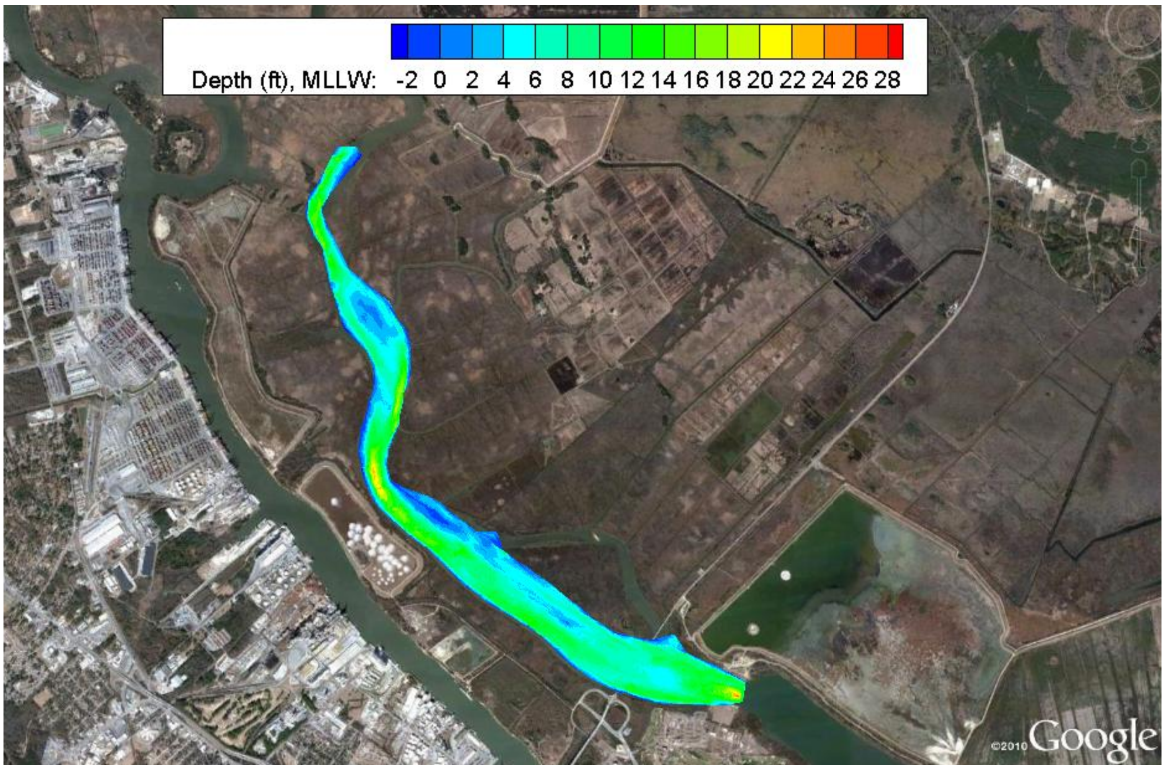
Analysis of Oxygen Injection in the Back River in Support of the Savannah Harbor Expansion Project



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1. Background

This report will answer specific questions from the South Carolina Department of Health and Environmental Control (DHEC) about the oxygen injection systems in the Savannah Harbor, specifically the shallower Back River. The USACE Savannah District met with South Carolina DHEC on 12 May 2011 to discuss the Savannah Harbor Expansion Project and South Carolina DHEC expressed concerns about how well the proposed Dissolved Oxygen (D.O.) systems would function in the shallower Back River. Tetra Tech developed the design of the systems that would inject oxygen at three locations (near International Paper on the Front and Back Rivers and Georgia Pacific on the Savannah River) and had conducted mixing zone modeling (Tetra Tech 2010). South Carolina DHEC requested additional information that would provide greater assurance that the Speece cones would perform as designed at the Back River location. There was a previous study that suggested Speece cones are primarily a deep water technology not suitable for shallow waters (Final Aeration Technology Feasibility Report for the San Joaquin River Deep Water Ship Channel, Jones and Stokes, October 2004) and that sufficient water depth at the injection point is a critical design consideration.

2. Physical Factors Controlling Oxygen Dynamics

South Carolina DHEC requested an explanation of the physical factors controlling oxygen injection dynamics on the shallow Back River, including DO concentration as a function of the depth at which effervescence would occur. This section was prepared by ECO2 and describes the physics of oxygen injection as it relates to water depth (injection depth). This section will also address differences between the proposed design and the San Joaquin River case where water depth was identified as a factor in eliminating this general design.

The efficacy of using the Speece cone oxygenation system to supplement 20,000 lbs D.O. per day to the deep navigation channel was successfully demonstrated in August 2008. Modeling studies have shown the need to supplement D.O. to the Back River region, which is shallower than the navigation channel. A report written by Jones for supplementation of D.O. to the San Joaquin shipping channel (San Joaquin Oxygen Aeration Study, 2004) included a statement that the Speece cone system was not suitable for "shallow" bodies of water. Therefore, it was requested that ECO2 justify the efficacy of using the Speece cone for supplementing the D.O. in the Back River section of Savannah Harbor. In addition, it was requested that the physics of O_2 transfer in the Speece cone be more completely explained.

2.1 Approach

The final design of the Speece cone oxygenation system for supplementing D.O. into the Savannah River has been optimized incorporating discharge location characteristics and observations made during the 2008 demonstration. It is important to note that although the Speece cone system is similar to what was used in the demonstration, the operating parameters will be materially different.

In the Speece cone design, there is a balance between ambient D.O. saturation level of the surface water being treated and the D.O. level in the Speece cone discharge. While the ambient D.O. saturation level is a function of site characteristic, the Speece cone discharge saturation level can be manipulated to generate D.O. levels higher than saturation, if desired. This was seen in 2008 demonstration when the Speece cone D.O. discharge was 150 mg/L (i.e. 208% saturation at the discharge depth of 34 feet) on the Front River.

When the Speece cone is operated near the ambient D.O. saturation level, there is no potential for D.O. to come out of solution by effervescence. The higher the differential in cone discharge D.O. level to the ambient saturation D.O. level, the higher the potential for effervescence. It is under these operating conditions, that the diffuser design is critical to ensure quick depressurization/dilution/mixing of the highly oxygenated water to prevent the potential for effervescence. This report will show that it takes at a minimum 170% saturation before effervescence is possible.

ECO2 has proposed implementation of a Speece cone to add 4,000 lbs D.O./day to the Back River which has a cross section of about 2,000 ft by 30 ft (MLLW) depth at the deepest point. To accomplish this, a side stream flow of 10,200 gpm would be pumped through a Speece cone and the D.O. raised to 40 mg/L in the discharge and sent to a diffuser located just above the bottom of this cross section. Surface D.O. saturation level of the Back river is 36 mg/L. Therefore, 40 mg/L in the discharge of the cone represents 111% saturation (40/36) at the river surface. If this 40 mg/L D.O. water was discharged from a diffuser located 15 feet below the surface it would be at only 77% of saturation. This is much below the 170% to 240% saturation effervescence potential documented in this report. (Effervescence potential is defined as the % saturation level below which no effervescence can occur.) The Back River system would have to have a D.O. of 122 to 173 mg/L to reach the 170% to 240% saturation threshold for potential effervescence. This does not take into consideration the fact that it would be diluted to about 1/10 of this concentration in a fraction of a second in a properly designed diffuser/depressurization system. The ECO2 design of 40 mg/L D.O. discharged at 15 feet below the surface is only at 77% saturation and incapable of manifesting effervescent loss of D.O. mass from the receiving water. Even though the ECO2 design precludes any effervescence of D.O., one of the charges of this project is to clarify the physics of O_2 transfer in a Speece cone and to quantify the conditions required for effervescent loss of D.O. from highly superoxygenated water. The remainder of this report summarizes the experimental results that document the effervescence phenomena in water that contains a range of D.O. concentrations from 50 to >400 mg/L produced using pressurized pure O_2.

2.2 O_2 Transfer

O_2 is considered to be a relatively insoluble gas in water. The saturation concentration of O_2 in fresh water in contact with air (21% O_2) at 20°C and sea level is approximately 9 mg/L. The D. O. saturation concentration for pure O_2 is approximately 43 mg/L under these conditions. Physical factors which affect the saturation concentration of O_2 in water are as follows:

- Salinity
- Altitude
- Temperature

As the salinity increases, the solubility of O_2 decreases. As the altitude increases, the partial pressure of O_2 in air decreases and the saturation concentration decreases. As the temperature increases, the solubility of O_2 decreases. For instance, at 28°C and 5,000 mg/L salinity, the saturation concentration of water in contact with pure O_2 is 36 mg/L D.O.

Gas transfer equation:

$$dC = K_L A/V (C_{SAT} - C_{ACT})dT$$

where: dC is the change in D.O.

K_L is related to the turbulence at the gas-water interface

A is the gas interfacial area

V is the volume of water

C_{SAT} is the D.O. saturation concentration

C_{ACT} is the actual D.O. in the water

dT is the time over which the gas transfer occurs

All O_2 transfer systems work according to this equation.

2.3 Speece Cone Design

There are two critical design components when designing a Speece cone oxygenation system. The first is the design of the Speece cone itself, and the second is the design of the diffuser. Each is critical and will be discussed in detail.

2.3.1 Oxygen Transfer in a Speece Cone

The Speece cone is designed to achieve high O_2 absorption efficiency. Low O_2 absorption efficiency results in undissolved O_2 gas bubbles in water which present two problems. First, low O_2 absorption efficiency increases operational costs and second, the undissolved O_2 gas bubbles can cause operational and safety problems. Therefore, it is most important to preclude loss of O_2 bubbles in the discharge of the O_2 transfer system for both economics and practicality.

Since pure O_2 is a commercial commodity, absorption efficiency drives the economics. To achieve high O_2 absorption efficiency, the pure O_2 must be kept in contact with the water for approximately 100 seconds. Since the rise velocity of bubbles is nominally about 1 ft/sec it would require a 100 foot deep column of water to achieve efficient absorption if O_2 bubbles were injected at the base. This is the basis of the oxygenation system Prof. Speece designed, tested and installed in the late 1970's to add 100 tons/day of D.O. to the hypolimnion of Clark Hill Reservoir on the Savannah River above Augusta (for development of the design to be used in the future Richard Russell Reservoir). The fine bubble diffusers located at a depth of 140 ft achieved 90% O_2 absorption efficiency. (Injection of pure O_2 into a bubble diffuser at the bottom of a 15 feet deep aeration tank would result in unacceptably low O_2 absorption efficiency even if it was a fine bubble diffuser.)

The Speece cone oxygenation system is designed to address the crucial need to maintain large bubble swarms with their very high gas surface areas for O_2 transfer. The Speece cone maintains the O_2 gas in contact with the water for well over the required 100 seconds and thus achieves the prolonged O_2 gas detention times needed for highly efficient absorption of pure O_2. The system combines the capability to efficiently dissolve pure O_2 as well as produce a highly superoxygenated discharge of 50 to >400 mg/L D.O. The water detention time within the cone is uncoupled from the O_2 bubble detention time and is much shorter. The turbulence within the cone caused by the high inlet velocity determines the hydraulic shear regime in the cone and maintains a large swarm of bubbles having relatively small bubble sizes with their high gas surfaces. The tendency for the bubbles to coalesce and collapse is countered by the continual hydraulic shear provided within the cone. Thus the large gas surface for O_2 transfer is continually maintained. The conical configuration of the Speece cone results in a progressively decreasing downward water velocity. The inlet velocity at the top of the column is designed to exceed the buoyant velocity of the bubbles as well as to counter the tendency of the bubble swarm to collapse and the large gas surface area of the bubble swarm is maintained. Thus, the O_2 bubbles cannot escape out the top. As the cone cross-section increases as the water moves through it, the downward velocity of the water toward the base of the cone becomes less than the buoyant velocity of the O_2 bubbles and consequently the bubbles are not lost in the discharge. Therefore, the detention time of the bubbles is prolonged to achieve highly efficient O_2 absorption.

The saturation concentration of D.O. and the O_2 transfer capacity of the cone are determined by the O_2 composition of the gas and the hydrostatic pressure. The D.O. concentration in the discharge of the Speece cone is related to the hydrostatic pressure within the cone. With pure O_2 and hydrostatic pressurization, it is easily possible to develop C_{sat} concentrations in the cone of 50 to > 400 mg/L and thus achieve high discharge D.O. of nearly comparable concentrations.

A system which efficiently dissolves pure O_2 and produces a highly superoxygenated discharge opens up a whole new realm of possibilities in water quality management not possible with conventional aeration techniques. Using pure O_2 the D.O. in the discharge is nominally 1 mg/L per 1 foot of absolute pressure of hydrostatic head in the cone. This, of course, varies with temperature and salinity. The hydrostatic pressure within the cone can be increased by placing the cone in an excavated caisson to achieve energy-free pressurization or the cone can be pressurized by pumping against a throttling valve on the discharge. Placing the Speece cone in a caisson for energy-free pressurization results in a unit energy consumption of about 300 kWhr per ton of D.O. dissolved. Whereas pressurization by pumping against a discharge valve results in a unit energy consumption of a little more than 1000 kWhr per ton of D. O.

When the Speece cone is pressurized by pumping against a throttling valve on the discharge in order to produce D.O. of 50 to >400 mg/L in the discharge, special attention to prevent effervescent loss of the high D.O. is required in the diffuser design to dilute the superoxygenated water quickly in the receiving water as will be addressed below. With proper design, D.O. concentrations in the 100's of mg/L range can be depressurized and diluted without significant effervescent loss of D.O.

Figure 1 shows the operating characteristics as the O_2 injection rate increases. The discharge D.O. concentration increases linearly with the O_2 injection rate up to the design point when pressure is held constant. The physics of gas transfer within the Speece cone are such that over 90% of O_2 absorption efficiency occurs up to the design O_2 injection load. In this range the cone is able to maintain the bubble swarm with insignificant loss of bubbles in the discharge. Below the O_2 design load of the cone, the bubble swarm is smaller and does not occupy the entire cone.

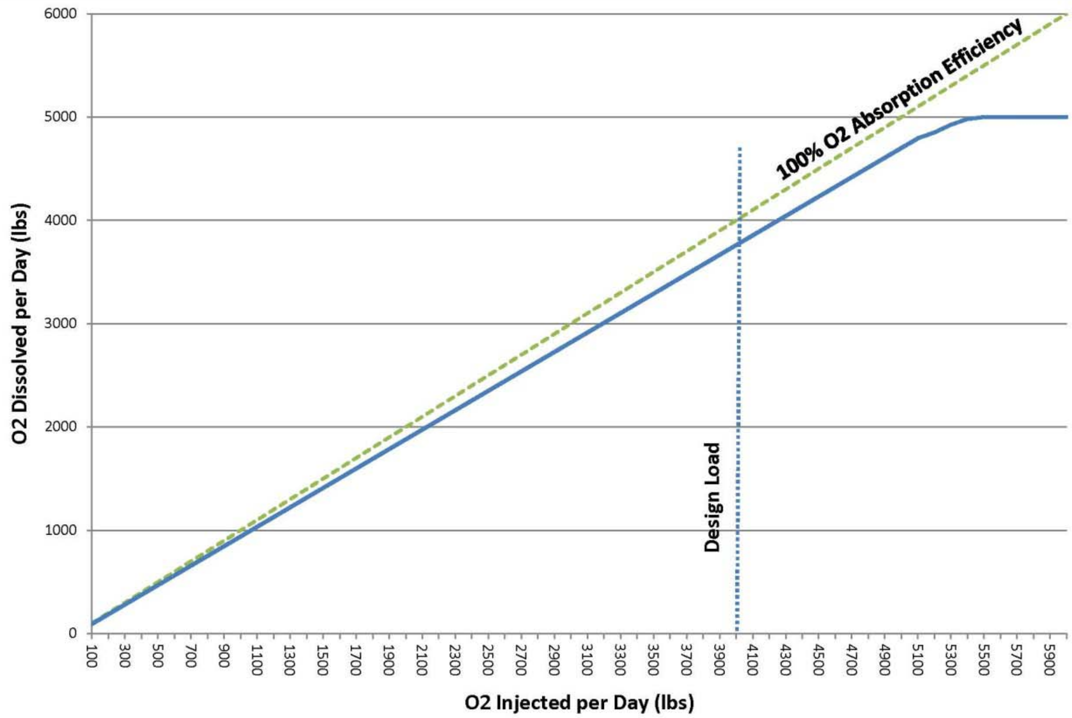


Fig. 1 O2 Dissolved vs O2 Injected

As the O_2 injection rate increases, a greater bubble swarm must develop to provide the increased bubble surface necessary to accommodate the demand for more O_2 absorption. However, there is a maximum bubble swarm which can be maintained in any given size of cone. When more O_2 is injected than is being dissolved, the bubble swarm grows beyond the capacity of the Speece cone to retain it and the excess O_2 bubbles are crowded out the bottom of the cone and lost in the discharge. Thus, the O_2 absorption efficiency is relatively constant at over 90% up to the maximum bubble swarm size. Any O_2 injected above this critical design rate is essentially all lost in the discharge.

It is to be noted that there is a fundamental difference between effervescent loss of highly supersaturated D.O. from the depressurized discharge and loss of O_2 bubbles that never were dissolved in the first place. The latter bubbles are physically crowded from the bubble swarm at an O_2 injection rate that exceeds the design load corresponding to a maximum bubble swarm volume that can be retained in the specific cone size. Effervescent loss of D.O. is characterized by tiny bubbles (<0.1 mm diameter) which barely disturb the surface when they emerge and O_2 bubbles that were never dissolved in the first place and which are about 10 to 20 times larger in diameter and are readily observed breaking at the water surface. Even though the 2008 study discharge D.O. was 150 mg/L at 34 feet below the surface (i.e.) 208% saturation at that depth (150/2x36=208%), the discharge was diluted in less than a second by the ambient low D.O. water. Thus negligible effervescent loss from the very high D.O. occurred.

In the pilot demonstration project in Savannah Harbor, there were occasions when considerable loss of larger bubbles was noted in the discharge to the harbor. Examination of the data revealed that during these times the O_2 injection rate was considerably above the design loading, resulting in massive loss of undissolved O_2 gas in the discharge. In summary, when the O_2 injection rate is below the design load, over 90% O_2 absorption occurs. When the O_2 injection rate exceeds the design load, there is essentially 0% O_2 absorption efficiency of that portion of O_2 which exceeds the design loading.

Figure 2 shows the O_2 absorption efficiency at constant cone pressure as a function of the O_2 injection rate. This plot demonstrates that the O_2 absorption efficiency exceeds 90% all the way up to the design load. As mentioned above, at this point, the bubble swarm volume that can be maintained within a given cone cannot further increase due to physical limitations and any O_2 injected above the design load is not absorbed.

Figure 3 indicates that O_2 absorption efficiency is maintained constant at approximately 94% efficiency at design O_2 loading over a pressure range of 0 to 100 foot of head and above i.e. pure O_2 absorption efficiency is independent of the hydrostatic pressure in the cone. The discharge D.O. increases linearly with hydrostatic pressure within the cone at design O_2 loading over this range up to 100 feet of head and above.

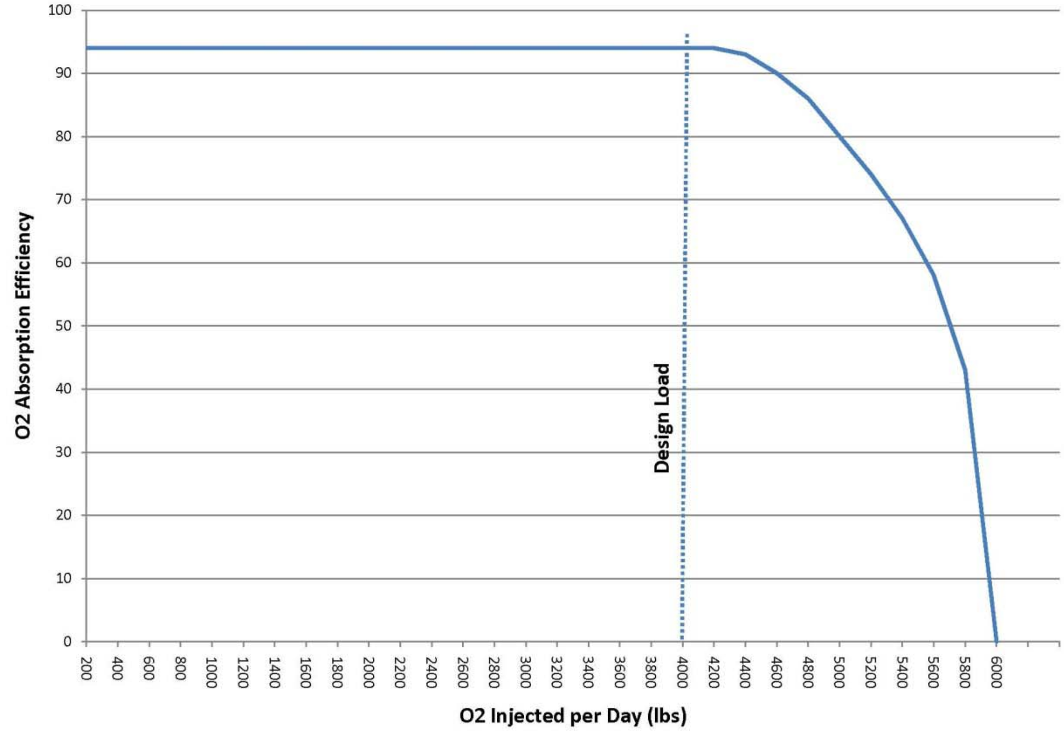


Fig. 2 O2 Absorption Efficiency vs O2 Injected per Day

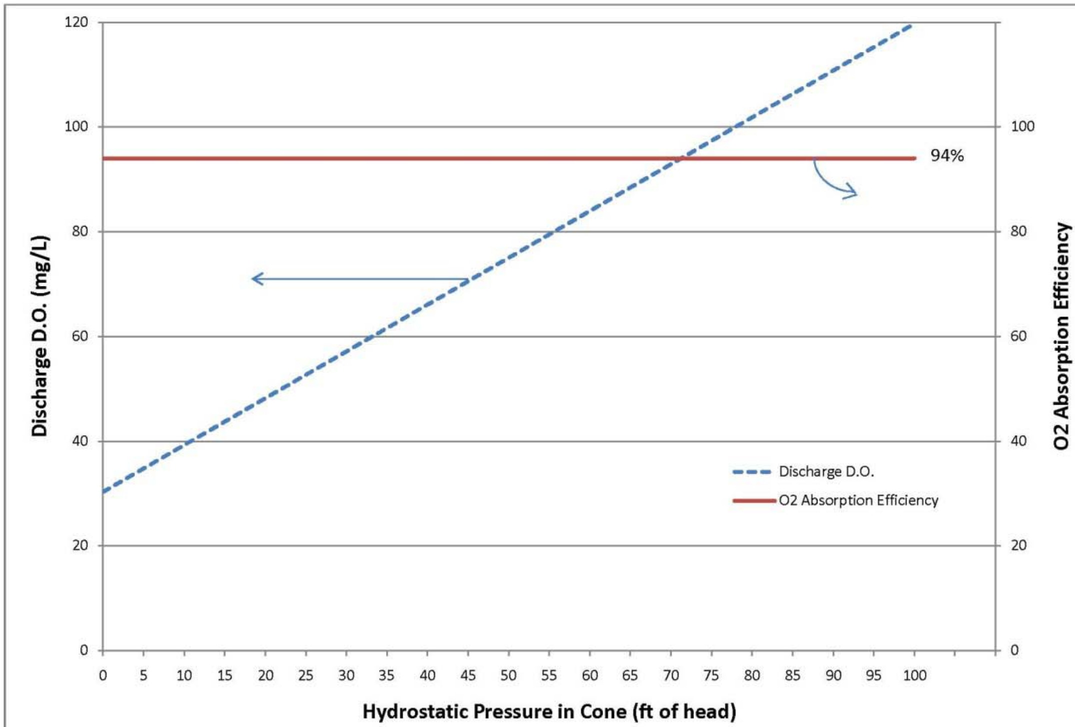


Fig.3 Discharge D.O. and O2 Absorption Efficiency vs Hydrostatic Pressure

2.3.2 Conditions Required for Precluding Effervescence to Achieve Retention of High D.O. (>400 mg/L) Conditions in the Discharge

Effervescence is a phenomena whereby a dissolved gas comes out of solution in water as tiny bubbles (<0.1 mm diameter) from a liquid having a highly supersaturated concentration of D.O. There is a common misconception that when dissolved gas concentrations exceed 100% saturation that effervescence results with the dissolved gas level quickly dropping to 100%. This is commonly based on the visual observation of vigorously shaking a champagne bottle and popping its cork or of pouring a can of Coke into a glass. Indeed effervescence is a critical phenomena which must be addressed when dealing with supersaturated D.O. concentrations in water . However, with proper diffuser/depressurization design, effervescence is successfully precluded.

Effervescence is generally controlled by the following parameters:

- Supersaturation concentration
- Time
- Turbulence
- Temperature
- Presence of colloids

By manipulation of these parameters, effervescence can be either maximized or prevented, whichever is the design objective. The most common example of effervescence, dissolved air flotation, effervescence is designed to be maximized. Therefore, a very high supersaturation level is achieved by operating the gas transfer vessel pressure at ~75 psig. This results in a saturation level that approaches 600%. In order to enhance turbulence in the discharge from the saturator, a pressure letdown nozzle is directed at a flat plate for maximum turbulence. This combination of exceptionally high supersaturation concentrations and exceptionally high turbulence in the discharge results in rapidly reducing the supersaturation concentration down to some level above 100%. It is of note that very high supersaturation levels are required to achieve efficient effervescence of the dissolved gas. As will be documented later in this report there is an effervescence threshold level of nominally between 170 to 240% supersaturation, below which effervescence cannot be induced even with high turbulence levels.

As a point of reference, the pressure in a Coca Cola can at room temperature exceeds 45 psig due to pressurization with CO_2, which corresponds to about 400% CO_2 saturation for taste appeal (this also allows the cans to be stacked on top of each other without crushing). This corresponds to dissolving about 3.7 volumes of CO_2 per volume of Coke. Thus a 355 ml can of Coke contains over 1300 mL of CO_2. If a Coke can is allowed to sit for about 10 min. so that any tiny bubbles rise to the surface, and the can is opened, less than 50 mL of CO_2 escapes in the first minute. Thus, over 96% of the dissolved CO_2 remains in solution during this period, even though it is at a highly supersaturated condition. Coca-Cola personnel estimate that it takes about two hours for all of the dissolved CO_2 to escape if the can is opened under quiescent conditions. On the other hand, if a Coke can is vigorously shaken, so that a multitude of tiny bubbles is entrained, creating a very high gas bubble surface area, and the can is subsequently opened, it immediately foams over due to the loss of a high amount of dissolved CO_2.

Water in the Columbia River normally is passed through electricity turbine generators and discharged below the downstream surface with none flowing over the spillway. However during flood flows the turbine generators cannot accommodate the entire flow and spillway discharge is required during these times. Supersaturation of the water flowing over Columbia River dams, which suck in air at the plunge point and drag the air bubbles deep into the stilling basin, results in total dissolved gas levels exceeding 130% saturation downstream. Due to the very low surface gas exchange coefficient of the deep, slow moving Columbia River, it has been observed that after flowing 80 miles, more than two days, there is an insignificant reduction in the 130% saturation level of the water.

It has also been observed that in farm ponds which are highly eutrophic, with resulting high algal activity, the D.O. rises to as high as 30 mg/L in the middle of the afternoon and persists for hours. These examples prove that a D.O. concentration considerably above 100% saturation is required to cause effervescence.

2.3.3 Discharge Diffuser Design Criteria

The Speece cone designed for the Back River will have a discharge D.O. of 40 mg/L (111% saturation at the surface but only 77% at the discharge point 15 ft below the surface). This is dramatically lower than the 2008 demonstration system in which the D.O. was raised to 150 mg/L (208% saturation at discharge depth of 34 feet). Effervescence in the Back River location is precluded because the discharge D.O is not 100% saturated at the discharge depth.

The Speece cone can be designed to raise the D.O. in the discharge to >400 mg/L. In these cases, careful attention must be paid in the design of the discharge diffusers which mix these very high D.O. levels with the receiving waters and quickly dilutes the D.O. to below the effervescent potential concentration of 170 to 240 % saturation (as described below).

If it is desired to retain highly supersaturated D.O. in solution after discharge from the Speece cone, special measures can be taken to avoid effervescent loss of highly super oxygenated water. Since effervescence requires a finite period of time for the D.O. to come out of solution, if the highly supersaturated water is quickly diluted with water containing only a few mg/L of D.O., there is insufficient time for the effervescent bubbles to form before the D.O. concentration is diluted below its effervescence potential.

The higher the D.O. supersaturation, the quicker the discharge must be diluted below the effervescence potential to preclude effervescent loss of D.O. Thus the proper design of the discharge diffuser to minimize the time before dilution to below the effervescence potential level is paramount. At very high supersaturation D.O. concentrations in the Speece cone discharge, the discharge must be depressurized, diluted and distributed in the receiving water quickly in order to minimize the time at which the superoxygenated discharge is at reduced pressure.

The jet from a diffuser is rapidly mixed/diluted with the receiving water. The dimensions of the undiluted core of superoxygenated water exiting from the port of a diffuser are a function of:

- Superoxyenation concentration in jet
- Port diameter
- Jet velocity (pressure drop across discharge port)
- Port spacing
- D.O. in receiving water

The impact of a diffuser design can be easily modeled to show the mixing and dilution effects.

It has been shown that water containing >100 mg/L of D.O. (>200 % saturation) can be effectively diluted into D.O. free water in a BOD bottle with no effervescent loss of the D.O. This has been a demonstrated laboratory technique for measuring D.O. concentrations much above that possible with electronic D.O. meters.

Figure 4 is a cross section of a diffuser header with multiple discharge ports. The shaded area represents superoxygenated water that is undiluted. As the undiluted water is forced through the discharge ports, its high velocity generates considerable shear/entrainment in the surrounding water containing low D.O. Consequently, the plume is eroded and diluted by the surrounding water, which contains low D.O. The duration of time for which the discharge jet is undiluted is very short and thus rapidly diluted down below the effervescence potential.

Figure 5 shows the cross-section through the diffuser jet versus the D.O. concentration. The cross-section AA initially contains ambient water with the ambient D.O. concentration. The D.O, then abruptly increases to the concentration coming out of the port and then abruptly decreases to the ambient D.O. concentration. Cross-section BB, which is located farther from the face of the diffuser nozzle still contains some undiluted discharge water and is characterized by an increasing concentration next to the jet because of entrainment of the ambient water with the superoxygenated water. Then the concentration in the undiluted core equals the discharge from the header and then subsequently tails off on the other side. Cross-section CC is taken beyond the distance where the undiluted jet exists and shows an elevated concentration that rises and peaks at the centerline of the jet at some level, much less than the superoxygenated water in the diffuser and tails off symmetrically on the other side. The object of the diffuser design is to dilute the superoxygenated water quickly below its effervescence potential. This is done by mixing it with the ambient water in the high turbulence jet.

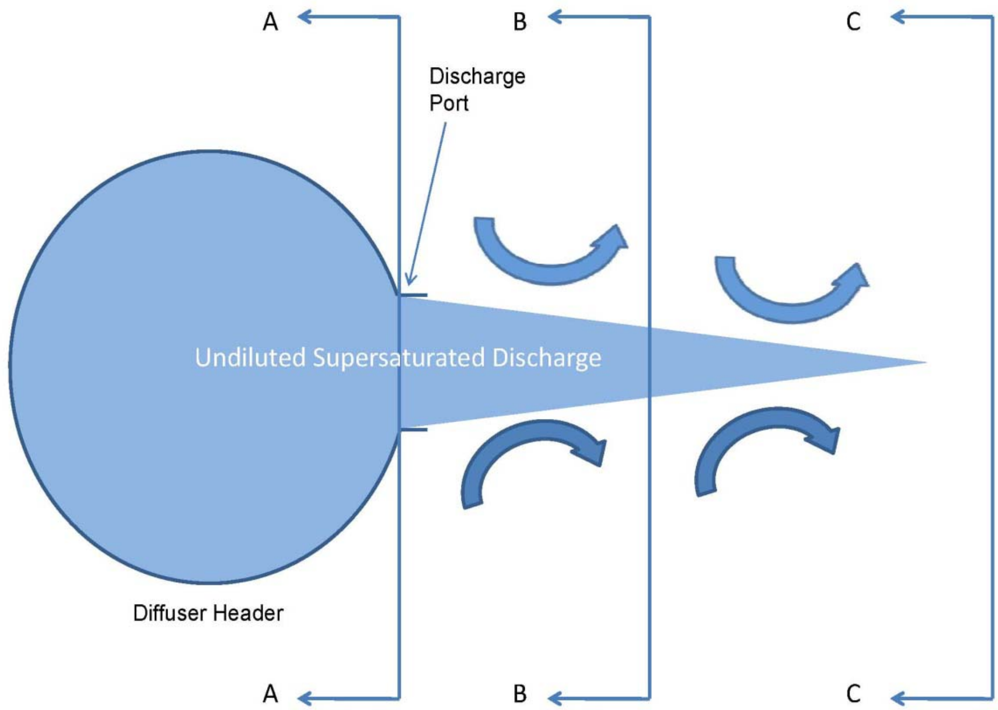


Fig. 4 Schematic of Mixing in Diffuser Jet

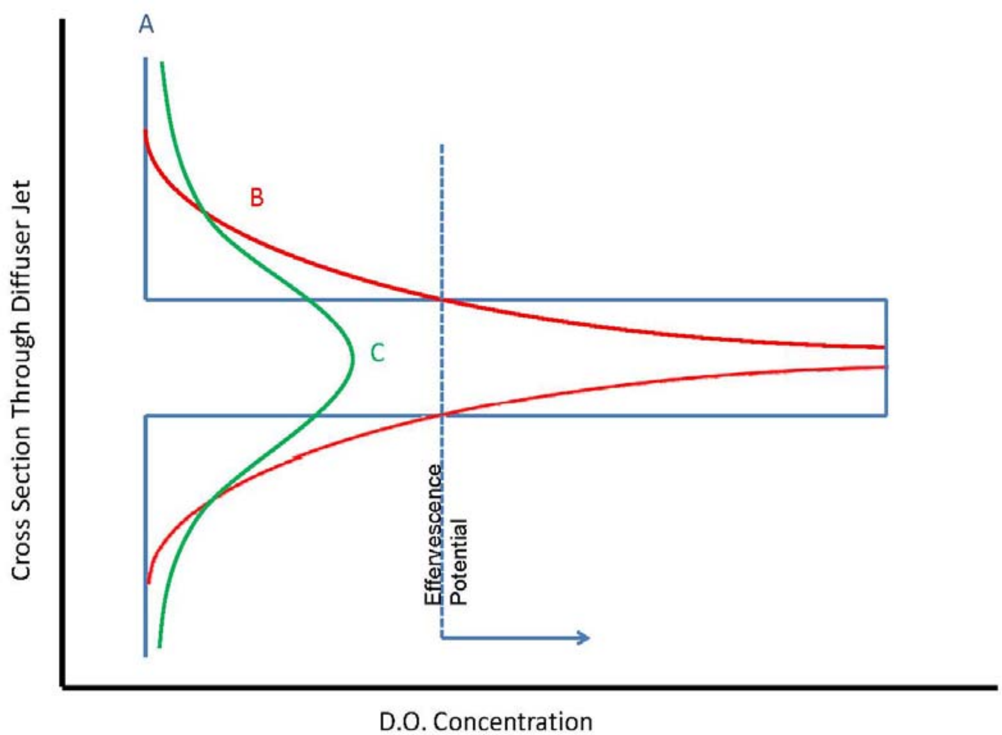


Fig 5. D.O. Profile in Diffuser Jet

<u>In summary all of the pressure drop must occur at the discharge port to minimize the time at which discharges are highly superoxygenated and thus capable of supporting effervescent loss of D.O..</u> In such a case, the jets coming from the discharge port will be rapidly diluted with the ambient water in less than a fraction of a second. There is a cone shaped volume of undiluted water coming out of a discharge port and it is crucial to minimize the time before its dilution to below the effervescence potential level. The undiluted core of superoxygenated water exiting the discharge port will be rapidly mixed with the ambient water within a distance of nominally less than 10 diameters of the discharge port (depending on the parameters listed above). If the pressure within the cone was 34 feet of hydraulic head, the discharge velocity through the port would be approximately 50 ft/sec (V^2 / 2g= H_L). And if the ports were 2 inches in diameter, then 10 diameters would be 20 inches and at 50 ft/sec, then the duration of time that the undiluted water would exist in the jet core would be 0.03 seconds. The high velocity jet also results in more than a 10 fold dilution of the jet with the receiving water in a fraction of a second. This rapid dilution in the high velocity of the discharge/depressurization port is crucial for rapid dilution of highly superoxygenated water to below its effervescence potential.

Even though the Speece cone's capacity to dissolve oxygen does not change in shallow water, the diffuser design becomes more critical in shallow water installations. However the Speece cone design for the Back River system only raises the D.O. to 56% of saturation at the discharge depth and is thus incapable of effervescent loss of D.O. Therefore the diffuser design only needs to insure distribution of the superoxygenated discharge across the Back River.

2.4 Superoxygenation Discharge into "Shallow" Waters

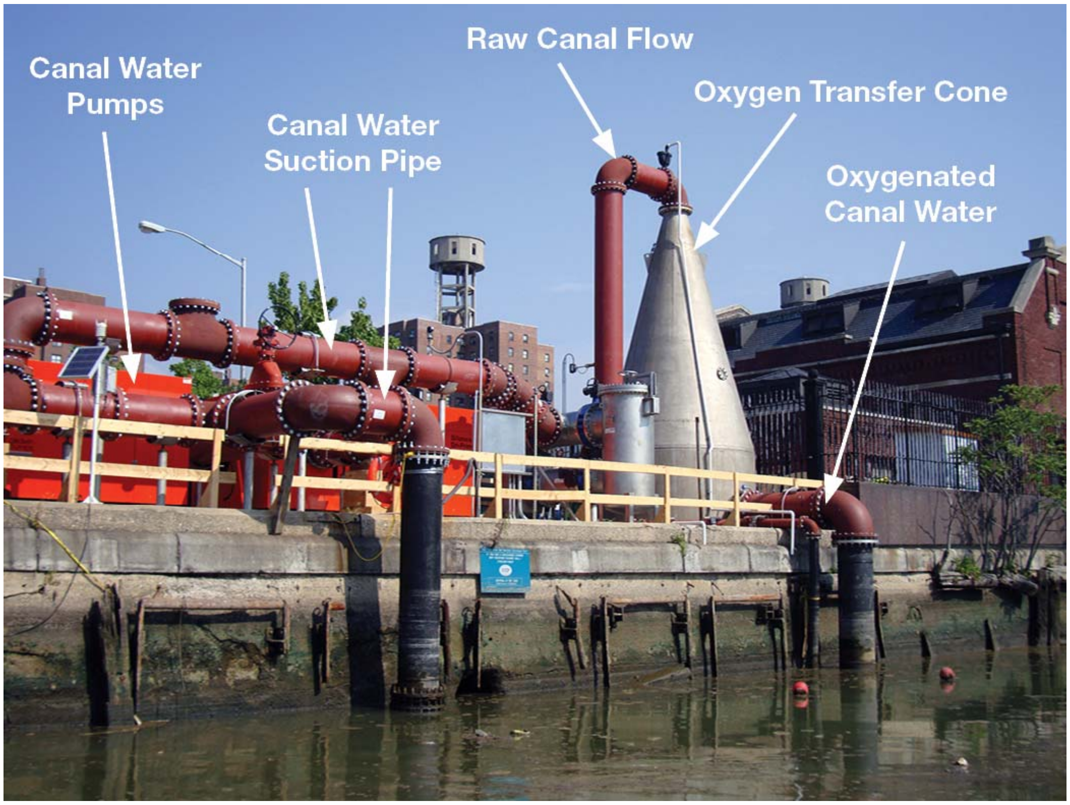
It has been reported by Jones in a publication describing pure O_2 supplementation to the San Joaquin ship channel in Stockton, California, that the Speece cone was inappropriate for applications when discharging into shallow waters. Unfortunately, this is an unsubstantiated conclusion. The Speece cone can be successfully operated to discharge into shallow waters. The Speece cone can be operated to discharge a D.O. level which is at the D.O. saturation level of the shallow water whereby precluding the potential for effervescence. Secondly, highly superoxygenated water can be discharged into a depth of water of 1 foot with nil effervescent loss of D.O. if the diffuser is properly designed to quickly dilute the superoxygenated water with ambient D.O. water and there is transport/movement to carry away the D.O. dissolved therein.

In California, Farrelldean reports that the aquaculture industry uses superoxygenation of a side stream for maintenance of the D.O. at >8 mg/L in the fish rearing tanks. In one preliminary study, the superoxygenated side stream coming into the fish tank had 117 mg/L of D.O. The superoxygenated side stream is quickly mixed with the 29^{o}C water in an 8 ft deep tank and no effervescence was observed.

2.5 Example Speece Cone Installations

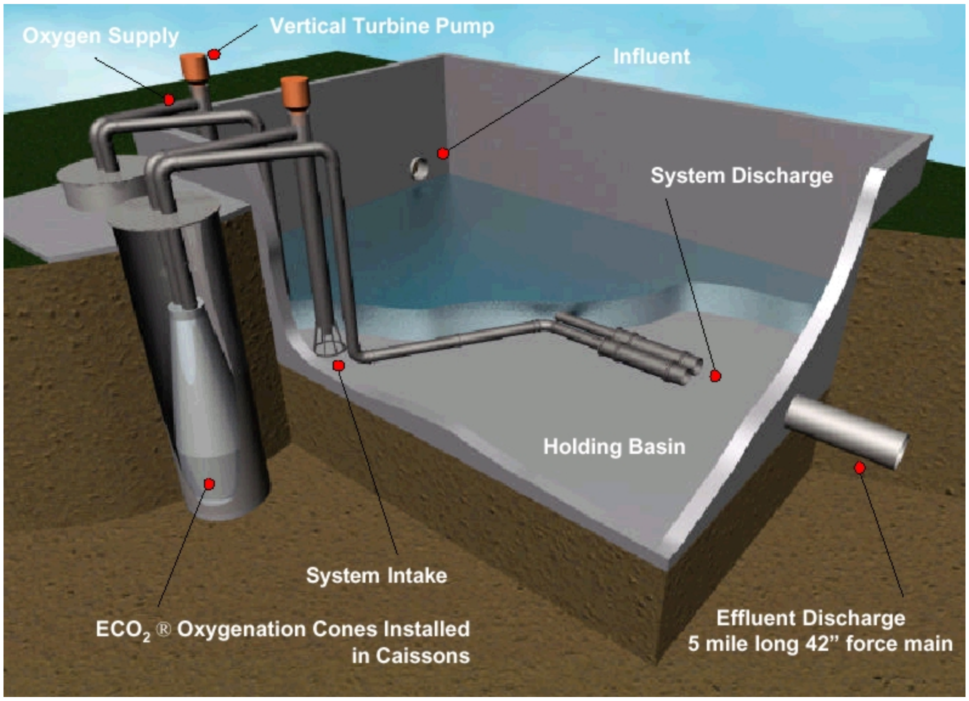
2.5.1 Gowanus Canal

The Gowanus Canal is a sea level, dead end canal constructed in Brooklyn N.Y. in the 1800's. It is about 9 feet deep at the head end and less than 2 miles long and has very little replacement of the stagnant water at the head end. Consequently it was a major odor source. Many years ago a tunnel and pump station were constructed to bring in fresh sea water to flush the canal and eliminate the odor source. Recently rehabilitation of the pump station was required and a means for maintaining oxic conditions within the canal during this 2 year period of construction was needed. A Speece cone oxygenation system was installed and pumps about 5,000 gpm of water from the canal, superoxygenates it to about 50 mg/L D.O. and discharges it into a half mile long, submerged, distribution header/diffuser system. This distribution header/diffuser is attached on one side of the canal. It maintains the head end of the canal at about 14 mg/L D.O. under summer conditions.



2.5.2 Paper Mill Wastewater Oxygenation

A Speece cone superoxygenation system was installed at a paper mill to superoxygenate the treated discharge to an elevated D.O. level which was sufficient to maintain oxic conditions throughout the length of a five-mile long force main (five hours detention time). A basin with 9 ft water depth received the treated discharge. Water from this basin was pumped as a sidestream through a Speece cone located in a 65 foot deep caisson at a flow rate of 14 ft^3 per second and a temperature of 27.8°C. The discharge D.O. was 81 to 83 mg/L (230% saturation). The O_2 absorption efficiency exceeded 90% in the Speece cone. The Speece cone discharge having a D.O. of 81 to 83 mg/L was discharged back into the 9 foot deep basin and diluted to 32 mg/L with less than 3% of the initial D.O. lost due to effervescence.



2.5.3 Logan Martin Dam

Logan Martin Dam on the Coosa River in Alabama is operated for peaking power production. During off peak periods of electricity demand, no flow occurs. Due to the fact that the foundation of the dam is channeled karst that was not 100% grouted, leakage of 700 CFS occurs underneath the dam. This large volume of leakage water is deficient in D.O. and causes stress to the aquatic life in the 35 foot deep tail water.

In order to rectify the unacceptably low D.O. during the night and over the weekend when water is not discharged through the turbines, a Speece cone oxygenation system was installed. Water is taken through a siphon over the dam and conducted through the Speece cone located at the base of the dam. The water is raised to approximately 50 mg/L D.O. in the Speece cone and then immediately diluted by discharge 15 feet below the surface. A relatively high D.O. is added to the small side stream without effervescent loss when it is discharged into the tail water. This system adds approximately 6000 pounds of D.O. per day to the tail water and effectively relieves the stress on the resident fishery. This cone is 9 foot in diameter and 20 feet high. It handles a flow of 24 cfs of water at 86°F. The system achieves 94% of the theoretical saturation concentration of D.O. within a residence time of 30 seconds due to the exceptionally high gas transfer surface area provided in the bubble swarm.

2.5.4 Tombigbee River

In the 1980's Prof. Speece designed a U-Tube oxygenation system for the Tombigbee River between Alabama and Mississippi for supplementing D.O. near an industrial complex. The Tombigbee River was less than 35 ft deep at this location. The U-Tube oxygenation system pumped 120 MGD of water from the Tombigbee down through the 175 ft deep U-Tube and raised the D.O. to ~50 mg/L in the discharge which was then sent to a diffuser installed across the bottom of the river for dilution with the main flow of the river. This system could add ~40,000 lbs D.O./day to the river and no effervescent loss occurred after discharge to the river. This system operates on an as needed basis at low flow conditions in the river.

2.5.5 Laboratory Studies to Define Effervescent Loss of Highly Superoxygenated Water

Laboratory studies were conducted by Prof. Speece to determine the residual D.O. in superoxygenated water after depressurization occurs and all effervescence has ceased. This was used to determine the D.O. below which effervescence did not occur i.e. the effervescence threshold. Various methods of depressurization were evaluated and the dilution requirements to preclude effervescent loss of the D.O. were determined.

A. Quiescent Depressurization of Superoxygenated Water

Water was saturated with pressurized pure O_2, then progressively depressurized until the occurrence of effervescence was noted. Water was placed in a pressure vessel with a pure O_2 headspace that was connected to an O_2 pressure cylinder. The pressure inside the water pressure vessel was maintained by a pressure regulator on the discharge from the O_2 cylinder. Then the vessel was agitated for a prolonged period of time until the water reached saturation equilibrium with the pressurized O_2 headspace. The various pressure levels were over a range of 4 to 10 atm of pressure achieving 150 to 400 mg/L D.O. After the water reached equilibrium at the study pressure, the system was slowly depressurized until effervescence was noted to commence. Over this entire pressure range of 4 to 10 atm of pressure it was observed that whenever the D.O. concentration exceeded 170% saturation, that effervescence would commence. Below 170%, D.O. saturation, effervescence was not observed upon depressurization.

Figure 6 shows the results of supersaturating water with D.O. in a pure O_2 headspace at pressures up to 125 psig. The system was abruptly depressurized to ambient conditions and allowed to effervesce. After all effervescence has ceased, the D.O. concentration was in the range of 100 to 160 mg/L. This indicates that the effervescence threshold was above 200 to 300% saturation.

Figure 7 shows another study tap water was placed in a pressure vessel with a pure O_2 headspace and the pressure was raised from 4 to 10 atm. Subsequently, the pressure was gradually reduced and it was observed that whenever the D.O. concentration exceeded 200 to 300% saturation, effervescence would occur. No effervescence was noted below these levels.

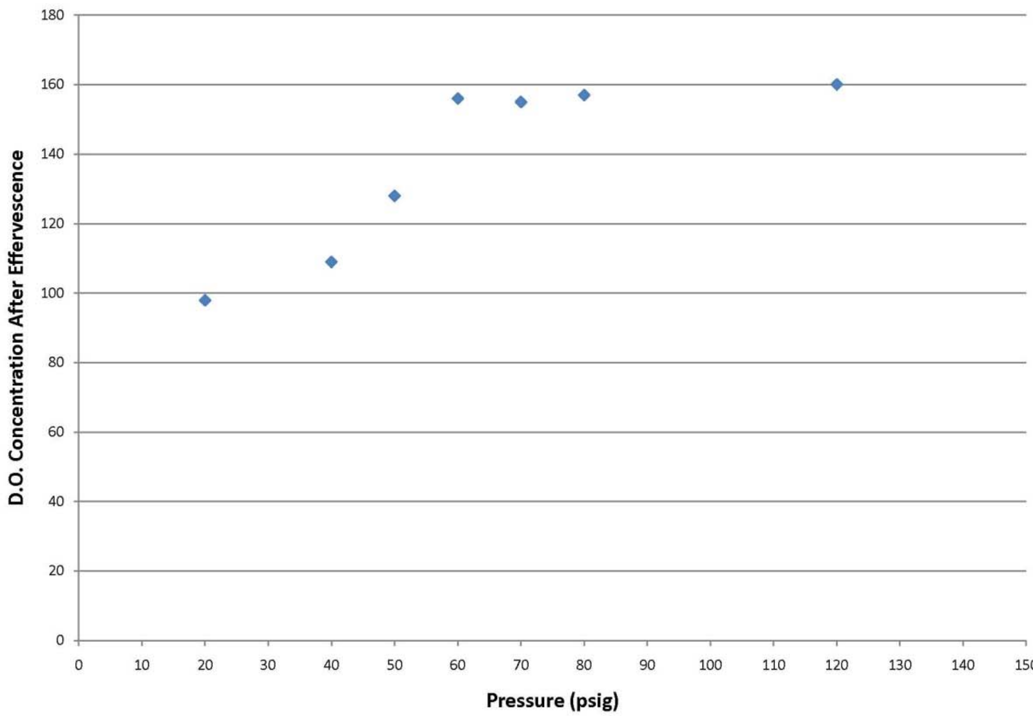


Fig. 6 Residual D.O. After Effervescence at Various Saturation Levels

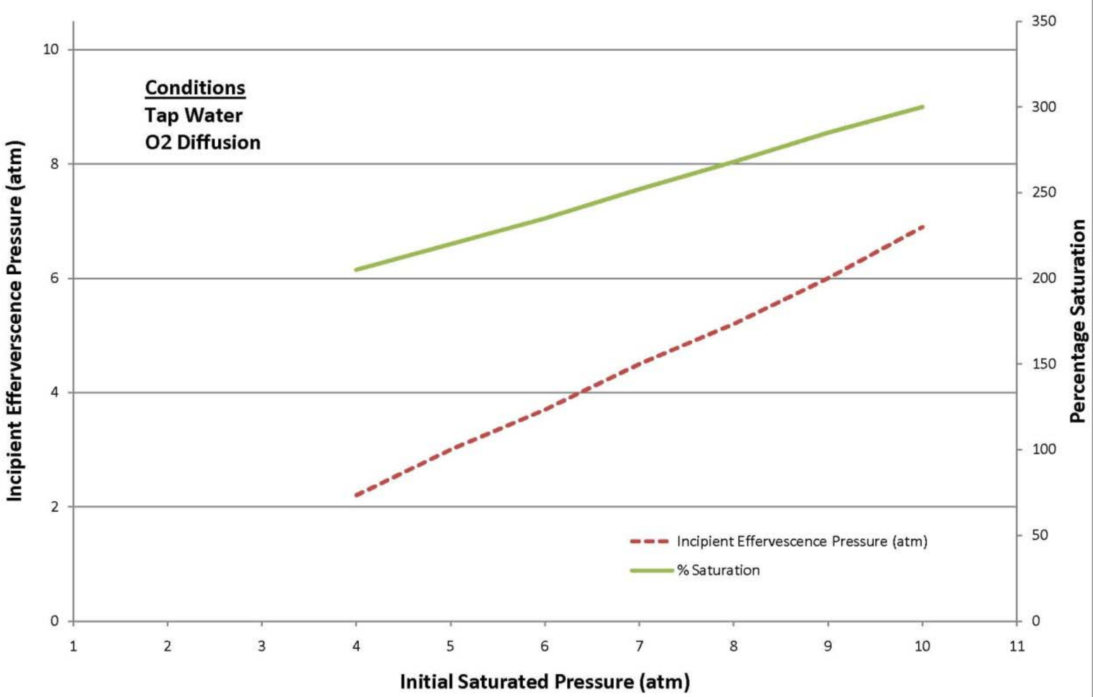


Fig. 7 Incipient Effervescence Studies

Figure 8 shows the residual D.O. in a system that was pressurized with pure O_2 in the headspace at a temperature of 29° C to 185 mg/L D.O., The system was abruptly depressurized and the D.O. was measured after all effervescence ceased. This experiment was conducted over a range of bentonite concentrations from 0 to 400 mg/L. Bentonite serves as a colloidal nucleation agent to enhance effervescence. Above a concentration of approximately 60 mg/L of bentonite, the residual D.O. was constant at approximately 150 mg/L (~400% saturation).

Figure 9 shows that the residual D.O. after all effervescence had stopped are approximately 150 mg/L with tap water saturated with pure O_2 at pressures of 45 to 120 psig.

Figure 10 shows that as long as D.O. was less than 170% saturation no effervescence will occur. Thus, 170% D.O. saturation was the effervescence potential threshold.

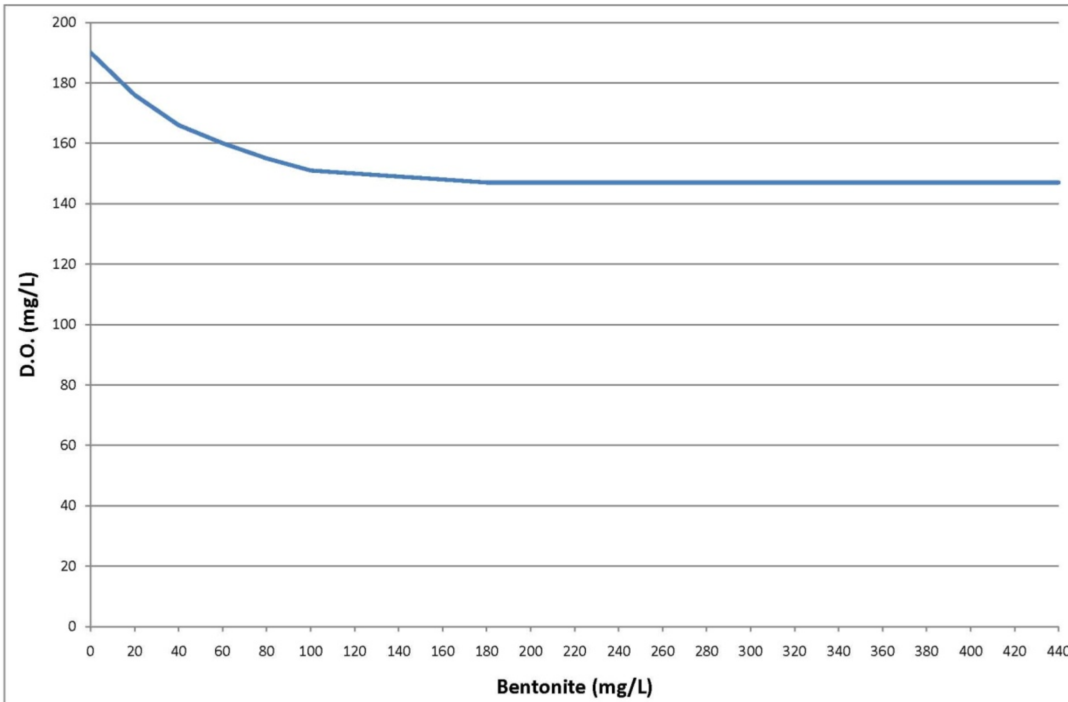


Fig. 8 Residual D.O. After Depressurization in Presence of Bentonite Colloids

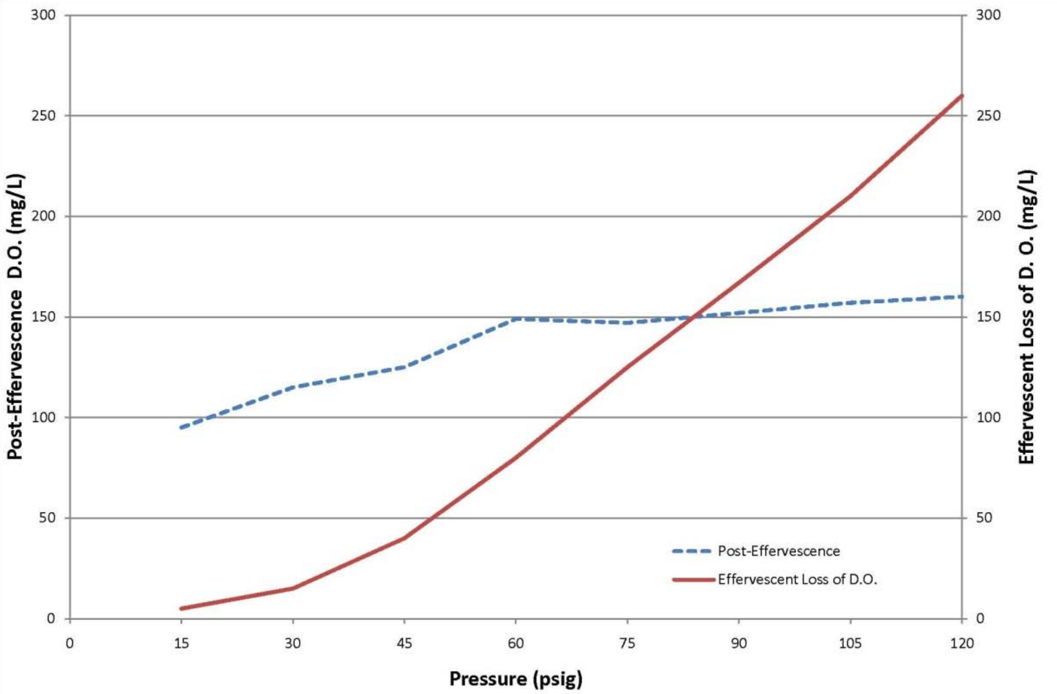


Fig. 9 D.O. After Effervenscence and Oxygen Lost Due to Effervescence (No Sulfite)

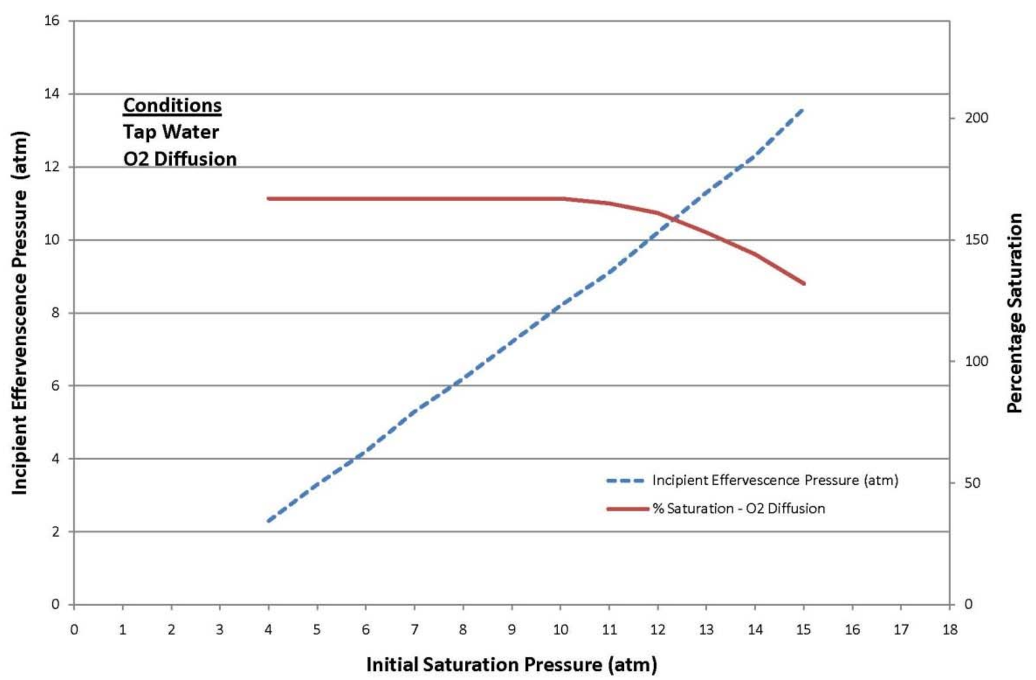


Fig. 10 Incipient Effervescence vs Saturation Pressure

B. Turbulent Depressurization of Superoxygenated Water

Figure 11 shows tap water was saturated at a pressure of 9 atm with pure O_2, and the vessel was depressurized while being stirred and the D.O. was recorded for various stirring times. The D.O. deficit initially was approximately 280 mg/L (320 mg/L D.O.). Upon depressurization while being mixed, the D.O. deficit dropped to approximately 60 mg/L, (which would correspond to 100 mg/L D.O.) within 3 min. No further effervescence was noted after 3 min. The D.O. deficit then decreased in a linear manner up to 10 min. when the D.O. deficit was 35 mg/L (the actual D.O., was 75 mg/L). The purpose of this curve is to show that no effervescence potential was noted below a D.O. deficit of 80 mg/L, (corresponding to 120 mg/L D.O.). It is also noteworthy that it took about 60 seconds for the D.O. deficit to drop from 280 to 95 mg/L., The curve shows that if D.O. can be diluted below its effervescence potential within a fraction of a second, no loss of highly superoxygenated D.O. will occur. Thus, rapid dilution is a means of retaining the highly superoxygenated D.O in solution.

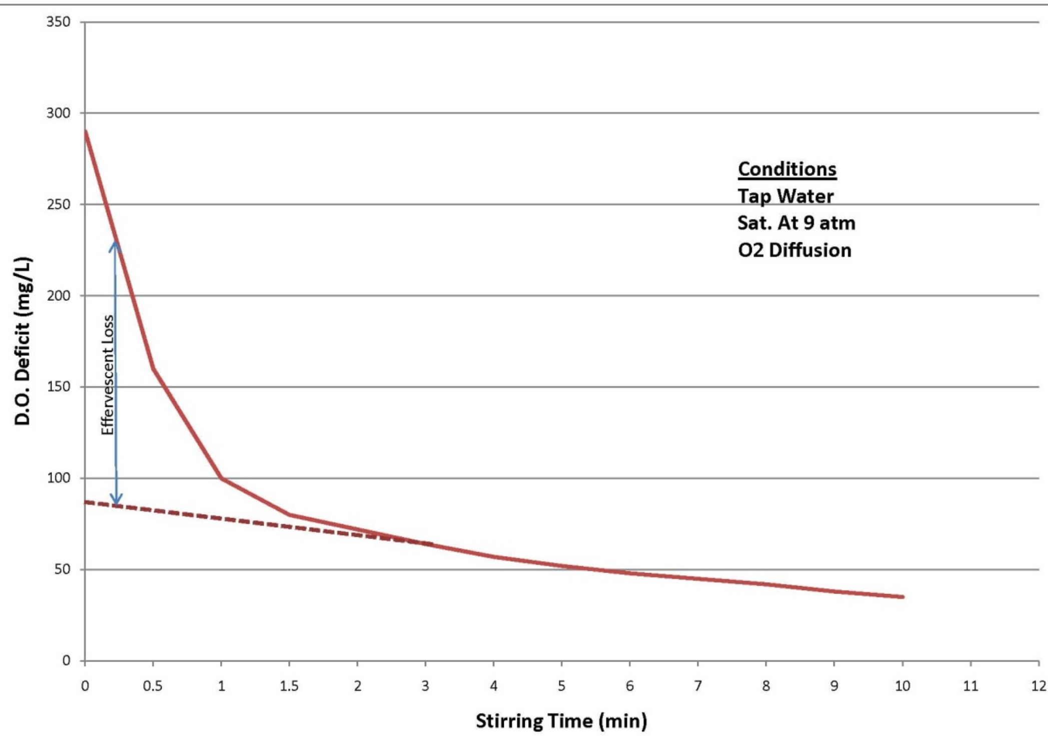


Fig. 11 D.O. Deficit vs Stirring Time

In another study, using a pressurized pure O_2 headspace at 45 psig, tap water was brought to 165 mg/L D.O. in equilibrium with the pressurized headspace and then passed through a throttling valve with the following pressure drops across the throttling valve:

45, 30, 15, and 0 psig.

After all effervescence had ceased, the residual D.O. was measured and found to be:

87, 83, 87, and 89 mg/L of D.O. (~230% saturation).

In another study, water was brought into equilibrium with a pure O_2 atmosphere at 100 psig, corresponding to a saturation concentration of 328 mg/L, D.O. It was then passed through a throttling valve with the following pressure differential across the valve of 100, 30, 15 psig. The residual D.O. was then measured after all effervescence had ceased and found to be respectively:

65, 77, and 89 mg/L of D.O. corresponding to:

176, 208 and 240% saturation.

In another study, tap water at 27.4°C was used to evaluate a 15 psig pressure drop after equilibrium at the following pressures:

15, 30, 45, 60, 100, 150, and 200 psig.

The D.O., after equilibrium with the pure O_2 pressurized headspace was correspondingly:

81, 122, 163, 203, 312, 447, and 584 mg/L.

After passing water with these respective concentrations of D.O. across a 15 psig throttling valve, the D.O. was measured in the discharge after all effervescence had ceased and found to be respectively:

65, 90, 76, 77, 85, 89, and 89 mg/L D.O..

These values correspond to:

173, 240, 206, 205, 230, 237 and 237% saturation after all effervescence ceased.

C. Dilution Requirements to Prevent Effervescent Loss of High D.O.

Figure 12 shows water at 28°C was brought to equilibrium with pure O_2 at a pressure of 60 psig. (185 mg/L D.O). The discharge of this highly superoxygenated water was immediately diluted with ambient D.O. (8 mg/L D.O.) tap water . Increasing dilution flow resulted in increasing retention of the D.O. mass in solution. At approximately 2 volumes of dilution flow with the ambient D.O. (8 mg/L) water per volume of superoxygenated water with 185 mg/L D.O., 95% of this original D.O. mass was retained in solution. The D.O. at this dilution would be 62 mg/L i.e. 170% saturation.

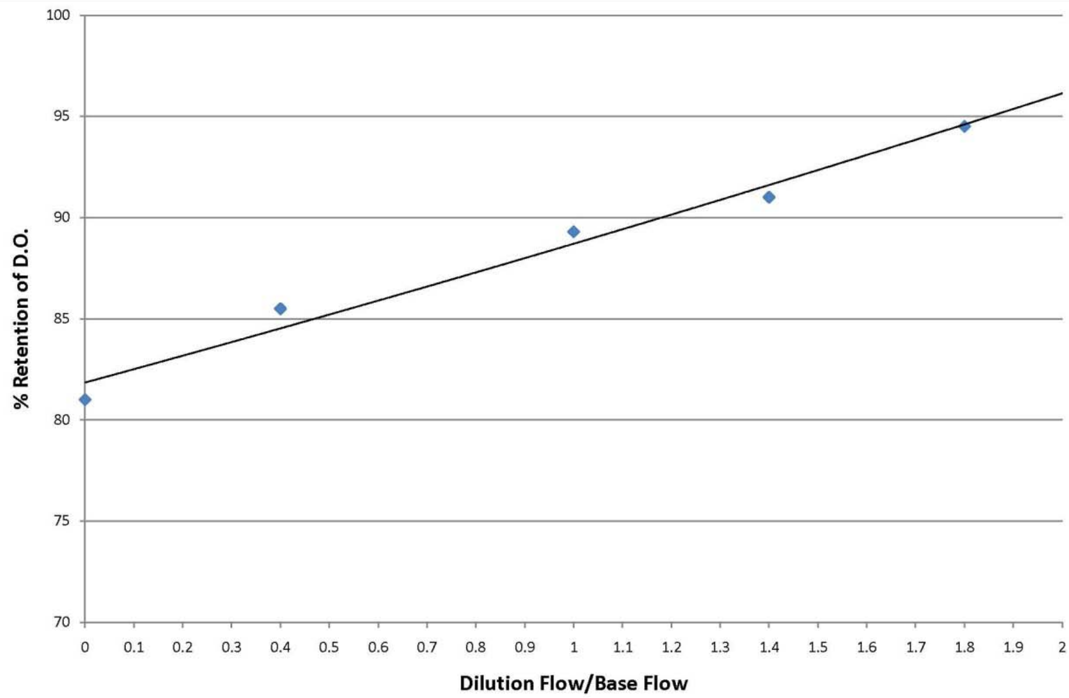


Fig. 12 Percentage Retention of D.O. vs Dilution Flow/Base Flow (Pressure = 60 psig)

Figure 13 shows water at 28°C was brought to equilibrium with pure O_2 at a pressure of 90 psig. i.e. 250 mg/L D.O. The discharge from this pressure vessel was immediately diluted with a range of flows with ambient air saturated water containing 8 mg/L D.O. The percent retention of D.O. mass in solution reached approximately 95% when the dilution flow was three times the base flow. Again the diluted concentration was 62 mg/L D.O. and 170% saturation.

Figure 14 show a series of studies was conducted in which water was brought to equilibrium with a pressurized pure O_2 headspace over a pressure range of 45 to 90 psig. The superoxygenated water from this pressurized reactor was then immediately diluted into a cobalt catalyzed sulfite (for scavenging the D.O. and thus maintaining 0 mg/L D.O. in the water) reservoir of water and the volume of effervescent O_2 was measured. At a pressure of 45 psig, corresponding to 148 mg/L D.O., there was no detectable loss due to effervescence because of the immediate dilution. Even at 90 psig, corresponding to 259 mg/L D.O., only 10% loss of the D.O. was noted after depressurization into a cobalt catalyzed sulfite reservoir of water.

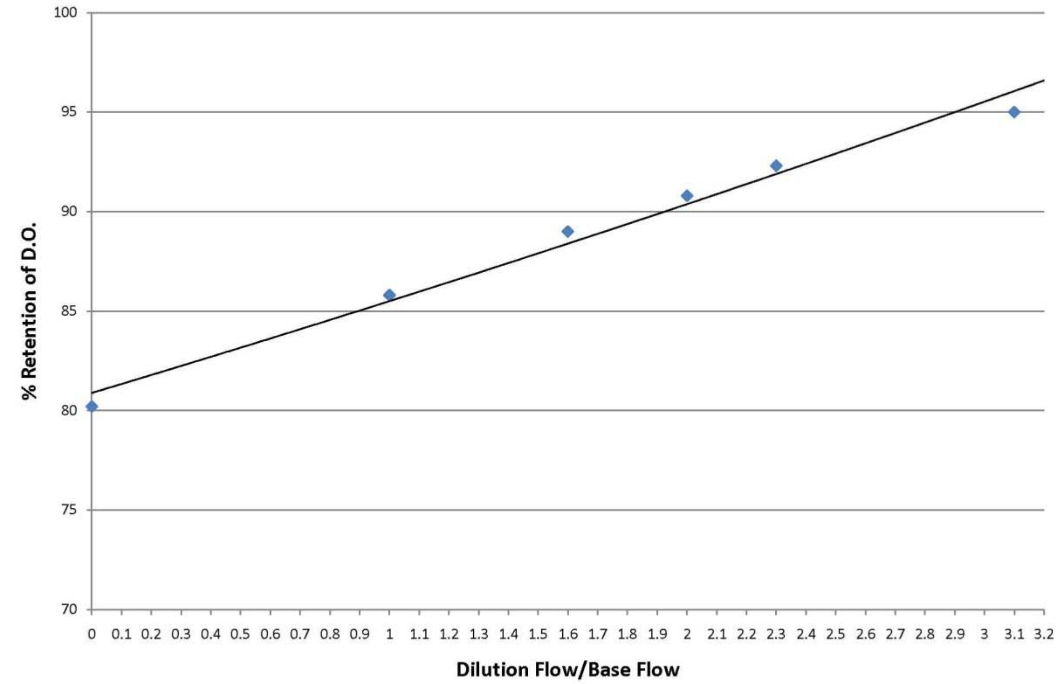


Fig. 13 Percentage Retention of D.O. vs Dilution Flow/Base Flow (Pressure = 90 psig)

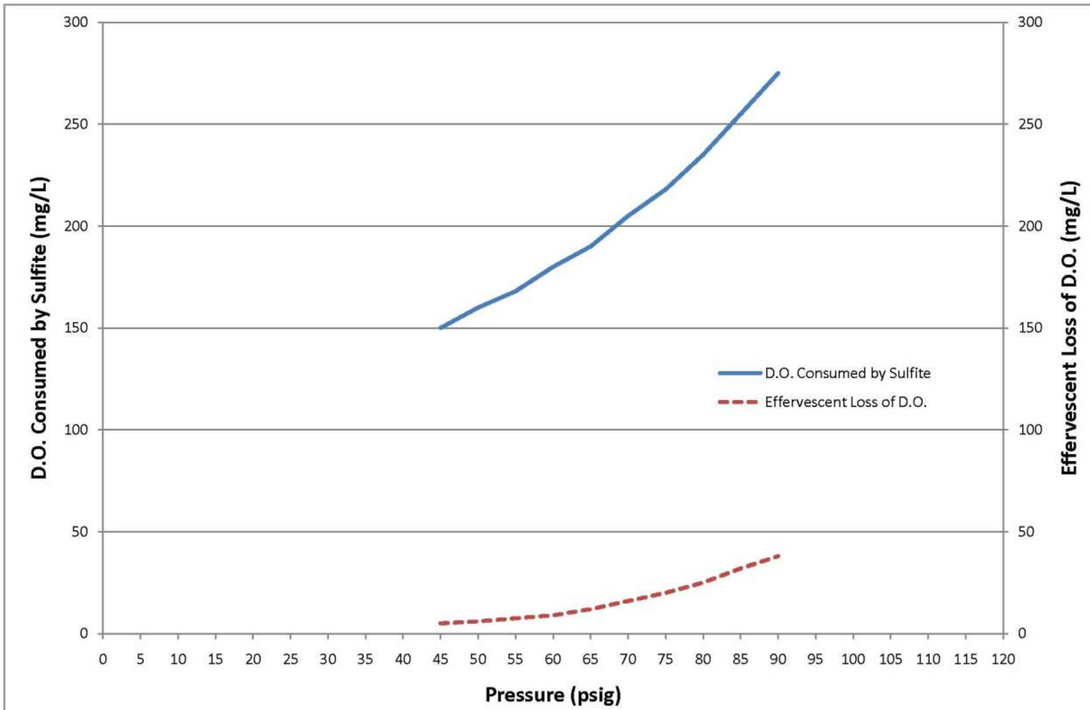


Fig. 14 D.O. Consumed by Sulfite and D.O. Lost by Effervescence (Excess Sulfite)

Figure 15 graph shows the D.O. and the pressurized discharge versus the pressure maintained at equilibrium in the pressure vessel. There is a linear increase in D.O., in the discharge versus pressure that corresponds to about 90% of theoretical saturation. The retention of D.O. after discharge directly into tap water containing cobalt catalyzed sulfite was 100% at 45 psig and about 90% D.O. retention at 90 psig.

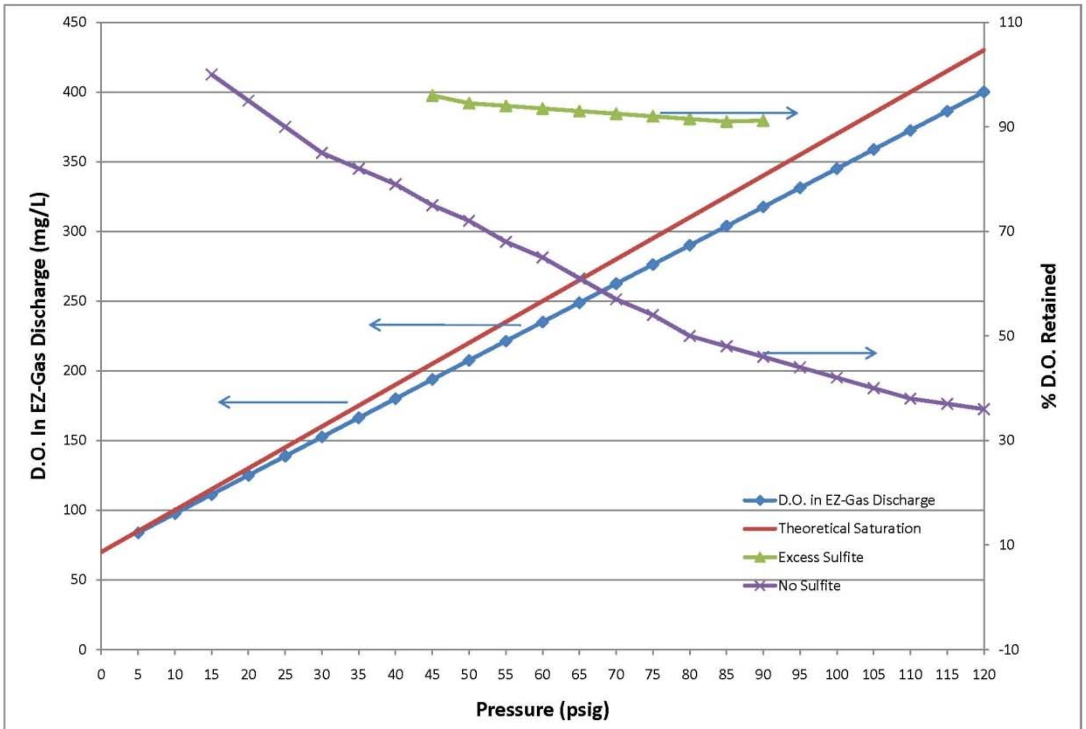


Fig. 15 D. O. in EZ-Gas Discharge and Percentage D.O. Retained

Back pressure studies were conducted in which superoxygenated water was raised to180 mg/L of D.O. and discharged into a reservoir at the equivalent of 50 feet below the surface and no effervescence loss of D.O. was observed. When water was raised to 140 mg/L of D.O., it could be injected 20 feet below the surface with no effervescent loss of D.O.

2.6 Tidal Mixing and Slack Tide

The two key requirements for supplemental oxygenation of a surface water body are:

- Means of supplementing the D.O.
- Means of transporting the oxygenated water away from the location where it is added.

There is significant tidal mixing to transport the oxygenated water away from the point where it is being injected in Savannah Harbor except at the very head of the estuary. The locations where the Speece cones are to be located have significant tidal transport mixing. However at slack tide, mixing transport of the water ceases for a period of less than an hour. During this period, the D.O. will accumulate in the vicinity of the O_2 injection station. At the rate which D.O. is being supplemented to the Back River region ~4,000 lbs D.O./day, into a cross section of 1,500 ft wide by 15 ft deep by an assumed length of 100 ft for the diffuser influence (a volume of 2,250,000 ft^3), it would take about 52 hours of slack tide for the D.O. to accumulate to 13 mg/L. Thus in the relatively short slack tide interval of less than an hour, the D.O. in the vicinity of the D.O. supplementation station will only increase less than ~ 0.5 mg/L above steady state, not impacting the fishery with an unacceptably high D.O. environment. Thus slack tide will not significantly impact the performance of this oxygenation station.

2.7 Recommendations

The ECO2 oxygenation design for Back River will only result in 77% saturation of D.O. at the 15 ft depth at which it will be depressurized and discharged. Therefore effervescent loss of D.O. is not even possible. Aquaculture installations successfully discharge superoxygenated water at 29^oC and having a D.O. of 117 mg/L into 8 ft deep tanks and observe no effervescent loss of D.O. because of the rapid dilution achieved with the ambient D.O. water in the tank. Three examples are given of operating ECO2 Speece cone systems which superoxygenate a side stream of water and discharge it into “shallow” water with negligible loss of D.O. due to effervescence e.g. Logan Martin Dam on the Coosa River in Alabama (50 mg/L), Gowanus Canal in Brooklyn (50 mg/L) and a paper mill discharge (81 mg/L). For highly superoxygenation concentrations of 100 to >400 mg/L D.O. proper design of the depressurization/dilution diffuser is important to efficiently retain the D.O. mass in solution by minimizing effervescent loss of D.O. Results of laboratory studies to determine effervescent loss of D.O. from highly superoxygenated water reveals an effervescence threshold of nominally 170% to 240% saturation below which effervescence does not occur, regardless of the turbulence or nucleation sites involved. Studies have demonstrated that with proper depressurization/diffuser design, D.O. concentrations of >250 mg/L can be retained in solution with 95% mass efficiency. Lower D.O. concentrations can be 100% retained in solution.

3. Bathymetry of Back River

The Savannah District recently completed a hydrographic survey of the Back River in June 2011. The downstream extent of the survey was at the Tide Gate structure and the upstream was at New Cut closure. The hydrographic survey was provided to Tetra Tech in xyz format on June 21, 2011.

Figure 16 shows the bathymetric data plotted and the variations in the Back River. Figure 17 is a close-up view of the discharge point.

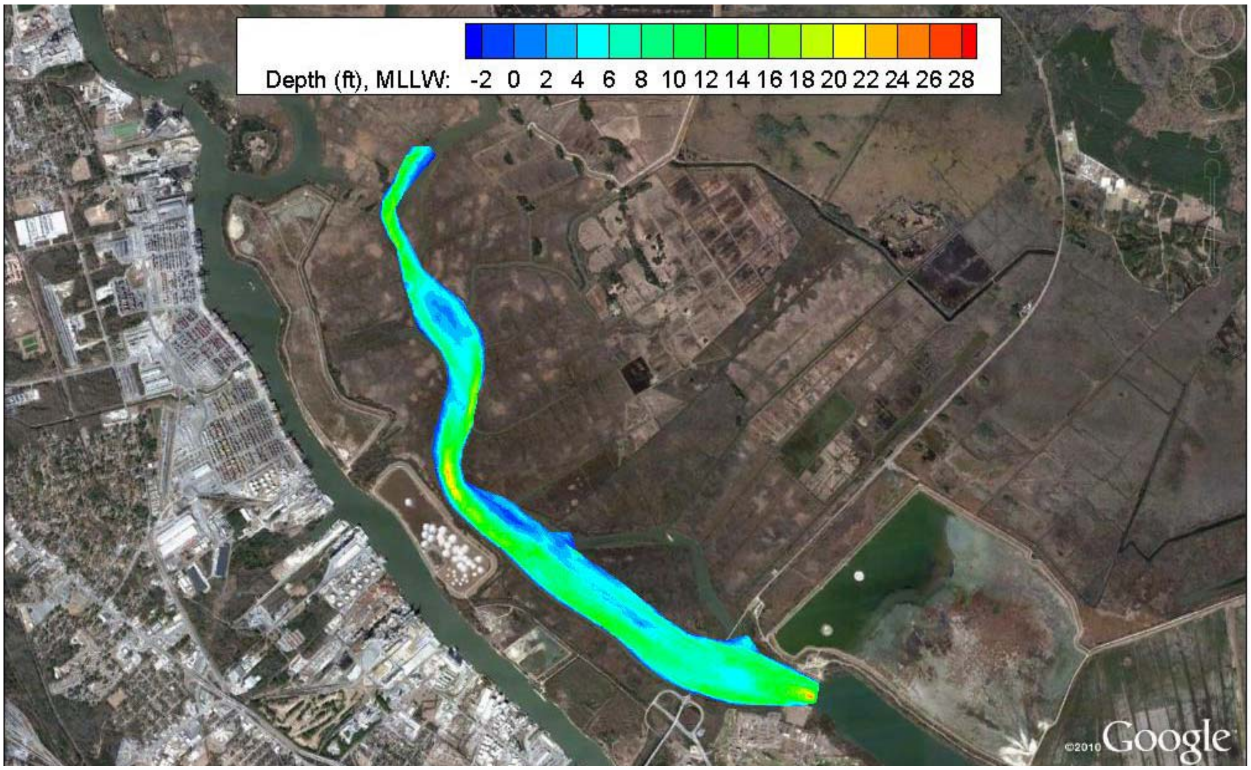


Figure 16 Bathymetry on the Back River (Data collected June 2011, USACE Savannah District)

The 2011 bathymetric data assisted in locating the water depth that would be appropriate for the oxygen injection discharge. The proposed discharge will be located on the Back River just downstream of the aeration lagoon on Hutchinson Island. Discharge point shown with an arrow in Figure 17 with a depth of approximately 15 feet of water.

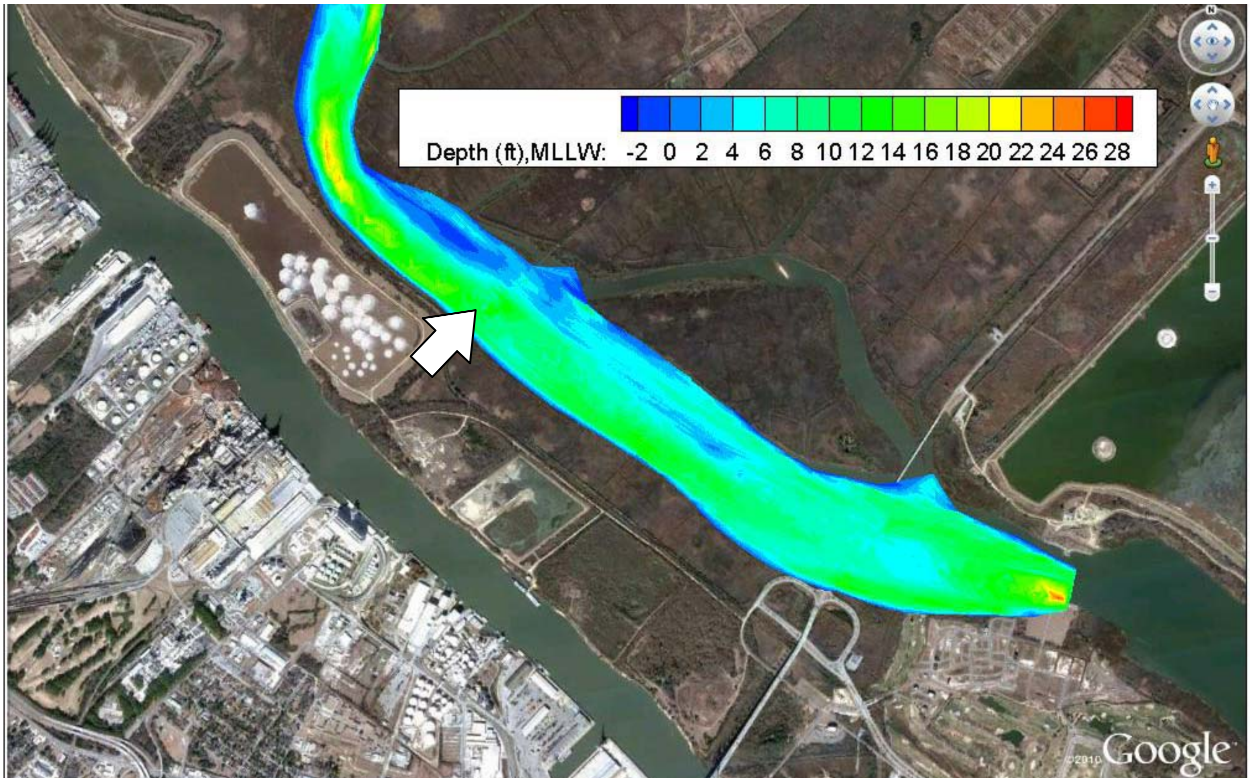


Figure 17 Close-up Bathymetry of Discharge Location (Data collected June 2011, USACE Savannah District)

4. Diffuser Design Calculations

Tetra Tech reviewed and identified pertinent sections of previous analyses performed on the Savannah Harbor hydrodynamic and water quality models and oxygen injection systems, with a focus on the depths and dynamics of Back River. A diffuser design spreadsheet was developed to calculate the head loss at the effluent pipe and minimum velocity required for the diffuser.

In order to accurately demonstrate how a Speece cone would perform in shallow water, Tetra Tech created multiple designs for the Back River location to compensate for the shallowness of the river. The design that created the most head losses was chosen so that effluent flow would dilute before approaching the water surface. This design was broken into three parts: influent, Pump to Speece cone, and effluent. A description of each part is given below.

- Influent – The influent entrance will be 3.5 feet from the river bottom. There will be a 90-degree turn piece installed. From here, 25 feet of 24-inch diameter ductile pipe is laid at a depth of 15 feet into the Savannah River. Once the pipe reaches the river's edge, a 45-degree angle will be installed and the pipe will travel 21 feet along the river's edge. Another 45-degree angle will be placed at the top of this pipe so that the pipe can now travel parallel with the ground. The pipe will travel 75 feet parallel with the ground. The pump will be located at the end of the 75 foot pipe. For the influent design, a total of 121 feet of 24-inch diameter ductile pipe will be used.

- Pump to Speece cone – From the pump, 600 feet of 18-inch diameter ductile pipe will be laid. At the end of the 600 feet, a 90-degree turn will be installed so that the water will flow up. From here 27 feet of pipe will be installed. At the end of this, another 90-degree turn will be installed, pointing downstream and parallel with the ground. From there, 6 feet of pipe will be installed with a 90-degree turn at the end of that, pointing towards the ground. This 90-degree turn will enter into the Speece cone. The total amount of 18-inch piped used in this section is 633 feet.

- Effluent – As the water exits the Speece cone, it will enter a 14-inch diameter ductile pipe. This pipe will be 73.25 feet long, aiming perpendicular to the river. This pipe will reach the river's edge. From here, a 45 degree angle pipe will be placed so that the water can travel parallel with the river's edge. A pipe 21 feet long will extend into the river. At the end of this, there will be a 45-degree angled turn will be installed so that the water can travel parallel with the river bottom. The 866.75-foot long pipe will lay parallel to the river bottom. Diffusers will be attached to this pipe, with the outflow at the same height as the inflow. The first diffuser will be located 145.75 feet from the beginning of the pipe, then each diffuser will be installed after every 100 feet. This will allow the dissolved oxygen to be more evenly distributed throughout the Back River. The total amount of 14-inch diameter ductile pipe used for this part of the design is 940 feet.

The total amount of pipe used for the entire design is roughly 1,694 feet. Using this value as well as the total amount of turns used in the design, the total head loss for the entire system could be determined. After finding the total head loss, the ideal pump could be determined. Tetra Tech determined that the Godwin CD500M C15 460 Horsepower pump would be the best for this project. This is the same pump used in the initial testing by MACTEC. It was determined that this pump would not cause cavitation under these conditions. It was also determined that the Speece cone would pump 40 mg/L of dissolved oxygen (17.34 psi) into the river. Once all of these factors were considered, Bernoulli's equation was used, which showed that the effluent velocity would be 38.61 fps. Using this value, it was calculated that 8 diffuser ports, each with a diameter of 4 inches, would be required for this design.

The spreadsheet calculates the head loss through cone and pipe system. It calculates the effluent velocity which is critical in the mixing zone calculation. The following calculations are included in the spreadsheet.

Pipe Head Loss $= 0.002083 \bullet L \bullet \left(\frac{100}{c}\right)^{1.85} \bullet \left(\frac{gpm^{1.85}}{D^{4.8655}}\right)$

Minor Loss $= \sum k \bullet \frac{v^2}{2g}$

Pump Head Loss $= \frac{HP \bullet 550 \bullet E}{Q \bullet \gamma}$

Then based on the Bernoulli equation, the total pressure loss and velocity head can be computed with the following equation:

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1}{2g} - h_f - h_m + h_p = \frac{p_2}{\gamma} + z_2 + \frac{v_2}{2g}$$

Table 1 shows the results of several scenarios based on pump sizing (horsepower, HP) and flowrate.

Table 1 Table of Exit Velocity Based on Flow Rate

Scenario	Flowrate (gpm)	Pump (HP)	Pump Name	Pipe Length (ft)	Pipe Diameter (in)	Effluent Velocity (ft/s)
1	11,600	460	CD500M C15	121.00	24	38.61
				633.00	18	
				940.00	14	
2	8,000	275	CD400M	209.50	18	75.77
				816.00	18	
3	4,800	275	CD300M	209.50	12	96.45
				816.00	12	
4	2,880	147	CD250M	209.50	10	91.65
				816.00	10	
5	2,880	300	HL225M	209.50	10	49.09
				816.00	8	
6	4,560	440	HL250M	209.50	12	121.67
				816.00	10	
7	4,000	151	DPC300	209.50	12	78.68
				816.00	12	

5. Mixing Zone Model

Tetra Tech revisited the mixing zone analysis performed previously (Tetra Tech 2010) based on new information such as the 2011 bathymetry and diffuser recommendations from Dr. Speece and ECO2.

5.1 MACTEC Summary

The MACTEC ReOx report was reviewed and summarized for use in the Back River design. The demonstration project consisted of two custom-built, 12-foot diameter ECO2 Speece cones with river water supplied by four 400-horsepower water intake pumps mounted on a 110-foot barge. The barge was temporarily moored at The Industrial Company (TIC) waterfront property on Hutchinson Island (river mile 14.1). The nominal water-flow capacity for the pump configuration was about 15,000 gallons per minute (gpm) at a hydraulic head of 150 feet (in the center of the cones). The overall transfer efficiency was 85 percent for the temporary demonstration system with some loss during tank filling. The average amount of oxygen added to the river was about 27,000 pounds per day (ppd). The oxygen concentration delivered from the cones to the river ranged from about 120 to 180 milligrams per liter (mg/L).

The Speece cones that were used were each capable of injecting up to 15,000 ppd of oxygen. This superoxygenated flow from the Speece cones was piped directly back to the river and discharged at a depth of about 30 feet where it was dispersed in the river by tidal action without benefit of a diffuser. Some effervescence of oxygen was evidenced at the water surface in the form of rising fine bubbles.

Maintenance was performed on the pumps approximately every 250 hours of operation. The pumps were manufactured by Godwin Pumps and were electrical.

5.2 Mixing Zone Results

The Visual Plumes model was used again based on information from ECO2 and the head loss calculations described in the previous section. The ambient data were received from EFDC simulation results on the Back River at the discharge location during the summer of 1997.

For the design information, the following were used:

- Diffuser = 4 in. diameter
- Quantity = 8 diffusers
- Spacing = 1 port every 100 feet = 700 feet of pipe
- DO Input from cone = 40 mg/L
- Pump = 460HP Godwin CD500M C15
- 80% Efficiency output = 11,600 gpm (approx.)

After determining the effluent flow and velocity, the pipe diameter and depth, the DO concentration, and the number of ports, the mixing zone analysis could begin. The ports are spaced 100 feet apart along the 845.75 foot pipe starting at the 145.75 foot mark, each pointed 90 degrees up toward the river's surface. After producing multiple runs through Visual Plumes, the scenario with the best dilution rate was chosen. Once the water exits the diffuser, the concentration dilutes to around 7 mg/L before reaching the surface. Using data from Visual Plumes, an image could be generated through Tecplot to give a small demonstration as to what the effluent would look like in the river. Figure 18 shows the results from the Visual Plumes model.

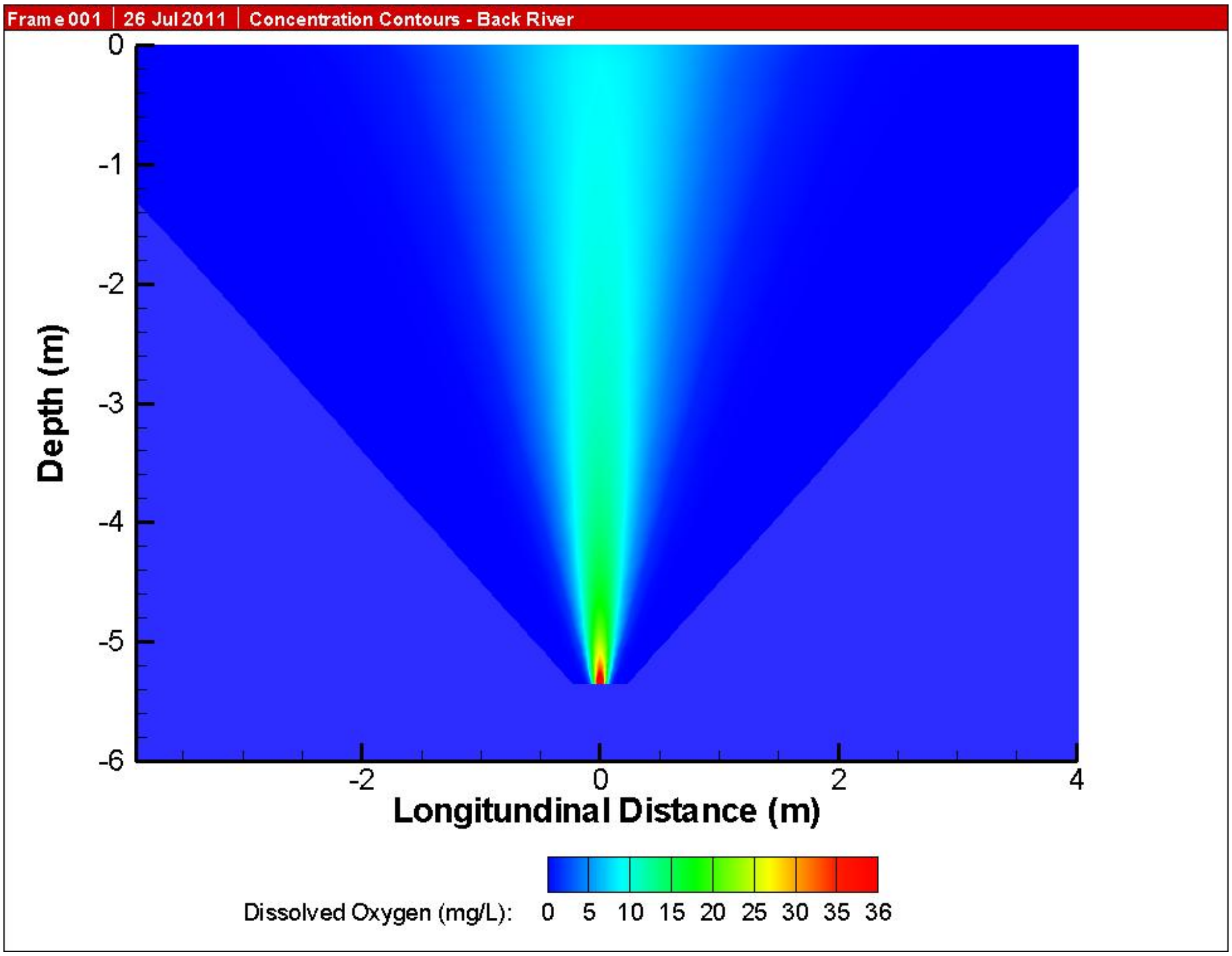


Figure 18 **Mixing Zone results from Visual Plumes**

6. Summary and Conclusions

The technology of the Speece cones will work at the Back River location. ECO2 performed an analysis based on percent saturation, discharge depth, and effluent pressure. The analysis proved that discharging 40 mg/L at a depth of 15 feet results in 77% saturation of D.O. This is under 100% and much lower than the minimum of 170% saturation needed for effervescence. The Speece cone can be successfully operated to discharge into shallow waters. Multiple examples were provided of successful Speece cone technology applications in waters that are 8 to 9 feet in depth. The Speece cone can be operated to discharge a D.O. level which is at the D.O. saturation level of the shallow water whereby precluding the potential for effervescence. Effervescent loss of D.O. is not even possible. An explanation of why effervescence occurred in the 2007 demonstration project was provided based on operation of the cones.

Aquaculture installations successfully discharge superoxygenated water at 29^{o}C and having a D.O. of 117 mg/L into 8 ft deep tanks and observe no effervescent loss of D.O. because of the rapid dilution achieved with the ambient D.O. water in the tank. Also, this analysis demonstrated the D.O. concentrations do not accumulate to unhealthy (toxic) levels during high or low slack tides in the Back River.

A detailed bathymetry of the Back River was conducted by the Savannah District and shown in this report. The discharge depth in the vicinity of the Back River injection is approximately 15 feet. The Tetra Tech mixing zone analysis showed the pressure head calculations and mixing zone determination was sufficient to discharge the poundage required. With a reasonable number of ports and the exit velocity, the oxygen plume is readily mixed due to advection and dispersion in the Back River.

7. References

Jones and Stokes, 2004: "Final Aeration Technology Feasibility Report for the San Joaquin River Deep Water Ship Channel" Final Report, October 2004.

MACTEC, 2008: Savannah Harbor Reoxygenation Demonstration Project, Savannah, Georgia. Prepared for the Georgia Ports Authority, January 8, 2008.

Speece, R.E., 2004: The Role Of Superoxygenation In Achieving TMDL Requirements, R. E. Speece, Ph.D., Centennial Professor Emeritus of Civil and Environmental Engineering Vanderbilt University, Nashville, TN and Board Member of ECO2. Indianapolis, Indiana.

Tetra Tech, 2010 "Oxygen Injection Design Report, Savannah Harbor Expansion Project, Savannah, Georgia" Final Report, October 15, 2010.

Tetra Tech, 2008: Final Report, Design of Dissolved Oxygen Improvement Systems in Savannah Harbor. Atlanta, Georgia.

Tetra Tech, 2009: Modeling of GPA's Oxygen Injection Demonstration Project Savannah Harbor, Georgia. Atlanta, Georgia.

Appendix A – Diffuser Options

Type: Tide Flex Diffuser (TFD's)

Company: Tide Flex Technologies (http://www.tideflex.com/tf/index.php/)

Analysis

- Extremely versatile – easily retrofitted to fit any pipe size you give
- Prevents backflow into the system
- **More even flow distribution among mutli ports**
- **Significantly improved salt water purging characteristics**
- **Lower headloss at peak flow increases flow capacity**
- **Higher jet velocity at low flows improves initial dilution**
- **Less variability in jet velocity and headloss thru range of flows**
- **30 year operation life**

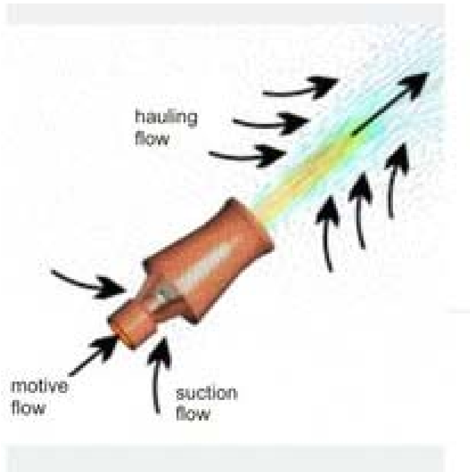
Disadvantages

- Data and calculations are produced directly by the company
- Unkown cost

Other info

http://www.scribd.com/doc/30924376/MeasurIT-Tideflex-Effluent-Diffuser-Systems-0910
http://www.aeiltda.com.co/descargas/Red%20Valve/Tideflex-Check-Valve-brochure.pdf

http://www.sgm-inc.com/fileadmin/sgm/home/happenings/2009_Effluent_Diffusers.pdf

Type: SBR-Plants (Sequenced Batch Reactor) Körting Ejectors

Company: KörtingHannover AG (http://www.koerting.de/index_html_en?set_language=en&cl=en)

Analysis:

- Creates a more direct stream of flow
- Mutiple nozels can be attached to one fitting
- Low cost
- Water jet
- No sealing problems
- This nozel provides pre-mixing before the DO would even enter the channel

Other info

http://www.koerting.de/dateien/strahlpumpen/watertreatment.pdf