By Liquidtek LLC

Oxygen Transfer Science

3/15/2023

By providing “Continual Surface Renewal” SUNFLO^2 equipment creates the optimum kinetics (mixing) and recirculation (reaeration) necessary to accelerate biological activity in a wastewater treatment pond.

Prepared by:

LiQUiDTEK LLC

Manufacturers of

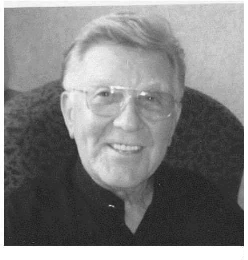
SUNFLO^2
By Liquidtek LLC

Contents

Contributors:

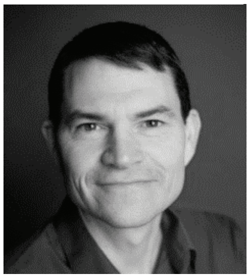
Wayne Ruzicka

Wayne Ruzicka is often described as one who "Thinks Different" which is an apt description of the way he looks at oxygen transfer. Beginning in 1986 he began measuring and evaluating pond treatment performance using a portable meter in a boat. He was able to assess the impact of splashers, aspirators and diffused air systems in hundreds of systems/applications. The "uncommon knowledge" about the real-world reactions, as opposed to test tanks and manufacturers claims, provides a unique perspective about how to achieve optimum oxygen transfer with minimal energy input. Wayne is fond of the expression *"The oxygen is already there, what's needed is not transfer – that occurs instantaneously, what's needed is distribution".* By understanding the origins of wastewater treatment ponds (aeration methods) Wayne has directed research and equipment that provides real time information on water quality parameters "in process" to identify and document improving treatment efficiency while reducing energy and maintenance.



Warren Enyart

To provide scientific explanations to field observations and measurements, Warren reviewed 100+ years of scientific literature on the known biological, physical and chemical reactions taking place in the natural treatment of wastewater and fresh water contained in a basin. He completed several "white papers" and process specifications related to solar powered mixing equipment. Warren was CEO of the Renewable Resources Research Institute and Director of the North Dakota Manufacturing Technology Partnership. In addition to his education in physics, Warren was also a writer, painter, poet, historian, preacher, pilot, blacksmith, gunsmith, gun-slinger, guitar-slinger, sailor, scoutmaster, social worker, seamstress, sketch artist, self-made scientist, and armchair astrophysicist.



Evan Anderson

Evan Anderson is the "Mad Scientist" and operates Gizmonics LLC, a design, prototyping, and product development company in Bismarck, ND. With engineering software, an on-site prototyping shop and several 3D printers, he can design and build a wide range of products and equipment. Evan has 25 years of product development, manufacturing, and project management experience, has owned 6 businesses, and has brought several innovative products to national and international markets.

Evan holds Master's and Bachelor's Degrees in Industrial Technology from the University of North Dakota. He enjoys solving problems of any kind and spends a good deal of his free time on a mountain bike.

Ganya Anderson

Ganya Anderson identifies herself as the "Plucky Sidekick" and is the data crunching geek at Gizmonics. She uses applied research methods to optimize design for certain performance characteristics. That is a fancy way of saying she uses math to make products and processes better. She is also the owner of Proactive Business Solutions, a professional business services company serving medium to large businesses internationally. Ganya has a Master of Arts in Economics from the University of North Dakota and a Bachelor of Arts in Economics from Smith College. She is a certified Master Black Belt in Lean Six Sigma and loves getting away from the computer to go on bike rides with her husband.

A Summary of Oxygen Transfer Via Progressive Reaeration & Recirculation

The following is an attempt to describe, quantify, and formulate the various observed phenomenon believed to be attributable to the SUNFLO^2 technology. The research was primarily based upon literature reviews of relevant principles researched by other renowned scientists that are known to be influenced by PRR, (Progressive Reaeration and Recirculation), and believed to be probable causes for observed pond-based waste water and fresh water treatment. The object of the paper is to provide a rational background for developing formulae that will enable engineers and/or trained wastewater treatment personnel to predict the BOD removal rate that one could expect from the introduction of SUNFLO^2 units in a given pond environment.

The observed variables have been discussed in order of their theoretical importance to the outcome; measured in "BOD removal rate" (RR%). Ideally, the ultimate formula should be of the following order: RR% = f1 x f2 x f3x fn…, where, f1, f2, f3, etc are the variables discussed in the attached White Paper; the first of which has the most significant influence on the outcome, the next variable having less impact, and so on. Of course, at best this is only a theoretical framework to attempt to give relative weight to the variables as each might affect the treatment process, when the SUNFLO^2 Technology is properly applied.

The observed target is dictated by frequently observed performance of SUNFLO2 Technology operating in typical wastewater ponds. In many such cases, the measured RR% after the application of the SUNFLO2 Technology, was found to be five times that achieved by the unassisted facultative pond. Most of these ponds, while now overloaded, were originally designed under the USEPA standards for areal loading in each climate. This is a strategic targeted metric, as many of the 8,000 pond-based treatment facilities in the United States were originally designed under the EPA criteria. In any case, the primary metric for any treatment process, is the reduction of BOD. And because the SUNFLO2 unit's operating principles depend a great deal on surface area time, in addition to defining the mixed portion of the pond, these three parameters should be inherent in the ultimate formula to be derived.

A mathematician might review the tested formulae included in the paper and draft an empirical relationship among them that incorporates the observed phenomena attributable to the SUNFLO^2 units. The empirical formula could serve as the hypothesis for controlled experimentation; with the ultimate goal to deduce a reliable, but simplified, design formula that will predict the RR% of the SUNFLO^2 units' application in a given pond. Although it is an oversimplification, if our theory is correct, the empirical formula for RR% should be equal to five times the basic formal used to predict the performance of an unassisted facultative pond designed in accordance with EPA guidelines.

Research Sources

In addition to the sources listed behind each "white paper" material was also sourced from some of the documents shown below.

1. 2nd International Symposium for Waste Treatment Lagoons. / [Edited and distributed by Ross E. McKinney.

   https://trove.nla.gov.au/work/21880804?q&versionId=26349749

2. Design manual: Municipal wastewater stabilization ponds E. J Middlebrooks, 1983

   https://scholar.google.com/scholar?q=Design+Manual,+Municipal+wastewater+

3. Environmental Systems Engineering, Linvil G. Rich
   https://books.google.com/books/about/Environmental_Systems_Engineering

4. Waste stabilization lagoons: a review of research and experience in design, construction, operation and maintenance: proceedings of a symposium at Kansas City, Mo., Aug. 1-5, 1960
   https://search.library.wisc.edu/catalog/999617268502121

5. Operations Manual, Stabilization Ponds, Chuck Zickefoose
   https://nepis.epa.gov/Exe/ZyNET.exe/9100

6. Sewage Stabilization Ponds in the Dakotas, W. Van Heuvelen, ND Department of Health
   https://nepis.epa.gov/Exe/ZyNET.exe/2000QW93.TXT?

7. Industrial Waste Treatment Practice, E.F. Eldridge

8. Sewage Treatment, Karl Imhoff and Gordon Fair
   https://www.amazon.com/Sewage-Treatment-Karl-Imhoff

9. Nitrogen Removal in Wastewater Stabilization Lagoons, Joe Middlebrooks
   http://www.bvsde.paho.org/bvsacd/leeds/removal.pdf

LiquidTEK LLC

Manufacturer of SUNFLO^2 Products

Provides increased reaeration and recirculation through improved mixer design and greater laminar flow.

A. Solar energy powers a motor that drives an impeller.

B. The unit floats on the surface supported by a stainless steel framework.

C. An intake dish and a distribution dish funnel water from lower levels to the surface.

O2 transfer occurs because:

1. The impeller and distribution dishes deliver water in a thin layer onto the surface for maximum exposure to atmospheric oxygen.
2. The intake design means the source of the water is from a level of low oxygen concentration (greatest Delta).
3. Successive thin layers of re-oxygenated water are migrate downward into the water strata to progressively increase oxygen concentrations throughout the basin.

Developer of Sunflo2 Technology

Provides the onboard computer control systems, radio communication, data collection and SCADA data reporting capabilities increasing the operator's understanding of current and historical status of the ponds chemical and biological activity.

A. An electronic probe measures water quality.
B. A signal is sent to the Cloud and the data is accumulated for transmission.
C. A cellular signal is sent to the Cloud, then uploaded to the internet for private analysis of results.

Oxygen Transfer Calculations

Summary:

The following illustrates the calculated oxygen transfer rate of a standard SUNFLO^2 unit, along with the assumptions made. It is the author's intention to provide a conservative estimate, actual transfer rate is assumed to be higher.

Assumptions and Calculations:

- Based upon research conducted by Imhoff and Fair(1), a quiescent reservoir is capable of absorbing 34 pounds of oxygen per acre per day. Though wind and circulation increase this figure dramatically, this constant is used in the interest of the conservative approach and to account for other variations due to temperature and the base percentage saturation of a given pond.
- Based upon 60 days of actual run data in Gridley, California, a unit averages 70 RPMs day (Figure 1) and night. At 70 RPMs, a SUNFLO^2 unit moves 767 gallons per minute (GPM) of water (Figure 2), 1" deep across the lip of its distribution dish. This equates to 1,104,480 gallons per day.
- At a depth of 1" (flowing across the top of the distribution dish), 1,104,480 gallons would cover 40.67 acres. Thus, the SUNFLO^2 unit is providing 40.67 acres of water to the surface per day.
- If each acre of water absorbs 34 pounds of oxygen per day, a single SUNFLO^2 unit will be responsible for 40.67 x 34 = 1,383 pounds of oxygen transfer per day, or 1,383/24 = 57.6 pounds of oxygen per hour.
- If 1,383 pounds of oxygen are transferred to the 1,104,480 gallons of water pumped each day, that equates to 1,383/1,104,480 = 0.001252 lbs/gallon of water pumped, or 129.3 milligrams/liter of water pumped.
- Assuming 2 pounds of oxygen is absorbed per horsepower from typical equipment process water (Figure 3), a single SUNFLO^2 unit can replace 57.6 pounds of oxygen per hour/2 pounds per horsepower = 28.8 horsepower = 21.5 kW. At $0.10/kWh, this is a savings of 21.5 kW x 24 hours x $0.10 per kWh = $51.60/day. $51.60 x 365 = $18,834 in savings per year.

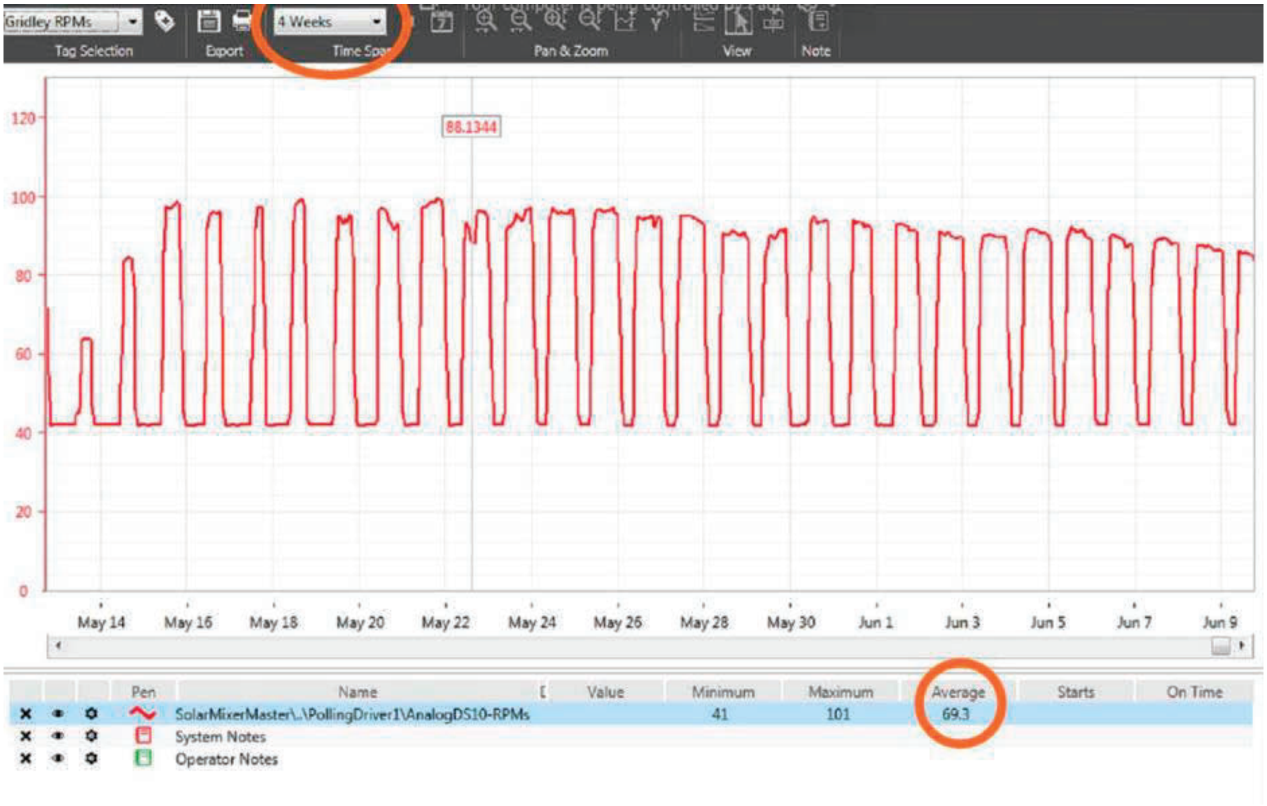
Summary of Results:

- Oxygen transfer rate of a single SUNFLO^2 unit = 1383 lbs/day or 57.6 lbs/hour
- Oxygen transfer per volume of water pumped is 129.3 milligrams/liter
- Horsepower replaced is 28.8
- Annual savings versus electric aeration is $18,834 per Sunflo^2 unit

(1) Imhoff, Karl and Gordon Fair, *Sewage Treatment*, John Wiley & Sons, New York, 1956, pg. 287-292

(2) Yunt F.W., and Stenstrom M.K. (1996) *Aeration equipment evaluation – phase II: process water test results*, EPA Report 68-03-2906

Figure 1: Average RPMs

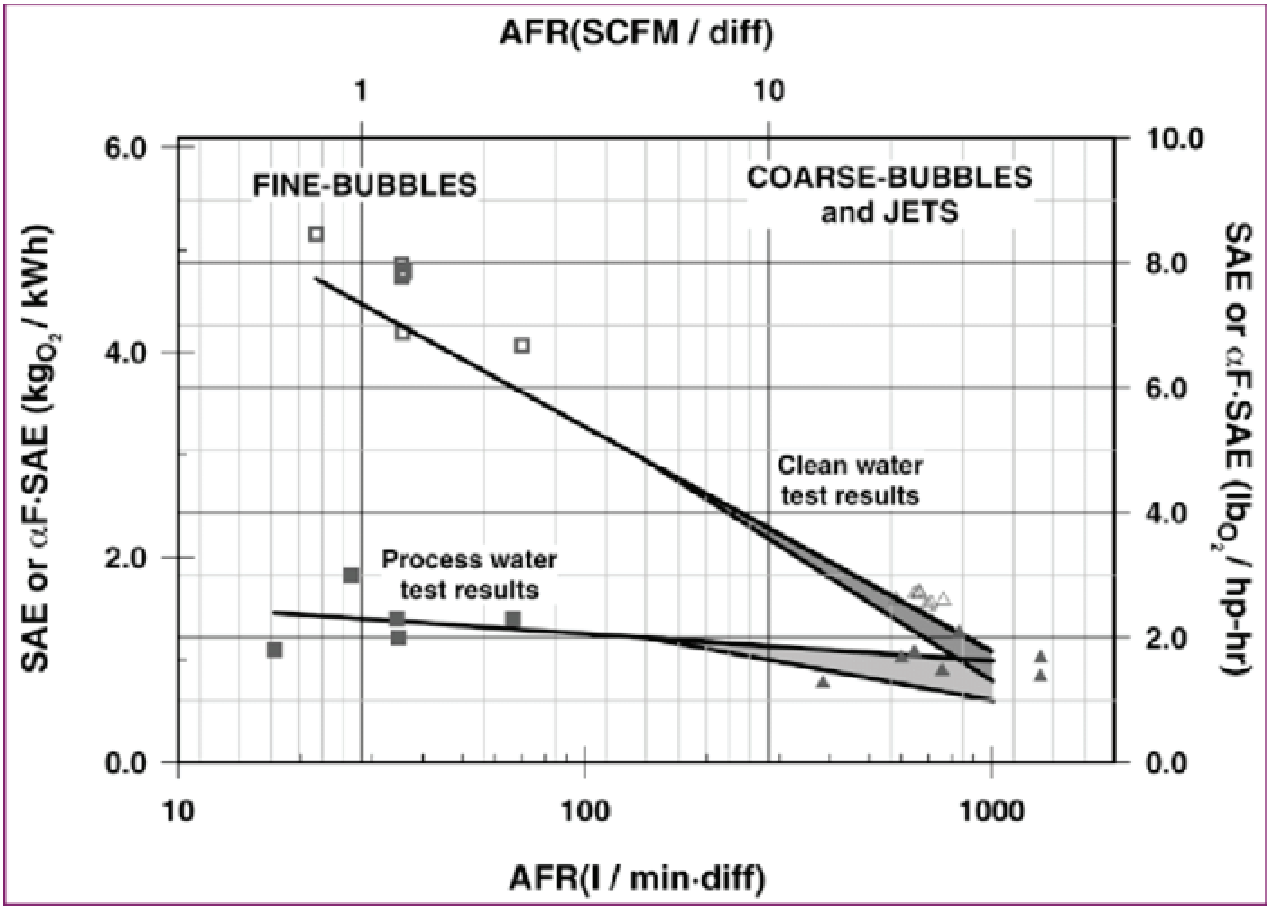


			Pen	Name	Value	Minimum	Maximum	Average	Starts	On Time
×				SolarMixerMaster\..\PollingDriver1\AnalogDS10-RPMs		41	101	69.3		
×				System Notes						
×				Operator Notes						

Figure 2: GPM vs. RPM test data from 6/20/18 – 6/22/18. Conducted by Paul H. Bott, P.E.

Actual RPM	Watts	Flow GPM	Solar W/Sq M
39	13	387	993
51	19	492	1008
60	24	639	1016
70	35	767	1018
81	42	898	1026
90	55	1054	1032
102	69	1179	1035
107	73	1284	1032

Figure 3:



Standard Aeration Efficiency In Clean-(SAE) and Process-(aFSAE) Water for FinePore and Coarse-Bubble Diffusers (data after Yunt and Stenstrom, 1996).

Technical “White Paper” #1

O^2 TRANSFER VIA REAERATION and RECIRCULATION

Oxygen is the vital element for the biological decomposition of organic waste. When it is available, and in the presence of oxidizable organic matter and oxidizing bacteria (and other organisms), natural purification processes will take place. For nearly a century, designers of wastewater stabilization ponds have attempted to enhance the known treatment mechanisms of nature. Two of the more obvious natural mechanisms are reaeration; the supply of oxygen from the atmosphere and photosynthetic plants, and recirculation; the distribution of the pond contents resulting from wind and thermal forces. Realizing the significance these factors have on stabilizing wastewater, scientist and engineers have developed pond designs and various mechanical apparatus with which to improve oxygen transfer from the atmosphere and its subsequent distribution. This paper addresses the conditions necessary for the absorption of oxygen from the atmosphere and the recirculation of pond contents and how one apparatus; the SUNFLO^2 Waste-Flo unit (solar powered), affects those conditions.

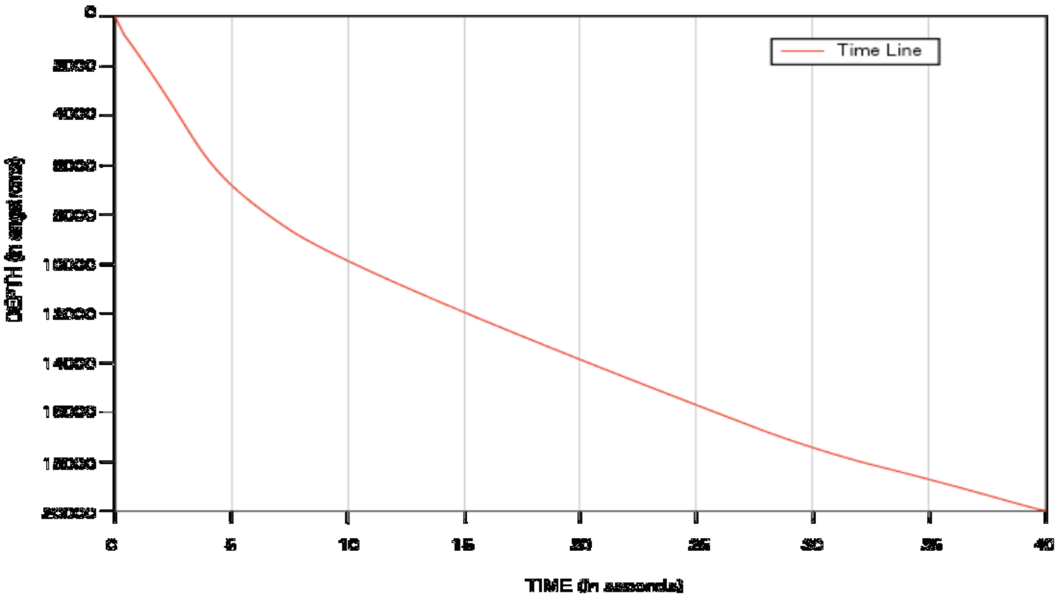
Technically, the term “reaeration” includes the supply of oxygen by both the direct absorption of free molecular oxygen (O_2) from the atmosphere and that which is supplied by photosynthetic plants. As used in this paper, the term *reaeration* refers to oxygen transferred by absorption only. However, it should be noted that both these oxygen transfer principles are affected simultaneously by the recirculation functions of the SUNFLO^2 Technology. The SUNFLO^2 Technology influence over the supply of oxygen by algal growth is the subject of another paper (*Algae Control in Wastewater and Fresh Water Ponds*).

About 21% of the atmosphere is pure molecular oxygen. The rate of oxygen transfer from the atmosphere is a function of surface area, the qualities of the surface film, time, temperature, recirculation, and the deficit between saturation and the dissolved oxygen (DO) concentration at a given time. Oxygen is initially transferred from the atmosphere to a thin surface film that rapidly saturates when the water is quiescent as shown in Figure 1. It should be noted that surface tension will affect the rate of oxygen (and other gases) transfer through the gaseous-liquid interface. Also, wave action will effectively increase the surface area, which in turn affects the rate of oxygen transfer. These complex issues are the subject of another paper (*Evaporation Effects in Ponds*).

As oxygen is dissolved into the water, a point is reached where no more can be added, without a sustained force, or source, as is the case when there are high concentrations of algae in the surface stratum. This point is called "saturation." Although there are some circumstances under which water will become super saturated, this is usually a transient condition and any excess oxygen is rapidly lost to the atmosphere.

The saturation point for oxygen is dependent upon several factors, but temperature is the most important. As the temperature increases, the oxygen becomes less dense and the water holds fewer oxygen molecules per unit of water volume. For example; from Table 1, the saturation point for oxygen in water at 32°F is about 14.6 mg/l and at 86°F is about 7.6 mg/l. It is important to note here that while higher temperatures decrease the capacity of a wastewater treatment pond to hold dissolved oxygen, the rate of oxygen uptake (use of oxygen in biological and chemical reactions) is dramatically increased.

Figure 1. Transfer rate of atmospheric oxygen into water starting at 20% saturation and achieving 80% saturation.



In a quiescent pond, the rate at which oxygen will dissolve in water after it is partially or wholly depleted depends on the amount of oxygen in the surface film and on the area of the surface exposed to the atmosphere. The intensity of absorption is a direct function of the lowering of the oxygen content; that is, the lower the oxygen concentration in the surface, the more rapidly will absorption take place.

Table 1. Saturation value of oxygen in water.

Temperature		Dissolved Oxygen	
Deg. C.	Deg. F.	P.p.m.	Lb.per million gal.
0	32.0	14.62	122.3
1	33.8	14.23	119.0
2	35.6	13.84	115.8
3	37.4	13.48	112.5
4	39.2	13.13	109.5
5	41.6	12.80	106.9
6	42.8	12.48	104.0
7	44.6	12.17	101.5
8	46.4	11.87	98.9
9	48.2	11.59	96.5
10	50.0	11.33	94.5
11	51.8	11.08	92.4
12	53.6	10.83	90.4
13	55.4	10.60	88.4
14	57.2	10.37	86.4
15	59.0	10.15	84.6
16	60.8	9.95	83.0
17	62.6	9.74	81.1
18	64.4	9.54	79.5
19	66.2	9.35	78.0
20	68.0	9.17	76.5
21	69.8	8.99	75.0
22	71.6	8.83	73.7
23	73.4	8.68	72.5
24	75.2	8.53	74.2
25	77.0	8.38	70.0
26	78.8	8.22	68.6
27	80.6	8.07	67.4
28	82.4	7.92	66.2
29	84.2	7.77	65.0
30	86.0	7.63	63.7

Table 2 is derived from Eldrige's work with pollution in streams.(1) It gives the rate at which oxygen will dissolve in water at various percentages of saturation. The rate is given in grams per square foot of surface per day and is applicable to water in a quiet condition.

Table 2. Rate at which oxygen dissolves in water.

Percentage saturation	Oxygen dissolved, g. per sq. ft. per day	Percentage saturation	Oxygen dissolved, g. per sq. ft. per day
0	1.00	45	0.15
5	0.83	50	0.12
10	0.58	55	0.10
15	0.47	60	0.08
20	0.38	65	0.06
25	0.31	70	0.05
30	0.27	80	0.03
35	0.23	90	0.01
40	0.18	100	0.00

Notice that the above absorption rates do not consider the volume of water that may be beneath the surface-atmosphere interface. Without a mechanism for continually replacing the surface film, it rather quickly becomes saturated and the rate of transfer diminishes accordingly. Similarly, without a mechanism for continually depleting the dissolved oxygen from the strata below the surface, the penetration (diffusion) of the oxygen is slowed to a stop.

In their extensive studies of receiving streams, Imhoff and Fair noted that a quiescent reservoir of 6 foot depth was capable of absorbing 34 pounds of oxygen per acre per day, if its average (bottom to top) oxygen deficiency is held at 20% saturation by decomposition. These scientists pointed out however, that winds and waves can increase the rate of reaeration dramatically. Wind sweeping over the water surface destroys interfacial films which obstruct the transfer of oxygen may be expected to double the oxygen absorption. Waves ruffle the surface and create circulation of water resulting in a tenfold increase in the rate of absorption of oxygen from the atmosphere.

Imhoff and Fair observed: “The oxygen absorbed by reaeration must enter the receiving water through the water surface and pass into the lower water strata by the slow process of diffusion unless the water is mixed or circulated. Hence the rate of reaeration depends also: (1) upon the depth of the water, or, more specifically, upon the volume of water underlying a unit surface area of water, and (2) upon the rate at which the water is mixed by vertical and horizontal currents that distribute the absorbed oxygen through the water and bring new volumes of under saturated water into contact with the atmosphere.”(2)

It was in this textbook, originally published in 1920, that the notion of “surface renewal” was introduced by Imhoff and Fair. In their closing chapter they reminded the reader: **“Creation of conditions favorable to oxygen absorption, namely large surface and change of surface, is a fundamental principle of biological sewage-treatment processes.”**

Eldridge provides a more analytical description of the effects of recirculation than that offered by Imhoff and Fair. Eldridge said that after the initial concentration of the water on the surface, the rate of vertical distribution becomes the controlling factor. Oxygen absorbed on the surface will diffuse downward, and in time a condition is established in which the concentration varies from almost saturation on the surface to initial contact at some point below. The quieter the water, the slower is this rate of diffusion, until in quiescent water, equilibrium is established. This may occur even at a low oxygen concentration, but when the equilibrium is established the diffusion almost ceases. Recirculation of the water causes an even distribution of the oxygen and allows absorption to proceed to a new equilibrium. It is evident, therefore, that as the water beneath the surface is more thoroughly mixed, both vertically and laterally, the rate of absorption increases, and the equilibrium of the oxygen concentration is established at a higher level.

Because the diffusion of oxygen from the nearly saturated surface layer is much slower than absorption, and is in turn dependent upon recirculation, this is often the rate controlling step. Eventually, oxygen is dispersed throughout the body of the system by diffusion, convection, and advection until the point of complete saturation throughout the contained volume, provided nothing in the water uses the oxygen as it is dispersed. Experience with various mechanical apparatuses has caused many "pond scientists" to conclude that: the most effective means of enhancing natural oxygen supply from the atmosphere (reaeration) is the mechanism that provides the most effective rate of surface renewal and subsequent dispersion. ***Free molecular oxygen is readily available via atmospheric absorption; what is needed is oxygen delivery***.

The concept of supplying free oxygen to a pond through enhanced reaeration and recirculation is based on the premise that some of the natural conditions that enable reaeration and dissolved oxygen distribution can be influenced, resulting in increased mass transfer into, and throughout, the pond. The operating principles predict that a quantifiable amount of O_2 will dissolve in the surface layer of a pond in proportion to the oxygen deficit of the surface water, and that dissolved oxygen will subsequently be thoroughly distributed through the effects of recirculation. It is also asserted that the mass transfer per day is proportionate to the total oxygen depleted surface area exposed to the atmosphere on a daily basis (surface renewal). Furthermore, the oxygen deficit in the surface layer can be maintained at some specified level by continuously drawing water from a stratum of low concentrations of DO and spreading it upon the surface.

In support of this concept, the findings of Eldridge, Imhoff and Fair, and Oswald(3) in their studies of reaeration of natural ponds and streams are drawn upon. In summary, they observed that a gently flowing stream, having received a given quantity of BOD, will undergo “self-purification“ within a predictable distance (time). They advance the principles of continual surface renewal, vertical and lateral recirculation, and the forces of nature. Compared to mechanical apparatuses that are specifically designed to force air into water, requiring considerable horsepower, the oxygen transfer mechanisms operating in the slow-moving stream are worthy of close examination and replication.

Although the treatment capabilities of moving streams have been amply documented, oxygen provided by reaeration alone in a quiescent pond is insufficient to meet the requirements of sustained aerobic waste treatment. Yet it is a well-known fact that properly designed pond-based treatment systems are quite effective in wastewater stabilization. The key to this apparent contradiction is that ponds are not quiescent. Wind and wave action, thermal dynamics, rising gasses, and other forces within a pond do indeed cause recirculation of the pond contents and increased reaeration rates. Nearly 70 years of engineered pond-based wastewater treatment experience has demonstrated that the expected results are predictable and reliable. “Pond Scientists” have developed design criteria that take into account the subtle, natural influences that contribute to the stabilization of BOD. Those influencing factors that affect the rate of oxygen absorption are the focus of this paper.

First and foremost, since we are dealing with a surface phenomenon, the surface area of the pond has the greatest influence on reaeration. The greater the area exposed to the atmosphere, the greater the rate of absorption, provided there is “room” for oxygen to dissolve (be absorbed) in the water. Within the surface film, for any given surface area and temperature, the next greatest influence on O_2 absorption is, of course, the degree of saturation and temperature. Upon reaching saturation, further mass transfer is dependent upon the downward diffusion, which in turn, in a quiescent pond, is dependent upon the gradient of saturation.

Where there is little or no recirculation of the pond contents, the rate of diffusion becomes the mass transfer controlling function. To transfer large quantities of oxygen into water, additional interfaces (rippling and surface renewal) must be created. A maximum oxygen deficit must be maintained in the surface layer; resistance (such as surface tension) in the interface must be reduced; and the volume beneath the surface must be well mixed (as might be expected in a gently rolling stream).

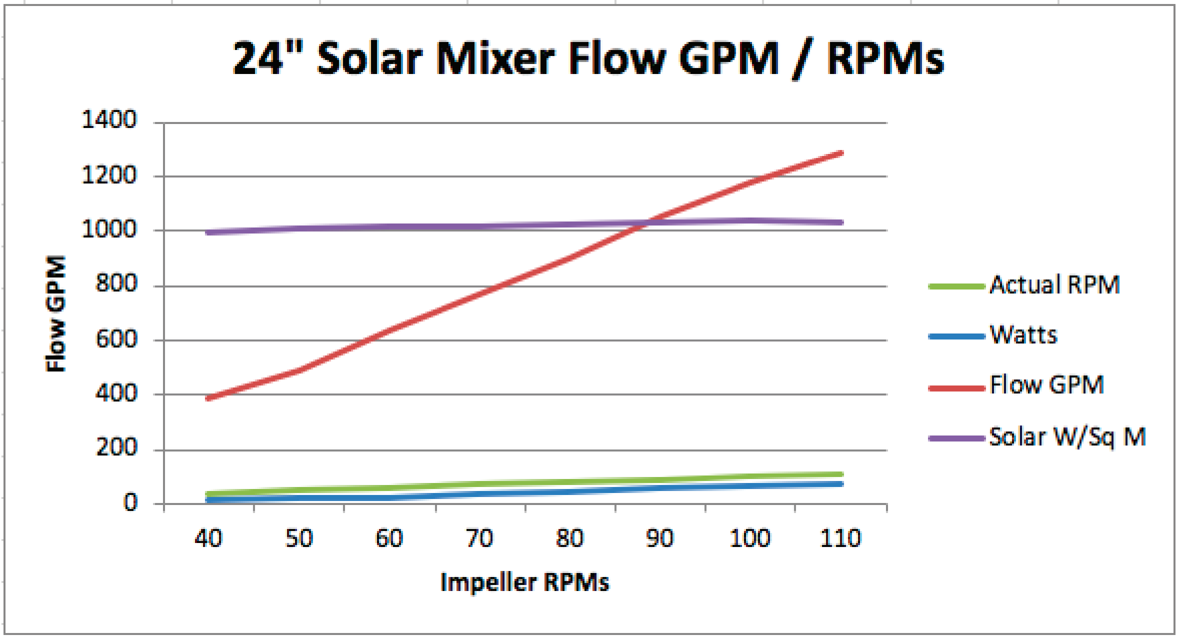
The principle functions of the SUNFLO^2 units involve drafting water from a given (and controllable) depth in the pond and disbursing it across the surface in near-frictionless laminar flow. When the dissolved oxygen concentration at the depth of the intake dish is less than its saturation point, the water, upon reaching the surface, will absorb pure oxygen from the atmosphere (reaeration). The water layer on the surface, at about 0.5 inches thick, spreads radially, in successive sheets, outward from the unit to the embankment of the pond, or until it encounters another laminar flow moving in a converging direction. The exit velocity of the water over the lip of the distribution dish is about 0.8 feet per second. At the embankment, or upon encountering converging laminar flow, a shallow head is created. This causes the water to descend to a depth roughly equal to the depth of the intake dish. At this depth, water migrates (in somewhat laminar fashion) inward to the intake dish. In this stratum, dissolved oxygen is further distributed laterally by advection and convection due to the physical recirculation of the fluid.

The volume of water placed on the surface is derived from two sources: the direct mechanical displacement (DMD) by the pumping action of the impeller and a secondary, induced flow, referred to as Radial Induction (RI). The DMD is the volume, measured in gallons per minute (GPM), of fluid that is drawn into the intake and discharged past the edge of the distribution dish over a given amount of time.

The DMD is not linear. The flow is the result of two different components of pumping theory. The first component is nearly linear and calculates to about 9.0 gallons per revolution of the impeller. This component is essentially the result of work done by a rotating lifting plane or an inclined ramp. The second component of the flow varies from 0.91 – 3.0 gallons per revolution. This flow is the result of a centrifugal force imparting an increased velocity to the water at the outer edges of the impeller. The rpm of the impeller depends principally on the solar radiation energy at a given geographic location. Its optimum range is 70 –115 rpm. The combined effect of these pumping dynamics produce the DMD and are shown in Figure 2.

Radial Induction (induced flow) volumes have been calculated using complex fluid dynamics formulae that describe: laminar flow, induced flows created by relative velocity changes, diverging and converging streamlines (Bernoulli's equations), boundary layer phenomenon, and wave mechanics.(4) Hydraulic pressure changes at the boundary layer between the laminar layer and the quiescent water at the surface, and at the depth of the intake, induces a vertical and upward, secondary flow, as shown in Figure 3. This vertical flow is inversely proportional to the square of the distance from the distribution dish. The volume of the Radial Induction contribution to the volume on the surface is a function of the DMD. The Radial Induction flow in gallons per minute is about 4 to 5 times the DMD flow, depending on the impeller rpm. The currents depicted in Figure 3 have been confirmed by tracer dyes and neutral-buoyancy chips. Assuming an average 70 rpm over 24 hours running time, the DMD volume moved to the surface amounts to about 1,104,480 gallons without taking into consideration the Radial Induction flow.

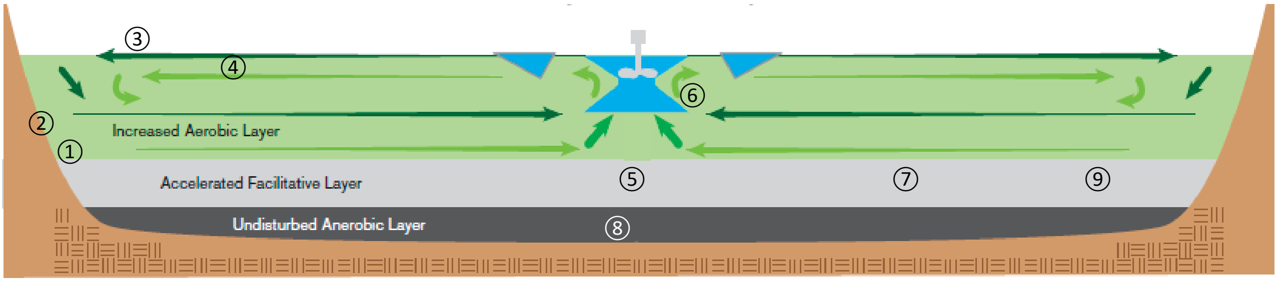
Figure 2. SUNFLO^2 Direct Mechanical Displacement Flow.



Compared to a rolling stream, 1,104,480 gallons of water rising to the surface per day represents only a fraction of a stream's potential for surface renewal. For example, water in a slow flowing (1'/sec) stream, 100' wide, would need to travel almost 5 miles to renew 60 acres of surface area, exposing it to the atmosphere for oxygen absorption. Compared to even a slow flowing rolling stream, the energy provided by the SUNFLO^2 Technology is very small. However, compared to the natural energy sources operating in a quiescent pond, the additional recirculation of 1,104,480 gallons per day is a significant enhancement of otherwise natural treatment processes.

Unlike energy-consumptive, aggressive recirculation equipment, the SUNFLO^2 Technology takes advantage of time to do its work. It moves relatively high volumes of water slowly. Since it elevates the water only 0.75" - 1.00" above the surface of the pond, its work against the head is minimal. It takes oxygen depleted water to the atmosphere rather than compressing large volumes of atmospheric oxygen and attempting to inject it into the depths of a pond. Low-energy controlled recirculation and surface renewal principles permit a SUNFLO^2 unit to treat about five times more BOD per acre per day than could normally be expected of the natural forces in a quiescent pond.

Figure 3. Schematic cross section of a facultative wastewater treatment pond in which a SUNFLO^2 unit renews surface with water, drawn from a controlled depth, resulting in enhanced reaeration and recirculation:



1. Aerobic, mixed, zone (24"–45")
2. Intake dish depth (inbound flow from embankment)
3. Outbound laminar flow on surface to embankment
4. Oxygen transferred by diffusion, advection, and convection
5. Oxygen depleted water drawn to the surface
6. Induced flows
7. Solids precipitate uniformly
8. Sludge allowed to digest undisturbed
9. Minimal stratification in mixed zone

To understand how the SUNFLO^2 Technology can increase the absorption rate, one needs to examine what happens to the 1,104,480 gallons attributed to its daily pumping capacity. Although the oxygen-deficient water initially exiting the distribution dish on the surface will rapidly (less than a minute) reach its saturation point, the quantity of oxygen absorbed near the dish is limited, due to the relatively small surface area exposed to the atmosphere.

However, as this pulse of saturated surface water moves radially outward from the dish, three changes occur that increase the quantity of oxygen absorbed; the surface area of the laminar flow increases in proportion to the square of the distance it travels from the dish, thereby increasing the area of the surface film exposed to oxygen transfer, the nearly saturated surface stratum provides a broadened, continuous force, thereby stimulating the diffusion of oxygen downward to regions of lower dissolved oxygen concentrations, and more oxygen depleted water is drawn to the surface through what has been referred to as "radial induction."

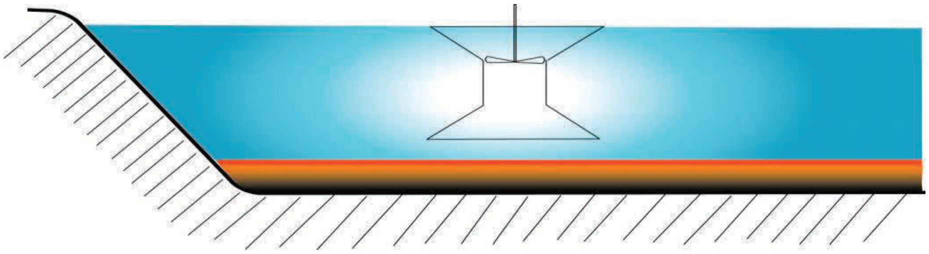
In the first case, as the surface layer spreads outward, there is increased area exposed to the atmosphere. Although this pulse of laminar flow becomes nearly saturated (80%) within about 40' of the dish, as it spreads it thins out, allowing the remaining 20% capacity to be filled. At about 75' from the distribution dish, the surface stratum is 100% saturated.

In the second case, as the concentration of dissolved oxygen in the surface stratum increases, it supplies “pressure” on the slower function of diffusion. This downward pressure, which is directly proportional to the surface area, increases with the square of the distance from the distribution dish, resulting in a broadening area of stimulated diffusion.

In the third case, the additional volume of water produced by radial induction occurring outside the distribution dish carries water with low oxygen concentration to the surface. This action increases the DO gradient, creating a “vacuum” effect for the diffusion function. However, because the upward velocity of the induced flow is greatest near the distribution dish, the rate of diffusion is somewhat dampened near the dish, despite the “pressure/vacuum” effects in that region. At distances greater than 75’ from the dish, the combined effect of the “pressure/vacuum” gradient, the diminished upward velocity of the induced flow, and increased time that the diffusion function has, results in an increased mass transfer of absorbed oxygen. The optimum transfer rate takes place at about 175’ – 200’ from the distribution dish (i.e., a surface area of about 2.5 acres).

This absorption–diffusion–absorption sequence is repeated with each successive pulse at a frequency of twice the impeller rpm. Since the rate of downward diffusion is much slower than absorption, time (i.e., distance from the dish) is required for maximum oxygen transfer through this "surface renewal" mechanism. Therefore, the initial distribution of DO increases with the distance from the SUNFLO^2 unit as represented in Figure 4.

Figure 4. Initial distribution of dissolved oxygen (higher concentrations represented in darker shades of blue) via SUNFLO^2 technology.



After the volume of the pond has been "turned over" (from the depth of the intake dish to surface of the pond) a few times, the dissolved oxygen theoretically becomes completely dispersed within that zone. However, the biochemical oxygen demand experienced in a wastewater stabilization pond tends to deplete the dissolved oxygen in the lower strata, thereby maintaining the condition for the SUNFLO^2 Technology to continually renew the surface with oxygen-deficient water.

In summary, the total amount of oxygen absorption influenced by the SUNFLO^2 Technology is function of the volume of water Direct Mechanical Displacement and Radial Induction brought to the surface and the size of the pond in which it is operating. While the rate of absorption is greatest at the point of dispersion of the new oxygen depleted surface layer, at this radius, its surface area is comparatively small. As the oxygen-saturated water flows radially outward, its area increases dramatically, opening the door (increased exposure) for absorption. As this expanding surface area of high concentrations of DO spreads, it exerts pressure that stimulates the downward diffusion of dissolved oxygen. The induced flow brings additional volumes of oxygen-deficient water to the surface near the dish, which tends to increase the DO gradient in close proximity to the dish. However, there is a diffusion-dampening effect caused by the high rate of ascending water near the dish. The combined effect of the enhanced absorption-distribution functions of the SUNFLO^2 Technology is optimal within a radius of about 175' – 200'. Upon encounter with the embankment or another laminar flow, the saturated water on the surface descends and is folded back into the depths of the pond via the physical function of convection and advection (recirculation).

Theoretically, one can calculate the rate of enhanced oxygen absorption provided by the Sunflo^2 Technology's PPR process using the data derived from slow flowing streams. From Eldridge's work(1), the rate at which oxygen dissolves in water per day is shown to be inversely proportional to its percent of saturation value. Table 2 shows this relationship. If the BOD_5 loading is strong enough and steady enough to reduce the dissolved oxygen levels, the level of saturation at the depth of the intake dish, together with the volume of the water placed on the surface through the Direct Mechanical Displacement and Radial Induction, will determine the mass transfer rate of O_2 via reaeration.

Under standard operating conditions, i.e., avg. 70 rpm, 24-hours running time, one SUNFLO^2 unit can renew 40.67 acres of surface area per day. This is based on the observation that the DMD volume of water (1,104,480 gallons per day) placed on the surface in near-laminar flow, spreads radially outward in sheets of 0.50" in depth. If the unit depth is set such that it continually draws 20% saturated water and the water is at 20° C, using Tables 1 and 2, one can calculate the potential oxygen absorbed in the surface layer as follows:

40.67 acres x 34 = 1,383 lbs./day

This amounts to about 57.6 lbs./hour. Unfortunately, in small ponds, not all this oxygen absorption potential can be utilized due to the slower function of diffusion previously explained. The oxygen transfer from the surface layer doesn't occur in appreciable amounts until the renewed surface moves 100'-200' from the unit. At this distance, the laminar flow on the surface has traveled long enough and has spread far enough for greater volumes to be transferred by diffusion.

The rpm range is based on the average revolutions during the working day of the unit. For example, in the northern latitudes of the United States, during the month of July, the unit will run for 24 hours, during which time it will average 70 rpm. In southern latitudes it will average about 80 rpm and will also run for 24 hours.

The recirculation effects of the SUNFLO^2 Technology are beneficial in BOD reduction, and the rippling action, surface renewal, and controlled recirculation effects contribute greatly to algal growth control and increased Mean Cell Residence Time.

For example, consider a three-acre pond with one SUNFLO^2 unit in it and reaeration rate of 57.6 lbs./hr., assuming a temperature of 68°F (20°C) and an average 70 rpm. If in that solar region the unit ran for 24 hours, the total daily reaeration would amount to 1,383 lbs. or an areal supply of 462 lbs. O_2/acre/day. Given the supply-to-demand ratio of 1.56, "theoretically", this SUNFLO^2 assisted three-acre pond is capable of supplying enough oxygen to satisfy an areal loading of 296 lbs. BOD_5/acre/day (462/1.56).

This is about 9 times the typical designed areal loading (50 lbs. BOD_5/acre/day) specifications for ponds in the southern tier states. In other words, under ideal conditions of uniform loading and flows, the three-acre SUNFLO^2 assisted stabilization pond in this environment can be expected to perform far better than typical, unassisted natural facultative pond treatment designs.

These calculations do not take into account any oxygen supplied (or inhibited) by algal photosynthesis. Also, these calculations do not account for the effect of increased surface area due to the wave action created by the unit.

It must be emphasized here that these calculations are reliable under steady state conditions and when used to predict the treatment of daily areal loading only. When the pond has accumulations of volatile sludge, the action of the SUNFLO^2 stimulates further aerobic digestion of the existing sludge. This results in an unpredictable, but significant increased demand on dissolved oxygen resources. Depending upon the volatility and volume of the sludge, this increased demand could exceed the oxygen supply, stripping all dissolved oxygen from the pond. This condition may persist until the sludge is sufficiently stabilized and/or digests anaerobically. For more detailed information on this subject, the reader is referred to another paper (*Sludge Deposition and Digestion*).

Multiple units are applied to a single pond when treatment conditions demand a reaeration rate and mixed volume beyond the optimum capacity of one unit. Generally, as Figure 5 indicates, the optimum zone of influence for a single unit ranges from 2.4 - 3 acres. If there are accumulations of volatile sludge, more than one unit may be required in a 3-acre pond. In a heavily loaded (daily areal loading) pond of 9 acres, three units may be required for adequate treatment. However, when the oxygen demand is low, one unit may be adequate to treat 9 acres or more.

The above calculations and other considerations are taken into account in prescribing the SUNFLO^2 units for a given treatment scenario and location. Table 3 lists the major siting parameters used to predict the expected performance of one SUNFLO^2 unit in a given sized pond in order to achieve a 90% BOD_5 removal rate. This table is based on average ambient temperatures of 20^0 C and assumes the operating depth and daily flow is such that the minimum MCRT listed can be achieved.

Table 3. SUNFLO^2 Units application parameters and site conditions.

PRELIMINARY SUNFLO^2 UNITS APPLICATION PARAMETERS						
	Surface Area (acres) (1)					
	<1	1-2	2-3	3-4	4-6	>6
Percent of Areal Loading Rate (2)	100% Not recommended	200%	300%	400%	500%	Multiple units may be required
MCRT(3) Northern Climates	15 days	20 days	25 days	30 days	35 days	40 days
MCRT Southern Climates	15 days	15 days	20 days	25 days	30 days	35 days

1) Field measured surface area at average operational depth.
2) Maximum surface loading rate for a SUNFLO^2 Technology assisted pond and is based on the U.S. Department of Agriculture Aerobic Lagoon Loading Rates (see Table 4 and Figure 6) subject to modifications by specific state or regional design guidelines.
3) The minimum time value for a SUNFLO^2 Technology assisted pond and is based on the Mean Cell Residence Time (MCRT), as defined by the fomula: MCRT = V_m/Q , where V_m, is the volume (mg) of the mixable contents and is calculated as maximum volume in the top 1/2 of the pond when the sludge displacement is taken into account, and Q, is the actual average daily flow rate (mgd).

Other Factors:

1. Typical operating pattern (parallel, series etc.)

2. Loading and flows: past, present, and future

3. Desired degree and type of treatment: ultimate BOD_5, TSS, ammonia levels etc.

4. Sludge characteristics: deposition (aerated or non-aerated), % grit vs. organic matter, age, depth of weight bearing sludge/slurry

5. Existence of a bar screen or grit chamber

6. Aeration equipment: past or present, type, duration of aeration treatment, and history of results

7. Type and percentage of waste: domestic, industrial, agricultural process, etc.

8. Seasonal flow variations (I & I)

9. Site characteristics: elevation, wind exposure, shading, etc.

10. Age of system and past performance

11. System structure and maintenance: embankment and bottom liners, vegetation in and near water, etc.

12. Influent, effluent and transfer pipe locations and elevations.

Because the functions of the SUNFLOo^2 unit is primarily dependent upon the surface area in which the unit is placed, and because the principles of reaeration are also surface-dependent, it is reasonable to rely on the time-proven designs that are also based upon surface area. The areal loading rate method is used by many of the western states, and requires the least amount of design data. It is based on operational experiences in different geographical areas of the United States. This empirical database takes into account overturns, rising sludge, and seasonal algae concentration variations that can affect treatment. The areal loading method is recommended over the other methods unless comparable systems are available upon which to base rate constants for the other models. Table 4 shows the EPA recommended areal loading parameters for different temperatures.

When more climatic conditions are taken into account, the zone map for varying areal loading parameters can be drawn as shown in Figure 6. It is interesting to note that the areal loading zones in Figure 6 are incongruous with the solar energy zones as depicted in Figure 7. Facultative ponds are very dependent upon photosynthetic plants for the oxygen supply. The SUNFLO^2 Technology also affects the growth and distribution of algae, but that is the subject of another dissertation. From this fact and experience in a broad range of solar energy zones, LiquidTEK LLC has concluded that areal loading parameters are more accurate when based on solar energy as well as average temperatures. Yet, solar energy (except for its influence on regional ambient temperatures) is often not included in the design parameters for facultative treatment.

Table 4. Areal loading rate values for different temperatures (U.S. EPA, 1983).

	BOD loading rate	
Average winter air temperature, °C	kg/ha•d	lb/ac•d
>1 5	45 – 90	40 – 80
0 - 15	22 – 45	20 – 40
< 0	11 - 22	10 - 20

Figure 6. Aerobic lagoon loading rate in lbs. BOD$_5$/acre/day, (USDA, National Resources and Conservation Service, 1995).

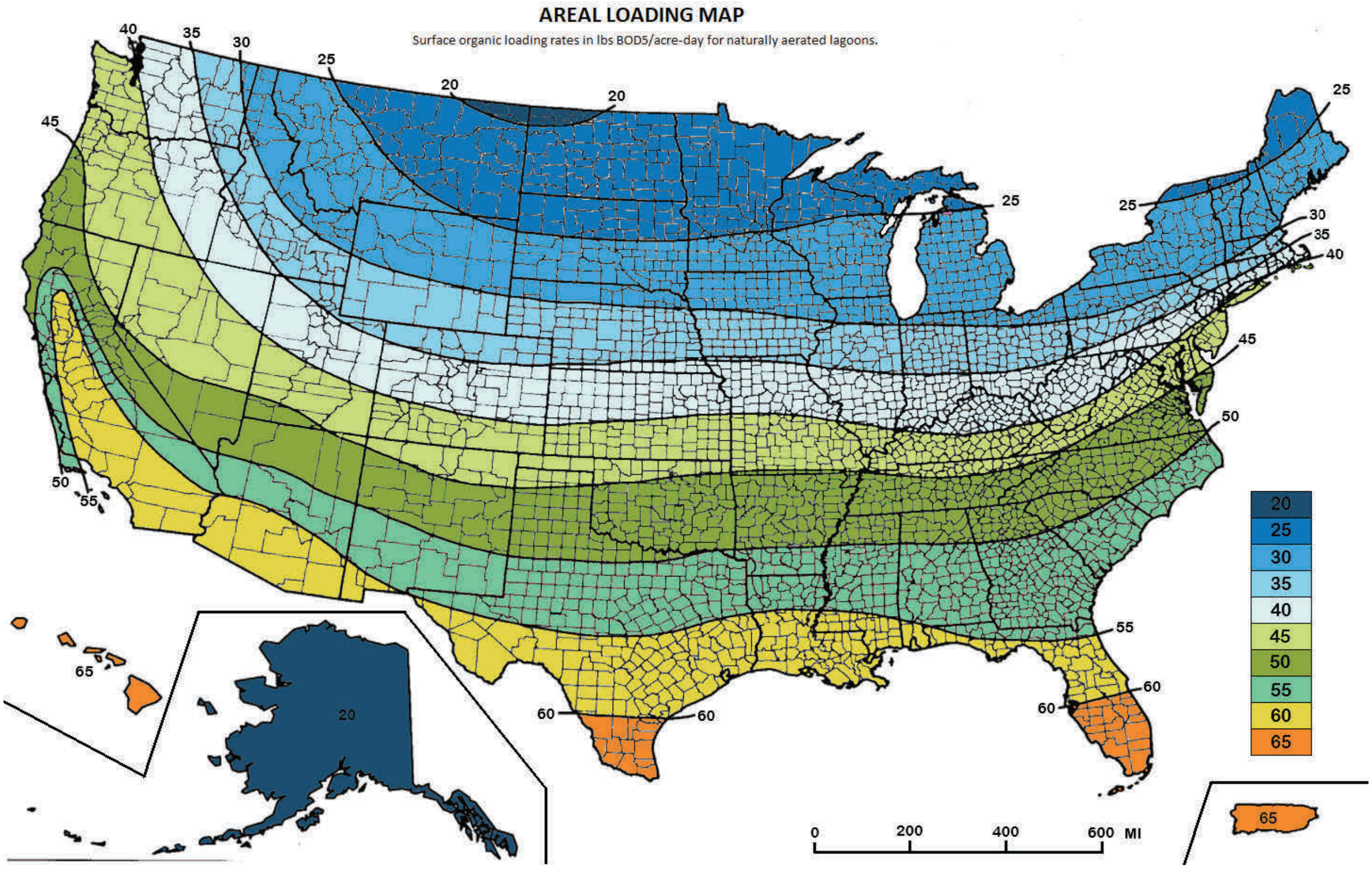
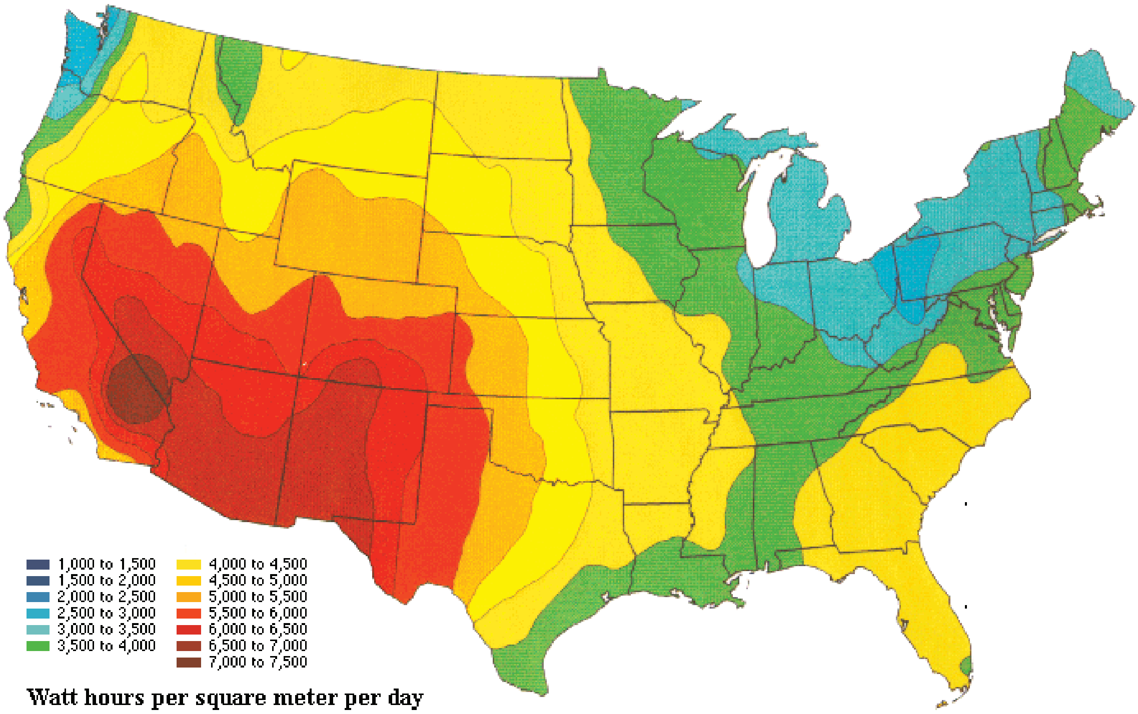


Figure 7. Solar energy regions in the United States in watt-hours per square meter per day.



Because solar energy is the driving force for photosynthetic oxygen production, temperature, wind, and other natural phenomena critical to wastewater treatment, engineers are well advised to select designs that include solar energy considerations. Because the SUNFLO^2 unit is solar powered, solar energy regions are important in calculating its treatment effects, as it not only affects the circulating capacity, but also influences the kinetics of the biological and chemical reactions in that pond.

With the experience gained from more than 200 units in operation across the United States and detailed data collected on more than 20 SUNFLO^2 units installations in representative facultative wastewater treatment facilities, actual performance results concur with the theoretical calculations for oxygen transfer via enhanced reaeration and controlled recirculation. Pond Solutions LLC engineers carefully analyzes each application before prescribing the number and location of units on the pond. Expected treatment objectives are set forth in the treatment plan together with a recommended monitoring protocol. The collective application of expertise and the SUNFLO^2 technology is referred to as the Progressive Reaeration and Recirculation Process (**PRR™ Process**).

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Technical “White Paper” #2

OXYGEN UPTAKE CALCULATIONS

Of all the ingredients necessary for the stabilization of wastewater, oxygen is primary. It has a role in almost all chemical and biological reactions in a stabilization pond environment. When accessible to the biology and chemicals requiring it, oxygen will be used at a pace dictated by the speed of the reactions in which it takes part (kinetics). An abundance of oxygen, however, does not, of itself, accelerate these reactions. This paper focuses on the mechanisms of oxygen uptake and how the functions of Sunflo^2 Technology, operating under the PRR Process, influences these principles.

“Oxygen uptake” is the term generally ascribed to the rate at which “users” of oxygen subtract it from the environment in which it may be present. A number of life forms and chemicals existing in a stabilization pond demand oxygen in some form (free oxygen, O_2, or elemental oxygen, O) and at some stage in their progression towards stability. The magnitude of this demand varies in terms of quantity, strength, and time. The measure of each of these variables against all of the possible users of oxygen is very complex but has been reasonably approximated through experimentation and theoretical calculations.

For example, disregarding phosphorus, sulfur, and trace elements, the use of oxygen by organic matter in sewage in a thoroughly mixed pond has been found experimentally by Oswald, Hee, and Gottaas to follow the reaction:

$$C_{11}H_{29}O_7N + 14O_2 + H^+ \rightarrow 11CO_2 + 13H_2O + NH_4^+ \qquad (1)$$

This is considered a “first stage” reaction since the first demand that must be satisfied is made by the carbonaceous components, sometimes referred to as the *ultimate carbonaceous* BOD (UBOD).

The second stage begins when the carbonaceous BOD ($CBOD_5$) is mostly satisfied and the demand by nitrogen compounds begins, as illustrated in Figure 1. This nitrification demand requires a "habitat" for nitrofying organisms, such as the fixed biofilm that may develop on surfaces in the aerobic zones of a pond. Since the sides and bottom of a typical facultative lagoon are normally anaerobic, there is little chance that these nitrofiers can become established.

In addition to a biofilm habitat, the nitrofiers' growth and sustenance are dependant upon dissolved oxygen (DO) and soluble BOD_5 concentrations, wastewater temperature, pH and alkalinity, flows, and loading variability. Field data obtained from rotating biological contactor nitrification designs (a device that provides an artificial habitat), indicate that nitrification is typically observed when the soluble BOD_5 declines to 15 mg/l, and maximum nitrification occurs when soluble BOD_5 concentrations drop to 10 mg/l or less.(1) Oswald found that the oxidation of ammonium ion (NH_4^+) to nitrate rarely occurs in stabilization ponds, as it is either lost to the air, assimilated by algae, or precipitated during high periods of pH, before nitrification can be established.(2)

Without consideration for oxygen uptake in nitrification, from equation (1), one can calculate the weight of molecular oxygen required to completely oxidize organic matter. Using molecular weights and a stoichiometric (electron-balanced) equation, the amount of oxygen required is found to be 1.56 times the weight of the organic matter oxidized. This finding implies that the free oxygen supply (from all sources) must be about 56% greater than the desired $CBOD_5$ reduction.

This calculation only predicts the total weight of oxygen required. The rate at which this quantity is used, or uptake, requires another calculation. Oxygen uptake is influenced by temperature, mixing, and the stage of the life cycle microorganisms may be in.

With regard to the life cycle influence, three oxygen-consuming phases occur. First, a portion of the waste is oxidized to end products that produce energy for cell maintenance and the synthesis of new cell tissue. This is the "Oxidation" phase. Simultaneously, in the second phase, some of the waste is converted into new cell tissue using part of the energy released during oxidation. This is the "Synthesis" phase. In the final phase, when the organic matter is used up, the new cells begin to consume their own cell tissue to obtain energy for cell maintenance. This is referred to as the "Endogenous Respiration" phase.

Using the term *COHNS* (which represents the elements of carbon, oxygen, hydrogen, nitrogen, and sulfur) to represent the organic waste, and the term $C_5H_7NO_2$ to represent cell tissue, the three phases can be defined by the following generalized chemical reactions:

Oxidation:

$$COHNS + O_2 + \text{bacteria} \rightarrow CO_2 + H_2O + NH_3 + \text{other end products} + \text{energy}$$

Synthesis:

$$COHNS + O_2 + \text{bacteria} + \text{energy} \rightarrow C_5H_7NO_2$$

Endogenous respiration:

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$$

Taking these phases into account, the general equation for oxygen uptake rate during the first stage or the oxidation of carbonaceous BOD ($CBOD_5$), can be written as follows:

$$R = a' \frac{(S_o - S_e)}{t} + b'X , \qquad (2)$$

in which, R = oxygen uptake rate (lbs./day),

$\frac{S_o - S_e}{t}$ = $CBOD_5$ removal rate (lbs./day),

X = mass of mixed volume of suspended solids (lbs. of MLSS),

a' = oxygen required for synthesis of $CBOD_5$ removed (lbs. O_2/lbs. $CBOD_5$), and

b' = oxygen required for endogenous respiration (lbs. O_2/lbs. MLSS-day).

Typical values of *a'* and *b*' for municipal wastewater are *a'* = 0.53 (0.40 to 0.65) and *b'* = 0.15 per day. The value for *b'* is affected markedly by temperature. The value presented is typical of summer conditions and is widely used. The mixed liquor suspended solids (MLSS) volume is an indirect measure of the volume of matter that consists of living cells (suspended) that have begun to consume their own cell tissue (endogenous respiration). In a facultative lagoon, this volume is difficult to measure. However, it is likely that the slurry zone of sludge, when mixed would roughly approximate the MLSS volume in a facultative pond.

In a heavily loaded facultative pond, the concentration of the slurry (MLSS) may reach 1,000 mg/L; a level approaching the empirical loading design parameters for an activated sludge process. When the Sunflo^2 Technology is used for mixing and reaeration, and the depth of the intake dish is set such that the slurry zone is circulated, this concentration is diluted. This is simply due to the fact that the un-circulated slurry zone, which normally lies in a variable stratum just above the weight bearing sludge layer, is redistributed throughout the volume of the pond from the surface to the depth of the intake dish.

Equation (2) represents the daily oxygen requirements for the biodegradation of organic material (CBOD$_5$); however, at low organic loading rates and long detention times, nitrification can be expected, provided the biofilm habitat and adequate oxygen exist.(3) Nitrification is normally not a factor in heavily loaded facultative ponds in which SUNFLO^2 Technology is working. This is primarily because the surface area (pond bottom) required by nitrofiers is likely anaerobic in a heavily loaded pond and will not support this life form. Secondarily, the oxygen supply mechanism of a SUNFLO^2 unit, which is based upon continually exposing oxygen depleted water to the surface for reaeration from the atmosphere, does not supply the "excess" oxygen required by nitrification reactions.

However, if conditions for nitrification do exist, typically the oxygen demand due to nitrification will occur from 5 to 8 days after the start of a conventional BOD$_5$ test as shown in Figure 1. The oxygen requirements for nitrification, known as nitrogenous oxygen demand (NOD), may be expressed as a stoichiometric relationship:

$$2NH_4^+ + 4O_2 \rightarrow 2NO_3^- + H_2O + 4H^+ \qquad (3)$$

This reaction indicates that approximately 4.6 pounds of oxygen are required to convert one mole of ammonia-nitrogen to nitrated nitrogen. The oxygen per pound of nitrogen converted can be calculated as; 64/14 = 4.57.(4) The rate of oxygen uptake for nitrification can be expressed as:

$$RN = 4.60 \frac{\Delta NH_3}{t}, \qquad (4)$$

in which, RN = oxygen uptake rate for nitrification (lbs./day),

ΔNH_3 = ammonia nitrogen removed (lbs.), and

t = aeration time (days).

In aerated treatment plants that have a low organic load, and where, presumably, there are adequate oxygen supplies, partial nitrification can be expected. Consequently, if nitrification is not included in calculations of oxygen required, higher values of the coefficient, *a'*, must be used in equation (2). The total oxygen required, including nitrification, can be expressed by combining equations (2) and (4) as follows:

$$R_{tot} = a' \frac{(S_o - S_e)}{t} + b'X + 4.60 \frac{\Delta NH_3}{t} \qquad (5)$$

Figure 1 illustrates the first and second stage rate of BOD removal over time, at three different temperatures. One can see by these curves that increased temperature greatly increases the stabilization rate. The organic makeup of the waste to be treated is also an important factor. This graph depicts the natural treatment process of pollutants discharged into a river as observed and measured by Imhoff and Fair.

As explained earlier, under typical circumstances in which the SUNFLO^2 Waste-Flo unit is expected to operate, only the carbonaceous (first-stage) oxygen demand is exerted. In this case, equation (2) may be used to estimate the rate of uptake. This amount will provide an estimate of the total amount of oxygen to be supplied by the SUNFLO^2 unit(s) per day for a given CBOD$_5$ removal rate, assuming there are no other sources of free oxygen.

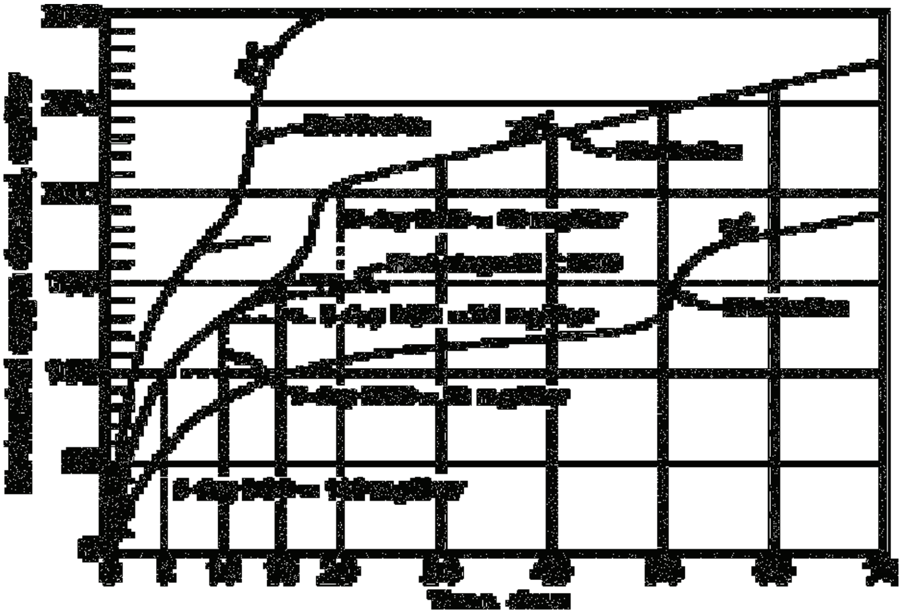

Figure 1. Progress of biochemical oxygen demand at 9, 20, and 30°C (after Theriault).

Generally, the rate of oxygen uptake is governed by the natural kinetics of the biological and chemical reactions which require oxygen. Excess oxygen, by itself, does not accelerate the reactions, except to stimulate nitrification when other requirements are met. However, if the oxygen supply is less than the demand, the biological and chemical reactions will be incomplete.

Measuring a residual concentration of DO is an indication that the oxygen supply is more than enough to meet the natural kinetics and uptake rate. On the other hand, measuring no residual DO does not necessarily mean that the oxygen supply is inadequate. The demand and supply might be in balance, that is, the natural kinetics and O_2 uptake are equal to the oxygen supply. In this case an observer might measure substantial BOD_5 reduction in the absence of residual DO.

It is also interesting to note that when the oxygen supply is just enough to satisfy the first stage demands, but not sufficient to support nitrification, there is a substantial "savings" in precious oxygen resources. In this case however, any desired nitrogen removal will depend on other mechanisms such as gassing off, assimilation by algae, etc.

One might also observe a difference (gradient) in DO at various depths of a stabilization pond. This is an indication that a greater rate of uptake may be occurring in the lower DO region or there is inadequate mixing of the pond contents. Typically, higher DO concentrations will be observed in the upper strata of an unassisted pond. This is likely due to the presence of photosynthetic plants near the surface, and the concentration of DO at the surface due to the slower function of diffusion.

The SUNFLO^2 Technology, through its ability to control the mixed volume while facilitating reaeration, influences the oxygen uptake rate, *R*, from equation (2), and therefore the rate of decomposition over that of an unassisted pond by the following affects:

1) The volume of biomass zone that is mixed is controllable. It is defined as the depth (ft.) at which the intake dish is set, times the surface area (ft.^{2}) of the pond in which a unit is placed (up to a maximum of 3×10^5 ft.^{2} for a single unit) x 7.48 gal/ft.^{2} (up to a maximum of 800,000 gal/day). The mass of the volatile components, X (in equation 2.), can be determined by multiplying the concentration of the MLSS (mg/L) times the volume of the mixed zone (MG), as determined above, times 8.34 lbs./gal.
2) Oxygen supply (reaeration rate) is driven by the demand, i.e., the greater the rate of depletion (oxygen uptake), the greater the mass transfer coefficient. Assuming adequate surface area, and thorough distribution through mixing, reaeration via the one SUNFLO^2 unit will supply oxygen at a rate equal to demand, provided the surface area of the pond is greater than one acre but less than six acres.*
3) Like the volume of mixed biomass zones, the volume of the aerobic zone is somewhat controllable by the depth setting of the intake dish of the SUNFLO^2 unit. However, the depth of the aerobic zone will be further limited by the total daily supply of oxygen via reaeration and photosynthesis in relation to the demand expected on a daily basis by the ultimate biochemical oxygen demand (UBOD). The depth of the intake dish is adjusted to balance the oxygen supply, providing a residual DO in the upper strata.
4) Gentle mixing of aerobic zone allows the natural kinetics to proceed at optimum pace under any given environmental conditions.
5) $CBOD_5$ removal rate, $S_o - S_e$ /t (lbs. BOD_5/day), can be expected to be 90% or higher in a properly designed facultative wastewater treatment pond having a Mean Cell Residence Time** of 15 days or more.

*Multiple units may be prescribed in a pond when areal loading, detention time, or other factors dictate the need for greater reaeration and/or mixing.

**One of the siting criteria for a SUNFLO^2 Waste-Flo Model is based on the Mean Cell Residence Time (MCRT), as defined by the formula: MCRT = V_m/Q , where V_m, is the volume of the mixable contents and is calculated by multiplying the depth of the intake dish (ft.), times the surface area (ft^2), times 7.48 gal/(ft^3), and *Q,* is the actual average daily flow rate (gal/day).

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This "white paper" was researched and prepared by LiquidTEK LLC., 31700 Highway 1804, Wilton, ND 58579. Content consists mainly of excerpts from well respected, published, "pond scientists." Its purpose is to present the known physical, biological and chemical principles of wastewater stabilization pond treatment and to point out the influence that the SUNFLO^2 Technology is known to have on these principles. Since some of the original authors' work has been edited and original research by LiquidTEK LLC, added, LiquidTEK assumes full responsibility for the accuracy of the contents of this document. Revised 7/1/2020.