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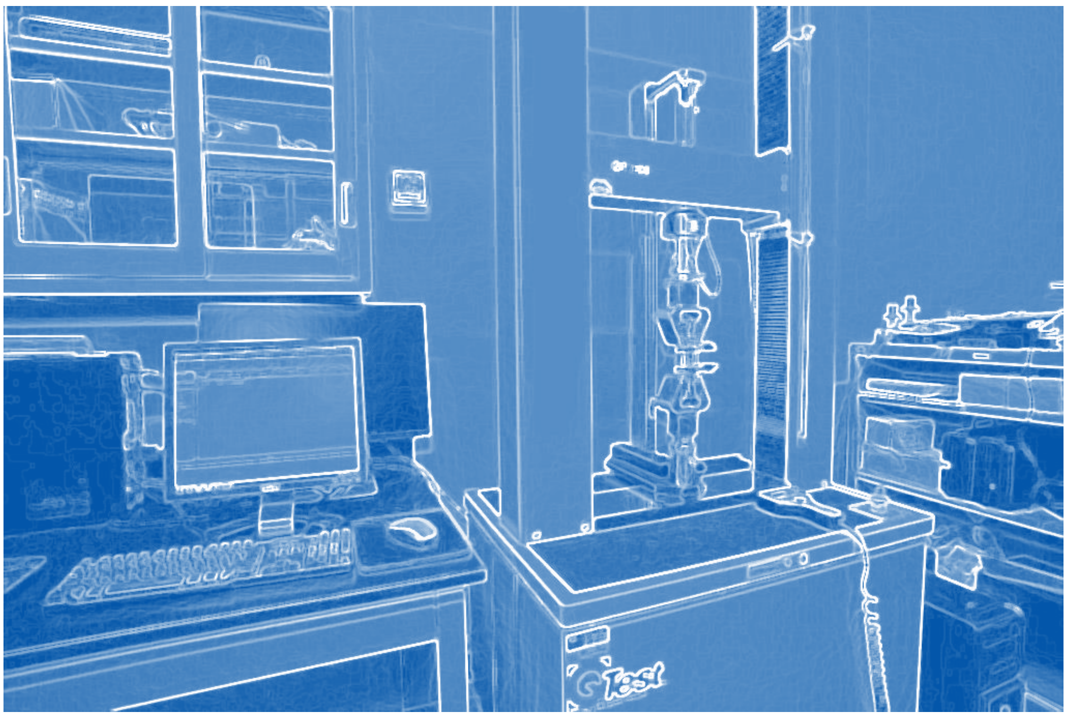
84 Spring Lane, Farmington, CT 06032-3159
860-747-6333 Fax 860-747-8529
www.mottcorp.com

Mott Laboratory Test Report



Bio-Fermentation Study

Author: J. Steele
Title: R&D Scientist

Executive Summary

A sparging test station was fabricated in Mott's R&D laboratory to simulate conditions as seen at a typical bio-fermentation production facility. The intent was to measure sparging performance comparing Mott technology to drilled pipe spargers.

With Mott's porous metal sparging system:

- Higher O_2 absorption was achieved with less agitation
- Smaller bubble sizes lead to higher surface contact ratio reducing the total gas needed
- Faster O_2 absorption allows for significant process time savings
- There is a 10-40% increase in initial O_2 absorption
- The rate of rise increases 2-3X for mild agitation systems

- It is recommended that onsite testing is performed at the client's site to analyze sparging designs in order to maximize performance and minimize system and processing costs.

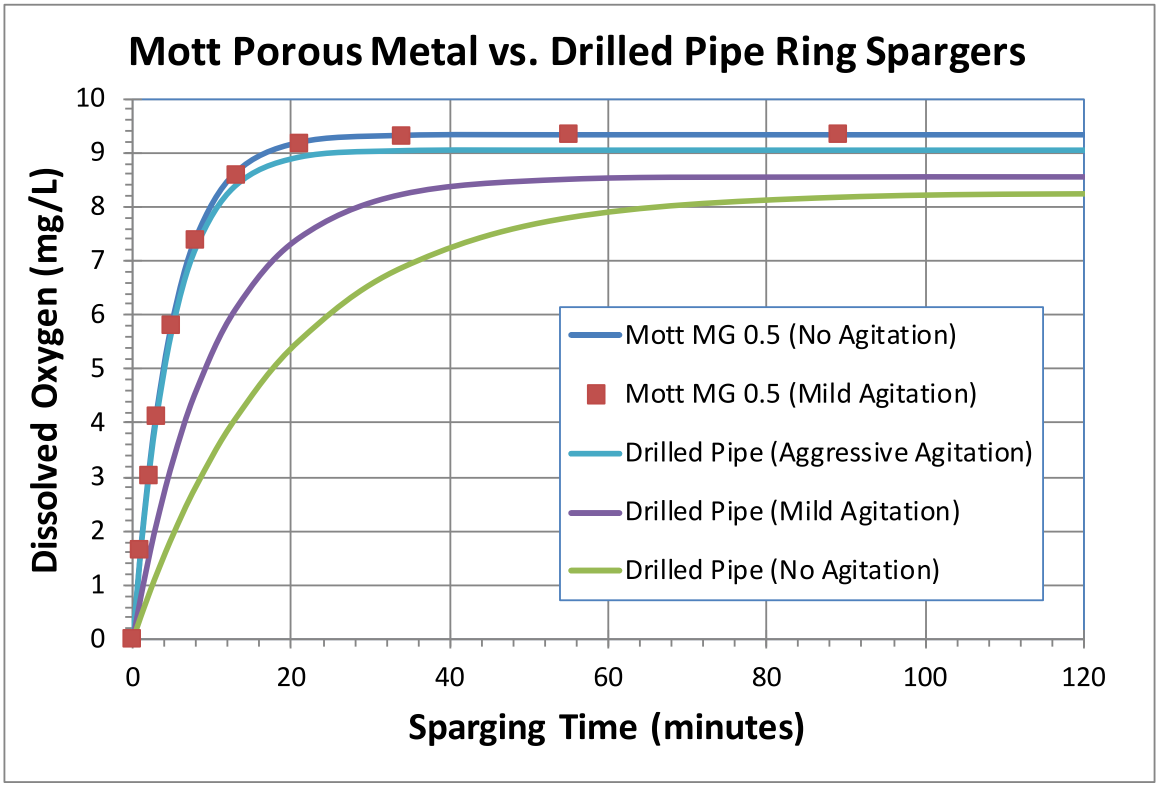


Figure 1 Plot showing the measured dissolved oxygen level versus sparging time for Mott porous metal sparger and the drilled pipe spargers with and without mechanical agitation all at an air flow of 50 CFH.

Appendix

Testing Procedures, Data, Charts and Drawings

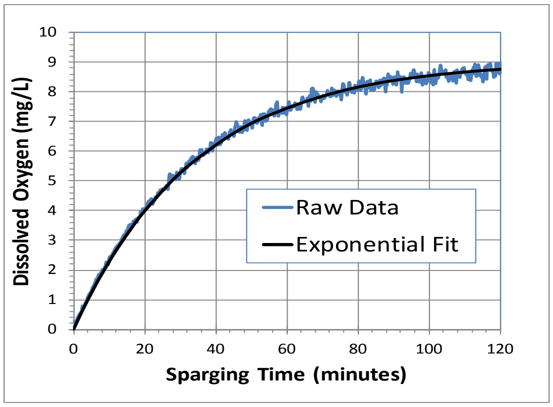
Experimental Procedure

Assumptions were made that a typical bio-fermentation reactor is 8' diameter and 24' tall containing up 7,500 gallons of working fluid. A drilled pipe ring sparger is located near the bottom of the tank with a mechanical mixer mounted just above the sparger. The ring sparger is approximately a 2" diameter pipe bent to a radius of 2' with 3/4" holes drilled along the top surface equally spaced around the ring. Air flow rates through the sparger were assumed to be 300 CFM. Based on these parameters, a scaled down test sparging test systems was assembled in the Lab to measure sparging performance data as a function of flow rate with and without mechanical agitation

A 2.5' diameter by 6' tall open top tank holding 175 gallons of water was used for the sparging experiments. Two spargers were fabricated for the study, the first being an 8" diameter ring sparger fabricated from ½" stainless steel tubing with (21) 1/8" diameter holes drilled along the top surface equally spaced around the ring. This size of the drilled pipe sparger was selected by scaling down from the size of the typical bio-fermentation reactor tank and sparger geometry to the smaller tank used at Mott for this study. The second sparger was an 18" diameter sparging ring fabricated using ½" diameter stainless steel Mott Media Grade 0.5 porous tubing and welded to 45^o fittings creating and octagonal shaped ring. The total surface area of the Mott sparger was 0.485 ft^2 and was sized to match typical geometries for the size of the Mott sparging tank. Drawings of these rings and a photo of the sparging setup are presented in Appendix A.

Total air flow rates ranging from 0.5 CFH through 50 CFH were used in this study with the lowest flow rate providing minimal bubble action and the highest flow rate providing vigorous bubble action. A YSI dissolved oxygen probe model Professional Plus connected to a computer was used to record the dissolved oxygen (DO) levels with the probe located 6" below the surface of the water and 6" away from the tank wall. Flow rates were controlled using Dwyer flow controllers and the air pressure recorded using a Heise ST2H digital pressure indicator.

All experiments were performed by sparging nitrogen gas into the water at a high flow rate to drive the DO level to below 0.5 ppm. The data logging system was enabled and the gas flow changed to air and DO levels recorded until the levels approached saturation. For the higher flow experiments, these times were about 45 minutes while for the lower flow rates, the sparging times exceeded 2 hours.



Presented in Figure 2 is the DO versus time for a typical run with a Mott sparger along with an exponential fit to the data. In all cases, the DO versus sparge time were excellent fits to an exponential for the Mott porous metal and drilled pipe spargers, and all data presented here is displayed using the exponential models fitted to the data.

Figure 2 Example of non-linear fit to raw measured DO data showing that the data follows an exponential function.

Results

Presented in Figure 1 (earlier) is a graph showing the measured dissolved oxygen level (mg/L) versus sparging time for the Mott porous metal sparger and the drilled pipe sparger with and without agitation all at a flow rate of 50 CFH air. The dissolved oxygen level in units of mg/L is shown on the vertical axis and sparging time in minutes is displayed on the horizontal axis. Remember, prior to sparging with air, the dissolved oxygen level was driven down to below 0.5 mg/L by sparging nitrogen gas to strip away dissolved oxygen before sparging with air. Here we see that there is virtually no difference in the curves for the Mott media with and without agitation. We can also see from this figure that the drilled pipe sparger with aggressive agitation matches the performance of Mott media initially but separates after about 15 minutes settling out at a slight lower saturation value. The data also shows that the drilled pipe sparger with mild and low mechanical agitation have noticeably lower initial rates of rise and saturation values as compared to the Mott media sparger.

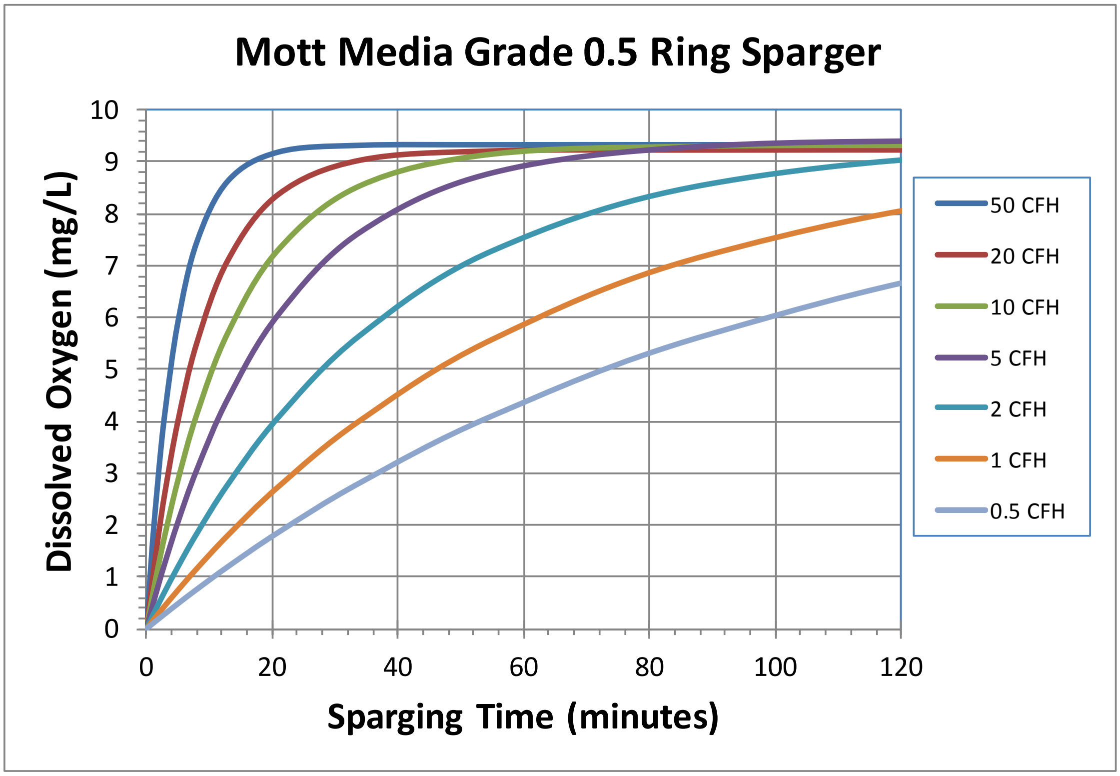


Figure 3 Plot showing the measured dissolved oxygen level versus sparging time for a Mott octagonal shaped Media Grade 0.5 ring sparger for total air flow rates from 0.5 CFH through 50 CFH.

Presented in Figure 3 are the results of sparging air through the octagonal shaped 18" Mott Media Grade 0.5 sparger for flow rates from 0.5 CFH through 50 CFH. The dissolved oxygen level in units of mg/L is shown on the vertical axis and sparging time in minutes is displayed on the horizontal axis.

As would be expected, the rate that the dissolved oxygen increased was greater with the higher flow rates. We also observe that the maximum value the dissolved oxygen attained varied slightly with the flow rate. The highest level attained was for the 50 CFH flow reaching 9.33 mg/l and this steady state level slowly decreased to 9.15 mg/L for the lowest flow at 0.5 CFH.

Not shown here but also performed was the same sparging measurement performed with mechanical agitation running at 500 rpm. The results showed little to no difference in the sparging rates with and without agitation for all flow rates for the Mott porous metal ring sparger.

Presented in Figure 4 is the dissolved oxygen level versus flow rate for the drilled pipe sparger as described in the experimental section with no mechanical agitation applied. Here we see the same trends that were seen with the Mott porous metal sparger but the absolute dissolved oxygen values being very different. The rate of rise on the dissolved oxygen level is slower and the maximum saturation levels are lower that what were observed for the porous metal sparger, especially for the lower total air flow rates.

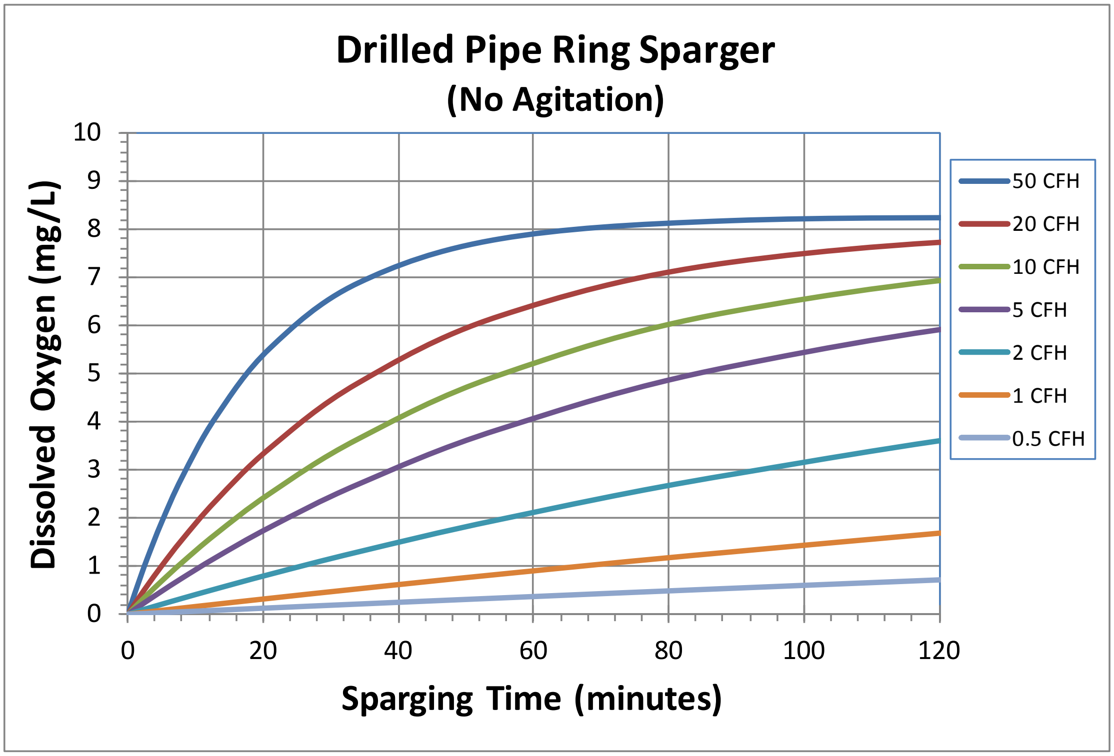


Figure 4 Plot showing the measured dissolved oxygen level versus sparging time for drilled pipe ring sparger for total gas flow rates from 0.5 CFH through 50 CFH with no mechanical agitation applied.

Presented in Figures 5 and 6 are the results for the sparging experiments for the drilled pipe sparger with two levels of mechanical agitation applied. For the results in Figure 5, 500 rpm agitation (Mild) was applied and for Figure 5, mechanical agitation using 1000 rpm (Aggressive) was applied. Again, the same trends in the dissolved oxygen levels with flow rate were observed but with increasing dissolved oxygen rates and saturation levels with increased mechanical agitation.

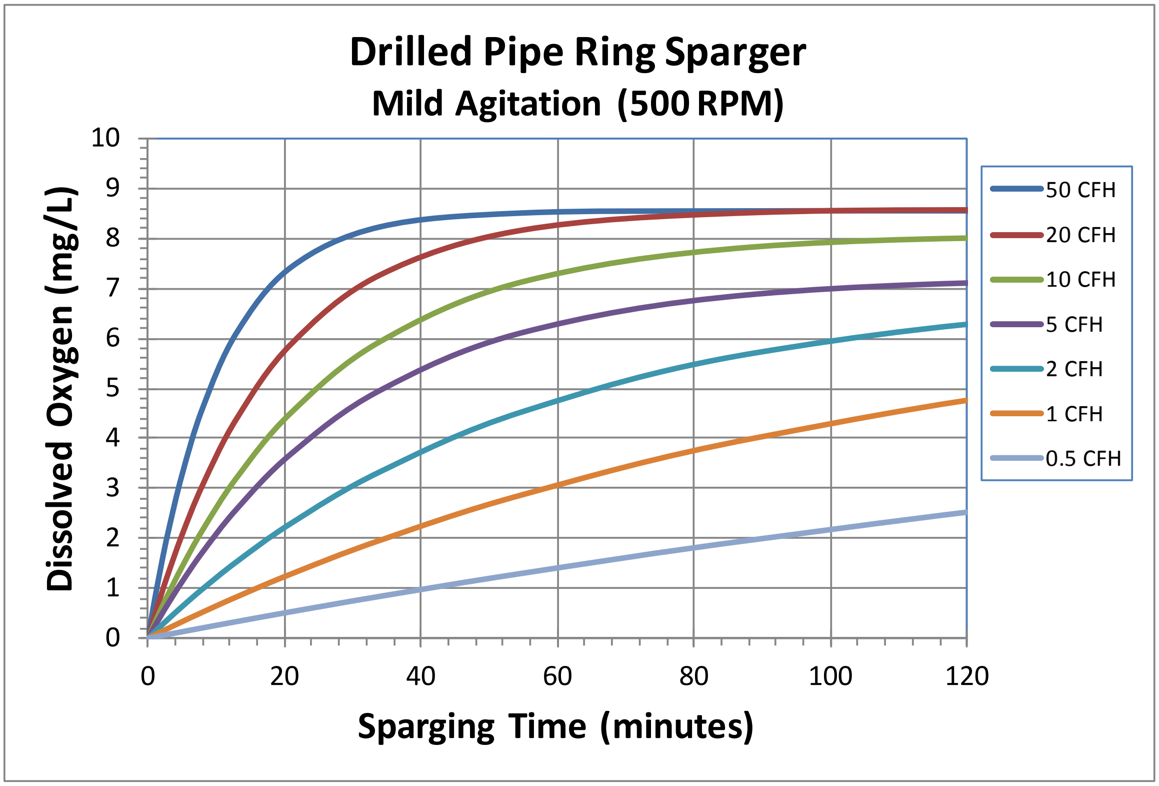


Figure 5 Plot showing the measured dissolved oxygen level versus sparging time for drilled pipe ring sparger for total gas flow rates from 0.5 CFH through 50 CFH with 500 rpm of mechanical agitation applied.

If we compare the results from Figure 6 (drilled pipe sparger with 1000 rpm mechanical agitation) to the results in Figure 3 (Mott porous metal sparger with no agitation) the results are somewhat similar for the high flow rates in terms of dissolved oxygen rate of rise and saturation levels but as the flow rate decreases, we observe the rates and saturation levels dropping off for the drilled pipe sparger at a faster rate than the Mott porous metal sparger.

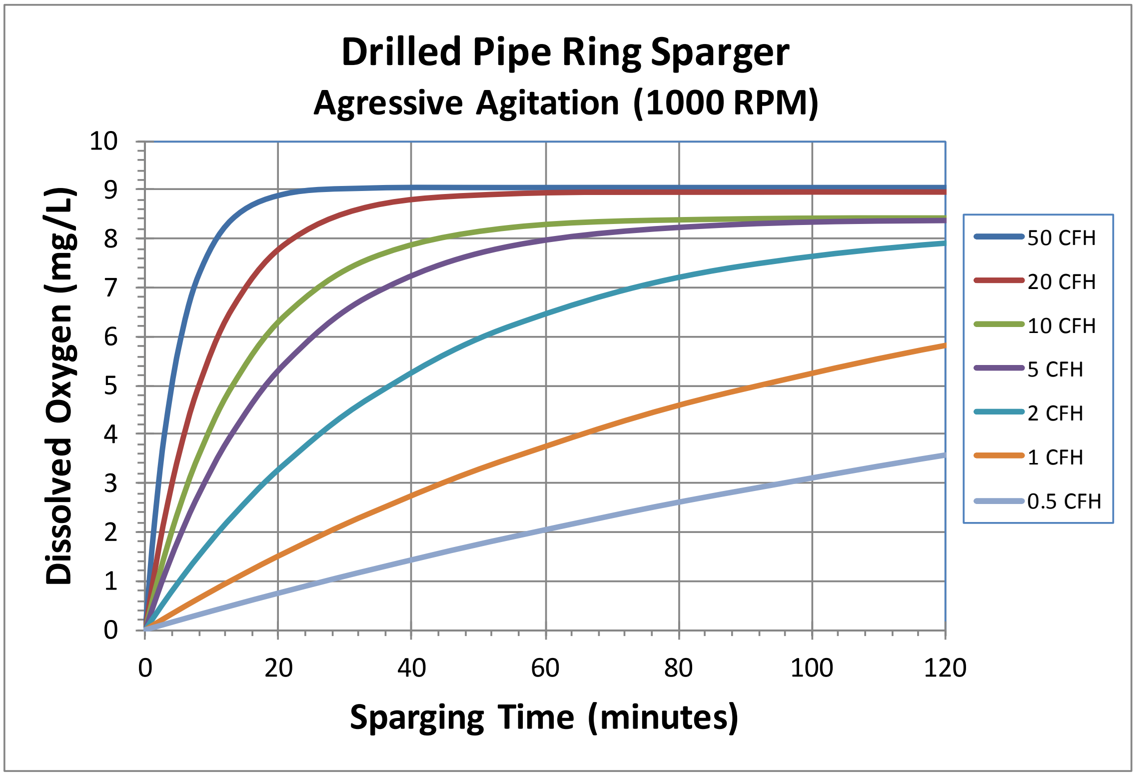


Figure 6 Plot showing the measured dissolved oxygen level versus sparging time for drilled pipe ring sparger for total gas flow rates from 0.5 CFH through 50 CFH with 1000 rpm of mechanical agitation applied.

To make it easier to compare performance levels between the Mott porous metal sparger and the drilled pipe sparger at the various flow rates with and without agitation, we can compile the significant results into a couple tables for easier analysis. As stated earlier, the two most significant factors for the DO curves are the initial rate of rise of the dissolved oxygen and the saturation level (value at time = infinity). We can calculate the initial rate of rise by calculating the time to reach 63% of the saturation level (1 time constant) and divide that time into the dissolve oxygen level at that 63% to get the rate of rise in mg/L/min. The saturation value is simply the dissolved oxygen level when the slope becomes horizontal (time = infinity).

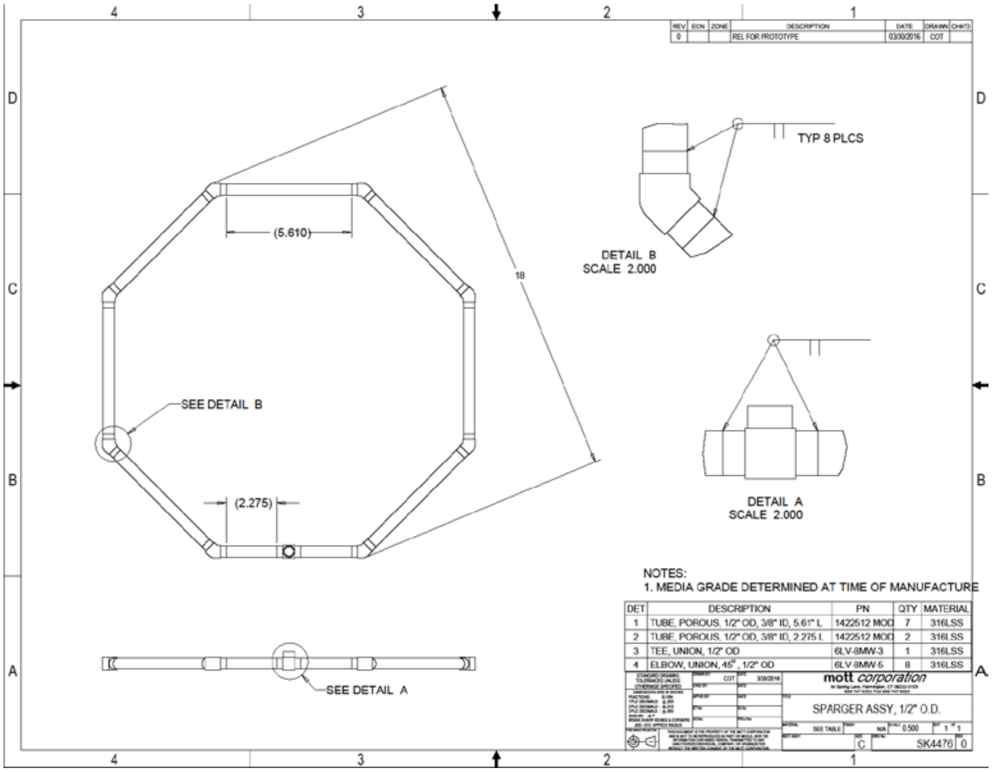
Presented in Table 1 are the calculated rates of rise for the Mott porous and drilled pipe spargers with and without agitation for air flow rates from 0.5 to 50 CFH. If you compare the rates of rise for the left two columns for all flow rates, you see the there is no significant change between no agitation and agitation for the Mott porous ring sparger. If you compare the rates of rise for the right three columns (drilled pipe sparger), you see that the dissolved oxygen levels vary significantly with the 1000 rpm values being the highest and the values decreasing for the 500 rpm and again decreasing for no agitation for the drilled pipe sparger.

Table 1	**Initial Dissolved Oxygen Rate of Rise (mg/L/min)**				
Total Air Flow	Mott Porous 0 RPM	Mott Porous 500 RPM	Drilled Pipe 1000 RPM	Drilled Pipe 500 RPM	Drilled Pipe 0 RPM
Agitation Level ->	None	Mild	Aggressive	Mild	None
0.5 CFH	0.05	0.06	0.03	0.02	.004
1 CFH	0.10	0.10	0.05	0.04	.01
2 CFH	0.17	0.16	0.13	0.08	.03
5 CFH	0.33	0.29	0.27	0.16	.06
10 CFH	0.47	0.43	0.37	0.20	.09
20 CFH	0.69	0.66	0.58	0.30	.14
50 CFH	1.18	1.18	1.16	0.52	.28

If we compare the dissolved oxygen levels for the drilled pipe sparger at 1000 rpm agitation to the Mott sparger with no agitation, we see that the rate of rise values are very close at the higher flow rates and the differences become greater as we decrease the flow rate with the drilled pipe sparger showing slower rates of rise compared to the Mott porous metal sparger. Looking at the drilled pipe with agitation at 500 rpm and no agitation, we see that the rates of rise are noticeably lower the both the Mott porous metal sparger and the drilled pipe sparger running with 1000 rpm of mechanical agitation

Table 2	Dissolved Oxygen Saturation Level (mg/L)				
Total Air Flow	Mott Porous 0 RPM	Mott Porous 500 RPM	Drilled Pipe 1000 RPM	Drilled Pipe 500 RPM	Drilled Pipe 0 RPM
Agitation Level ->	None	Mild	Aggressive	Mild	None
0.5 CFH	8.58	9.15	7.90	6.60	6.30
1 CFH	8.75	9.33	8.27	6.80	6.61
2 CFH	8.98	9.41	8.33	7.00	7.00
5 CFH	9.07	9.42	8.39	7.23	7.40
10 CFH	9.15	9.31	8.42	8.08	7.77
20 CFH	9.21	9.22	8.95	8.58	8.06
50 CFH	9.32	9.33	9.04	8.55	8.25

Shown in Table 2 are the maximum saturation dissolved oxygen levels for the Mott porous and drilled pipe spargers with and without agitation for air flow rates from 0.5 to 50 CFH. Here we see that the Mott porous outperforms all the drilled pipe spargers with and without mixing. Unlike the rate of rise values shown in Table 1, here we see a slight advantage with mechanical mixing with the Mott sparger with the 500 rpm data showing higher saturation values at the lower flowrates < 20 CFH while being the same at 20 CFH and higher. We also see that the maximum dissolved oxygen levels are lower than the Mott porous metal sparger for the drilled pipe sparger with and without mixing with the saturation values being the lowest with no mechanical agitation.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18
TYP 8 PLCS
DETAIL B
SCALE 2.000
SEE DETAIL B
DETAIL A
SCALE 2.000
(2.275)
SEE DETAIL A
NOTES:
1. MEDIA GRADE DETERMINED AT TIME OF MANUFACTURE
DET | DESCRIPTION | PN | QTY | MATERIAL
1 | TUBE, POROUS, 1/2" OD, 3/8" ID, 5.61" L | 1422512 MOD | 7 | 316LSS
2 | TUBE, POROUS, 1/2" OD, 3/8" ID, 2.275 L | 1422512 MOD | 2 | 316LSS
3 | TEE, UNION, 1/2" OD | 6LV-8MW-3 | 1 | 316LSS
4 | ELBOW, UNION, 45°, 1/2" OD | 6LV-8MW-5 | 8 | 316LSS
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SPARGER ASSY, 1/2" O.D.
SEE TABLE
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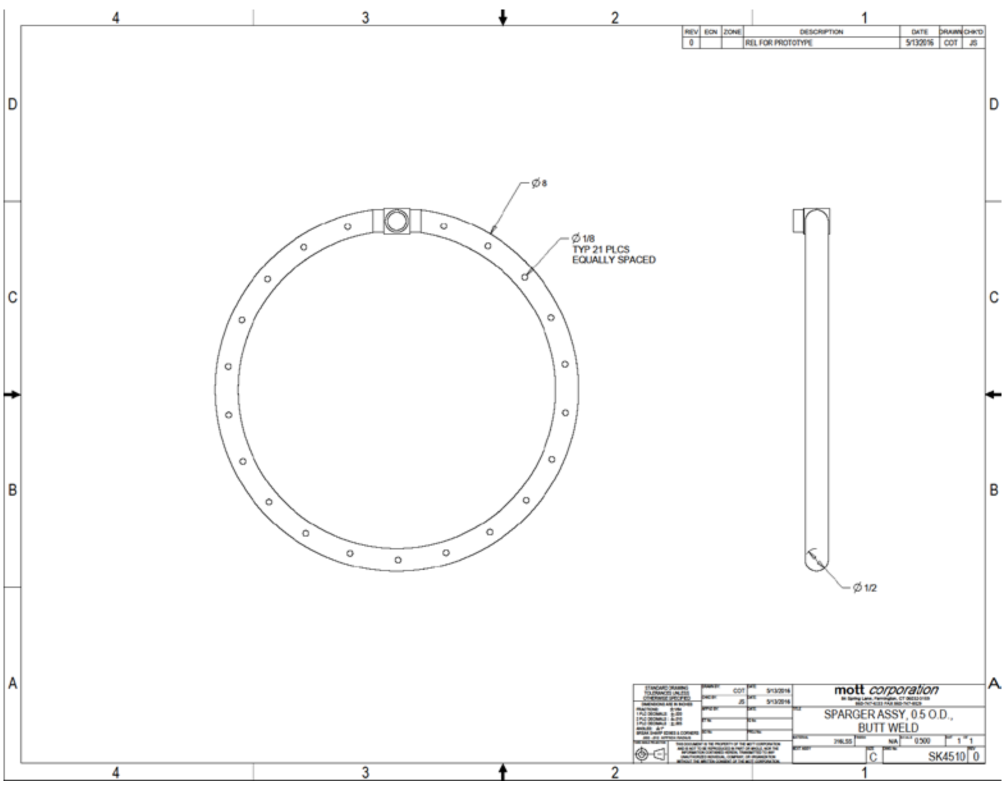
REL FOR PROTOTYPE
Ø 8
Ø 1/8
TYP 21 PLCS
EQUALLY SPACED
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SPARGER ASSY, 0.5 O.D.,
BUTT WELD
316LSS
SK4510

175 Gallon Sparging Tank with Mechanical Agitation