bed carbon adsorbers and carbon canisters. Fixed-bed carbon adsorbers are used to control continuous organic gas streams with flow rates ranging from 30 to over 3000 m³/min. Canisters are much simpler and smaller than fixed-bed systems and are usually installed to control gas flows of less than 3 m³/min.⁴ Removal efficiencies depend highly on the type of compound being removed. Pollutant-specific activated carbon is usually required. Average removal efficiency ranges from 90 to 99 percent.

Like gas phase carbon adsorption, liquid phase carbon adsorption takes advantage of compound affinities for activated carbon. Activated carbon is an excellent adsorbent, because of its large surface area and because it is usually in granular or powdered form for easy handling. Two types of liquid phase carbon adsorption are the fixed-bed and moving-bed systems. The fixed-bed system is used primarily for low-flow waste water streams with contact times around 15 minutes, and it is a batch operation (i. e., once the carbon is spent, the system is taken off line). Moving-bed carbon adsorption systems operate continuously with waste water typically being introduced from the bottom of the column and regenerated carbon from the top (countercurrent flow). Spent carbon is continuously removed from the bottom of the bed. Liquid phase carbon adsorption is usually used for low concentrations of nonvolatile components and for high concentrations of nondegradable compounds.⁵ Removal efficiencies depend on whether the compound is adsorbed on activated carbon. Average removal efficiency ranges from 90 to 99 percent.

Chemical oxidation involves a chemical reaction between the organic compound and an oxidant such as ozone, hydrogen peroxide, permanganate, or chlorine dioxide. Ozone is usually added to the waste water through an ultraviolet-ozone reactor. Permanganate and chlorine dioxide are added directly into the waste water. It is important to note that adding chlorine dioxide can form chlorinated hydrocarbons in a side reaction. The applicability of this technique depends on the reactivity of the individual organic compound.

Two types of membrane separation processes are ultrafiltration and reverse osmosis. Ultrafiltration is primarily a physical sieving process driven by a pressure gradient across the membrane. This process separates organic compounds with molecular weights greater than 2000, depending on the size of the membrane pore. Reverse osmosis is the process by which a solvent is forced across a semipermeable membrane because of an osmotic pressure gradient. Selectivity is, therefore, based on osmotic diffusion properties of the compound and on the molecular diameter of the compound and membrane pores.⁴

Liquid-liquid extraction as a separation technique involves differences in solubility of compounds in various solvents. Contacting a solution containing the desired compound with a solvent in which the compound has a greater solubility may remove the compound from the solution. This technology is often used for product and process solvent recovery. Through distillation, the target compound is usually recovered, and the solvent reused.

Biotreatment is the aerobic or anaerobic chemical breakdown of organic chemicals by microorganisms. Removal of organics by biodegradation is highly dependent on the compound's biodegradability, its volatility, and its ability to be adsorbed onto solids. Removal efficiencies range from almost zero to 100 percent. In general, highly volatile compounds such as chlorinated hydrocarbons and aromatics will biodegrade very little because of their high-volatility, while alcohols and other compounds soluble in water, as well as low-volatility compounds, can be almost totally biodegraded in an acclimated system. In the acclimated biotreatment system, the microorganisms easily convert available organics into biological cells, or biomass. This often requires a mixed culture of organisms, where each organism utilizes the food source most suitable to its metabolism. The organisms will starve and the organics will not be biodegraded if a system is not acclimated, i. e., the organisms cannot metabolize the available food source.

4.3.4 Glossary Of Terms

- Basin - an earthen or concrete-lined depression used to hold liquid.
- Completely mixed - having the same characteristics and quality throughout or at all times.
- Disposal - the act of permanent storage. Flow of liquid into, but not out of a device.
- Drain - a device used for the collection of liquid. It may be open to the atmosphere or be equipped with a seal to prevent emissions of vapors.
- Flowthrough - having a continuous flow into and out of a device.
- Plug flow - having characteristics and quality not uniform throughout. These will change in the direction the fluid flows, but not perpendicular to the direction of flow (i. e., no axial movement)

- Storage - any device to accept and retain a fluid for the purpose of future discharge. Discontinuity of flow of liquid into and out of a device.
- Treatment - the act of improving fluid properties by physical means. The removal of undesirable impurities from a fluid.
- VOC - volatile organic compounds, referring to all organic compounds except the following, which have been shown not to be photochemically reactive: methane, ethane, trichlorotrifluoroethane, methylene chloride, 1,1,1-trichloroethane, trichlorofluoromethane, dichlorodifluoromethane, chlorodifluoromethane, trifluoromethane, dichlorotetrafluoroethane, and chloropentafluoroethane.

Table 4.3-4. SIMS CHEMICAL PROPERTY DATA FILE (PART 1)

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
ACETALDEHYDE	75-07-0	44.00	760	0.000095	0.0000141	0.124
ACETIC ACID	64-19-7	60.05	15.4	0.0627	0.000012	0.113
ACETIC ANHYDRIDE	108-24-7	102.09	5.29	0.00000591	0.00000933	0.235
ACETONE	67-64-1	58.00	266	0.000025	0.0000114	0.124
ACETONITRILE	75-05-8	41.03	90	0.0000058	0.0000166	0.128
ACROLEIN	107-02-8	56.10	244.2	0.0000566	0.0000122	0.105
ACRYLAMIDE	79-06-1	71.09	0.012	0.00000000052	0.0000106	0.097
ACRYLIC ACID	79-10-7	72.10	5.2	0.0000001	0.0000106	0.098
ACRYLONITRILE	107-13-1	53.10	114	0.000088	0.0000134	0.122
ADIPIC ACID	124-04-9	146.14	0.0000225	0.00000000005	0.00000684	0.0659
ALLYL ALCOHOL	107-18-6	58.10	23.3	0.000018	0.0000114	0.114
AMINOPHENOL(-O)	95-55-6	109.12	0.511	0.00000367	0.00000864	0.0774
AMINOPHENOL(-P)	123-30-8	109.12	0.893	0.0000197	0.00000239	0.0774
AMMONIA	7664-41-7	17.03	7470	0.000328	0.0000693	0.259
AMYL ACETATE(-N)	628-37-8	130.18	5.42	0.000464	0.0000012	0.064
ANILINE	62-53-3	93.10	1	0.0000026	0.0000083	0.07
BENZENE	71-43-2	78.10	95.2	0.0055	0.0000098	0.088
BENZO(A)ANTHRACENE	56-55-3	228.30	0.00000015	0.00000000138	0.000009	0.051
BENZO(A)PYRENE	50-32-8	252.30	0.00568	0.00000000138	0.000009	0.043

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
CRESYLIC ACID	1319-77-3	108.00	0.3	0.0000017	0.0000083	0.074
CROTONALDEHYDE	4170-30-0	70.09	30	0.00000154	0.0000102	0.0903
CUMENE (ISOPROPYLBENZENE)	98-82-8	120.20	4.6	0.0146	0.0000071	0.065
CYCLOHEXANE	110-82-7	84.20	100	0.0137	0.0000091	0.0839
CYCLOHEXANOL	108-93-0	100.20	1.22	0.00000447	0.00000831	0.214
CYCLOHEXANONE	108-94-1	98.20	4.8	0.00000413	0.00000862	0.0784
DI-N-OCTYL PHTHALATE	117-84-0	390.62	0	0.137	0.0000041	0.0409
DIBUTYLPHTHALATE	84-74-2	278.30	0.00001	0.00000028	0.0000079	0.0438
DICHLORO(-2)BUTENE(1,4)	764-41-0	125.00	2.87	0.000259	0.00000812	0.0725
DICHLOROBENZENE(1,2) (-O)	95-50-1	147.00	1.5	0.00194	0.0000079	0.069
DICHLOROBENZENE(1,3) (-M)	541-73-1	147.00	2.28	0.00361	0.0000079	0.069
DICHLOROBENZENE(1,4) (-P)	106-46-7	147.00	1.2	0.0016	0.0000079	0.069
DICHLORODIFLUOROMETHANE	75-71-8	120.92	5000	0.401	0.00001	0.0001
DICHLOROETHANE(1,1)	75-34-3	99.00	234	0.00554	0.0000105	0.0914
DICHLOROETHANE(1,2)	107-06-2	99.00	80	0.0012	0.0000099	0.104
DICHLOROETHYLENE(1,2)	156-54-2	96.94	200	0.0319	0.000011	0.0935
DICHLOROPHENOL(2,4)	120-83-2	163.01	0.1	0.0000048	0.0000076	0.0709
DICHLOROPHENOXYACETIC ACID(2,4)	94-75-7	221.00	290	0.0621	0.00000649	0.0588
DICHLOROPROPANE(1,2)	78-87-5	112.99	40	0.0023	0.0000087	0.0782
DIETHYL (N,N) ANILIN	91-66-7	149.23	0.00283	0.0000000574	0.00000587	0.0513

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
DIETHYL PHTHALATE	84-66-2	222.00	0.003589	0.0111	0.0000058	0.0542
DIMETHYL FORMAMIDE	68-12-2	73.09	4	0.0000192	0.0000103	0.0939
DIMETHYL HYDRAZINE(1,1)	57-14-7	60.10	157	0.000124	0.0000109	0.106
DIMETHYL PHTHALATE	131-11-3	194.20	0.000187	0.00000215	0.0000063	0.0568
DIMETHYLBENZ(A)ANTHRACENE	57-97-6	256.33	0	0.0000000027	0.00000498	0.0461
DIMETHYLPHENOL(2,4)	105-67-9	122.16	0.0573	0.000921	0.0000084	0.0712
DINITROBENZENE (-M)	99-65-0	168.10	0.05	0.000022	0.00000764	0.279
DINITROTOLUENE(2,4)	121-14-2	182.10	0.0051	0.00000407	0.00000706	0.203
DIOXANE(1,4)	123-91-1	88.20	37	0.0000231	0.0000102	0.229
DIOXIN	NOCAS2	322.00	0	0.0000812	0.0000056	0.104
DIPHENYLAMINE	122-39-4	169.20	0.00375	0.00000278	0.00000631	0.058
EPICHLOROHYDRIN	106-89-8	92.50	17	0.0000323	0.0000098	0.086
ETHANOL	64-17-5	46.10	50	0.0000303	0.000013	0.123
ETHANOLAMINE(MONO-)	141-43-5	61.09	0.4	0.000000322	0.0000114	0.107
ETHYL ACRYLATE	140-88-5	100.00	40	0.00035	0.0000086	0.077
ETHYL CHLORIDE	75-00-3	64.52	1200	0.014	0.0000115	0.271
ETHYL-(2)PROPYL-(3) ACROLEIN	645-62-5	92.50	17	0.0000323	0.0000098	0.086
ETHYLACETATE	141-78-6	88.10	100	0.000128	0.00000966	0.0732
ETHYLBENZENE	100-41-4	106.20	10	0.00644	0.0000078	0.075
ETHYLENEOXIDE	75-21-8	44.00	1250	0.000142	0.0000145	0.104

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
ETHYLETHER	60-29-7	74.10	520	0.00068	0.0000093	0.074
FORMALDEHYDE	50-00-0	30.00	3500	0.0000576	0.0000198	0.178
FORMIC ACID	64-18-6	46.00	42	0.0000007	0.00000137	0.079
FREONS	NOCAS3	120.92	5000	0.401	0.00001	0.104
FURAN	110-00-9	68.08	596	0.00534	0.0000122	0.104
FURFURAL	96-01-1	96.09	2	0.0000811	0.0000104	0.0872
HEPTANE (ISO)	142-82-5	100.21	66	1.836	0.00000711	0.187
HEXACHLOROBENZENE	118-74-1	284.80	1	0.00068	0.00000591	0.0542
HEXACHLOROBUTADIENE	87-68-3	260.80	0.15	0.0256	0.0000062	0.0561
HEXACHLOROCYCLOPENTADIENE	77-47-4	272.80	0.081	0.016	0.00000616	0.0561
HEXACHLOROETHANE	67-72-1	237.00	0.65	0.00000249	0.0000068	0.00249
HEXANE(-N)	100-54-3	86.20	150	0.122	0.00000777	0.2
HEXANOL(-1)	111-27-3	102.18	0.812	0.0000182	0.00000753	0.059
HYDROCYANIC ACID	74-90-8	27.00	726	0.000000465	0.0000182	0.197
HYDROFLUORIC ACID	7664-39-3	20.00	900	0.000237	0.000033	0.388
HYDROGEN SULFIDE	7783-06-4	34.10	15200	0.023	0.0000161	0.176
ISOPHORONE	78-59-1	138.21	0.439	0.00000576	0.00000676	0.0623
METHANOL	67-56-1	32.00	114	0.0000027	0.0000164	0.15
METHYL ACETATE	79-20-9	74.10	235	0.000102	0.00001	0.104
METHYL CHLORIDE	74-87-3	50.50	3830	0.00814	0.0000065	0.126

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
METHYL ETHYL KETONE	78-93-3	72.10	100	0.0000435	0.0000098	0.0808
METHYL ISOBUTYL KETONE	108-10-1	100.20	15.7	0.0000495	0.0000078	0.075
METHYL METHACRYLATE	80-62-6	100.10	39	0.000066	0.0000086	0.077
METHYL STYRENE (ALPHA)	98-83-9	118.00	0.076	0.00591	0.0000114	0.264
METHYLENE CHLORIDE	75-09-2	85.00	438	0.00319	0.0000117	0.101
MORPHOLINE	110-91-8	87.12	10	0.0000573	0.0000096	0.091
NAPHTHALENE	91-20-3	128.20	0.23	0.00118	0.0000075	0.059
NITROANILINE(-O)	88-74-4	138.14	0.003	0.0000005	0.000008	0.073
NITROBENZENE	98-95-3	123.10	0.3	0.0000131	0.0000086	0.076
PENTACHLOROBENZENE	608-93-5	250.34	0.0046	0.0073	0.0000063	0.057
PENTACHLOROETHANE	76-01-7	202.30	4.4	0.021	0.0000073	0.066
PENTACHLOROPHENOL	87-86-5	266.40	0.00099	0.0000028	0.0000061	0.056
PHENOL	108-95-2	94.10	0.34	0.000000454	0.0000091	0.082
PHOSGENE	75-44-5	98.92	1390	0.171	0.00000112	0.108
PHTHALIC ACID	100-21-0	166.14	121	0.0132	0.0000068	0.064
PHTHALIC ANHYDRIDE	85-44-9	148.10	0.0015	0.0000009	0.0000086	0.071
PICOLINE(-2)	108-99-6	93.12	10.4	0.000127	0.0000096	0.075
POLYCHLORINATED BIPHENYLS	1336-36-3	290.00	0.00185	0.0004	0.00001	0.104
PROPANOL (ISO)	71-23-8	60.09	42.8	0.00015	0.0000104	0.098
PROPIONALDEHYDE	123-38-6	58.08	300	0.00115	0.0000114	0.102

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
PROPYLENE GLYCOL	57-55-6	76.11	0.3	0.0000015	0.0000102	0.093
PROPYLENE OXIDE	75-66-9	58.10	525	0.00134	0.00001	0.104
PYRIDINE	110-86-1	79.10	20	0.0000236	0.0000076	0.091
RESORCINOL	108-46-3	110.11	0.00026	0.0000000188	0.0000087	0.078
STYRENE	100-42-5	104.20	7.3	0.00261	0.000008	0.071
TETRACHLOROETHANE(1,1,1,2)	630-20-6	167.85	6.5	0.002	0.0000079	0.071
TETRACHLOROETHANE(1,1,2,2)	79-34-5	167.85	6.5	0.00038	0.0000079	0.071
TETRACHLOROETHYLENE	127-18-4	165.83	19	0.029	0.0000082	0.072
TETRAHYDROFURAN	109-99-9	72.12	72.1	0.000049	0.0000105	0.098
TOLUENE	109-88-3	92.40	30	0.00668	0.0000086	0.087
TOLUENE DIISOCYANATE(2,4)	584-84-9	174.16	0.08	0.0000083	0.0000062	0.061
TRICHLORO(1,1,2)TRIFLUOROETHANE	76-13-1	187.38	300	0.435	0.0000082	0.078
TRICHLOROBENZENE(1,2,4)	120-82-1	181.50	0.18	0.00142	0.0000077	0.0676
TRICHLOROBUTANE(1,2,3)	NOCAS5	161.46	4.39	4.66	0.0000072	0.066
TRICHLOROETHANE(1,1,1)	71-55-6	133.40	123	0.00492	0.0000088	0.078
TRICHLOROETHANE(1,1,2)	79-00-5	133.40	25	0.000742	0.0000088	0.078
TRICHLOROETHYLENE	79-01-6	131.40	75	0.0091	0.0000091	0.079
TRICHLOROFLUOROMETHANE	75-69-4	137.40	796	0.0583	0.0000097	0.087
TRICHLOROPHENOL(2,4,6)	88-06-2	197.46	0.0073	0.0000177	0.0000075	0.0661
TRICHLOROPROPANE(1,1,1)	NOCAS6	147.43	3.1	0.029	0.0000079	0.071

Table 4.3-4 (Part 1) (cont.).

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m ³ /mol)	Diffusivity Of Chemical In Water At 25°C (cm ² /s)	Diffusivity Of Chemical In Air At 25°C (cm ² /s)
TRICHLOROPROPANE(1,2,3)	96-18-4	147.43	3	0.028	0.0000079	0.071
UREA	57-13-6	60.06	6.69	0.000264	0.0000137	0.122
VINYL ACETATE	108-05-4	86.09	115	0.00062	0.0000092	0.085
VINYL CHLORIDE	75-01-4	62.50	2660	0.086	0.0000123	0.106
VINYLDENE CHLORIDE	75-35-4	97.00	591	0.015	0.0000104	0.09
XYLENE(-M)	1330-20-7	106.17	8	0.0052	0.0000078	0.07
XYLENE(-O)	95-47-6	106.17	7	0.00527	0.00001	0.087

Table 4.3-4. SIMS CHEMICAL PROPERTY DATA FILE (PART 2)

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
ACETALDEHYDE	8.005	1600.017	291.809	0.0000228944	419.0542	2.69153
ACETIC ACID	7.387	1533.313	222.309	0.000038889	14.2857	0.48978
ACETIC ANHYDRIDE	7.149	1444.718	199.817	0.000026944	1.9323	1
ACETONE	7.117	1210.595	229.664	0.000003611	1.1304	0.57544
ACETONITRILE	7.119	1314.4	230	0.0000425	152.6014	0.45709
ACROLEIN	2.39	0	0	0.000021667	22.9412	0.81283
ACRYLAMIDE	11.2932	3939.877	273.16	0.0000425	56.2388	6.32182
ACRYLIC ACID	5.652	648.629	154.683	0.000026944	54.7819	2.04174
ACRYLONITRILE	7.038	1232.53	222.47	0.000005	24	0.12023
ADIPIC ACID	0	0	0	0.000026944	66.9943	1.20226
ALLYL ALCOHOL	0	0	0	0.000048872	3.9241	1.47911
AMINOPHENOL(-O)	0	0	0	0.0000425	68.1356	3.81533
AMINOPHENOL(-P)	-3.357	699.157	-331.343	0.0000425	68.1356	3.81533
AMMONIA	7.5547	1002.711	247.885	0.0000425	15.3	1
AMYL ACETATE(-N)	0	0	0	0.000026944	16.1142	51.10801
ANILINE	7.32	1731.515	206.049	0.000019722	.3381	7.94328
BENZENE	6.905	1211.033	220.79	0.000052778	13.5714	141.25375
BENZO(A)ANTHRACENE	6.9824	2426.6	156.6	0.000086389	1.7006	407380.2778
BENZO(A)PYRENE	9.2455	3724.363	273.16	0.000086389	1.2303	954992.58602

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
BENZYL CHLORIDE	0	0	0	0.0000049306	17.5674	199.52623
BIS(2-CHLOROETHYL)ETHER	0	0	0	0.0000029889	20.0021	38.01894
BIS(2-CHLOROISOPROPYL)ETHER	0	0	0	0.0000029889	8.3382	380.1894
BIS(2-ETHYLHEXYL)PHTHALATE	0	0	0	0.0000002139	2.2	199526.2315
BROMOFORM	0	0	0	0.0000029889	10.653	199.52623
BROMOMETHANE	0	0	0	0.0000029889	30.4422	12.58925
BUTADIENE-(1,3)	6.849	930.546	238.854	0.0000042534	15.3	74.32347
BUTANOL (ISO)	7.4743	1314.19	186.55	0.0000021667	70.9091	5.62341
BUTANOL-(1)	7.4768	1362.39	178.77	0.0000021667	70.9091	5.62341
BUTYL BENZYL PHTHALATE	0	0	0	0.0000086389	14.1364	60255.95861
CARBON DISULFIDE	6.942	1169.11	241.59	0.0000042534	5.8175	1
CARBON TETRACHLORIDE	6.934	1242.43	230	0.0000004167	1	524.80746
CHLORO(-P)CRESOL(-M)	0	0	0	0.0000029889	5.2902	1258.92541
CHLOROACETALDEHYDE	0	0	0	0.0000029889	49.838	3.4405
CHLOROBENZENE	6.978	1431.05	217.55	0.0000001083	.039	316.22777
CHLOROFORM	6.493	929.44	196.03	0.0000008167	3.7215	91.20108
CHLORONAPHTHALENE-(2)	0	0	0	0.0000029889	2.167	13182.56739
CHLOROPRENE	6.161	783.45	179.7	0.0000029968	6.3412	1
CRESOL(-M)	7.508	1856.36	199.07	0.0000064472	1.3653	93.32543
CRESOL(-O)	6.911	1435.5	165.16	0.0000063278	1.34	95.49926

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
CRESOL(-P)	7.035	1511.08	161.85	0.000064472	1.3653	87.09636
CRESYLIC ACID	0	0	0	0.000041667	15	1
CROTONALDEHYDE	0	0	0	0.000026944	27.6285	12.36833
CUMENE (ISOPROPYLBENZENE)	6.963	1460.793	207.78	0.000086458	16.5426	1
CYCLOHEXANE	6.841	1201.53	222.65	0.000042534	15.3	338.0687
CYCLOHEXANOL	6.255	912.87	109.13	0.000026944	18.0816	37.74314
CYCLOHEXANONE	7.8492	2137.192	273.16	0.000031917	41.8921	6.45654
DI-N-OCTYL PHTHALATE	0	0	0	0.000000083	0.02	141253.7
DIBUTYLPHTHALATE	6.639	1744.2	113.59	0.000001111	0.4	158489.31925
DICHLORO(-2)BUTENE(1,4)	0	0	0	0.000029889	9.8973	242.1542
DICHLOROBENZENE(1,2) (-O)	.176	0	0	0.000006944	4.3103	2398.83292
DICHLOROBENZENE(1,3) (-M)	0	0	0	0.000017778	2.7826	2398.83292
DICHLOROBENZENE(1,4) (-P)	.079	0	0	0.000017778	2.7826	2454.70892
DICHLORODIFLUOROMETHANE	0	0	0	0.000029889	12.0413	144.54398
DICHLOROETHANE(1,1)	0	0	0	0.000029889	4.6783	61.6595
DICHLOROETHANE(1,2)	7.025	1272.3	222.9	0.000005833	2.1429	61.6595
DICHLOROETHYLENE(1,2)	6.965	1141.9	231.9	0.000029889	6.3294	1
DICHLOROPHENOL(2,4)	0	0	0	0.000069444	7.5758	562.34133
DICHLOROPHENOXYACETIC ACID(2,4)	0	0	0	0.000029889	14.8934	82.61445

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
DICHLOROPROPANE(1,2)	6.98	1380.1	22.8	0.0000047222	12.1429	1
DIETHYL (N,N) ANILIN	7.466	1993.57	218.5	0.00000425	27.0047	43.57596
DIETHYL PHTHALATE	0	0	0	0.000000753	1.28	1412.537
DIMETHYL FORMAMIDE	6.928	1400.87	196.43	0.00000425	15.3	1
DIMETHYL HYDRAZINE(1,1)	7.408	1305.91	225.53	0.00000425	15.3	1
DIMETHYL PHTHALATE	4.522	700.31	51.42	0.0000006111	0.7097	74.13102
DIMETHYLBENZ(A)ANTHRACENE	0	0	0	0.0000086389	0.3377	28680056.33087
DIMETHYLPHENOL(2,4)	0	0	0	0.0000029722	2.2766	263.0268
DINITROBENZENE (-M)	4.337	229.2	-137	0.00000425	29.9146	33.28818
DINITROTOLUENE(2,4)	5.798	1118	61.8	0.00000425	19.5233	102.3293
DIOXANE(1,4)	7.431	1554.68	240.34	0.0000026944	24.7001	16.60956
DIOXIN	12.88	6465.5	273	0.0000029968	6.3412	1
DIPHENYLAMINE	0	0	0	0.0000052778	8.4103	1659.58691
EPICHLOROHYDRIN	8.2294	2086.816	273.16	0.0000029968	6.3412	1.07152
ETHANOL	8.321	1718.21	237.52	0.0000024444	9.7778	0.47863
ETHANOLAMINE(MONO-)	7.456	1577.67	173.37	0.00000425	223.0321	0.16865
ETHYL ACRYLATE	7.9645	1897.011	273.16	0.0000026944	39.4119	4.85667
ETHYL CHLORIDE	6.986	1030.01	238.61	0.0000029889	22.8074	26.91535
ETHYL-(2)PROPYL-(3) ACROLEIN	0	0	0	0.00000425	15.3	1

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
ETHYLACETATE	7.101	1244.95	217.88	0.0000048833	17.58	1
ETHYLBENZENE	6.975	1424.255	213.21	0.0000018889	3.2381	1412.53754
ETHYLENEOXIDE	7.128	1054.54	237.76	0.0000011667	4.6154	0.50003
ETHYLETHER	6.92	1064.07	228.8	0.0000026944	17.1206	43.57596
FORMALDEHYDE	7.195	970.6	244.1	0.0000013889	20	87.09636
FORMIC ACID	7.581	1699.2	260.7	0.0000026944	161.3977	0.1191
FREONS	0	0	0	0.0000029968	6.3412	1
FURAN	6.975	1060.87	227.74	0.0000026944	14.1936	71.37186
FURFURAL	6.575	1198.7	162.8	0.0000026944	18.0602	37.86047
HEPTANE (ISO)	6.8994	1331.53	212.41	0.0000042534	15.3	1453.372
HEXACHLOROBENZENE	0	0	0	0.0000029889	0.6651	295120.92267
HEXACHLOROBUTADIENE	0.824	0	0	0.000003	6.3412	5495.408
HEXACHLOROCYCLOPENTADIENE	0	0	0	0.0000029968	0.3412	9772.372
HEXACHLOROETHANE	0	0	0	0.0000029889	3.3876	4068.32838
HEXANE(-N)	6.876	1171.17	224.41	0.0000042534	15.3	534.0845
HEXANOL(-1)	7.86	1761.26	196.66	0.0000026944	15.2068	59.52851
HYDROCYANIC ACID	7.528	1329.5	260.4	0.0000026944	1.9323	1
HYDROFLUORIC ACID	7.217	1268.37	273.87	0.0000026944	1.9323	1
HYDROGEN SULFIDE	7.614	885.319	250.25	0.0000029889	6.3294	1
ISOPHORONE	0	0	0	0.00000425	25.6067	50.11872

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
METHANOL	7.897	1474.08	229.13	0.000005	90	0.19953
METHYL ACETATE	7.065	1157.63	219.73	0.0000055194	159.2466	0.81283
METHYL CHLORIDE	7.093	948.58	249.34	0.0000029889	14.855	83.17638
METHYL ETHYL KETONE	6.9742	1209.6	216	0.0000005556	10	1.90546
METHYL ISOBUTYL KETONE	6.672	1168.4	191.9	0.0000002056	1.6383	23.98833
METHYL METHACRYLATE	8.409	2050.5	274.4	0.0000026944	109.2342	0.33221
METHYL STYRENE (ALPHA)	6.923	1486.88	202.4	0.000008639	11.12438	2907.589
METHYLENE CHLORIDE	7.409	1325.9	252.6	0.0000061111	54.5762	17.78279
MORPHOLINE	7.7181	1745.8	235	0.00000425	291.9847	0.08318
NAPHTHALENE	7.01	1733.71	201.86	0.0000117972	42.47	1
NITROANILINE(-O)	8.868	336.5	273.16	0.00000425	22.8535	67.6083
NITROBENZENE	7.115	1746.6	201.8	0.0000030556	4.7826	69.1831
PENTACHLOROENZENE	0	0	0	0.0000029889	0.4307	925887.02902
PENTACHLOROETHANE	6.74	1378	197	0.0000029889	0.4307	925887.02902
PENTACHLOROPHENOL	0	0	0	0.0000361111	38.2353	102329.29923
PHENOL	7.133	1516.79	174.95	0.0000269444	7.4615	28.84032
PHOSGENE	6.842	941.25	230	0.00000425	70.8664	3.4405
PHTHALIC ACID	0	0	0	0.0000026944	34.983	6.64623
PHTHALIC ANHYDRIDE	8.022	2868.5	273.16	0.0000048872	3.9241	0.23988
PICOLINE(-2)	7.032	1415.73	211.63	0.00000425	44.8286	11.48154

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
POLYCHLORINATED BIPHENYLS	0	0	0	0.000005278	20	1
PROPANOL (ISO)	8.117	1580.92	219.61	0.0000041667	200	0.69183
PROPIONALDEHYDE	16.2315	2659.02	-44.15	0.0000026944	39.2284	4.91668
PROPYLENE GLYCOL	8.2082	2085.9	203.5396	0.0000026944	109.3574	0.33141
PROPYLENE OXIDE	8.2768	1656.884	273.16	0.0000048872	3.9241	1
PYRIDINE	7.041	1373.8	214.98	0.0000097306	146.9139	4.46684
RESORCINOL	6.9243	1884.547	186.0596	0.0000026944	35.6809	6.30957
STYRENE	7.14	1574.51	224.09	0.0000086389	282.7273	1445.43977
TETRACHLOROETHANE(1,1,1,2)	6.898	1365.88	209.74	0.0000029889	6.3294	1
TETRACHLOROETHANE(1,1,2,2)	6.631	1228.1	179.9	0.0000017222	9.1176	363.07805
TETRACHLOROETHYLENE	6.98	1386.92	217.53	0.0000017222	9.1176	398.10717
TETRAHYDROFURAN	6.995	1202.29	226.25	0.0000026944	20.3702	27.58221
TOLUENE	6.954	1344.8	219.48	0.0000204111	30.6167	489.77882
TOLUENE DIISOCYANATE(2,4)	0	0	0	0.00000425	15.3	1
TRICHLORO(1,1,2)TRIFLUOROETHANE	6.88	1099.9	227.5	0.0000029889	3.3876	4068.32838
TRICHLOROBENZENE(1,2,4)	0	0	0	0.0000029889	2.4495	9549.92586
TRICHLOROBUTANE(1,2,3)	0	0	0	0.0000029968	6.3412	1450901.06626
TRICHLOROETHANE(1,1,1)	8.643	2136.6	302.8	0.0000009722	4.7297	309.02954
TRICHLOROETHANE(1,1,2)	6.951	1314.41	209.2	0.0000009722	4.7297	1

Table 4.3-4 (Part 2) (cont.).

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass)	Half Saturation Constant (g/m ³)	Octanol-Water Partition Coefficient At 25°C
TRICHLOROETHYLENE	6.518	1018.6	192.7	0.0000010833	4.4318	194.98446
TRICHLOROFLUOROMETHANE	6.884	1043.004	236.88	0.000003	6.3412	338.8441
TRICHLOROPHENOL(2,4,6)	0	0	0	0.00000425	58.8462	4897.78819
TRICHLOROPROPANE(1,1,1)	0	0	0	0.0000029889	10.7719	193.7827
TRICHLOROPROPANE(1,2,3)	6.903	788.2	243.23	0.0000029889	10.7719	193.7827
UREA	0	0	0	0.00000425	4.8169	4068.32838
VINYL ACETATE	7.21	1296.13	226.66	0.0000026944	31.8363	8.51722
VINYL CHLORIDE	3.425	0	0	0.000003	6.3412	1.14815
VINYLDENE CHLORIDE	6.972	1099.4	237.2	0.0000029968	6.3412	1
XYLENE(-M)	7.009	1426.266	215.11	0.0000086389	14.0094	1584.89319
XYLENE(-O)	6.998	1474.679	213.69	0.0000113306	22.8569	891.25094

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