Ozonation of Water Using the GasTran™ Unit

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Abstract

For decades ozone has been used effectively in low demand industrial wastewater treatment to reduce color, turbidity, and odor. However, ozone application for high COD, high demand industrial wastewater applications has been limited by the ability to transfer ozone gas to solution. In applications requiring high ozone dosage, the gas to liquid ratio (G/L) requirement increases dramatically, significantly limiting mass transfer efficiency. Mass transfer systems for these applications have therefore required multiple point addition and/or high pressure operation, driving up capital and operating costs and reducing the economic case for using ozone.

Recent application research and pilot testing of a Rotating Packed Bed (RPB) technology, commercialized by GasTran™ Systems, shows extremely promising results. GasTran Units have been successfully tested and deployed in installations for chemical process intensification, deaeration and VOC stripping. GasTran Units are designed to use specially engineered materials to shear an incoming fluid stream into ultra fine droplets dramatically increasing the surface area of the fluid and renewal of the gas-liquid interface.

This paper will detail a series of experiments performed to determine the effectiveness of the GasTran™ Unit for absorbing ozone into a liquid stream in clean water and wastewaters. Pilot test data on Xylene at 111 μg/L in an industrial effluent will be reviewed in addition to clean water testing at applied ozone doses ranging from 2 to 150 mg/L at operating pressures less than 10 psig.

From this experimental data, the volumetric mass transfer coefficients and the overall ozone transfer efficiency were determined in clean water. The process exhibited high overall mass transfer efficiency and volumetric mass transfer coefficients. Mass transfer efficiencies of >90% were achieved at doses higher than 10 mg/L with residence times of less than 2 seconds.

Introduction

For decades ozone has been used effectively in low demand industrial wastewater treatment to reduce color, turbidity, and odor. However, ozone application for high COD, high demand industrial wastewater applications has been limited by the ability to transfer ozone gas to solution. In applications requiring high ozone dosage, the gas to liquid ratio (G/L) requirement increases dramatically, significantly limiting mass transfer efficiency. Mass transfer systems for these applications have therefore required multiple point addition and/or high pressure operation, driving up capital and operating costs and reducing the economic case for using ozone.

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This paper will detail a series of experiments performed to determine the effectiveness of the GasTran™ Unit for absorbing ozone into a liquid stream in clean water and wastewaters.

Background

GasTran Units use specially engineered materials to shear an incoming fluid stream into ultra fine droplets. This process dramatically increases the surface area of the fluid to facilitate proven chemical processes. GasTran Technology is significantly more efficient than current alternatives because it is continuously shearing and coalescing the liquid exposing surface area to the gas medium.

Figure 1 shows how the GasTran Unit works. Liquid enters the liquid inlet where it is delivered to the internal portion of the rotor via feed tubes. The mass transfer occurs in the rotor, which is spun at high velocities by an attached motor. The liquid is forced through the rotor by centrifugal force while the gas is driven by pressure drop to the inside of the rotor causing countercurrent flow. The treated liquid drains out the bottom of the unit and the gas discharges at the top.

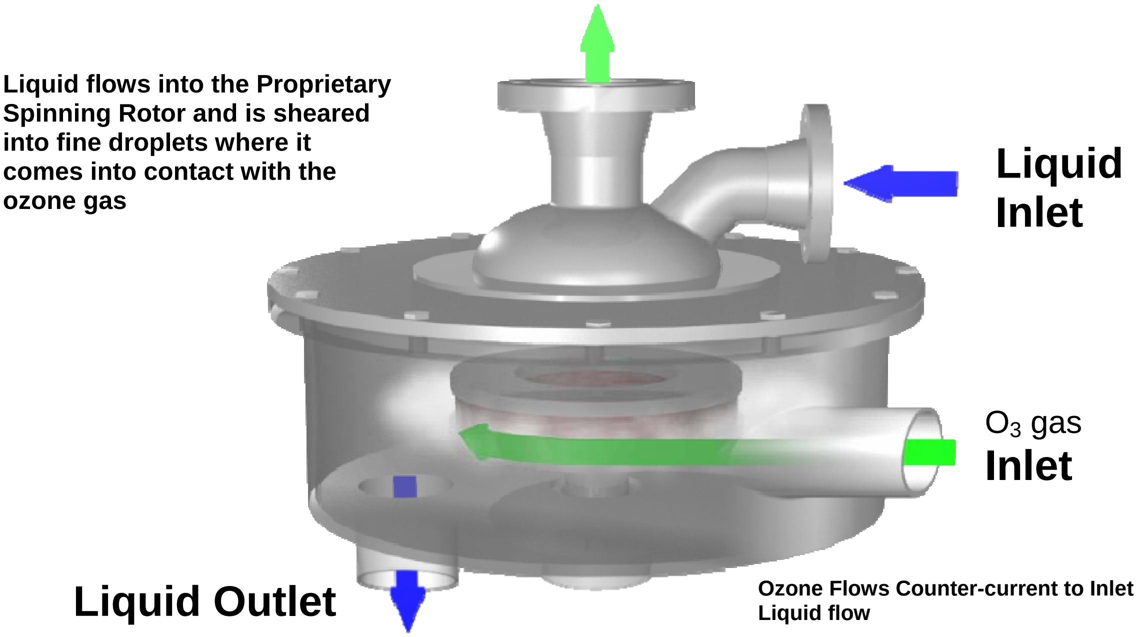

Figure 1- GasTran Unit Operation

The proprietary spinning rotor enhances the mass transfer to such an extent that the height of a transfer unit can be measured in inches as opposed to feet as with a typical countercurrent contacting device (packed column or tray tower). This reduction in necessary mass transfer volume leads to a much smaller footprint when compared with traditional countercurrent contacting devices and also reduces system residence time.

Because the GasTran Unit was designed to act as both a stripper and absorber it is able to handle small and large G/L ratios. The unitscan handle G/L ratios as high as 50:1 and is able to handle these large G/L ratios at much lower pressure with only one addition point, facilitating both the contacting and the off-gassing in one compact unit.

Another major advantage of the GasTran Unit is its ability to deliver mass transfer counter-currently, allowing the system to reach higher levels of dissolved ozone than is possible with a co-current contacting system at the same starting conditions. Figure 2 shows an example of a counter-current mass transfer chart compared with a co-current mass transfer chart for the same initial conditions. The counter-current system can reach higher levels of dissolved ozone because the operating line stays parallel with the equilibrium line, maintaining a consistent driving force for the entire process. The co-current system operating line terminates at the equilibrium line, which means no more mass can be transferred past that point. Also, as the operating line approaches the equilibrium line, mass transfer begins to slow down as the driving force is reduced. For this reason, large contacting systems are required for co-current flow systems to give the liquid and gas enough time to reach the equilibrium point. Examples of co-current contacting systems include bubble diffusers and venture injectors.

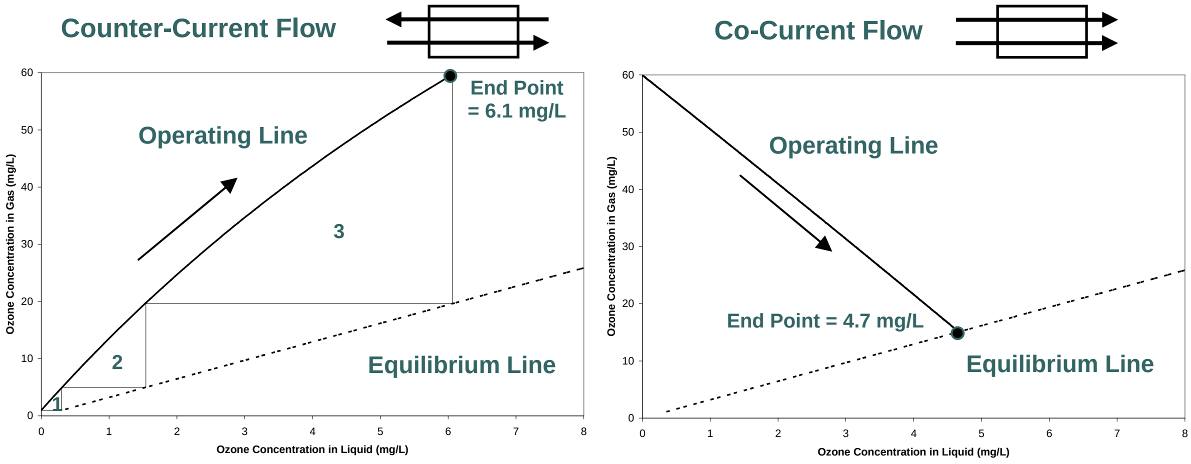

Figure 2 -Counter-Current vs. Co-Current Systems

Theory

Determining the Ozone Mass Transfer Coefficient

The volumetric mass transfer coefficient for the ozone dissolution can be determined by forming an equation for the differential mass balance through the rotor on the liquid side of the process (Equation 1). A first order reaction equation was used to model the ozone degradation that occurs once the ozone transfers to the liquid:

$$d(Qx) = k_{lOz}(x_e - x)dA_L - k_1\ x\ dV_L \tag{1}$$

Q = Liquid flowrate through the rotor (m^3/min, assumed constant)
x = Concentration of ozone in the liquid (mg/m^3)
k_{lOz}= Overall ozone mass transfer coefficient (m/min)
x_e = Concentration of ozone in the liquid at equilibrium (mg/m^3)
dA_L = Differential area of contact for mass transfer (m^2)
k_1 = First order reaction rate constant (1/min)
dV_L = Differential liquid volume in the rotor (m^3)

Some assumptions can be made that result in the equations below:

$$dA_L = dA\ a_e\ w_r \tag{2}$$

dA = Differential area of the rotor (m^2)

a_e = Effective area of contact in a unit volume of packing (m^2/m^3, assumed to be constant throughout the rotor)
w_r = width of the rotating packed bed (m)

$$dV_L = dA\,\varepsilon_L\,w_r \tag{3}$$

ε_L = Liquid volume holdup in a unit volume of packing (m^3/m^3, assumed constant throughout rotor)

$$dA = 2\pi r dr \tag{4}$$

r = radius of rotor (m)
dr = differential radius of the rotor (m)

Equations 2 – 4 can be substituted into Equation 1 to get Equation 5. Equation 5 can then be algebraically manipulated to give Equation 6.

$$Qdx = k_{lOz}(x_e - x)2\pi r dr\,a_e\,w_r - k_1\,x\,2\pi r dr\,\varepsilon_L\,w_r \tag{5}$$

$$\frac{2\pi r dr\,w_r}{Q} = \frac{dx}{k_{lOz}a_e(x_e - x) - k_1\varepsilon_L\,x} \tag{6}$$

This equation would need to be solved numerically. In order to perform the numerical calculations equation 6 was converted to equation 7 which is a numerical approximation. See Figure 3 below for diagram of the rotor with coefficients.

$$\frac{2\pi r_{i,avg}\Delta r\,w_r}{Q} = \frac{\Delta x}{k_{lOz}a_e(x_{e,yi} - x_{i,avg}) - k_1\varepsilon_L\,x_{i,avg}} \tag{7}$$

Where,

$$r_{i,avg} = \frac{r_i + r_{i-1}}{2} \tag{8}$$

$$\Delta r = r_i - r_{i-1} \tag{9}$$

$$x_{i,avg} = \frac{x_i + x_{i-1}}{2} \tag{10}$$

$$\Delta x = x_i - x_{i-1} \tag{11}$$

$$x_{e,yi} = \frac{y_{100-i}}{H_{e,oz}} \tag{12}$$

y = Concentration of ozone in the gas (mg/m^3)

Equation 13 was used to calculate the Henry's Law constant for ozone as a function of temperature.

$H_{e,oz} = \frac{1}{10^{(-0.25-0.013*T)}}$, where Temperature is in ºC [1] (13)

To solve equation 7 numerically the total Δx across the entire rotor (x_{100}-x_0, where x_{100} and x_0 are experimentally determined values) was broken into 100 segments. Each segment has the same Δx value ($\frac{x_{100}-x_0}{100}$). The values for $k_{lOz}a_e$ and $k_1\varepsilon_L$ were assumed to be constant throughout the rotating packed bed. Values for $k_1\varepsilon_L$ were determined to be negligible considering the short residence time in the system and the small liquid holdup in the GasTran Unit at low flowrates. Values for $k_{lOz}a_e$ were initially chosen for the first iteration of the numerical calculation. The numerical approach was then started at the outer radius of the rotor (segment 100) where the y_0 and x_{100} value were known from experimental data. Using the determined Δx value for the segment, x_{99} could be determined from x_{100} using equation 11. From equations 10 and 12 the average ozone concentration in the segment ($x_{i,avg}$) and the equilibrium liquid ozone concentration in the segment ($x_{e,yi}$) could be determined. From these values the right side of equation 7 can be calculated and then r_{99} can be determined from a combination of the left side of equation 7 and equations 8 and 9.

The total amount of ozone transferred from the gas to the liquid can then be estimated by converting the first part of the right side of equation 5 to a numerical form.

Total ozone transferred in segment i $= k_{lOz}a_e(x_{e,yi} - x_{i,avg})2\pi r_{i,avg}\Delta r\, w_r$ (14)

Also, the total oxygen transferred in section i is calculated by assuming an inlet liquid concentration of 8 ppm and an outlet concentration of saturated oxygen in the liquid stream. The saturated oxygen concentration is determined using Henry's law for oxygen based on the inlet gas concentration (typically around 30 ppm for this experimental data).

Total oxygen transferred in the rotor = (30,000 (mg/m^3) - 8000 (mg/m^3))*Q (m^3/min) (15)

Total oxygen transferred in segment i = Total oxygen transferred in the rotor/100 (16)

From equations 14 and 16 a simple mass balance can be performed around segment 100 to determine the value for y_1 and the value for the gas flowrate leaving segment 100. These values can then be used to calculate the x and y values for the next segment. The calculations can then be repeated for the remaining segments to determine the value for r_0 and y_{100}. The calculated values can be compared with the actual r_0 that was determined experimentally. Adjustments are made to $k_{lOz}a_e$ and the numerical calculations are repeated. This iterative process is continued until values for $k_{lOz}a_e$ are found that satisfy the actual r_0 that was determined experimentally.

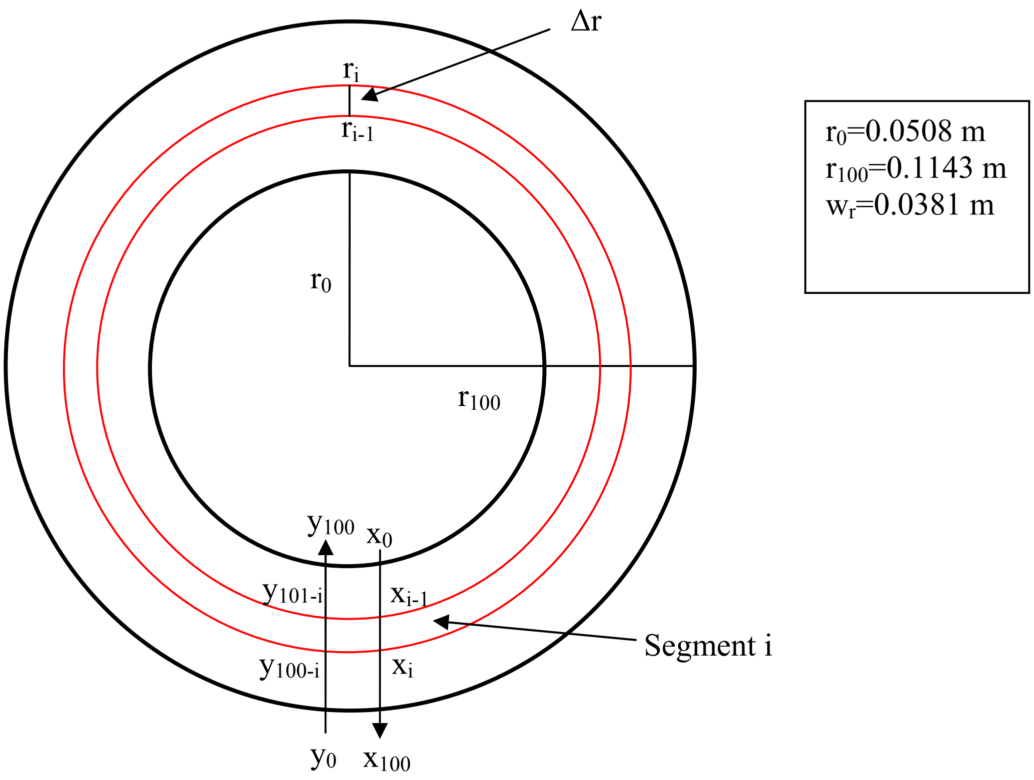

Figure 3 - Diagram of top view of rotor with numerical coefficients

Ozone Transfer Efficiency and Absorption Coefficient

The ozone transfer efficiency (OTE) can be determined using a mass balance on the gas side of the process.

$$OTE = \frac{G_0 y_0 - G_{100} y_{100}}{G_0 y_0} * 100\% \qquad (17)$$

G_0 = Gas Inlet Flowrate (m^3/min)
G_{100} = Gas Outlet Flowrate (m^3/min)

The Absorption coefficient (A) can be calculated using the equation below[2].

$$A = \frac{y_{In}/H_{e,oz} \quad (Ozone\ Liquid\ Saturation)}{G_{In}y_{In}/L \quad (Applied\ Ozone\ Dose)} = \frac{L}{G_{In}H_{e,oz}} \tag{18}$$

This equation divides the liquid equilibrium concentration at the gas inlet (liquid solubility of ozone) by the applied ozone dose. So at an absorption coefficient value of 1, the amount of applied ozone is equal to the amount of ozone the liquid can dissolve. At absorption coefficient values higher than 1, the amount of applied ozone is less than the amount of ozone the liquid can dissolve.

Equilibrium Stages and Number Transfer Units

The number of equilibrium stages can be determined using the absorption coefficient[2].

$$N_p = \frac{\log\left(\frac{y_{in} - x_{in}H_{e,oz}}{y_{out} - x_{in}H_{e,oz}}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right)}{\log A} \tag{19}$$

Equipment Setup

The equipment setup used to test the GasTran Unit's ability to dissolve ozone in water and wastewater is shown in Figure 4. An oxygen concentrator was used to feed an ozone generator which entered the GasTran Unit at the gas inlet port. The ozone concentration was measured in both the gas inlet and outlet stream using an IN-USA H1 high concentration ozone analyzer and a BMT 963C high concentration ozone monitor depending on when the data set was collected. Both units were rented from and calibrated by Ozone Water Solutions, Inc. The liquid outlet stream dissolved ozone concentration for a portion of the data was measured using an ATI Q45H/64 dissolved O3 monitor. The liquid was fed from an epoxy coated steel container.

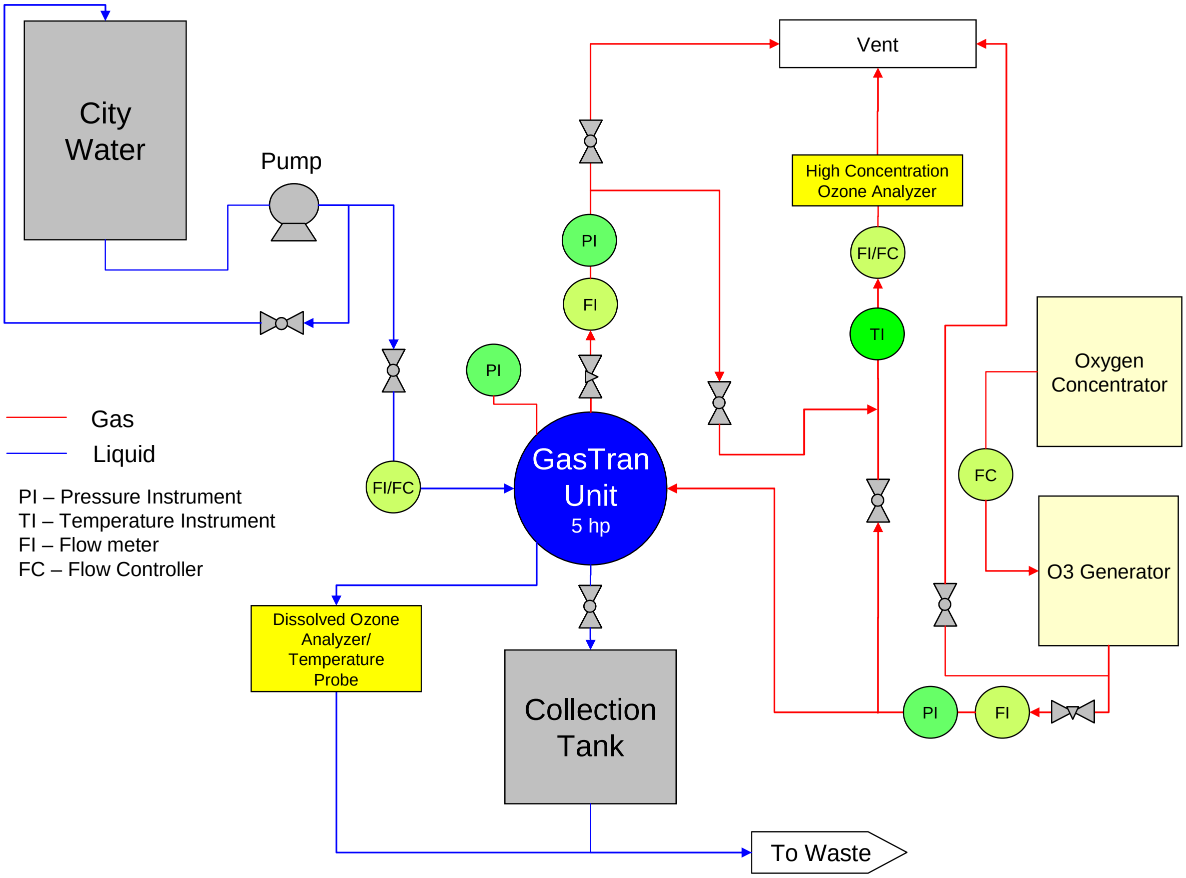

Figure 4 - Dissolution of Ozone in Water Equipment Setup

Procedure

The procedure used to obtain the ozone dissolution data is outlined below.

1. Verify exhaust fan is on.
2. Set gas flowrate to desired setpoint.
3. Set a water flowrate using the flow control on the liquid line.
4. Turn on the GasTran Unit motor.
5. Adjust outlet needle valve to regulate pressure on the system.
6. Direct flow from the ozone generator to the high concentration ozone analyzer to determine the inlet ozone concentration. Direct flow back to the GasTran Unit.
7. Direct a portion of the outlet gas flow into the high concentration ozone analyzer to monitor the run progress.
8. Allow the system to run for 30 - 90 minutes to achieve equilibrium on the outlet gas concentration.
9. Record the dissolved ozone reading from the dissolved O3 analyzer.
10. Record the outlet ozone concentration in the gas stream.
11. Record the gas inlet flowrate from flow instrument.
12. Record the gas outlet flowrate from flow instrument.

13. Record the pressure reading on both the inlet gas flowrate and the outlet gas flowrate. Also, record the system pressure.
14. Record the liquid temperature from temperature instrument on the dissolved ozone meter.
15. Record the gas outlet temperature.
16. Direct flow from the O3 generator to the O3 analyzer. Record the O3 concentration in the gas inlet stream.

Results and Discussion

Clean Water

Range of Run Conditions

The ranges of run conditions are outlined in Table 1. All the runs were performed at pressures less than 6 psig and doses were run from 1 to 120 ppm. The highest inlet ozone concentration achieved during experimentation was 8 wt%. Because it was an air cooled system , this was the limit of the ozone generator purchased. The water used was city water at an average pH of 7.2. The COD ranged from 2 – 3 mg/L in the city water.

Table 1 - Range of Run Conditions

Parameters	Low	High
Liquid Flowrate (L/min)	0.76	15.1
Gas Flowrate (L/min)	0.2	6.4
System Pressure (psig)	0	5
Temperature (°F)	64	80
Ozone Dose (mg/L)	1.2	122
Ozone Gas Concentration (wt %)	1.5	8

Mass Transfer Coefficients

The mass transfer coefficients for each run were calculated using the process described in the theory section of this report. The $k_{lOz}a_e$ value was fit to an equation where the mass transfer coefficient is related to the inlet gas and liquid flowrate along with the rotor volume.

$$k_{l,oz}a_e = 2.71\left(\frac{G_{in}}{V}\right)^{0.64}\left(\frac{L}{V}\right)^{0.38} \tag{20}$$

The experimentally determined values of $k_{lOz}a_e$ are compared with the calculated values of $k_{lOz}a_e$ determined from Equation 20 in Figure 5. From this graph it can be seen that the mass transfer coefficient determined experimentally is a good fit to Equation 20. This means that for clean water dissolution the mass transfer coefficient can be determined based on the system conditions, and performance can then be evaluated from the mass transfer coefficient.

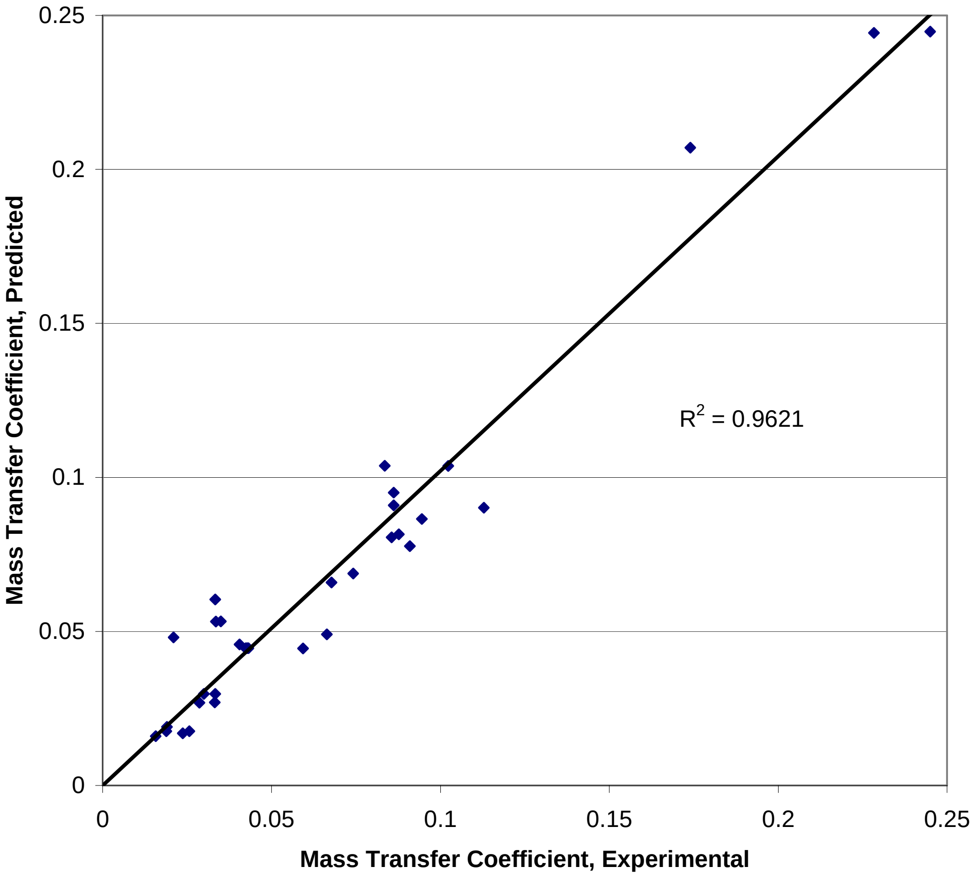

Figure 5 - Graph of experimental and predicted $k_{lOz}a_e$ by Equation 20

The ozone mass transfer coefficients were first compared to the volumetric gas/liquid ratio in Figure 6. The graph shows that the mass transfer coefficient increases with an increasing ratio of gas to liquid. Also, the slope of the line changes dramatically depending on the liquid flowrate. At the low liquid flowrate of 0.75 L/min the change in mass transfer coefficient is minimal with increasing G/L ratio. As the liquid flowrate becomes larger, the mass transfer coefficient increases dramatically with increasing G/L ratio.

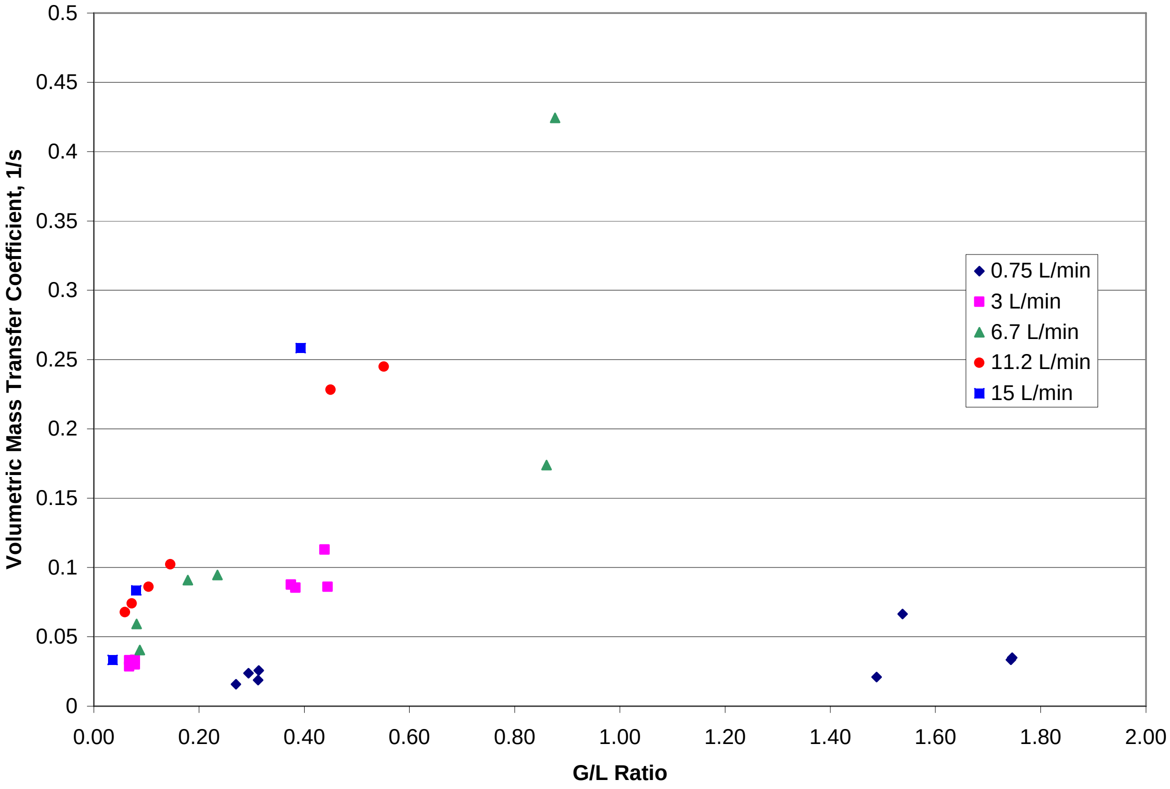

Figure 6 - Graph of ozone mass transfer coefficient compared with the volumetric gas/liquid ratio

Figure 7 shows the relationship between the mass transfer coefficient and the superficial gas velocity. The data also is categorized by liquid flowrate. The superficial gas velocity is measured at the inner radius of the rotor so that the maximum velocity in the rotor is used. The data shows that as the gas velocity increases the mass transfer coefficient also increases. This agrees with equation 20 which also shows an increasing relationship between the gas flowrate and the mass transfer coefficient.

At the low liquid flowrate (0.75 L/min) the mass transfer coefficient shows a very small increasing relationship when compared with the gas velocity. At flowrates higher than 0.75 L/min the slope of the relationship between the mass transfer coefficient and the gas velocity becomes similar even at different liquid flowrates. Although the slope does not appear to change with liquid flowrate the curves shift slightly upward with an increase in liquid flowrate. This increase in mass transfer coefficient with liquid flowrate also agrees with equation 20.

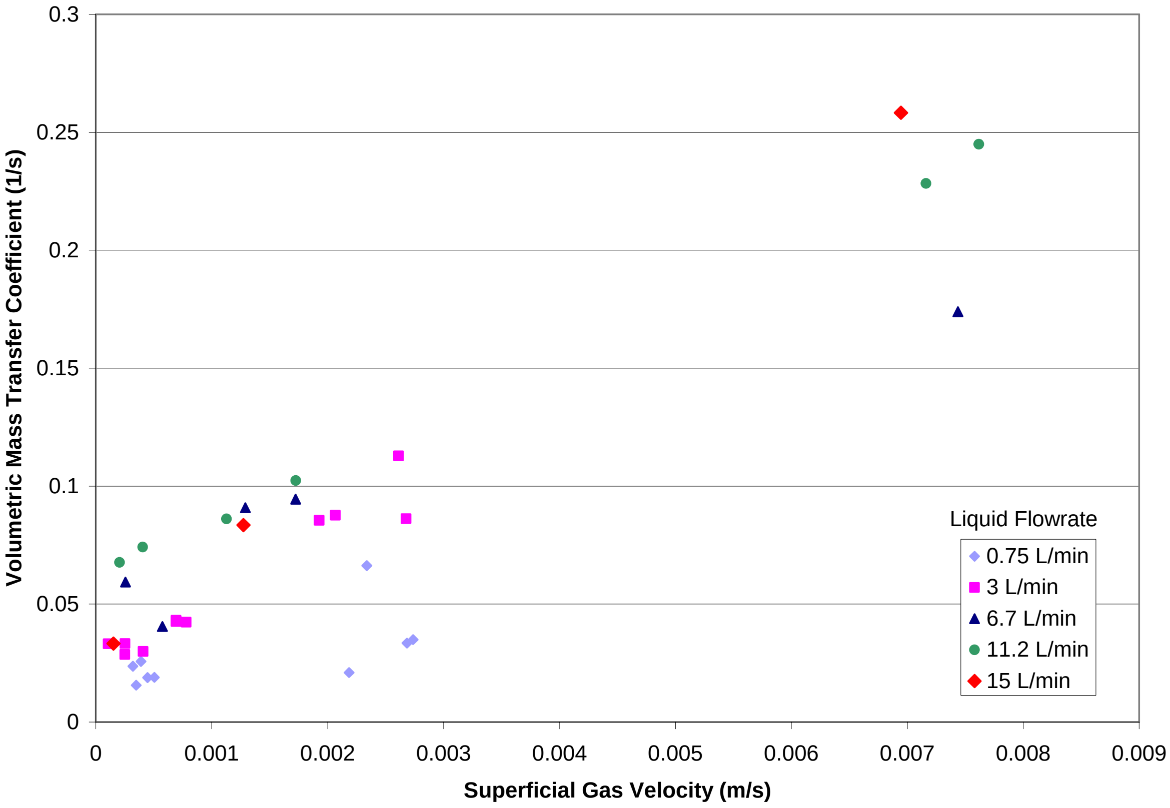

Figure 7 -Graph of ozone mass transfer coefficient compared with the superficial inlet gas velocity

Overall, the mass transfer coefficient determined from this experimental data appears to have a strong relationship between the liquid and gas velocity. Also, the GasTran Unit's determined ozone mass transfer coefficient is in the range that other rotating packed bed research has measured (0.0574 – 0.131 s^{-1})[3]. This mass transfer coefficient is higher than other technologies including bubble columns (0.0058 – 0.0141 s^{-1})[4] and stirred reactors (0.02 – 0.04 s^{-1})[5].

Ozone Transfer Efficiency

The ozone transfer efficiency was determined for each run and ranged from 16% to 98% depending on the applied ozone dose and solubility of the ozone at the run conditions. The first comparison was made between ozone transfer efficiency and the absorption coefficient in Figure 8.

The absorption coefficient can be thought of as the solubility of the ozone in the liquid divided by the applied ozone dose. This means that if the solubility of the ozone is 20 mg/L and the applied ozone dose is 5 mg/L, then the absorption factor would be 4. As the absorption coefficient gets larger, higher transfer efficiencies are easier to achieve. This means a system would be more efficient if it could achieve higher transfer efficiencies at lower absorption coefficients.

In Figure 8 the line indicates the maximum transfer efficiency that is theoretically achievable. Below an absorption coefficient of 1 the solubility is less than the dose so 100% transfer efficiency is not possible. The GasTran Unit data shows excellent mass transfer efficiencies. At an absorption coefficient of 4, the transfer efficiency achieved is greater than 90%.Higher than 6, the transfer efficiency is greater than 98%. At the very low absorption coefficients (< 0.3), the ozone mass transfer efficiency is very close to the maximum ozone transfer efficiency possible. This means the solution is saturated with ozone below an absorption coefficient of 0.3. At an absorption coefficient of ~1 (where the dose is equal to the ozone saturation concentration), the ozone transfer efficiency is 60%.

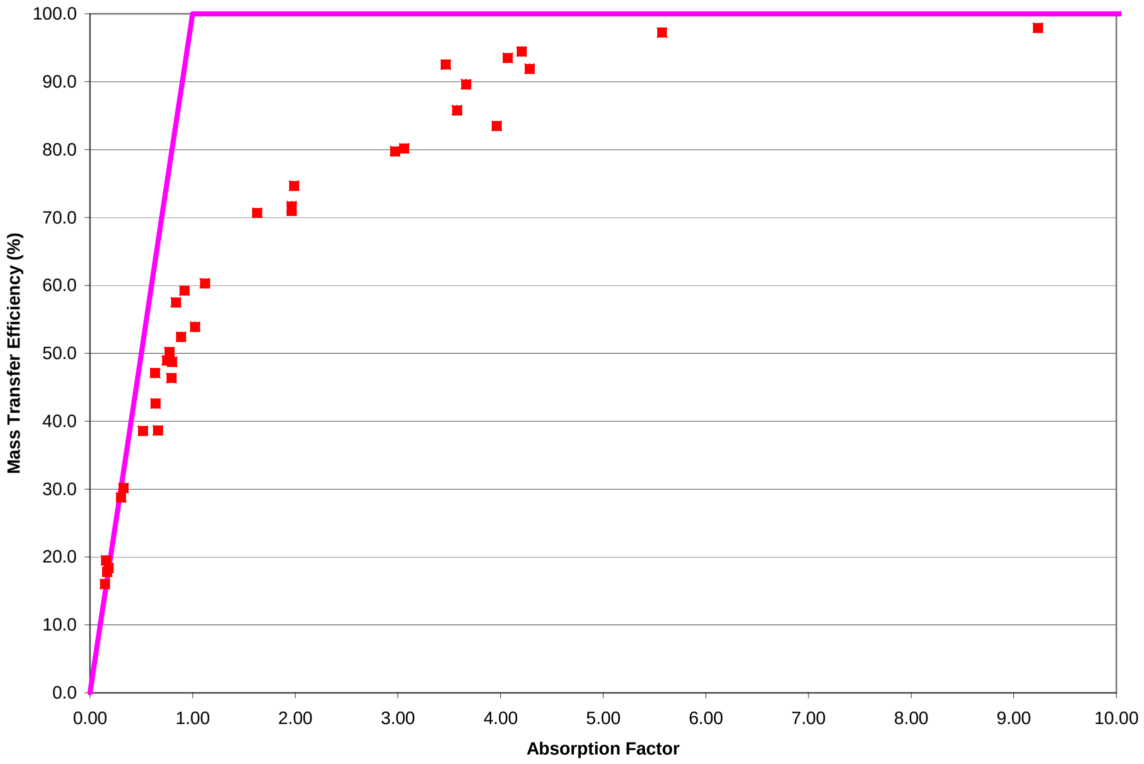

Figure 8 - Ozone Transfer Efficiency compared with Absorption Coefficient

Using equation 19 the performance at different equilibrium stages of mass transfer for a counter-current system can be compared with the GasTran Unit data to determine the number of equilibrium stages in the GasTran Unit. This data is shown in Figure 9. The solid lines represent the counter-current equilibrium stage data. The maximum achievable transfer efficiency for a co-current system is represented by the dotted line.

The GasTran Unit data falls along the one equilibrium stage line. This means that the unit currently is getting approximately one equilibrium stage of mass transfer in a single pass. In the future, the GasTran Unit performance will be increased to multiple stages in a single pass.

This type of improvement has been achieved in other applications and ozone absorption is no different. At multiple stages of 2 or more, 90% transfer efficiency is achieved at an absorption coefficient of two. This would mean that to reach 90% transfer efficiency at a 10 ppm dose the solubility of the ozone in water would only have to be 20 ppm. When this type of performance is compared with a co-current system the difference is dramatic. The maximum achievable efficiency of a co-current system dictates that to achieve 90% transfer efficiency the absorption coefficient would need to be 9. This means to dissolve 10 ppm at 90% transfer efficiency the solubility of ozone in water would need to be 90 ppm.

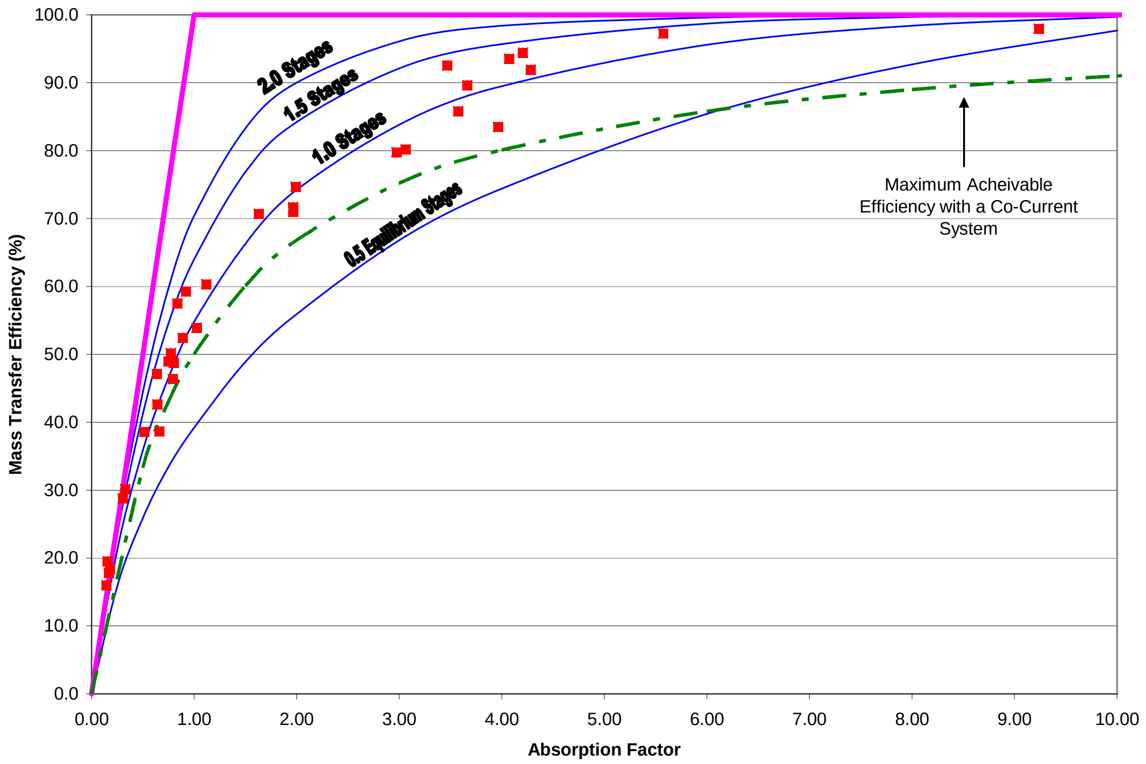

Figure 9 - GasTran Data Compared with Equilibrium Stages

The ozone transfer efficiency can also be compared with the applied ozone dose at different inlet ozone concentrations in the gas phase (Figure 10). In order to have higher than 90% transfer efficiency at doses of 10 ppm the inlet ozone concentration needs to be at least 8 wt% or higher for systems that are not under pressure. The relationship between ozone transfer efficiency and applied ozone dose appears to be linear at different inlet ozone concentrations until the ozone transfer efficiency nears 100%. This relationship shows that even higher transfer efficiencies into the water (> 95%) could be achieved for higher doses (10 – 15 ppm) with a higher inlet ozone concentration (> 10%) using the GasTran unit.

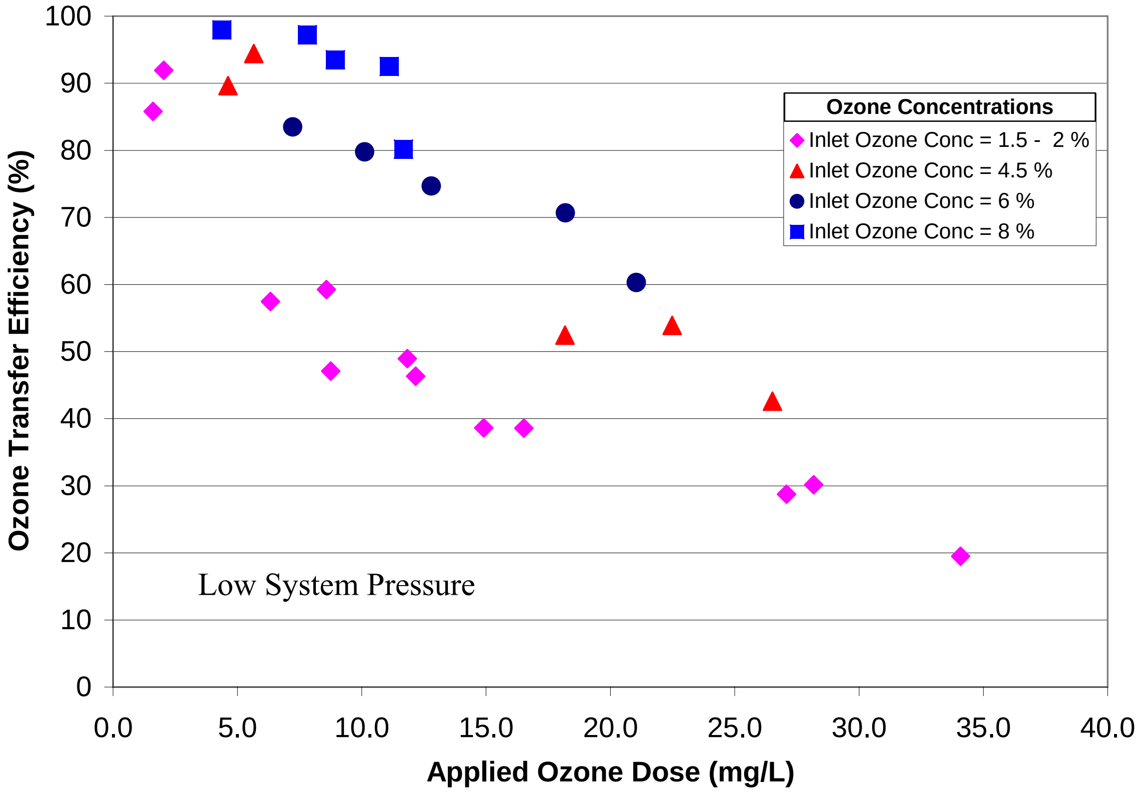

Figure 10 - Ozone Transfer Efficiency compared with Ozone Dose

Overall, the GasTran Unit was able to achieve high transfer efficiencies at near standard conditions (70 ºF, 5 psig) at high ozone doses. This is important for industrial applications due to the relatively high cost capital and energy costs of producing ozone on site All experiments performed were operating at residence times of less than 1 second in the GasTran Unit. This type of performance leads to smaller total system size.

High Dose Industrial Wastewater Treatment

Four different ozone applications and data for industrial wastewater treatment will be reviewed. All applications are examples of the GasTran Unit's ability to effectively deliver high dose ozone to high demand waste streams.

The first application is dye penetrant treatment and color removal. The data for this trial is shown in Table 2. The dye treated was HM406 Fluorescent Penetrant and was from a waste stream supplied to GasTran Systems by a client.

The stream was treated with ozone at 7.8 wt% at a low system pressure of 1 psig. The ozone dose to the waste stream was 17 mg/L which translates to a G/L ratio of 0.2. The transfer efficiency during the run was 93.6 % and the color was completely removed in a single pass. The fluorometry reading of the wastewater was dropped from 48 ppm to 0.21 ppm which is less than that of tap water.

A high dose of ozone (17 mg/L) was utilized efficiently to completely remove color from a waste stream in a single pass at a residence time of less than one second.

Table 2 - Dye Penetrant Treatment Data

Conditions	Inlet Ozone Concentration (wt %)	7.8
	System Pressure (psig)	1.0
	Liquid Temperature (F)	75.0
	G/L Ratio (volumetric)	0.2
	Ozone Dose (mg/L)	17.0
Results	Ozone Transfer Efficiency (%)	93.6
	Inlet Dye Fluorometry Reading (ppm)	48.0
	Tap Water Fluorometry Reading (ppm)	0.39
	Treated Fluorometry Reading (ppm)	0.21

The second application is BTEX treatment. The data for this trial is shown in Table 3. The BTEX treated was from a waste stream supplied to GasTran Systems by a local environmental firm.

Two trials were performed to treat the contaminated water. For both trials the stream was treated with ozone at ~1 wt% at a low system pressure. The ozone dose to the waste stream was 11.2 mg/L for the first trial and 41.2 mg/L for the second trial. This translates to G/L ratios of 0.5 and 2.2 respectively. Transfer efficiencies could not be determined for these trials as no high concentration gas analyzer was available for these runs. Favorable results were achieved for each run. Benzene was reduced by almost 50% in both runs. The toluene and Ethylbenzene were reduced to levels below the detection of the analytical method. Xylene was reduced by 90% with the 11.2 mg/L dose and was reduced below detection by the analytical method at the 41.2 mg/L dose.

Table 3 - BTEX Treatment Data

	Run		1	2
Conditions	Liquid Flowrate (gpm)		3.4	0.9
	Inlet Ozone Concentration (wt %)		1.3	1.2
	System Pressure (psig)		3.0	2.0
	Liquid Temperature (F)		57.0	57.0
	G/L Ratio (volumetric)		0.5	2.2
	Ozone Dose (mg/L)		11.2	41.2
Results	Benzene (ppb)	44.7	23.5	20.2
	Toluene (ppb)	3.6	< 2	< 2
	Ethylbenzene (ppb)	2.7	< 2	< 2
	Xylene (ppb)	111	9.2	< 6

The third application is COD destruction on a high COD waste stream. The data for this trial is shown in Table 4. The waste stream treated contained high levels of dispersant and was from a waste stream supplied to GasTran Systems by an industrial client.

Two trials were performed to treat the high COD wastewater. The wastewater was at a pH of 11.7. For trial 1 the waste stream was treated with ozone at an inlet concentration of 5.2 wt% and for the second trial the ozone inlet concentration was 1.4 wt%. For both trials the stream was treated at a low system pressure. The ozone dose to the waste stream was 22.6 mg/L for the first trial and 122.6 mg/L for the second trial. This translates to G/L ratios of 0.28 and 5.9 respectively. The transfer efficiency for the first run was 100% and for the second run was 85.6 %. This means that for a single pass over 100 mg/L of ozone was transferred into the waste stream. The COD in both cases was reduced by > 30%. This is excellent performance in a high demand waste stream where the initial COD level is 8280 mg/L.

These trials led to a system purchase and installation in August of 2006 to reduce COD surcharges at a Cleveland-area chemical plant. The system is performing as expected and meeting the customer needs for COD surcharge reduction.

Table 4 - High COD Wastestream Data

Conditions	Run	1	2
	Inlet Ozone Concentration (wt %)	5.2	1.4
	System Pressure (psig)	2.3	1.8
	Liquid Temperature (F)	75.0	75.0
	G/L Ratio (volumetric)	0.28	5.93
	Ozone Dose (mg/L)	22.6	122.6
Results	Transfer Efficiency (%)	100	85.6
	Liquid inlet COD (mg/L)	8280	8280
	Liquid outlet Cod (mg/l)	5690	5320

The last application to be reviewed is food waste and BOD reduction. The data for this trial is shown in Table 5. The water treated contained biological food waste and was from a waste stream supplied to GasTran Systems by an industrial plant.

The stream was treated with ozone at 4.5 wt% at a low system pressure of 0 psig. The ozone dose to the waste stream was 26.4 mg/L which translates to a G/L ratio of 0.44. The transfer efficiency during the run was 87.0 % and the color and odor were completely removed in a single pass. The COD was reduced by 20 % with a COD removal of 4.7 mg/L COD removed per mg/L ozone transferred. The BOD was reduced by 31 % with a BOD removal of 3.9 mg/L BOD removed per mg/L ozone transferred.

The COD and BOD destruction is very high not only because the unit has such good mass transfer at high ozone doses but also because of the GasTran Unit's excellent mixing capabilities. Once the ozone is dissolved in the liquid it has very little distance to travel before the small water droplet is completely saturated with ozone. This leads to excellent mixing characteristics and faster apparent reaction times.

Table 5 - Food Waste BOD Treatment Data

Conditions	Inlet Ozone Concentration (wt %)	4.5
	System Pressure (psig)	0
	Liquid Temperature (F)	79.0
	G/L Ratio (volumetric)	0.44
	Ozone Dose (mg/L)	26.4
Results	Ozone Transfer Efficiency (%)	87.0
	Inlet COD Level (mg/l)	623
	Inlet BOD Level (mg/l)	334
	Outlet COD level (mg/L)	497
	Outlet BOD Level (mg/L)	232

This industrial wastewater data shows the excellent capability of the GasTran Unit to not only transfer high amounts of ozone in a single pass but also then facilitate a fast reaction between the ozone and the BOD and COD. This makes the unit a perfect choice for high ozone demand waste streams.

Conclusion

The GasTran unit has proven to be an excellent contactor for ozone dissolution. The mass transfer coefficients determined experimentally are higher than other ozone contacting technology and are comparable to ozone dissolution data from other rotating packed bed experiments. A good correlation was determined for the ozone mass transfer coefficient showing that the volumetric mass transfer coefficient increases with increased gas and liquid inlet velocity.

The ozone transfer efficiency achieved with the GasTran Unit is high (> 90%) even at high ozone doses (10 mg/L). This is important for industrial applications so that the amount of ozone wasted is minimized.

This industrial wastewater data shows the excellent capability of the GasTran Unit to not only transfer high amounts of ozone in a single pass but also then facilitate a fast reaction between the ozone and the BOD and COD. This makes the unit a perfect choice for high ozone demand wastewater streams.

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