11/98

Technical Support Document for Evaluation of Thoroughly Mixed Biological Treatment Units

I. Overview and Purpose

This document is intended to provide information to assist anyone who needs to determine whether a biological treatment unit meets the definition of an "enhanced biological treatment system or enhanced biological treatment process" for the purpose of using certain compliance demonstration provisions in 40 CFR part 63, subpart G. Potential users of this document include owners and operators of sources subject to 40 CFR part 63, subpart G as well as enforcement personnel evaluating whether a specific biological treatment process meets the criteria in the definition. It is therefore assumed that readers of this document are familiar with the requirements of subpart G for treatment of wastewater and consequently those requirements are not restated in this document. This information is intended for clarification purposes only, does not constitute final agency action, and cannot be relied upon to create any rights enforceable by any party.

The purpose of this document is to provide technical support and procedures to determine whether a biological treatment unit meets the criteria for being considered a "thoroughly mixed treatment unit" within the meaning of the enhanced biological treatment process definition in 40 CFR 63.111. The objectives of these evaluation procedures are to determine whether the entering wastewater and recycled biomass are quickly dispersed throughout the unit and whether the unit's design would avoid volatilization of the compounds of concern prior to efficient biodegradation. Several alternative approaches are presented for determining whether a biological treatment process is "thoroughly mixed." All of these procedures are considered to provide equally acceptable assessments and no one procedure is considered to take precedence over another. For example, tracer testing does not take precedence over a system design evaluation as described in this document. These evaluation procedures have been designed to allow, to the extent reasonable, the use of existing information and to minimize the need to

develop new information to make the determination. It is recommended, however, that in cases where sufficient information is not available to make an unambiguous determination that readers should consider developing additional information to resolve the uncertainty.

II. Background

Subpart G provides two easier compliance demonstration options for activated sludge systems that meet the definition of an "enhanced biological treatment system or enhanced biological treatment process." First, §63.145(h)(1) provides an exemption from performance evaluation for an "enhanced biological treatment system or enhanced biological treatment process" that is used to control wastewater streams containing regulated compounds on list 1 in table 36 to subpart G. Second, if a system meets the definition of "enhanced biological treatment system or enhanced biological treatment process" and is used to treat wastewater containing compounds on list 1 and list 2, §63.145 (h)(2) (i) allows use of a simplified performance demonstration. The performance demonstration is considered to be easier because it may be limited to determining the first order biodegradation constant (K1) for the list 2 compounds. Section 63.145(h)(2)(i) allows the owner/operator to use the default K1s for enhanced biological treatment systems for the list 1 compounds that are provided in table 37 to subpart G.

Subpart G, in §63.111, defines "enhanced biological treatment system or enhanced biological treatment process" as:

> Enhanced biological treatment system or enhanced biological treatment process means an aerated, thoroughly mixed treatment unit(s) that contains biomass suspended in water followed by a clarifier that removes biomass from the treated water and recycles recovered biomass to the aeration unit. The mixed liquor volatile suspended solids (biomass) is greater than 1 kilogram per cubic meter throughout each aeration unit. The biomass is suspended and aerated in the water of the aeration unit(s) by either submerged air flow or mechanical agitation. A thoroughly mixed treatment unit is a unit that is designed and operated to approach or achieve uniform biomass distribution and organic compound concentration throughout the aeration unit by quickly dispersing the recycled biomass and the wastewater entering the unit.

The EPA's intent is that this definition reflect the modeling that was used, in part, as the basis for the decision (1) to exempt certain systems treating list 1 compounds from the requirement to determine the fraction biodegraded (Fbio) and (2) to allow the easier procedures for determining Fbio for systems meeting the definition but treating list 1 and 2 compounds. Important features of this definition are that biomass is recycled, the biomass approaches or achieves a state of being suspended uniformly throughout each aeration unit, the biomass concentration is not less than 1 kilogram/cubic meter, and that influent materials are rapidly dispersed throughout the unit. This last characteristic is one of the key design criteria for ensuring that the list 1 compounds are efficiently biodegraded in the biological treatment unit prior to the opportunity for significant volatilization to the atmosphere. Consequently, the criteria and procedures provided in this document for determining whether a biological treatment unit can be considered a "thoroughly mixed treatment unit" are based on evaluating the rate of mixing relative to the rate of stripping or volatilization.

III. Design Characteristics that Influence Mixing Time

This section describes the characteristics of units that are considered to contribute to good mixing in units approaching the continuous flow stirred tank reactor configuration resulting in optimum biodegradation as opposed to volatilization. Characteristics that are of concern for good mixing are also discussed in this section.

Biomass separation and agitation are two characteristics that require attention for the operation of a successful activated sludge system. The system should be designed or operated so that biomass separation occurs exterior to the aeration system (e.g., secondary clarifier with return of separated biomass to the aeration unit). In the design of the system, there are no zones that have no agitation (quiescent zones in the air emission models); however, real systems may as a practical matter, be found to have small insignificant stagnant zones. Even with such stagnant zones, there is enough mixing throughout the reactor to support suspension such that there is no significant accumulation of biomass on the bottom or sides of the aeration unit. With insufficient mixing, biomass can accumulate at the unit floor. Symptoms of this effect include biomass layers,

low dissolved oxygen or anaerobic decay at the base of the floor in these zones, and less biomass generation in the system than is theoretically expected.

Baffles reduce mixing in the unit as a whole and the presence of internal baffles suggests deliberate control and restriction of mixing. Baffles can be intentionally included when designing a plug flow system; however, the absence of baffles does not necessarily indicate a well mixed system.

Thoroughly mixed units do not have a high length to width ratio. Back-mixing in biological treatment units depends on the length to width ratio, the dispersion characteristics, and the retention time in the reactor. Long units are more difficult to mix uniformly. Generally, a length to width ratio of four to one, or greater, is considered a high ratio. Thoroughly mixed systems would typically have a length to width ratio less than 4:1. Vivona (1983) states that plug flow sizing would be based on a length to width ratio of 4:1 to 12:1 .

Thoroughly mixed units are aerated substantially uniformly across the surface of the unit. Aeration that is greater near the inlet of the unit suggests a design for non-uniformity. Non-uniform mixing could cause a greater oxygen demand near the inlet. This would imply that the inlet loading is not distributed throughout the unit and significant volatilization may occur prior to efficient biodegradation.

Quiescent zones separating agitated zones may or may not be well-mixed . For example, surface units are well mixed and uniform within the agitation zone around each surface aerator, but the aeration unit as a whole may not be well mixed throughout the entire unit. Units designed so that the wastewater flows sequentially from one aeration unit to another may be considered plug flow. This flow in series may be determined by inspection or by tracer testing and observing the path of the tracer.

Examples of design features that may result in poor mixing or dispersion of the entering wastewater throughout the aeration unit are listed in Table 1. There were 2 main factors

associated with the selection of the specifications in Table 1: (1) quick dispersion and thorough mixing and (2) volatilization prior to biodegradation. The two factors are interrelated in that quick dispersion and thorough mixing must occur prior to significant volatilization of the compounds of concern for the system to achieve the required destruction through biodegradation. Certain design characteristics may lead to problems with respect to these factors. Table 1 lists these factors.

IV. Procedures for Evaluating Mixing Performance

A. Overview of procedure

Figure 1 presents a logic flow diagram of the suggested approach for determining whether a unit meets the definition of "enhanced biological treatment system or enhanced biological treatment process." The determination consists of a four-step process that may be terminated at any point or continued through to conducting an evaluation of the mixing within the aeration unit. The process was designed this way to allow early elimination of any unit unlikely to be considered an "enhanced biological treatment system or enhanced biological treatment process."

The first step in any assessment should be to see if the unit is obviously ineligible because it does not meet criteria such as recycling of biomass or having a biomass concentration of greater than or equal to 1 kg/ m^3 MLVSS. If the unit does not meet these basic criteria, its performance would have to be evaluated using the procedures in appendix C to part 63.

The second step is to see if the unit has any of the characteristics listed in Table 1, which lists design characteristics that may result in a system that is not thoroughly mixed. If the answer to this question is yes, it is suggested that readers consider using the procedures in appendix C to part 63 and subdividing the unit into a series of zones that have uniform characteristics within each zone to determine performance instead of proceeding to the next step in the determination of mixing performance. If the reader wishes to continue with the determination of mixing

performance, the reader should proceed to step four and follow one of the three procedures for determining mixing in the unit.

The third step is to refer to Table 2 to see if the unit has one of the design characteristics in each of the parameter specifications for reactor shape, depth, aerator type, aeration equipment location, and effluent outlet, number 1 and 2 or 3 of the mixing parameter specifications, and all of the inlet parameter specifications. Meeting the Table 2 design characteristics will result in a system that can be considered thoroughly mixed. If the system does meet these requirements then it is considered to meet the criteria of the definition and no further evaluation is necessary. It should be recognized that Table 2 lists design characteristics of a biological unit designed to minimize air emissions and that not all enhanced biological treatment systems will necessarily meet all of these design criteria. The EPA intends that Table 2 reflect design characteristics of only those units that are clearly thoroughly mixed. The fact that a biological treatment system does not meet all the design characteristics in Table 2 should not be interpreted as implying that the system is not thoroughly mixed as discussed in section II or that it will not achieve good biodegradation. It only means that it is necessary to proceed with the next step in the evaluation.

The fourth step in the evaluation process is to evaluate mixing performance using any one of the three procedures described in this document and complete the appropriate calculation forms for the procedure. The three procedures are design evaluation, tracer studies, and in−basin measurements. As previously stated, all of these procedures are considered to provide equally acceptable assessments and no one procedure is considered to take precedence over another. Selection of the procedure will depend on the availability of information, the relative ease of obtaining the necessary information, and/or personal preferences. The time to achieve complete mixing in an enhanced biological treatment system should be substantially less than both the time to air strip chlorobenzene from the system and the retention time of the waste in the system. The following sections B, C, and D describe an overview of procedures for comparing the mixing time to the time of air stripping and the retention time.

B. Mixing time from design evaluation

Procedures are supplied for calculating mixing time in submerged aeration units, surface aeration units, and jet aeration units. The mixing time determined in each approach estimates the time to achieve 95% mixing. Therefore, even though different procedures are used, they are all on the same basis.

1. Submerged aeration biological treatment units

Use Form 1 to estimate the dispersion coefficient for spiral flow aeration systems by the method of Fugii or use the default value of 0.068 m^2/s (Chambers). Next, use Form 2 to Calculate the value of u and L from the mean velocity and length of the aeration unit; then, use those values to calculate the dispersion number (D/uL). Form 3 is used to estimate the 95% mixing time from the dispersion number and using dispersion theory (Levenspiel). This 95% mixing time is the theoretical time to reach 95% of the maximum peak concentration in the unit. Calculate the 50% stripping time of chlorobenzene (the time required to strip 50% of the chlorobenzene in the aeration unit without biodegradation, also known as the stripping half-life) or by the provided estimation forms (Complete Form 4 and supporting forms). Calculate the ratio of the 95% mixing time to the 50% stripping time of chlorobenzene. Form 5 is used to compare 1) mixing time and 50% stripping time ratio, and 2) the mixing time-retention time ratio to the target parameters. Are these two ratios less than the target ratios? If the answer is yes, then the unit would be considered thoroughly mixed.

2. Surface aeration and submerged jet aeration biological treatment units

Obtain the pumping capacity of the aerators from the supplier or from an accurate correlation for the system. Calculate the turnover time as the ratio of the aeration unit volume to the volumetric pumping capacity. Use Form 9 to calculate the mixing time as five times the turnover time. Calculate the 50% stripping time of chlorobenzene by WATER8 (or the most

recent update to this model) or by the provided estimation forms (Complete Form 4 and supporting forms). Calculate the ratio of the 95% mixing time to the 50% stripping time of chlorobenzene. Form 5 is used to compare 1) mixing time and 50% stripping time ratio, and 2) the mixing time-retention time ratio to the target parameters. Are these two ratios less than the target ratios? If the answer is yes, then the unit would be considered thoroughly mixed.

C. Mixing time from tracer test data

This method is based on measurement of a chemical tracer added to the influent as a pulse dose to demonstrate that the aeration unit of the biological treatment system is back-mixed to a degree that approaches the mixing characteristics of a theoretical completely back-mixed reactor. Tracer studies (Levenspiel) are often performed to determine the residence time distribution (RTD) of a reactor to compare with the theoretical retention time based on the reactor volume and the wastewater flow rate. Such studies are typically conducted before a unit is placed in service or returned to service in order to determine if the mixing and/or aeration systems are functioning in accordance with the design specifications. Tracer data from a RTD study will usually be suitable for use with the calculation procedures in this document for determining whether or not a biological treatment unit is sufficiently back-mixed to be considered a "thoroughly mixed treatment unit." Discussions of tracer studies can be found in references 4 through 8.

The tracer study can be performed with or without the presence of activated sludge in the unit. Any chemical tracer can be used that is not biodegradable and does not adsorb significantly to suspended solids. Examples of acceptable tracers include lithium chloride, rhodamine WT and dextran blue.

The tracer study is conducted by rapidly introducing a predetermined quantity of the tracer as a spike or step change in target compound concentration into the influent to the aeration unit. If the tracer can not be added to the influent because of limited access, it can be added to the

aeration unit directly at a location near the influent. Measure the concentrations of the tracer in the effluent as a function of time starting at the time of release of the tracer. Measurements of the tracer in the effluent can be performed with a continuous direct−reading instrument or can be performed by collecting grab samples at closely−spaced time intervals and measuring the tracer concentration in the laboratory.

Determine the mixing time as the time to reach 95% of the maximum peak tracer concentration in the effluent. One method to evaluate the tracer data is to plot the effluent tracer concentration data as the dependent variable (y axis) on a graph and the elapsed time as the independent variable (x axis). Determine the time where the curve reaches 95% of the peak concentration in the effluent. If the tracer was added as a step change input, the data could be analyzed by plotting concentration as the dependent variable (y axis) and inverse time as the independent variable (x axis) and extrapolating back to the y axis intercept for long time periods.

To determine if the biological treatment unit approaches the mixing performance of a thoroughly mixed reactor, first complete Form 7 to document the 95% mixing time determination. Next, Form 5 is completed to compare the 95% mixing time to the stripping time and the retention time. To complete Form 5, it is necessary to calculate the 50% stripping time of chlorobenzene by completing Form 4 and the supporting forms. Calculate the ratio of the 95% mixing time to the 50% stripping time of chlorobenzene. Form 5 is used to compare 1) mixing time and 50% stripping time ratio, and 2) the mixing time-retention time ratio to the target parameters. Are these two ratios less than the target ratios? If the answer is yes, then the unit would be considered thoroughly mixed. If the ratio on line 4 is less than or equal to the target ratio on line 5 and if the ratio on line 12 is less than or equal to the target ratio on line 13, then the biological treatment unit is considered to be a thoroughly mixed treatment unit.

D. Indicator Pollutant Testing

1. Description of procedure

This procedure is based on a statistical comparison of the concentration of an indicator parameter in the effluent (reactor exit) and the measured concentrations of this parameter in the aeration unit, all measured during the same time period. This procedure is used to evaluate the rate of mixing relative to the rate of loss by biodegradation or volatilization. This procedure is applicable to aeration units that have a single wastewater feed inlet or that split a wastewater feed among multiple inlets. This procedure is not applicable to aeration units in which different wastewater feeds are introduced separately through different inlets. If the concentrations of the indicator parameter in the effluent are statistically equivalent to the concentrations in the aeration units near the inlet at a 95% statistical significance level, then the aeration unit meets the criteria for a thoroughly mixed treatment unit (i.e., is back-mixed). Before conducting this procedure, you should confirm that there are no major variations in the flow rate and waste composition into the biological treatment system. In the case where the wastewater sent to the aeration unit is highly variable, it is recommended that the thoroughness of mixing be evaluated during a period of stable operating conditions or another procedure recommended in this document should be considered. If the variability of measured indicator concentrations is relatively great, the number of samples required to characterize the mixing characteristics of the aeration unit is so large that it is impractical to use this procedure. The steps in this procedure are described below.

Identify indicator parameter. An appropriate indicator parameter for this test is one that is being significantly biodegraded and not created by the biological treatment process. An appropriate indicator parameter is one that is measured in the influent with a high degree of confidence (greater than 99%) that the concentration is substantially greater than the concentration in the effluent. Examples of potential indicator parameters are: total organic carbon (TOC), chemical oxygen demand (COD), and specific volatile organic chemicals present in the wastewater. TOC and COD are not appropriate indicator parameters for wastewater containing significant quantities of compounds resistant to biodegradation, since the values of TOC and COD could be at constant values and may not be representative of the level of mixing . For example both a plug-flow reactor or a complete back-mix reactor with significant quantities of

biodegradation resistant compounds could exhibit a constant level of TOC or COD; therefore, in this case the level of mixing as determined by the TOC/COD procedure for the plug-flow reactor could erroneously look the same as the level of mixing determined for the complete back-mix reactor. Conservative parameters such as total dissolved solids or chlorides are also not appropriate indicator parameters for this procedure since they are not expected to be removed either by biodegradation or volatilization. If a specific chemical is used as the indicator parameter then one of the more volatile primary constituents in the feed stream should be selected. An acceptable indicator parameter will be present in the inlet feed stream at much greater concentrations than after dispersion near the inlet of the aeration unit. The indicator parameter should be present in the effluent from the unit at a concentration that is above the quantitation limit of the approved analytical method used for the measurement.

Determine the sampling locations for the aeration unit. Three sampling locations shall be determined: the inlet, within the unit, and the exit. The inlet is sampled directly before entering the particular unit, and the exit is sampled directly at the outfall of the particular unit. The sample may be collected upstream provided conveyance is by closed pipe and no additional streams are added to the conveyance system. The sample within the unit will be taken as described in the following paragraph.

First determine the 50% stripping time of chlorobenzene by completing Form 4 and the supporting forms. Then use Form 6 to determine the maximum in unit sampling distance from the aeration unit inlet. This distance is determined from the 50% stripping time for chlorobenzene using the operating characteristics of the specific biological treatment process and the mean velocity flow of water through the aeration unit. Calculate the value of u as the mean velocity flow of water through this aeration unit using Form 6. Calculate the maximum sampling distance from the aeration unit inlet as the product of the 50% stripping time for chlorobenzene and the calculated value of u. Samples of the aeration unit contents should be taken at no greater distance from the inlet than this maximum sampling distance in order to avoid some of the interferences

from potential volatilization losses. The success of sampling the unit with this method depends on an accurate sampling of the inlet stream after it mixes with the aeration unit contents. Sampling in the unit should be conducted in the flow path of the inlet stream after the inlet flow has an opportunity to mix with the unit contents. If the maximum sampling distance from the inlet as calculated using Form 6 is too close to the inlet for representative sampling of the mixing of the inlet with the unit contents, the lesser value of either ½ the distance to the closest aerator, a distance of 10 times the diameter of the wastewater inlet pipe , or 10 meters may be used as the alternative maximum sampling distance. This alternative maximum sampling distance may also be used for sampling the unit near the aeration unit exit.

Collection and handling of samples. A minimum of 3 grab samples should be collected from each of the following locations: (1) the influent to the biological treatment unit; (2) the effluent from the biological treatment unit; and (3) the aeration unit within the maximum sampling distance. The aeration unit samples shall be taken anywhere within the maximum sampling distance from the inlet. Note: these samples may be collected from the sides of the aeration unit. Measure the concentrations of the indicator parameter at each of these three locations. The aeration unit samples should be collected at a depth of 0.5 to 1.0 foot below the surface of the water. All samples shall be collected during the same 24 hour period, and each of the 3 sets of samples[1] should be collected to capture influent and effluent variability. If more than 3 samples are to be collected, then the sample collecting should be approximately equally spaced during the 24 hour period. The sets of influent and effluent samples shall be collected at time intervals separated by times roughly equal to 1/4 the hydraulic retention time (residence time). The aeration unit samples should be collected during the same time periods that the influent and effluent samples are collected. Grab samples should be collected with a device that can be opened beneath the water surface. Samples should be poured from the grab sampling device into sample bottles in a manner that will minimize volatilization of organic compounds. Sufficient

[1]More than 3 samples may be collected from any of the locations, if necessary.

hydrochloric acid (HCl) shall be added to each sample to reduce the pH to less than 2 to stop the biodegradation in the sample bottles. The samples shall be then refrigerated at 4^{o} C until analysis.

Number of Samples. When the coefficient of variance[2] for sampling is large, it is difficult to demonstrate differences between sets of data, even if the differences are significant. One method for improving the accuracy of the determination of differences between concentrations in the unit and concentrations in the exit of the unit is to increase the number of data sets that is used in the comparison. The following list presents a recommended minimum number of sequential data sets that should be collected from the unit, based upon the measured coefficient of variance.

Coefficient of variance	minimum sets
10	3
15	4
20	6
30	9
40	12
50	15

Measurement of indicator parameter. All sample preservation, storage, and analyses shall be performed in accordance with the NPDES analytical procedures at 40 CFR part 136. Only analytes with approved 40 CFR part 136 methods shall be used as indicator parameters. All quality assurance/quality control requirements of the applicable method shall be followed.

[2] The coefficient of variance is the ratio of the standard deviation of the sample mean to the sample mean, multiplied by 100.

2. Evaluation of the mixing

Form 8 is used to evaluate the indicator parameter for mixing time. Three sets of data are entered in the three columns of the form: inlet data, exit data, and unit data. Paired data are placed in each row of the table. For each column, the average and standard deviation are calculated. There are two different methods to evaluate the data for Form 8: (1) The Student's t-test procedure to demonstrate that the unit data and the exit data are not significantly different and (2) a correlation method for paired data. The correlation method shall be used when there is a significant time trend in the data.

First calculate the difference in the inlet average and the unit average. This difference should be large and positive relative to the unit average. If this difference is not large relative to the unit average, consider evaluating a different indicator parameter or using a different method to determine mixing time. Next, evaluate the trend characteristics of the paired data. If there is an obvious time trend (unit concentration significantly increasing with time, the exit concentration decreasing with time, or other trend) skip the Student's t-test and proceed to the correlation test.

To use the Student's t-test, calculate the difference in the unit average and the exit concentration. If this difference is negative (the exit has a higher average than the unit), then the unit has been demonstrated to be throughly mixed because there is no evidence that the unit has a higher concentration than is present in the exit concentration. If this difference is positive, then evaluate the appropriate number of degrees of freedom (equals 4 for 3 sets of paired data, 6 for 4 sets, and 8 for 5 sets). Look up the t-value for 95% confidence level, one-sided test with the appropriate number of degrees of freedom. Evaluate the test parameter as the following:

$$test = \frac{(C_{unit} - C_{exit})}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 + 1}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

σ is the standard deviation

n is the number of samples

C_{unit} is the unit concentration

C_{exit} is the exit concentration

1 refers to the unit

2 refers to the exit

If the test parameter is greater than the t-value for the 95% confidence level, then the unit concentrations are significantly greater than the exit concentrations, and the unit can not be considered well-mixed. If the test parameter is equal to or less than the t-value for the 95% confidence level, the unit can be considered well-mixed.

To use the correlation method, assume a linear correlation with a zero intercept. Use the least squares method to calculate the slope and standard error of the correlation. Subtract 1.00 from the slope and divide this result by the standard error. If this ratio is negative, use the absolute value of the ratio. Evaluate the appropriate number of degrees of freedom (equals 4 for 3 sets of paired data, 6 for 4 sets, and 8 for 5 sets). Look up the z value for 95% confidence level, one-sided test with the appropriate number of degrees of freedom. If the test parameter is equal to or less than the z value for the 95% confidence level, the unit can be considered thoroughly mixed . If the test parameter is greater than the z value for the 95% confidence level, the unit can not be considered thoroughly mixed.

V. References

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Figure 1. Steps to Determine Biological Treatment Demonstration Path

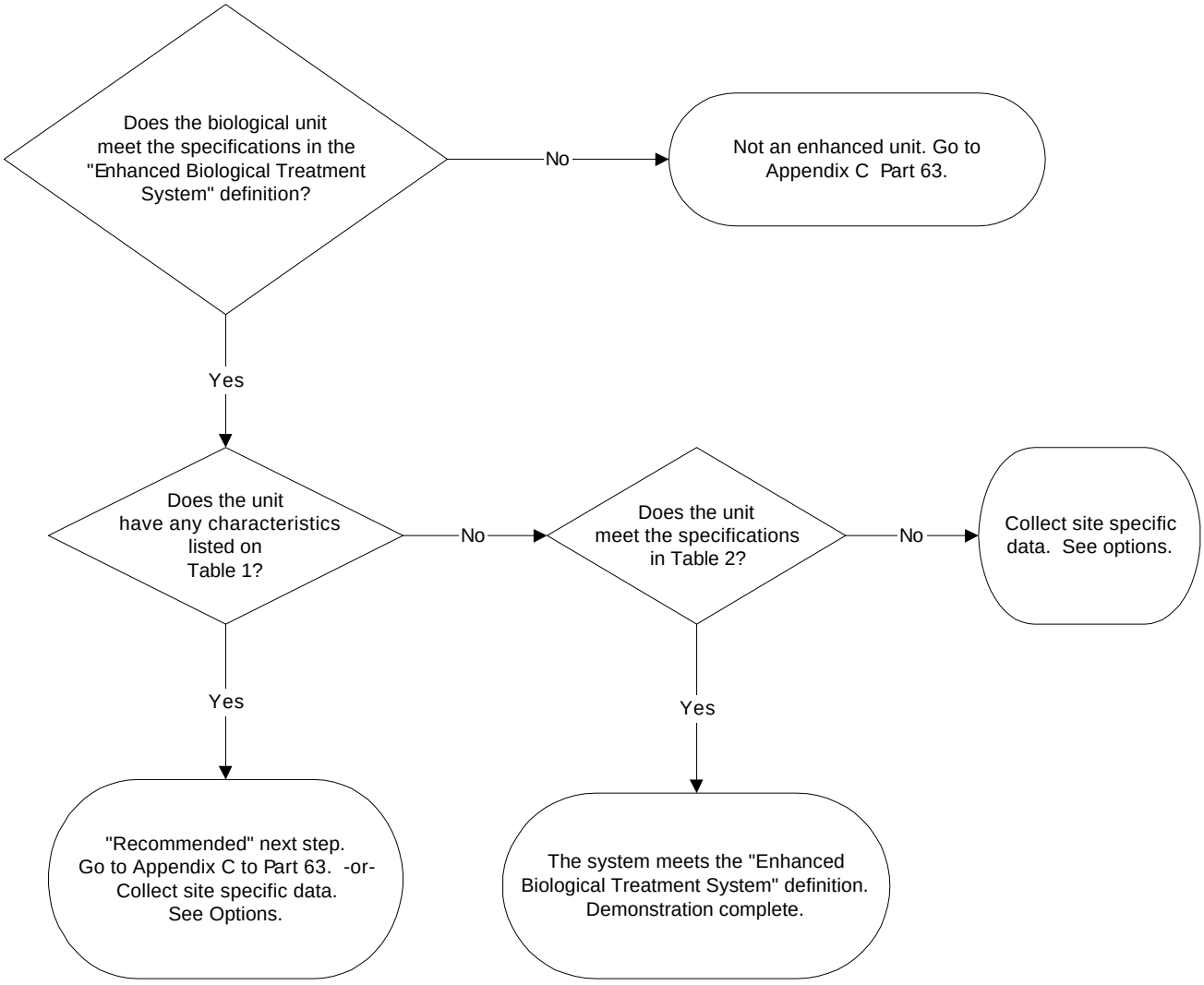

Table 1 Characteristics Indicative That a Biological Treatment System <u>May Not</u> Be Thoroughly Mixed *

Parameter	Specifications
Reactor Shape	1. Very long length to width ratio (greater than 4:1) with inlet at one end (width side) and outlet at opposite end. 2. System is designed or operated with biomass separation within the aeration system.
Mixing	1. Entering recycled biomass and wastewater are <u>not</u> quickly dispersed. Indications of poor dispersion may be: • visual indication of solids settling, • plume with visual differences in color or solids level. 2. The unit has baffles or partitions within the tank, or aeration units are operated in series. 3. Mixing does not occur between inlet and outlet.
Aeration Equipment	1. Rolling or tapered aeration. 2. Aerators (submerged or surface aerators) located such that there are zones that are not mixed (i.e., relatively stagnant or dead zones). 3. Significant distance between aeration equipment such that solids settling results.
Inlet	1. Wastewater inlet is located relative to the surface aerator such that the entering wastewater is exposed to the air before significant mixing. 2. Inlet located such that wastewater enters the unit at a relatively stagnant zone. 3. Inlet located above the surface, at the surface, or near the surface.
Effluent Outlet	Located such that short circuiting occurs between inlet and outlet.

* Biological systems must also meet the requirements in the "Enhanced Biological Treatment System" definition. Any one of the characteristics listed above would suggest that the biological unit may not meet the requirement to quickly disperse the recycled biomass and wastewater entering the unit to approach or achieve the uniform biomass distribution and organic compound concentration throughout the aeration unit.

Table 2 Thoroughly Mixed Treatment System Characteristics [1]

Parameter	Specifications
Reactor Shape	1. Circular Tank - No criteria, or 2. Rectangular Tank - Small length/width ratio (3:1 or less).
Depth	1. Diffused aeration systems - 15 ft minimum[2], or 2. Jet aeration system - Used in deep tanks (25 ft or greater)[2]. May be supplemented by mechanically driven mixing only at lower zone of tank.
Aerator Type	1. Diffused aeration - Well operated (unplugged) subsurface fine bubble diffused (Porous Diffusers) system such as plate, dome, disc, tube[2]. 2. Jet aeration system - per manufacturers criteria, with subsurface flow only.
Aeration equipment location	1. Diffused Systems - Full Floor Coverage (indicated by uniform bubble distribution on surface of basin). 2. Jet Systems - Liquid pumping with air diffusion occurs at bottom of tank.
Mixing	1. Unit does not have baffles or partitions. 2. Jet aeration system - Pumping rate should be > 5 times the entering wastewater and recycle flow rate. 3. Diffused system air flow rate > 10 scfm/1000ft^3
Inlet	1. Multiple inlet points or inlet located near point of significant mixing. 2. Submerged inlet.
Effluent Outlet	Located such that short circuiting does not occur between inlet and outlet.

1 Biological systems must also meet the requirements in the "Enhanced Biological Treatment System" definition.

2 Metcalfe and Eddy, Inc.

Form for the Estimation of Eddy Diffusivity with Submerged Aeration

Reference Fujie, 1983. Only use this form for spiral circulation due to aeration. Sprial circulation is usually found only in municipal plants. For more information, consult a reference book such as Metcalf and Eddy or WEF Aeration Manual.

	Name of site		
H	depth of unit (m)	1	
W	width of unit (m) (area/diameter for circular tanks)	2	
L	LENGTH [L] distance from inlet to reactor exit. (m) Represents the mean path of actual flow from inlet to exit. Can use diameter for circular tank. If the flow is across the width of a rectangular unit, enter the width here.	3	
Q	Flow rate water (m3/s)	4	
h	diffuser depth (m)	5	
A	Aeration rate per tank (m3 air/m3 liquid per h), volumetric rate of air divided by the volume of the unit.	6	
	for fine bubble system enter 1 on line 8.	7	

CALCULATION OF EDDY DIFFUSIVITY

Ugc	sup.air feed rate (cm/s) A*H/36	8	
theta	h*100*Ugc*(h/H)^0.5*(H/W)^0.333	9	
m	value from Table I.1 (see below)	10	
a	value from Table I.1 (see below)	11	
Uts	a*(theta^m) (cm/s)	12	
Utsc	Uts/100*3600 (m/h)	13	
lamda	0.0115*(1+H/L)^(-3)*Ugc^-0.34	14	
Ut	Q*3600/W/H	15	
E	diffusivity (m2/h) lamda*Utsc*(H+W)	16	
D	(m2/s) E/3600	17	

Table I.1

	m	a	
theta<=20	0.64	7	fine
theta>20	0.46	12	
theta<=20	0.78	3.5	coarse
theta>20	0.56	4.9	

DATA FORM FOR THE CALCULATION OF THE DISPERSION NUMBER FROM A SUBMERGED AERATION UNIT

NAME OF THE FACILITY for site specific dispersion number determination		

VOLUME OF REACTOR (m3)	1	
FLOW RATE of wastewater treated in the unit (m3/s)	2	
FLOW RATE OF RECYCLE (m3/s)	3	
LENGTH [L] distance from inlet to reactor exit. (m) Represents the mean path of actual flow from inlet to exit. Can use diameter for circular tank. If the flow is across the width of a rectangular unit, enter the width here.	4	
EDDY DIFFUSIVITY [D] from Form 1 line 17 if spiral agitation or default value of 0.068 (m2/s)	5	

CALCULATION OF THE DISPERSION NUMBER

TOTAL INLET FLOW (m3/s) Add the number on line 2 to the number on line 3. Enter the results here.	6	
RETENTION TIME IN THE REACTOR (s) Divide the number on line 1 by the number on line 6. Enter the results hers.	7	
MEAN VELOCITY [U] (m/s) Divide the number on line 4 by the number on line 7. Enter the results here.	8	
DISPERSION NUMBER [D/UL] Divide the number on line 5 by the product of the number on line 8 and the number on line 4. Enter the results here.	9	

DATA FORM FOR THE EVALUATION OF THE MIXING TIME BASED UPON A DISPERSION NUMBER FOR SUBMERGED AERATION SYSTEMS.

NAME OF THE FACILITY for site specific biorate determination

DISPERSION NUMBER From Form 2, line 9.	1	
RETENTION TIME IN THE REACTOR (s) From Form 2, line 7.	2	

Value of dispersion number	mixing time ratio
0.025	0.85
0.1	0.8
0.15	0.7
0.2	0.6
0.25	0.514
0.5	0.330
1	0.199
2	0.107
4	0.042
6	0.013
0.300	0.459

CALCULATION OF THE ESTIMATE OF THE MIXING TIME

In the above table, look up the mixing time ratio using the value of the dispersion number on line 1. Enter this mixing time ratio on line 3. These values were obtained from Monte Carlo simulations of dispersion within circular tanks.

	3	
MIXING TIME (s) multiply the number on line 2 by the number on line 3.	4	

equation for estimating the mixing time= =IF x>6 use 0.01 else use 0.314375*(x^-0.5) -0.114921
Use this equation if the dispersion number is not within the range of the table.

DATA FORM FOR THE CALCULATION OF THE STRIPPING TIME FOR CHLOROBENZENE IN A BIOREACTOR

NAME OF THE FACILITY for site specific biorate determination		
COMPOUND for site specific biorate determination		Chlorobenzene
AREA OF REACTOR SURFACE (m2)	1	
VOLUME OF REACTOR (m3)	2	
K, mass transfer coefficient (m/s) from Form 12, line F.	3	
Equivalent mass transfer coefficient (m/s) from Form 10, Line 6.	4	
Total Equivalent KL (m/s). sum of line 3 and line 4. Line 3 represents the contribution from surface volatilization and line 4 represents the contribution from volatilization into subsurface bubbles.	5	

CALCULATION OF THE ESTIMATE OF THE STRIPPING TIME

STRIPPING TIME (s) Divide the number on line 2 by the product of the number on line 1 and the number on line 5.	6	
50% STRIPPING TIME (s) Multiply the number on line 6 by 0.693.	7	

DATA FORM FOR THE COMPARISON OF THE MIXING TIME TO THE STRIPPING TIME AND THE RETENTION TIME IN THE BIOREACTOR

NAME OF THE FACILITY for site specific biorate determination		
COMPOUND for site specific mixing ratio determination		Chlorobenzene
MIXING TIME (s) From Form 3 line 4, or from Form 7 line 8, or from Form 9 line 12.	1	
Method of obtaining the mixing time	2	
50% STRIPPING TIME (s) From Form 4, line 7.	3	

COMPARISON OF THE MIXING TIME TO THE STRIPPING TIME

MIXING TIME-STRIPPING TIME RATIO Divide the number on line 1 by the number on line 3.	4	
Required target ratio	5	0.33
Is the stripping time ratio less than the target ratio?	6	

COMPARISON OF THE MIXING TIME TO THE RETENTION TIME

VOLUME OF REACTOR (m3)	7	
FLOW RATE of wastewater treated in the unit (m3/s)	8	
FLOW RATE OF RECYCLE in the full-scale bioreactor (m3/s)	9	
TOTAL INLET FLOW (m3/s) Add the number on line 8 to the number on line 9. Enter the results here.	10	
RETENTION TIME IN THE REACTOR (s) Divide the number on line 7 by the number on line 10. Enter the results hers.	11	
MIXING TIME RETENTION RATIO Divide the number on line 1 by the number on line 11.	12	
Required target ratio	13	0.33
Is the retention time ratio less than the target ratio?	14	

DATA FORM FOR THE EVALUATION OF THE SAMPLING DISTANCE LIMITS

NAME OF THE FACILITY for site specific biorate determination		
COMPOUND for site specific mixing ratio determination		Chlorobenzene
STRIPPING TIME (s) From Form 4, line 6.	1	
VOLUME OF REACTOR (m3)	2	
FLOW RATE of wastewater treated in the unit (m3/s)	3	
FLOW RATE OF RECYCLE in the full-scale bioreactor (m3/s)	4	
LENGTH [L] distance from inlet to reactor exit. (m) Represents the mean path of actual flow from inlet to exit. Can use diameter for circular tank. If the flow is across the width of a rectangular unit, enter the width here.	5	

CALCULATION OF THE SAMPLING LIMIT

TOTAL INLET FLOW (m3/s) Add the number on line 3 to the number on line 4 Enter the results here.	6	
RETENTION TIME IN THE REACTOR (s) Divide the number on line 2 by the number on line 6. Enter the results hers.	7	
MEAN VELOCITY [U] (m/s) Divide the number on line 5 by the number on line 7. Enter the results here.	8	
SAMPLING DISTANCE LIMIT (m) multiply the number on line 1 by the number on line 8. Enter the results here.	9	

DATA FORM FOR THE SUMMARY OF TRACER RESULTS

This form is based upon the concept that a tracer is placed in the inlet of a reactor and the concentrations in the exit of the reactor are measured as a function of time. Well-mixed systems will not have bypassing and the tracer curve may be analyzed to demonstrate that the retention time in the reactor is approximately the same as the theoretical value. Verbal descriptions are requested below to assist in the interpretation of the data.

NAME OF THE FACILITY for site specific tracer testing		
COMPOUND used for the tracer evaluation		
Attach a graph of the concentration of tracer vs. time and a short general description of the tracer test. The details of the test report should be available for inspection.		
Location of tracer release (general verbal description, such as inlet on the side of a circular tank with the exit on the opposite side)	1	
Location of tracer measurement (such as in exit of circular tank)	2	
FLOW RATE of wastewater treated in the unit (m3/s)	3	
FLOW RATE OF RECYCLE in the full-scale bioreactor (m3/s)	4	
VOLUME OF REACTOR (m)	5	
location of internal pumping inlet (draft tube of surface aerator, inlet of jet mixer, location of submerged agitators)	6	
Time of tracer concentration peak on graph (s)	7	
Time to reach 95% of tracer concentration peak on graph (s)	8	

CALCULATION OF THE MIXING TIME RATIO

TOTAL INLET FLOW (m3/s) Add the number on line 3 to the number on line 4 Enter the results here.	9	
RETENTION TIME IN THE REACTOR (s) Divide the number on line 5 by the number on line 9. Enter the results here.	10	
Mixing time ratio. Divide the number on line 8 by the number on line 10 and enter the results here.	11	
Target ratio for mixing time determination	12	0.33
Is the mixing time ratio less than the target ratio?	13	

Lines 9 through 13 are optional if the mixing time of line 8 is transferred to Form 5 line 1.

FORM FOR THE EVALUATION OF INDICATOR PARAMETER MIXING

	concentrations in the biological treatment unit		
	inlet	exit	unit
sum of data			
N, number			
average, sum/ number			
SD			
CV			

Method 1. Difference in inlet average and unit

Difference in unit and exit	D		
Degrees of freedom	Nunit + Nexit -2		
T value at 95% confidence level, 1 side test			
Sw	SQRT((SDunit^2*(Nunit-1)+Sdexit^2*(Nexit-1))/(Nunit+Nexit-2))		
test parameter	-D/Sw /SQRT(1/Nexit+1/Nunit)		
Is the test parameter greater than the t value?			
use t test		if no, suggests well mixed.	
reject alternative hypothesis			
accept null hypothesis, well mixed		Well mixed?	

Method 2. Slope equivalency method

Slope of the correlation between unit and exit concentrations.		
Intercept of the correlation		
standard error		
r squared		
difference, absolute value of (slope - 1)		
ratio, difference divided by the standard error		
z value at 95% confidence level, 1 side test		
Is the ratio greater than the z value?		
Is the slope equivalent to 1?	(yes if the ratio is not greater than z value)	
Can the unit be considered well mixed?	(yes if the ratio is equivalent to 1)	

DATA FORM FOR THE MIXING TIME FROM PUMPING RATE

Obtain the pump rate specifications for surface aerators from the equipment manufacturer.

NAME OF THE FACILITY for site specific pumping rate evaluation		

Type of mixing equipment 1	1	
number of units of equipment 1	2	
capacity of pumping unit 1 (m3/s)	3	
Type of mixing equipment 2	4	
number of units of equipment 2	5	
capacity of pumping unit 2 (m3/s)	6	
Volume of biological reactor (m3)	7	

CALCULATION OF THE MIXING TIME

TOTAL FLOW 1 (m3/s) Multiply the number on line 2 by the number on line 3 Enter the results here.	8	
TOTAL FLOW 2 (m3/s) Multiply the number on line 5 by the number on line 6 Enter the results here.	9	
TOTAL FLOW (m3/s) Add the number on line 8 and the number on line 9. Enter the results here.	10	
Recirculation time. Divide the number on line 7 by the number on line 10.	11	
Mixing time (s). Multiply the number on line 11 by the number 5.	12	

DATA FORM FOR THE ESTIMATION OF THE EQUIVALENT KL FOR A SUBMERGED AIR SYSTEM

NAME OF THE FACILITY for site specific biorate determination		
COMPOUND for site specific biorate determination		Chlorobenzene
VENT RATE of total gas leaving the unit (G, m3/s)	1	
TEMPERATURE of the liquid in the unit (deg. C)	2	
ESTIMATE OF Henry's law constant (H, g/m3 in gas / g/m3 in liquid). Obtained from Form 13 line 7.	3	
AREA OF REACTOR (m2)	4	

CALCULATION OF THE ESTIMATE OF EQUIVALENT KL FROM SUBMERGED AIR

[H G] ESTIMATE (m3/s) Multiply the number on line 1 by the number on line 3. Enter the results here.	5	
EQUIVALENT KL. Divide the number on line 5 by the number on line 4. Enter the results on line 6.	6	

FORM FOR CALCULATING THE MASS TRANSFER COEFFICIENT FOR A QUIESCENT SURFACE IMPOUNDMENT

FACILITY NAME for site specific biorate determination	1	
COMPOUND for site specific biorate determination	2	Chlorobenzene

Input values

Enter the following:

F - Impoundment fetch (m)	3	
D - Impoundment depth (m)	4	
U10 - Windspeed 10 m above liquid surface (m/s)	5	
Dw - Diffusivity of compound in water (cm2/s)	6	
Dether - Diffusivity of ether in water (cm2/s)	7	
µG - Viscosity of air, (g/cm-s)	8	
G - Density of air, (g/cm3)	9	
Da - Diffusivity of compound in air, (cm2/s)	10	
A - Area of impoundment, (m2)	11	
H - Henry's law constant, (atm-m3/g mol)	12	
R - Universal gas constant, (atm-m3/g mol. K)	13	
µL - Viscosity of water, (g/cm-s)	14	
L - Density of liquid, (g/cm3)	15	
T - Impoundment temperature, (C)	16	

Calculate the following:

Calculate F/D: 17

A. Calculate the liquid phase mass transfer coefficient, kL, using one of the following procedures, (m/s)

1 Where F/D < 14 and U10 > 3.25 m/s, use the following procedure from MacKay and Yeun:

Calculate the Schmidt number on the liquid side, ScL, as follows:

ScL = µL/ (L x Dw) 18

Calculate the friction velocity, U*, as follows, (m/s):

U* = 0.01 x U10(6.1 + 0.63 U10)^0.5 19

Where U* is > 0.3, calculate kL as follows:

kL = (1.0 x 10^-6) + (0.00341)U* x ScL^-0.5 20

Where U* is < 0.3, calculate kL as follows:

kL = (1.0 x 10^-6) + (0.0144)(U*)^2.2 x ScL^-0.5 21

2 For all other values of F/D and U10, calculate kL using the following procedure from Springer:

Where U10 is < 3.25 m/s, calculate kL as follows:

kL = 2.78 x 10^-6(Dw/Dether)^(2/3) | 22 |

Where U10 is > 3.25 and 14 < F/D < 51.2, Calculate kL as follows:
kL = [2.605 x 10^-9(F/D) + 1.277 x 10^-7] U10^2 (Dw/Dether)^(2/3) | 23 |

Where U10 > 3.25 m/s and F/D > 51.2, calculate kL as follows:
kL = (2.611 x 10^-7)U10^2 (Dw/Dether)^(2/3) | 24 |

B. Calculate the gas phase mass transfer coefficient, kG, using the following procedure from MacKay and Matsasugu, (m/s):

Calculate the Schmidt number on the gas side, ScG, as follows: ScG =µG/(G x Da) | 25 |

Calculate the effective diameter of the impoundment, de, as follows, (m):
de = (4A/3.14)^0.5 | 26 |

Calculate kG as follows, (m/s): kG = 0.00482 U10^0.78 ScG^-0.67 de^-0.11 | 27 |

C. Calculate the partition coefficient, Keq, as follows: Keq = H/[R(T+273)] | 28 |

D. Calculate the overall mass transfer coefficient, Kq, as follows, (m/s):
1/Kq = 1/kL + 1/(Keq x kG) | 29 |

Where the total impoundment surface is quiescent:
KL = Kq | 30 |

Where a portion of the impoundment surface is turbulent, continue with Form 12.

DATA FORM FOR CALCULATING THE MASS TRANSFER COEFFICIENT FOR AN AERATED SURFACE IMPOUNDMENT

Facility Name:	
Waste Stream Compound:	Chlorobenzene

Enter the following:

J - Oxygen transfer rating of surface aerator, (lb O2/hr-hp)	
POWR - Total power to aerators, (hp)	
T - Water temperature, (C)	
Ot - Oxygen transfer correction factor	
MWL - Molecular weight of liquid	
area per agitator (M2)	
At - Turbulent surface area of impoundment, (ft2)	
(If unknown, use values from Table 1)	
A - Total surface area of impoundment, (ft2)	
rho L - Density of liquid, (lb/ft3)	
Dw - Diffusivity of constituent in water, (cm2/s)	
Do - Diffusivity of oxygen in water, (cm2/s)	
d - Impeller diameter, (cm)	
w - Rotational speed of impeller, (rad/s)	
a - Density of air, (gm/cm3)	
N - Number of aerators	
gc - Gravitation constant, (lbm-ft/s2/lbf)	
d* - Impeller diameter, (ft)	
Da - Diffusivity of constituent in air, (cm2/s)	
MWa - Molecular weight of air	
R - Universal gas constant, (atm-m3/g mol. C)	
H = Henry's law constant, (atm-m3/g mol)	

Calculate the following:

A. Calculate the liquid phase mass transfer coefficient, kL, using the following Equation from Thibodeaux:,

kL =[8.22 x 10^-9 J (POWR)(1.024)^(T-20) Ot 10^6 MWL/(At x rhoL/62.37)] (Dw/Do)^0.5, (m/s)

B. Calculate the gas phase mass transfer coefficient, kG, using the following procedure from Reinhardt:,

Calculate the viscosity of air, µa, as follows, (g/cm.s):
µa = 4.568 x 10^-7 T + 1.7209 x 10^-4

Calculate the Reynold's number as follows:
Re = d^2 w a/µa

Calculate power to impeller, PI, as follows, (ft.lbf/s):
PI = 0.85 (POWR) 550/N

Calculate the power number, p, as follows:
p = PI gc/(rho d*^5 w^3)

Calculate the Schmidt number, ScG, as follows:
ScG = μa/ (a x Da)

Calculate the Fronde number, Fr, as follows:
Fr = d* x w^2 /gc

Calculate kG as follows:
kG = 1.35 x 10^-7 Re^1.42 p^0.4 ScG^0.5 Fr^-0.21 Da MWa/d, (m/s)
if quiescent gas phase mass transfer coefficient is used, enter here else use above line.

C. Calculate the partition coefficient, Keq, as follows:
Keq = H/[R(T+273)]

D. Calculate the overall turbulent mass transfer coefficient, Kt, as follows, (m/s):
1/Kt = 1/kL + 1/(Keq x kG)

E. Calculate the quiescent mass transfer coefficient, Kq, for the impoundment using Form 11 line 29.

F. Calculate the overall mass transfer coefficient, KL, for the impoundment as follows: KL = (A-At)/A*Kq + At*Kt/A

PROCEDURES FORM FOR THE ESTIMATION OF THE KL FROM WATER8 a.b

Motor horsepower, hp	At, Turbulent area, ft2	At, Turbulent area, m2	Effective depth, ft	V, Agitated volume, ft3	aV, Area per volume ft2/ft3
5	177	16.4	10	1,767	0.1002
7.5	201	18.7	10	2010	0.1000
10	227	21	10.5	2383	0.0953
15	284	26.4	11	3119	0.0911
20	346	32.1	11.5	3983	0.0869
25	415	38.6	12	4986	0.0832
30	491	45.7	12	5890	0.0834
40	661	61.4	13	8587	0.0770
50	855	79.5	14	11970	0.0714
60	1075	100	15	16130	0.0666
75	1452	135	16	23240	0.0625
100	2206	205	18	39710	0.0556

a Data for a high speed (1,200) rpm) aerator with 60 cm propeller diameter (d).

b This table provides information potentially useful for the value of At in Form 12.

DATA FORM FOR THE ESTIMATION OF THE HENRY'S LAW CONSTANT FOR A COMPOUND IN THE BIOLOGICAL TREATMENT UNIT

NAME OF THE FACILITY for site specific biorate determination		
COMPOUND for site specific biorate determination		Chlorobenzene
LISTED HENRY'S LAW VALUE AT 25 degrees Celsius. (ratio of mol fraction in gas to mole fraction in water)	1	
TEMPERATURE of the liquid in the unit (deg.C)	2	
CALCULATION OF K		
Temperature adjusted Henry's law value (equals the value on line 1 if the temperature on line 2 is 25)	3	
Discuss the basis of the temperature adjustment.		
Temperature in degrees Kelvin. Add 273.16 to the number on line 2. Enter the results here.	4	
Temperature ratio. Divide 273.16 by the number on line 4. Enter the results here.	5	
Henry's Law adjustment factor. Multiply the number on line 5 by 0.804 and enter the results here.	6	
Henry's Law value (g/m3 gas per g/m3 liquid) Multiply the number on line 3 by the number on line 6 and divide the results by 1000. Enter the results here and on Form 10 line 3.	7	
Henry's Law value (atm m3 per mol) Divide the number on line 3 by 55555 and enter the results here.	8	