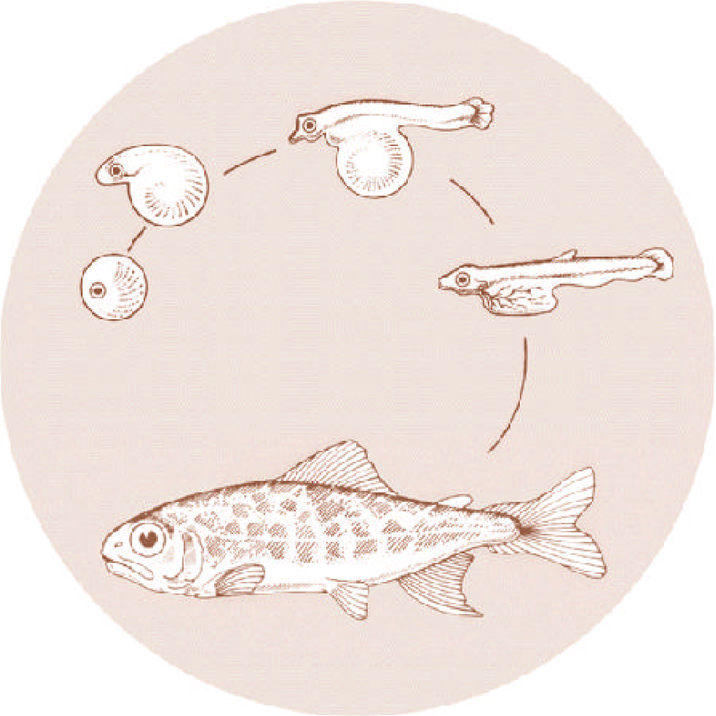
May 1990

EVALUATION OF PURE OXYGEN SYSTEMS AT THE WILLAMETTE HATCHERY

Completion Report



DOE/BP-00852-1

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do not necessarily represent the views of BPA.

This document should be cited as follows:

Fish Factory, Evaluation of Pure Oxygen Systems at the Willamette Hatchery Completion Report, Report to Bonneville Power Administration, Contract No. 1989BP00852, Project No. 198816002, 69 electronic pages (BPA Report DOE/BP-00852-1)

Evaluation of Pure Oxygen Systems at the Willamette Hatchery

Completion Report

Prepared by

Fish Factory

Prepared for

Gerald W. Bouck, Project Manager

Funded by

U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
Portland, Oregon 97208

Contract No. DE-AP79-89BP00852

May 1990

Table of Contents

Page

List of Figures

List of Tables

Executive Summary

The oxygen transfer columns at the Williamette Hatchery are based on a design used by the Michigan Department of Natural Resources. The geometry and internal construction *of* the Mlilliamette *Hatchery Oxygen Transfer Columns* differ from the Michigan columns in several important ways.

The performance of the columns was evaluated during May, 1990. The absorption efficiency of the 24 and 30 inch *Williamette Hatchery Oxygen Transfer Columns* ranged from 30 to 60%, which is comparable to published information on the Michigan columns. The performance of the 24 inch *Williamette Hatchery Oxygen Transfer Columns* was superior to either the 30 inch columns or the Michigan columns.

The yearly oxygen demand for the Williamette Hatchery oxygen supplementation project is estimated to be 31,713 lb. Based on a oxygen purity of 99.6% and oxygen costs of \$0.40/100 ft^3, increasing the absorption efficiency from 50 to 75% would decrease oxygen costs of the present project by only approximately \$1018/year, which is small compared to the annual project cost. The pure oxygen system at Williamette Hatchery is designed for experimental purposes, therefore the existing system is adequate its intended use.

While oxygen is not a major cost in the present experimental system, it will be much more critical in full-scale applications. It was necessary to build separate columns for the Williamette Oxygen Supplementation Project, but a centralized system may be more cost-effective in larger applications.

There is considerable interest in the use of the Michigan type column in the Pacific Northwest and better definition of their operating characteristics or improvement in their performance would be useful to hatchery operations. In addition, there are a number of other oxygen transfer systems that may have potential in the Pacific Northwest.

The following additional experimental work is recommended:

1. Test the impact of changing the diameter of the effluent piping. It may be desirable to test several different effluent pipe diameters. Because of the sensitivity of the column performance on hydraulic Rloading, the modified column should be tested over a wide range of water flows.
2. Test other oxygen transfer options such as the LHO, low-head spray systems with nozzles, low-head downflow bubble contact aerators, or direct injection of oxygen into the supply pipeline.

Additional tests can be scheduled so as not to adversely affect the on-going oxygen supplementation experiment and the hatchery program.

Introduction

The Northwest Power Planning Council has established a goal of doubling the size of salmon runs in the Columbia River Basin. The achievement of this important goal is largely dependent upon expanding the production of hatchery fish. Pure oxygen has been commonly used to increase the carrying capacity of private sector salmonid hatcheries in the Pacific Northwest (Gowan, 1987; Severson et al., 1987). The use of supplemental oxygen to increase hatchery production is significantly less expensive than the construction of new hatcheries and might save up to $500 million in construction costs.

The Williamette Hatchery Oxygen Supplementation project is being conducted at the Williamette Hatchery (near Oakridge, Oregon) and operated by the Oregon Department of Fish & Wildlife to evaluate the use of pure oxygen in hatcheries using surface water sources. This project is funded by the Bonneville Power Administration. The project required modification of the existing raceways and intake structure (project details can be found in the design and operating documents provided by FishPro, Port Orchard, Washington). Four 24 inch and six 30 inch pure oxygen columns were installed for use in the oxygen supplementation experiment. The pure oxygen columns at the Williamette Hatchery are based on a design used by the Michigan Department of Natural Resources (Boersen and Chesney, 1987; Westers et al., 1987).

Because of the importance of column performance on the overall economics of supplemental oxygen, Bonneville Power Administration contracted with Fish Factory (DE-AP79-89BP00852) to perform an independent evaluation of the pure oxygen columns at the Williamette Hatchery. This report documents the performance evaluation of pure oxygen columns at the

Williamette Hatchery and compares their performance to those used by the Michigan Department of Natural Resources.

Types of Oxygen Transfer Systems

At least seven types of oxygen transfer systems have been commonly used in fish culture (Colt and Watten, 1988):

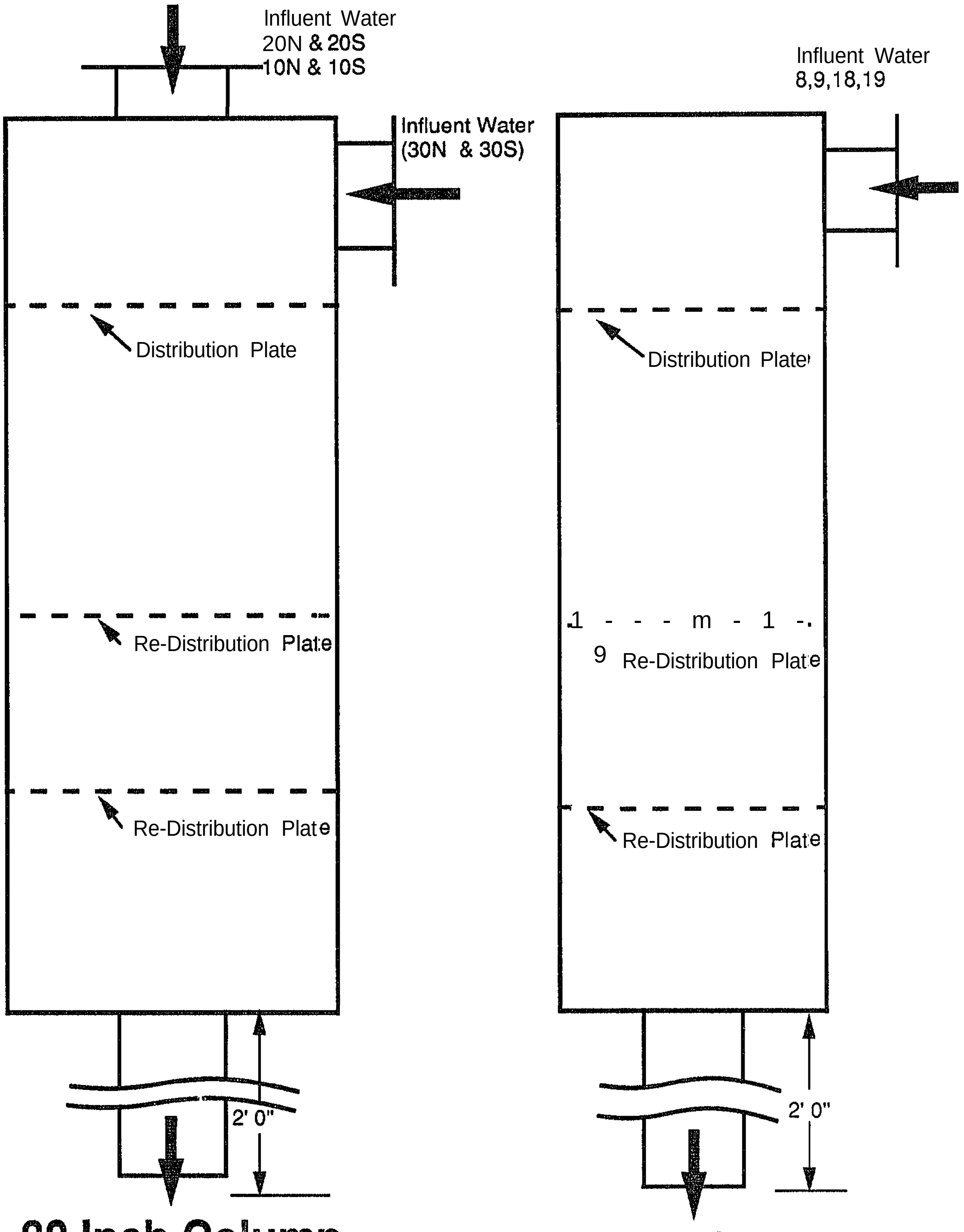
Packed column aerators
Spray column aerators
Pressurized column aerators
Downflow bubble contact aerators
U-tube aerators
Oxygen injection aerators
Diffused aerators

Each type of unit has its advantages and disadvantages. The “best” type of unit will depend on a number of site and operating factors.

The pure oxygen columns being used at the Williamette Hatchery based on a design used by the Michigan Department of Natural Resources. Key characteristics of the Michigan columns are:

(1) The lack of any type of media inside the column.
(2) The discharge pipe from the column is smaller than the column.
(3) The units produce a vacuum within the column.

The constructed pure oxygen columns at the Williamette Hatchery will be referred to in this report as the *Williamette Hatchery Oxygen Transfer Columns.* A diagram of the 24 and 30 inch in diameter Williamette Hatchery Oxygen *Transfer Columns* are presented in Figure 1.



30 Inch Column

24 Inch Column

Figure 1 Diagram of 24 and 30 Inch in Diameter *Williamette Hatchery Oxygen Transfer Columns.*

Key design characteristics of the Williamette and Michigan columns are compared in Table 1.

Table 1 Comparison of the Williamette and Michigan Designs

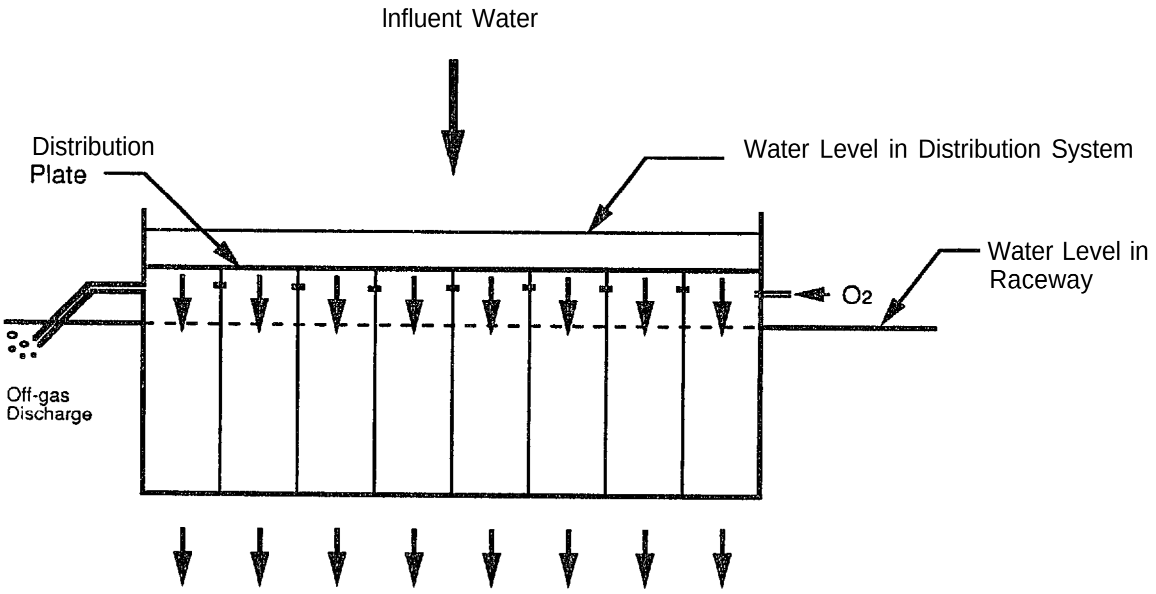
		Williamette Hatchery	
Parameter	Michigan	24 Inch	30 inch
Design Loading (gpm/ft^2)	122	159	153
Influent Piping	top	side	side[a] top[b]
Distribution Plates	none	one[c]	one[c]
Redistribution Plates	none	two[c]	two[c]
Location of Discharge Pipe	concentric with column	not concentric with column	not concentric with column
Area Ratio of Discharge Pipe to Column	4:1	9:1	9:l

[a] Columns 30N and 30s

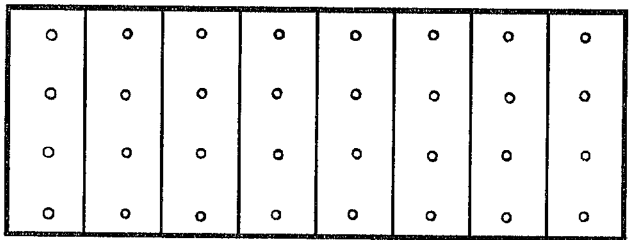
[b] Columns 20N, 2OS, 1 ON, and 1 OS

[c] Prior to testing, the distribution and re-distribution plates were removed due to clogging problems

In addition to the testing *of* the *Williamette Hatchery Oxygen Transfer Columns,* a 50 gpm prototype of a newly developed system manufactured by Zeigler Brothers, Gardners, PA was tested. This system is comprised of a distribution plate and a number of hydraulically independent “cells”. The water flows through the distribution plate and then through the “cells” in parallel. All the oxygen gas is introduced into one “cell” and then flows through the other “cells” in a cross-flow manner. The cells are not filled with any type of media. Absorption efficiencies as high as 90% are claimed for this unit with as little fall as 12-24 inches.



Side View



Top View

Mot to Scale

Figure 2 Diagram of the Prototype Low Head Oxygen (LHO) System Supplied by Zeigler Brothers, Gardners, PA.

Methods and Materials

Scope of Work

During May 14-17, 1990, a series of 4 test runs were performed on the *Williamette Hatchery Oxygen Transfer Columns* at the Williamette Hatchery, Oakridge, Oregon. The tests were conducted using columns 19 (24 inch, side entrance) and 20s (30 inch, top entrance). In addition, one preliminary test was conducted on a 50 gpm low head oxygen (LHO) system supplied by Zeigler Brothers, Gardners, PA. Specific information on the gas flow rate, water flow rate, and hydraulic loading for each test run are presented in Table 2.

Table 2 Summary of Test Run at the Williamette Hatchery

Run	Column Diameter (Inches)	Water Flow (gpm)	Loading (gpm/ft^2)	Gas Flow Rate (scfh)
1	24	500	159	2-43
2	24	200-708	64-225	9-45
3	30	740	151	3-37
4	30	548-957	112-195	14-29
5	LHO	33	11	1.6

Previous tests conducted on October 16-23, 1989 and December 4, 1989 are not discussed in this report due to changes in column configuration and potential experimental problems.

Dissolved Gas Analysis

Oxygen partial pressure (mm Hg), gas supersaturation (mm Hg), barometric pressure (mm Hg), and water temperature (C) were measured using a Common Sensing tensiometer. The dissolved oxygen probe was calibrated using the measured barometric and water vapor pressure according to the manufacturer's instructions.

Water Flow

Water flow was measured using a portable Polysonics transit-time ultrasonic flow meter (Model TF-P). This meter is non-invasive and uses ultrasonic sound to measure the fluid velocity inside a pipe. Because this unit averages the fluid velocity across the pipe, it is less sensitive to upstream and downstream conditions than point measurements such as paddlewheel flowmeters.

Gas Flow

Nominal gas flowrates in cubic feet of air/hour were read off the installed rotameter (Brooks Sho-rate Model 2) on the column. The manufacturer supplied a calibration curve based on 12.7 psia and 70 F. The nominal reading was corrected to standard oxygen flowrates (70 F, 1 atm) using the following equation:

$$Qo_2 = Q'\left[\left(\frac{BP+P}{760}\right)\left(\frac{294.26}{273.15+T}\right)\right]^{1/2} \qquad (1)$$

where

Qo_2 = Oxygen flow under standard conditions (cubic feet/hour)

Q' = Equivalent flow of air under local temperature and pressure (cubic feet of air/hour)

BP = Local barometric pressure (mm Hg)

P = Effluent pressure (gauge) from rotameter (mm Hg)

T = Gas temperature at rotameter (C)

The effluent pressure from the rotameter (P in Equation 1) was measured on the top of the column. Gas temperature was measured using a glass thermometer mounted directly on the rotameter. Typically, the computed standard oxygen flowrates were only 93-99% of the uncorrected rotameter reading.

Data Reduction

Dissolved oxygen concentrations in mg/l (DO) were computed from partial pressures using the conversions listed by Colt (1984). Nitrogen saturation was computed using standard methods (Clesceri et al., 1989). The gas-to-liquid (G/L) ratio was expressed as a percent:

$$G/L\ (\%) = \left[\frac{Q_{O_2}}{60Q_{water}/7.48}\right]100 \qquad (2)$$

where

Q_{water} = water flow (gpm)

The gas-to-liquid ratio is based on the volumetric flowrate of the actual gas supplied rather than the volumetric flowrate of pure oxygen. Absorption efficiency (AE) was computed from the oxygen gas flow and the change in dissolved oxygen in the column:

$$AE(\%) = \left[\frac{(Q_{water})(3.78)(60)(DO_{out}-DO_{in})(2.205)(10^{-6})}{(Q_{O_2})(0.08278\,lb/ft^3)(X_{in})}\right]100 \qquad (3)$$

where

DO_{out} = Effluent dissolved oxygen (mg/l)

DO_{in} = Influent dissolved oxygen (mg/l)

X_{in} = Mole fraction of oxygen gas (a standard value of 0.994 was used)

The density of oxygen at 1 atm and 70 F is 0.08278 lb/ft^3. The performance of the columns is discussed in terms of hydraulic loading (water flow/column cross sectional area) expressed as gallons per minute/square feet (gpm/ft^2).

Experimental Procedure

At the start of each experimental test, the water flowrate was adjusted to the required flowrate and allowed to stabilize. During each experimental test, the water flowrate remained constant and the gas-to-liquid ratio was changed over the desired range.

At a given gas-to-liquid ratio, the following parameters were measured first in the column effluent and then in the untreated water:

Barometric pressure
Water temperature
Oxygen partial pressure
Gas supersaturation (AP)

Generally, the columns reached steady-state in 20-30 minutes. At the end of each gas-to-liquid ratio test, the system pressure at the top of the column, pressure at the rotameter, air temperature, and water flowrate were recorded.

Results

The basic data collected in the 5 individual test runs are summarized in Tables A-l to A-5 in Appendix A. Detailed results are presented below. All of the figures presented in this section have been placed at the end of this results section. Performance data is presented in terms of hydraulic loading expressed in terms of water flow/column cross sectional area (gpm/ft^2).

24 Inch Column (Design Loading)

Column performance was evaluated at design loading (159 gpm/ft^2). The change in dissolved oxygen (ADO) through the column showed a linear increase with increasing gas-to-liquid ratio (Figure 3). The majority of the absorption efficiency values were in the range of 48-61% (Figure 4). As the gas-to-liquid (G/L) ratio increased, the absorption efficiency first increased then slowly decreased. The dependence between absorption efficiency and ADO (Figure 5) was similar to that for absorption efficiency and G/L ratio (Figure 4) The Oxygen Transfer Rate and available oxygen (based on a minimum DO of 7.00 mg/l) increased with increasing gas-to-liquid (G/L) ratios (Figure 6). The effluent AP was higher than the influent value (Figure 7). The effluent nitrogen saturation was lower than the influent values. The effluent nitrogen saturation values were lower at higher G/L ratios and were less than 100% for G/L ratios > 0.20 % (Figure 8). The column pressure depended on G/L ratio (Figure 9).

24 Inch Column (Reduced Water Flow)

In test 2, the water flow was varied from 200 to 708 gpm. Based on a rotameter reading of 60 at the design flow of 500 gpm, the rotameter setting was adjusted to try to maintain a constant product of water flow x rotameter reading

(Figure 10). While the amount of oxygen transfer rate decreased at higher water flows, the amount of available oxygen increased (Figure 11).

30 Inch Column (Design Loading)

Column performance was evaluated at a loading of 151 gpm/ft^2, which was within 2 gpm/ft^2 of the design loading. The change in dissolved oxygen (ADO) through the column showed a linear increase with increasing gas-to-liquid ratio (Figure 12). The absorption efficiency ranged from 35-53% and linearly decreased with increasing G/L ratio or ADO (Figure 13 and 14). The added oxygen showed a linear increase with increasing G/L ratio (Figure 15). The observed break in the available oxygen curve resulted from a change in water temperature. The effluent APs ranged from 0 to 5 mm Hg and were typically lower than the influent values (Figure 16). The effluent nitrogen saturation ranged from 101 to 94 % (Figure 17). The column pressure did not depend on G/L ratio (Figure 18).

30 Inch Column (Reduced Water Flow)

In test 4, the water flow was varied from 548 to 957 gpm. Based on a rotameter reading of 77 at the design flow of 750 gpm, the rotameter setting was adjusted to try to maintain a constant product of water flow x rotameter reading (Figure 19). While the oxygen transfer rate decreased at higher water flows, the amount of available oxygen was relatively constant (Figure 20).

LHO System

Because of problems measuring the water and gas flows with the prototype LHO system, detailed performance information will not be presented. These problems were related to the small size of the unit. To adequately test this unit, a new rotameter would be needed and the piping to the unit modified. These changes could not be completed within the time constraints of the present testing program.

The change in DO through this unit significantly changes along the length of the unit (Table A-5) and ranged from 4.94 mg/l on the influent oxygen cell to 2.24 mg/l on the discharge cell. This further complicates the evaluation of this type of unit as it is more difficult to obtain a representative effluent water sample. The variation of dissolved gas concentrations along the length of the unit is characteristic of this unit.

Influent Dissolved Gas Levels

Over the testing period, influent dissolved gas levels were relatively constant:

Parameter	Maximum	Minimum
AP (mm Hg)	3	14
DO (mg/l)	11.4	9.8
Nitrogen (%)	102.6	100.5

The variation in dissolved gas levels appears to be driven by diel temperature changes. The gas parameters were measured only over daylight hours and their variation over the full 24 hour period was not determined.

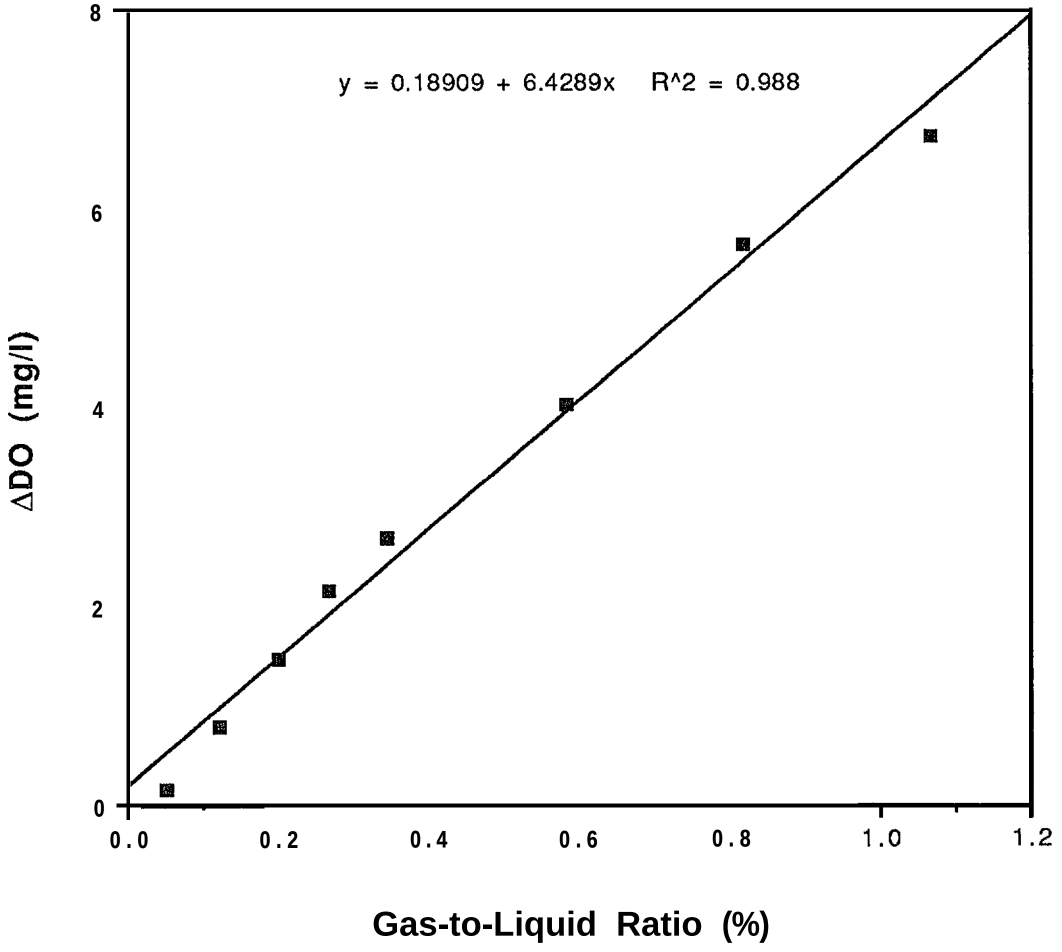


Figure 3 The Change in Dissolved Oxygen (ADO) as a Function of Gas-to-Liquid Ratio - 24 Inch Column

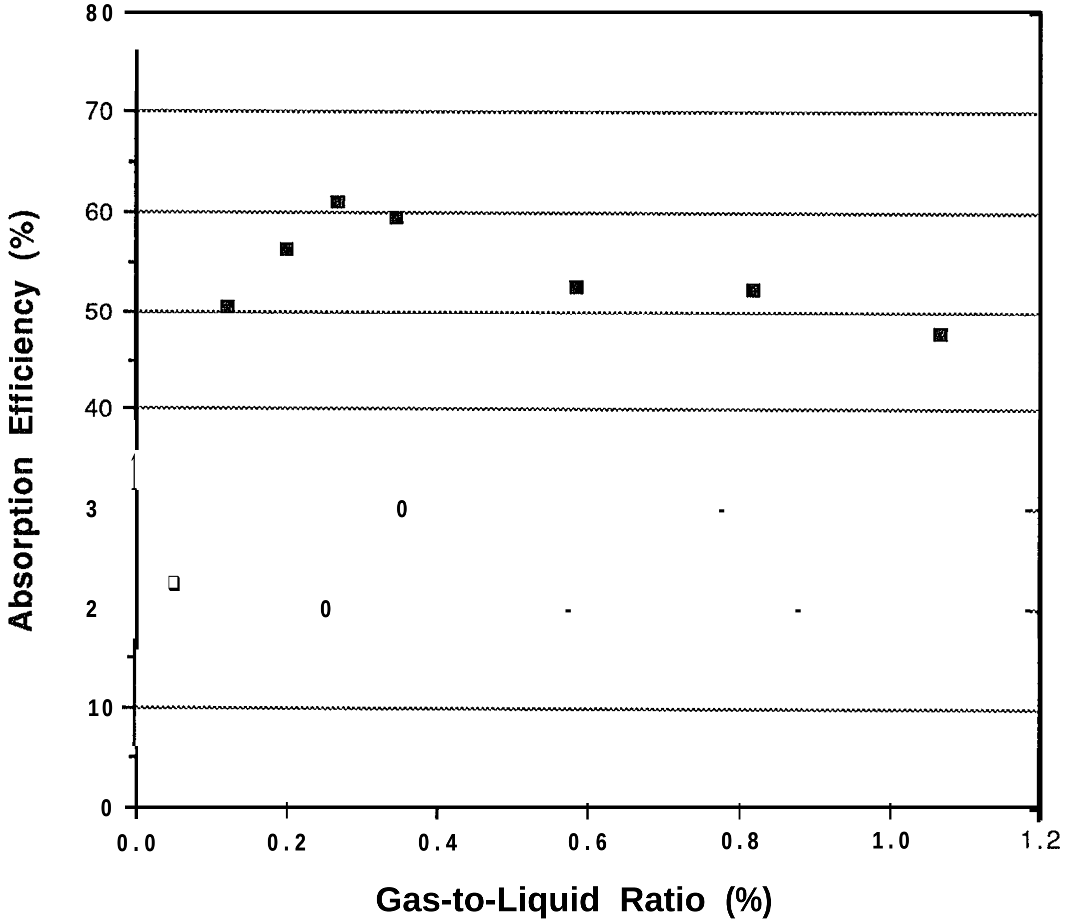


Figure 4 Absorption Efficiency as a Function of Gas-to-Liquid Ratio - 24 Inch Column

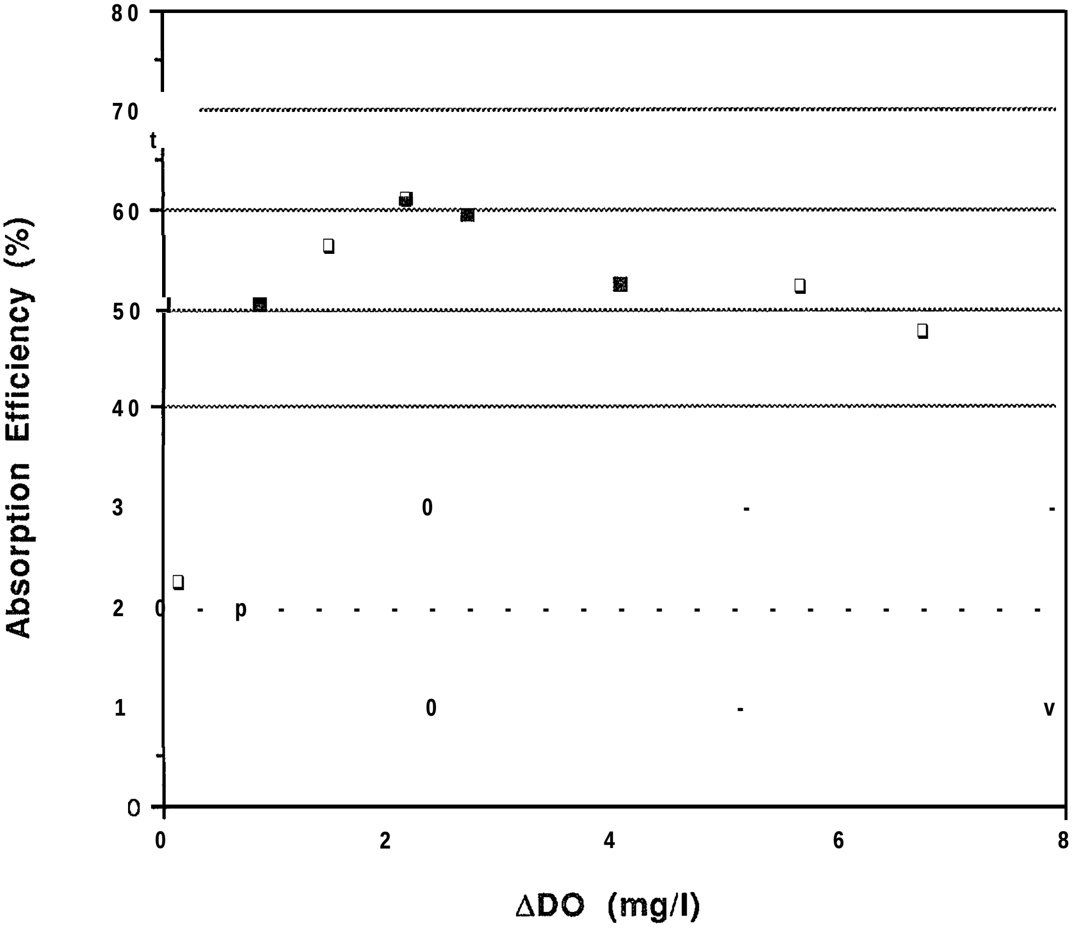


Figure 5 Absorption Efficiency as a Function of **ADO** - 24 Inch Column

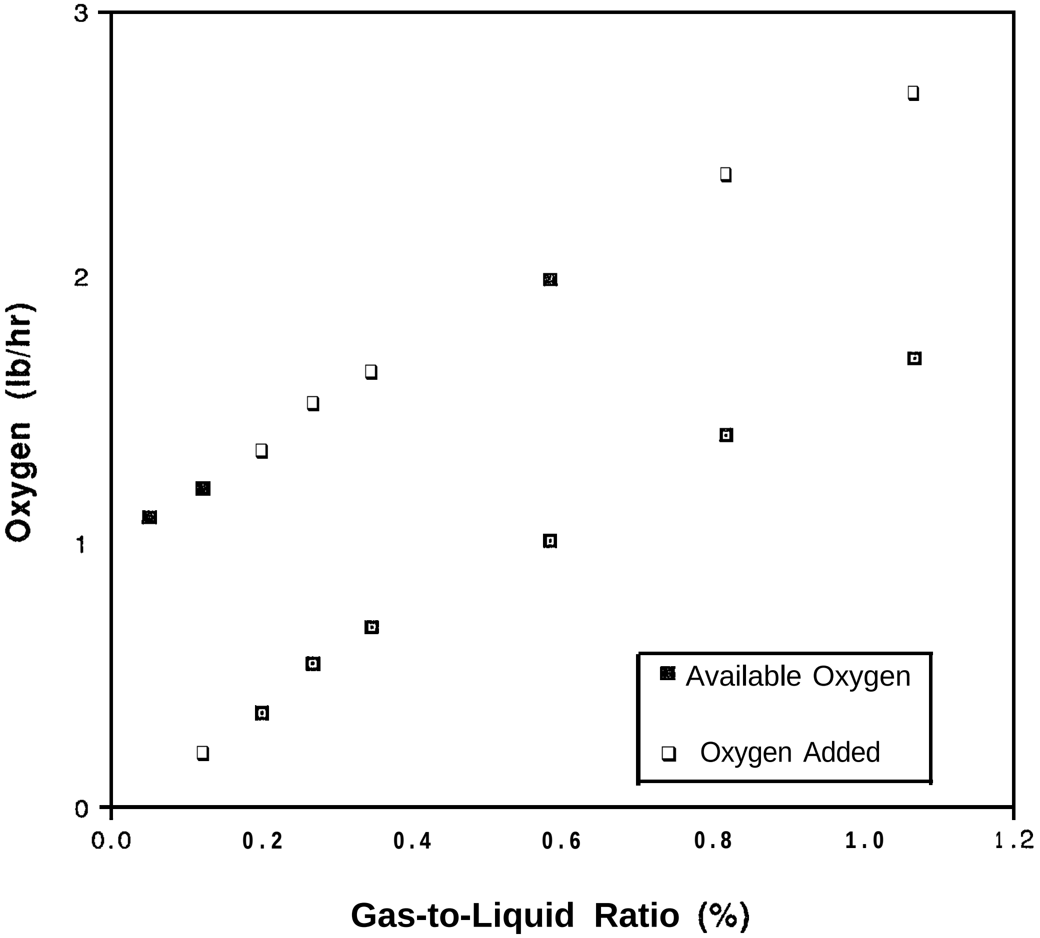


Figure 6 Oxygen Transfer Rate and Available Oxygen (based on an effluent criteria of 7 mg/l) as a Function of Gas-to-Liquid Ratio - 24 Inch Column

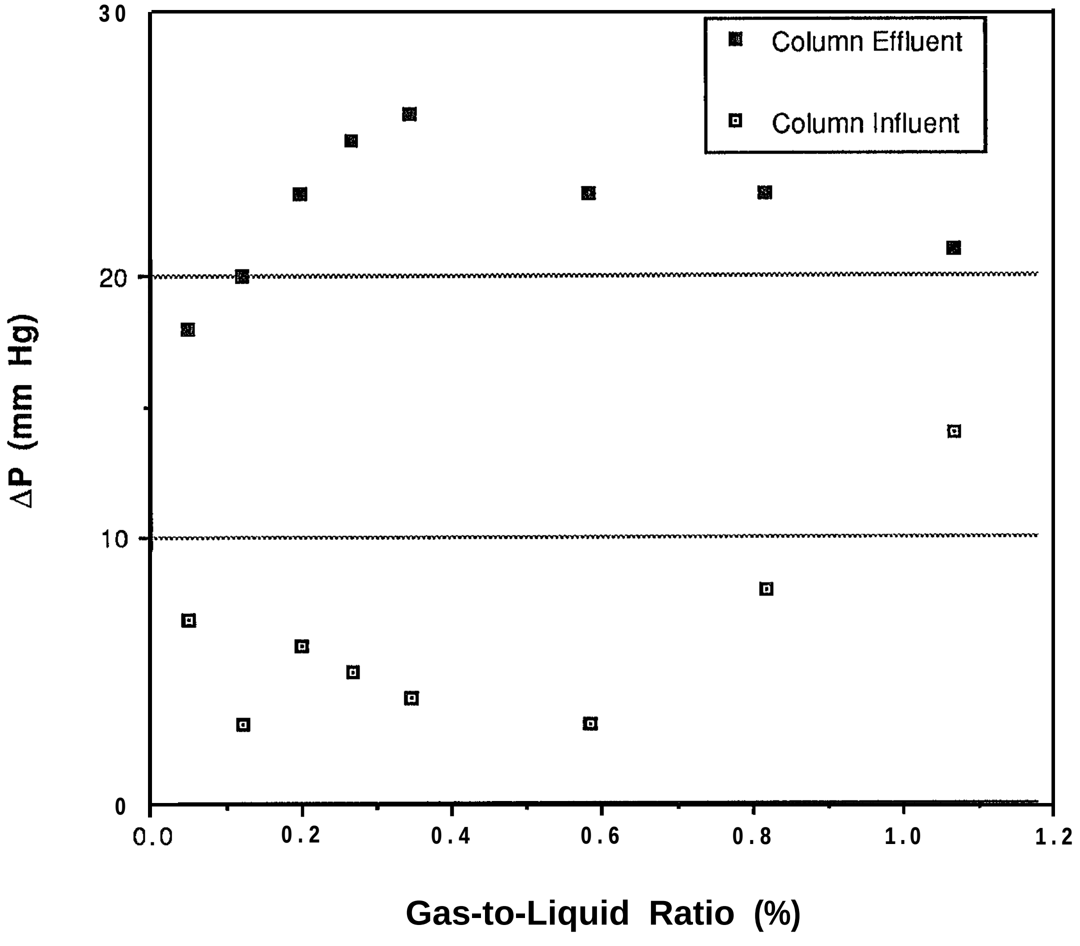


Figure 7 Influent and Effluent AP as a Function of Gas-to-Liquid Ratio - 24 Inch Column

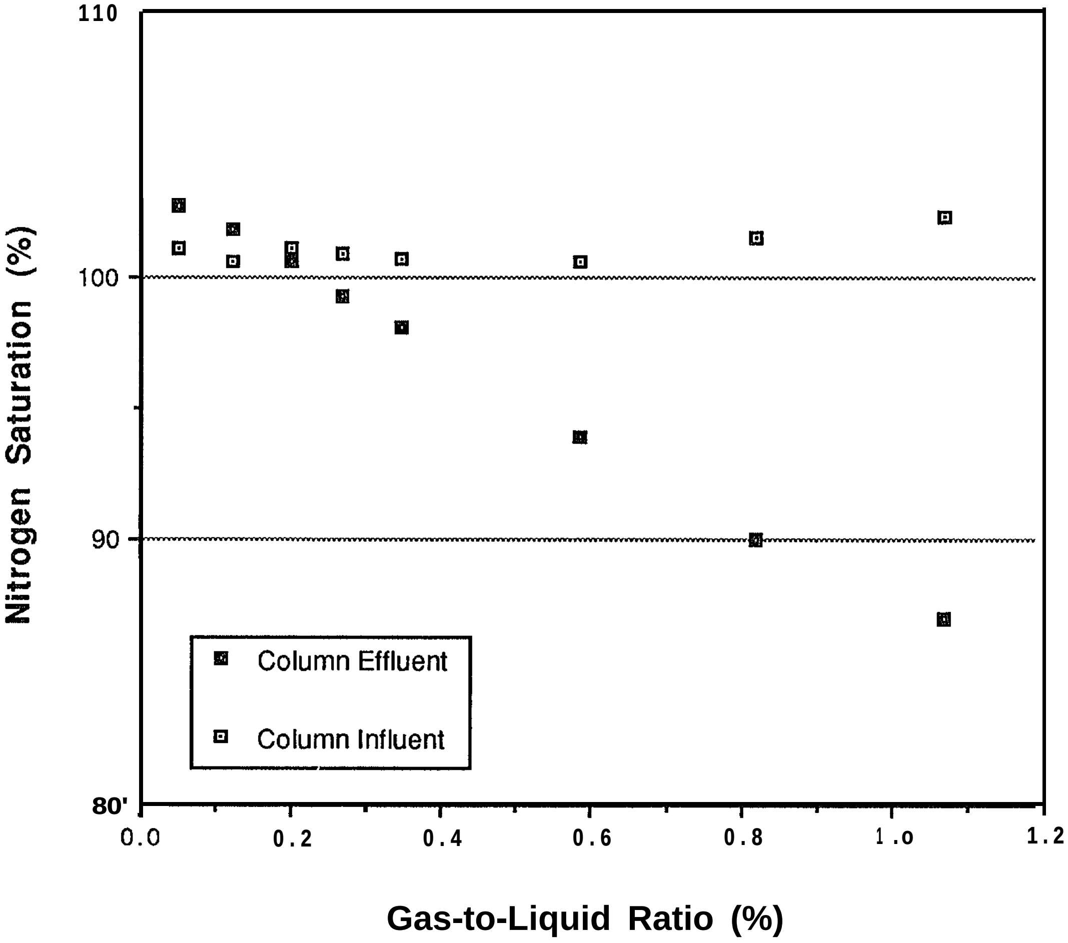


Figure 8 Influent and Effluent Nitrogen Saturation as a Function of Gas-to-Liquid Ratio - 24 Inch Column

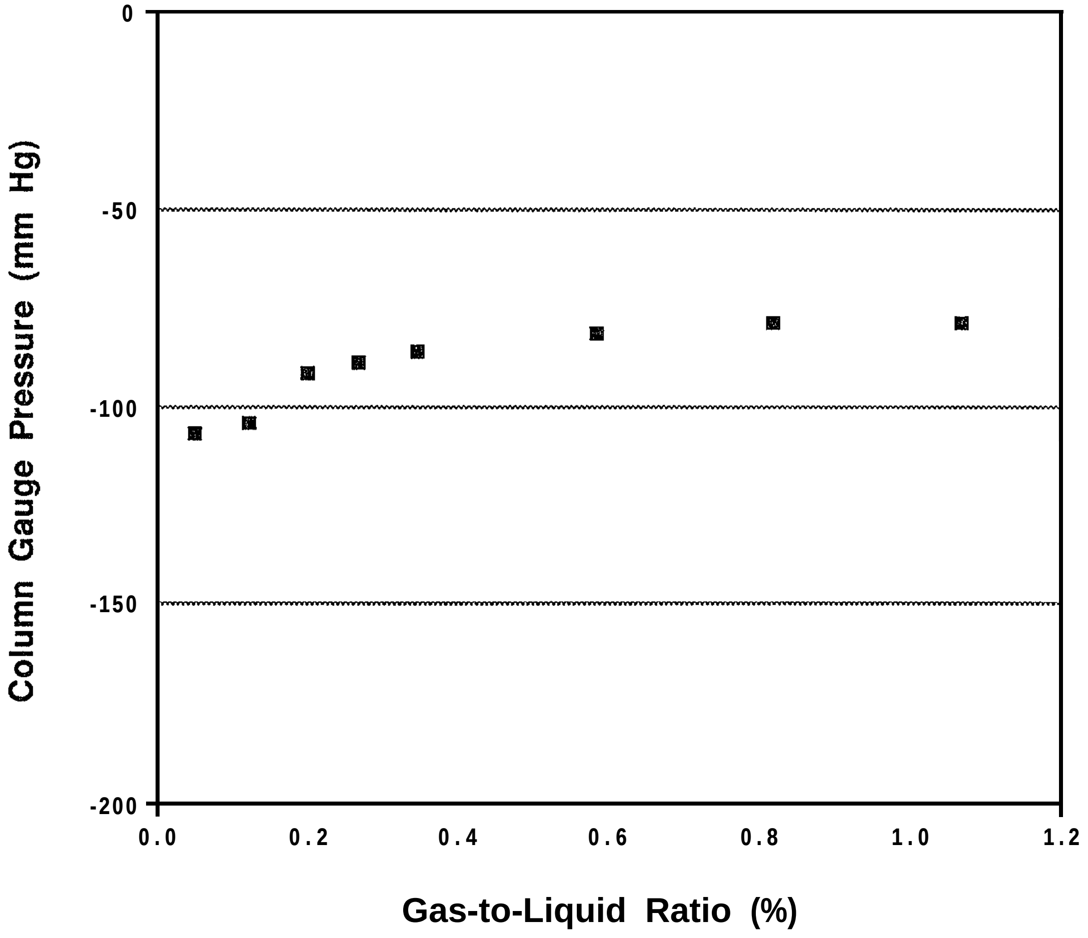


Figure 9 Gauge Pressure on Top of Column as a Function of Gas-to-Liquid Ratio - 24 Inch Column

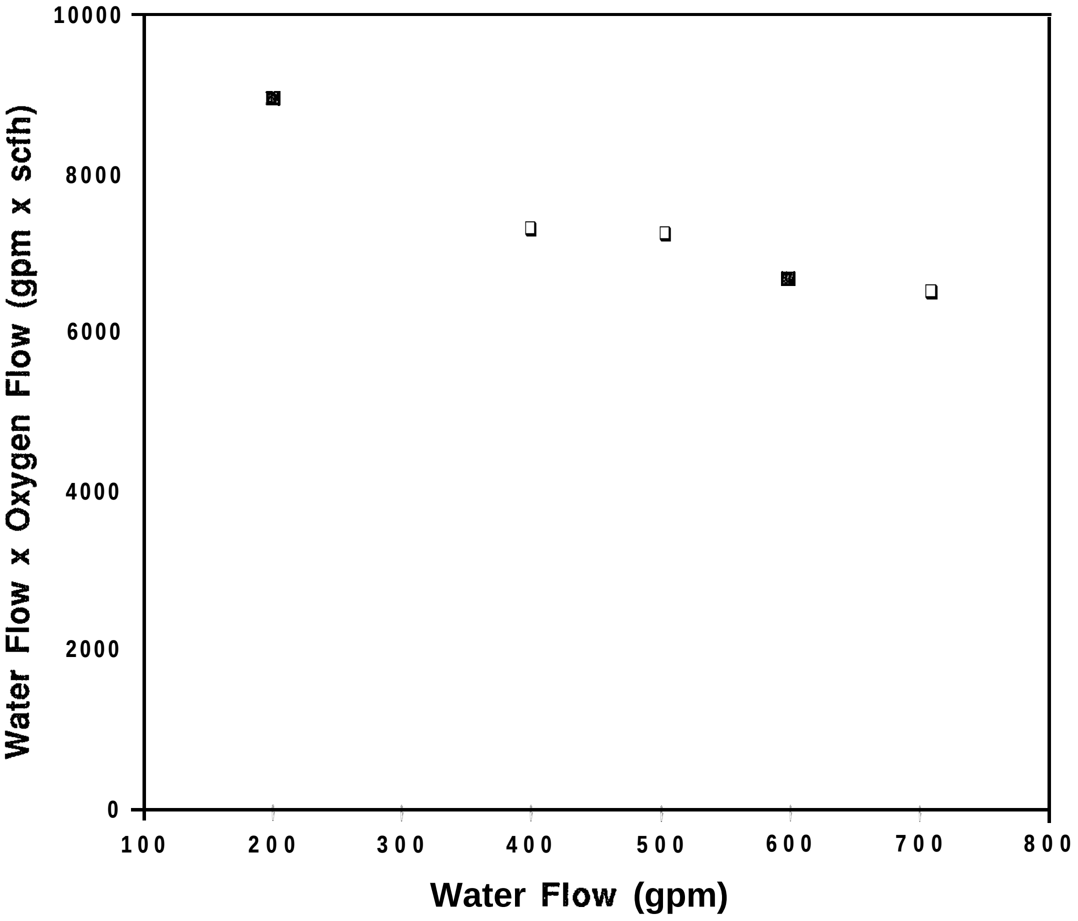


Figure 10 The Product of Water Flow x Gas Flow as a Function of Water Flow in Test 2 - 24 Inch Column

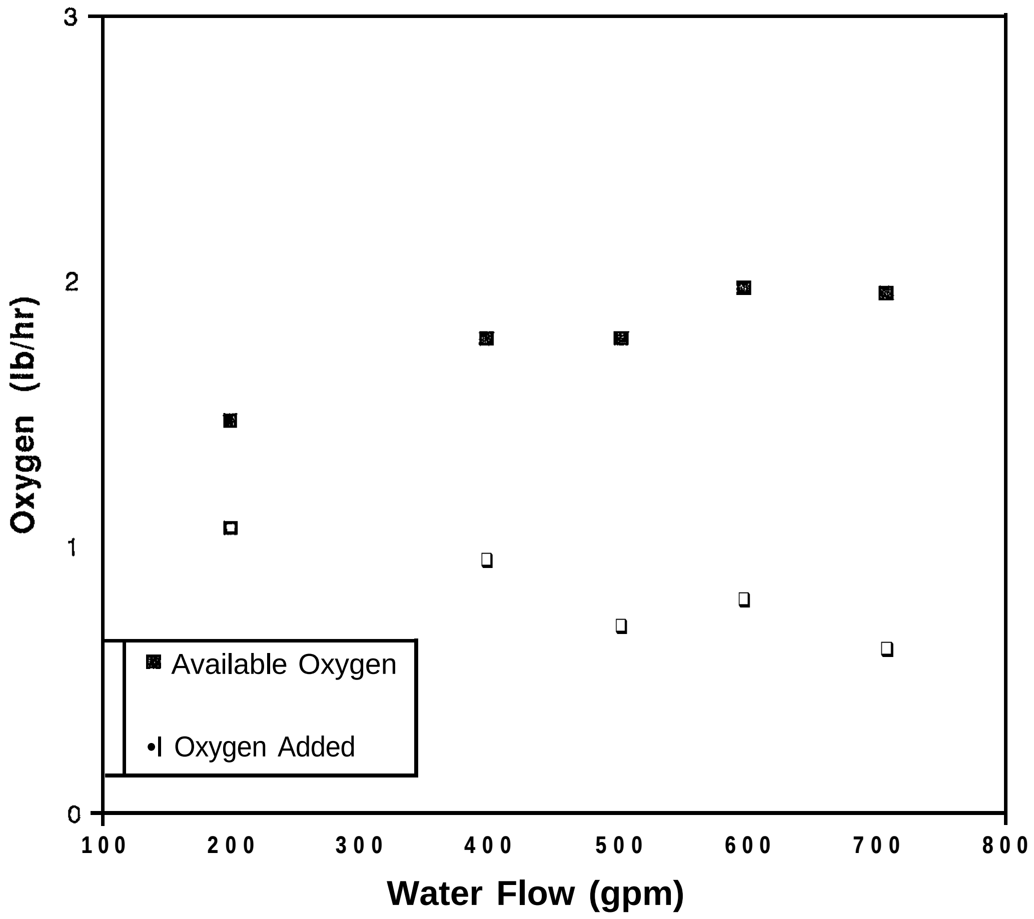


Figure 11 Oxygen Transfer Rate and Available Oxygen (based on an effluent criteria of 7 mg/l) as a Function of Water Flow Rate in Test 2 - 24 Inch Column

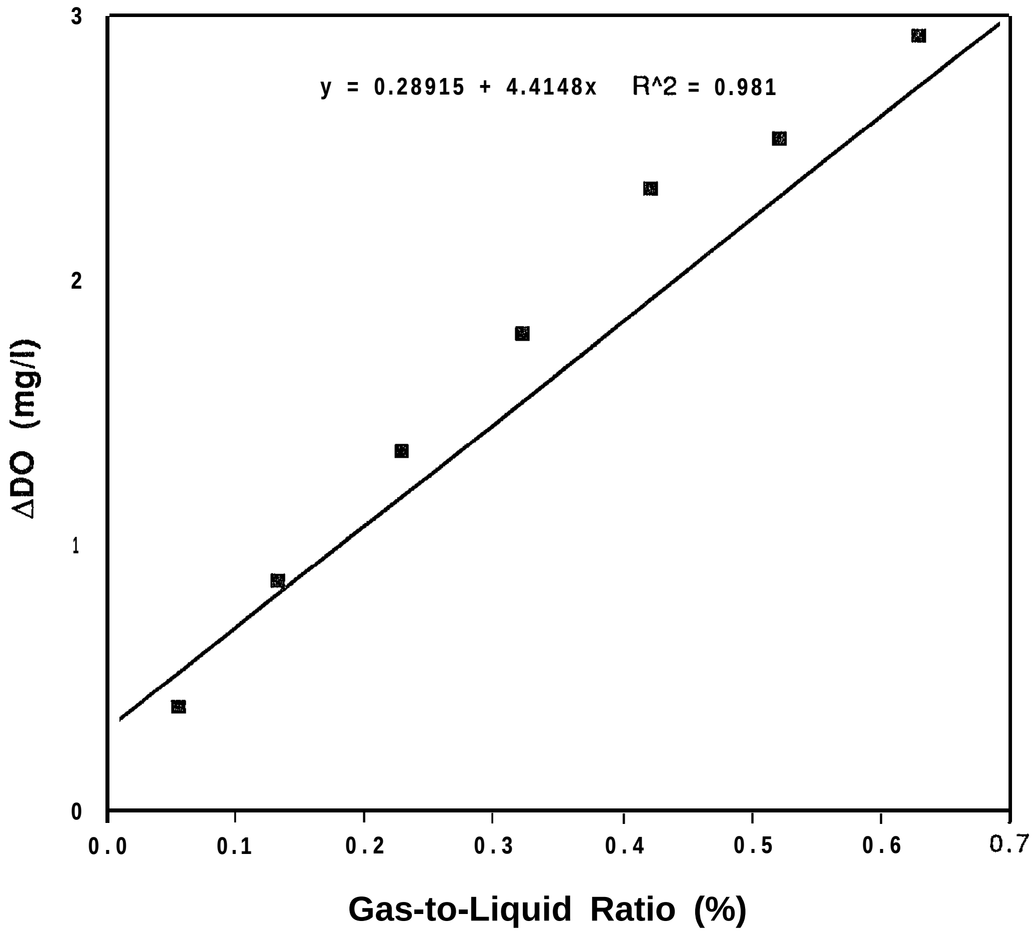


Figure 12 The Change in Dissolved Oxygen (ADO) as a Function of Gas-to-Liquid Ratio - 30 Inch Column

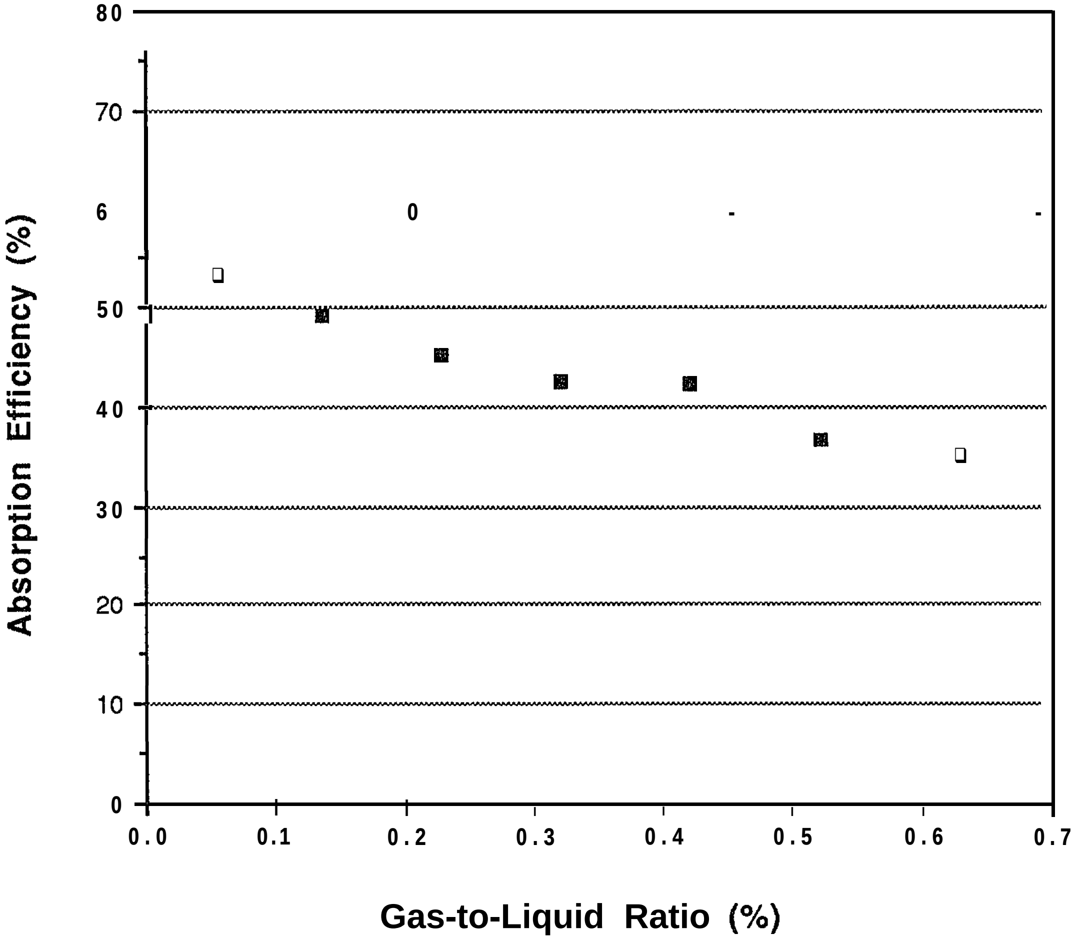


Figure 13 Absorption Efficiency as a Function of Gas-to-Liquid Ratio - 30 Inch Column

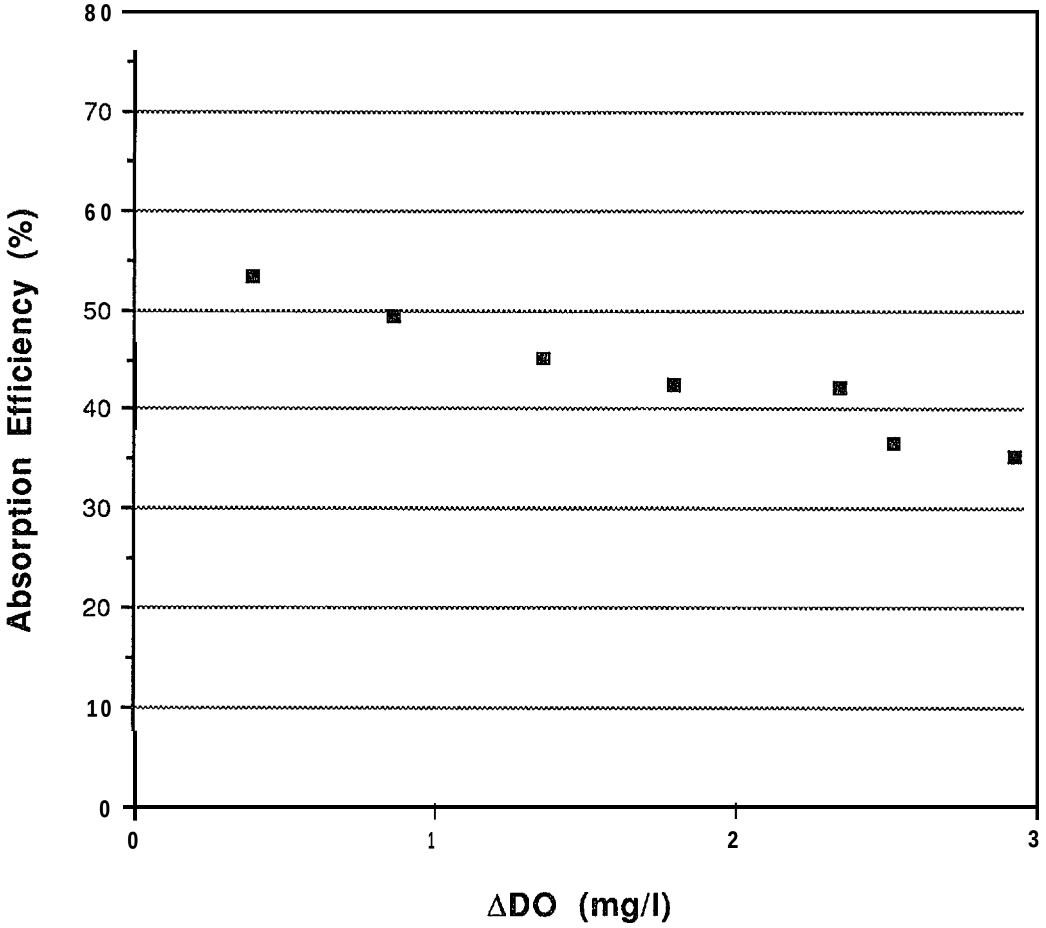


Figure 14 Absorption Efficiency as a Function of **ADO** - 30 Inch Column

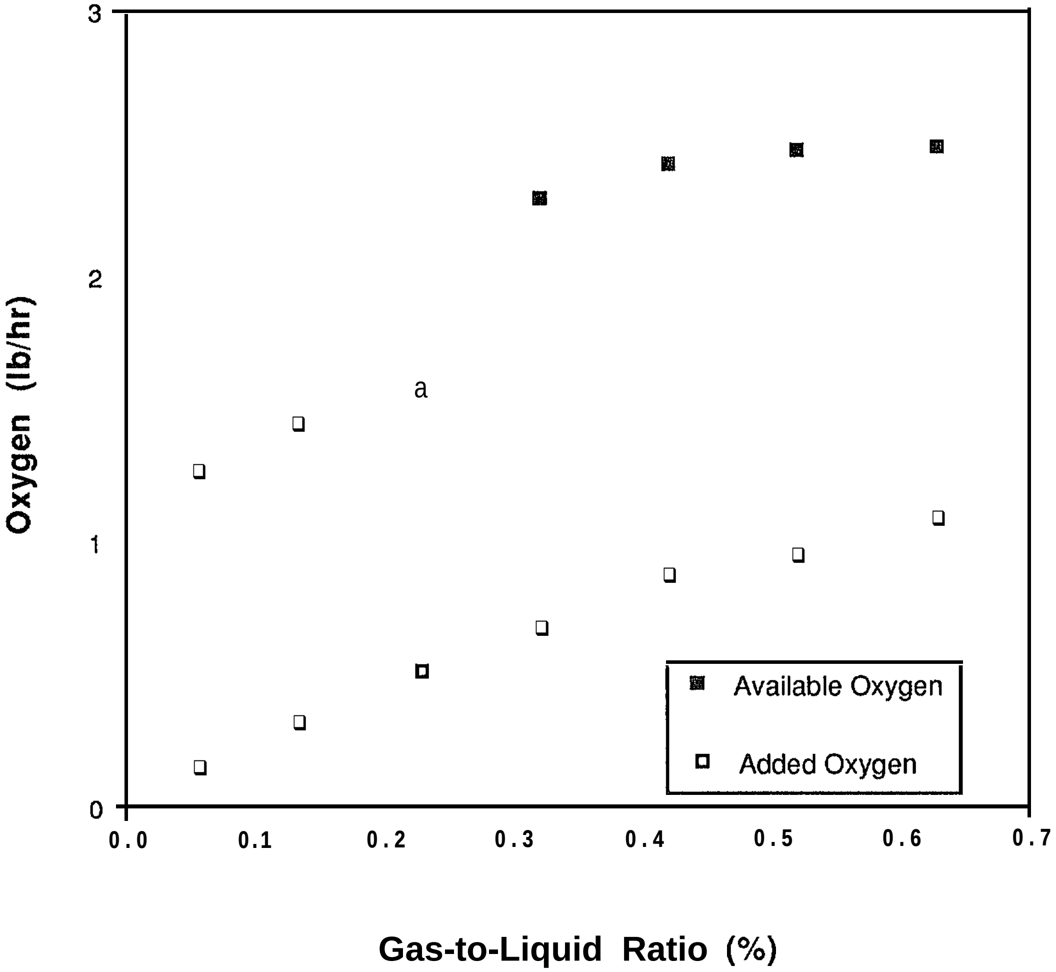


Figure 15 Oxygen Transfer Rate and Available Oxygen (based on an effluent criteria of 7 mg/l) as a Function of Gas-to-Liquid Ratio - 30 Inch Column

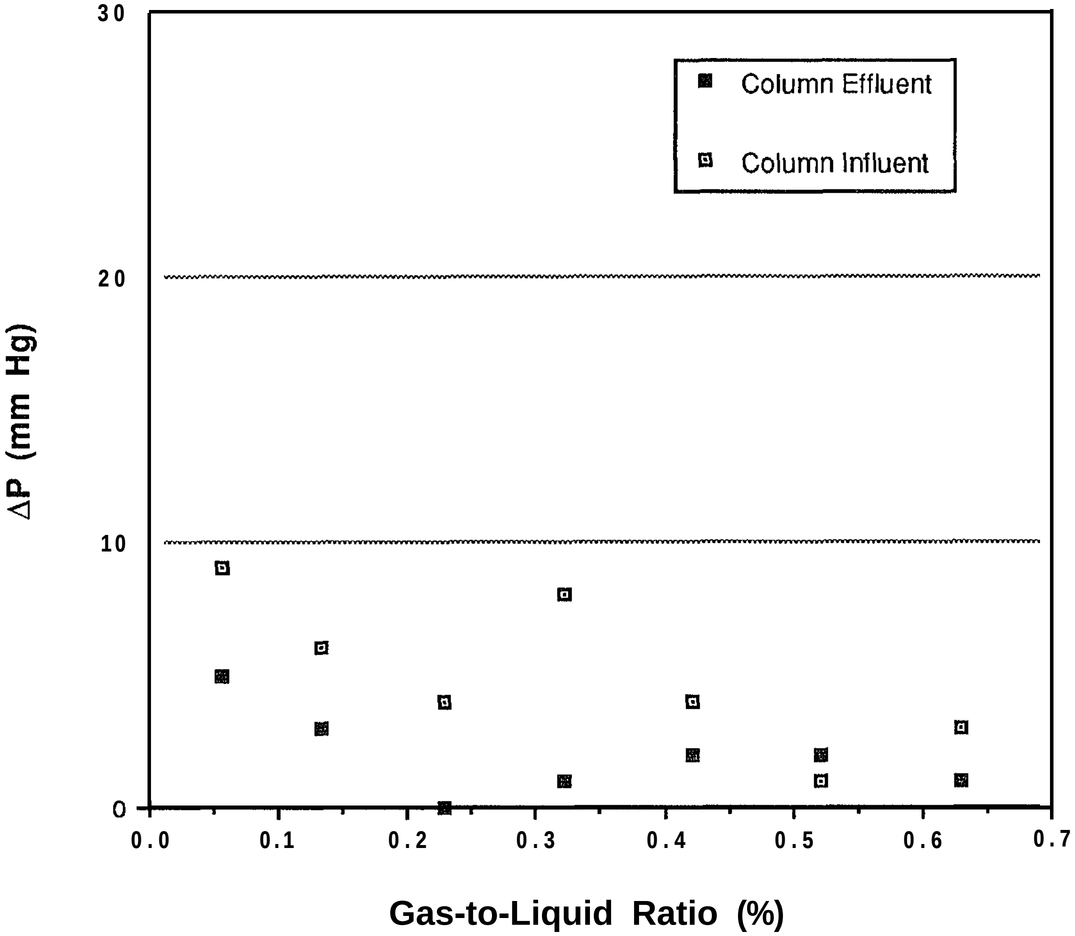


Figure 16 Influent and Effluent AP as a Function of Gas-to-Liquid Ratio - 30 Inch Column

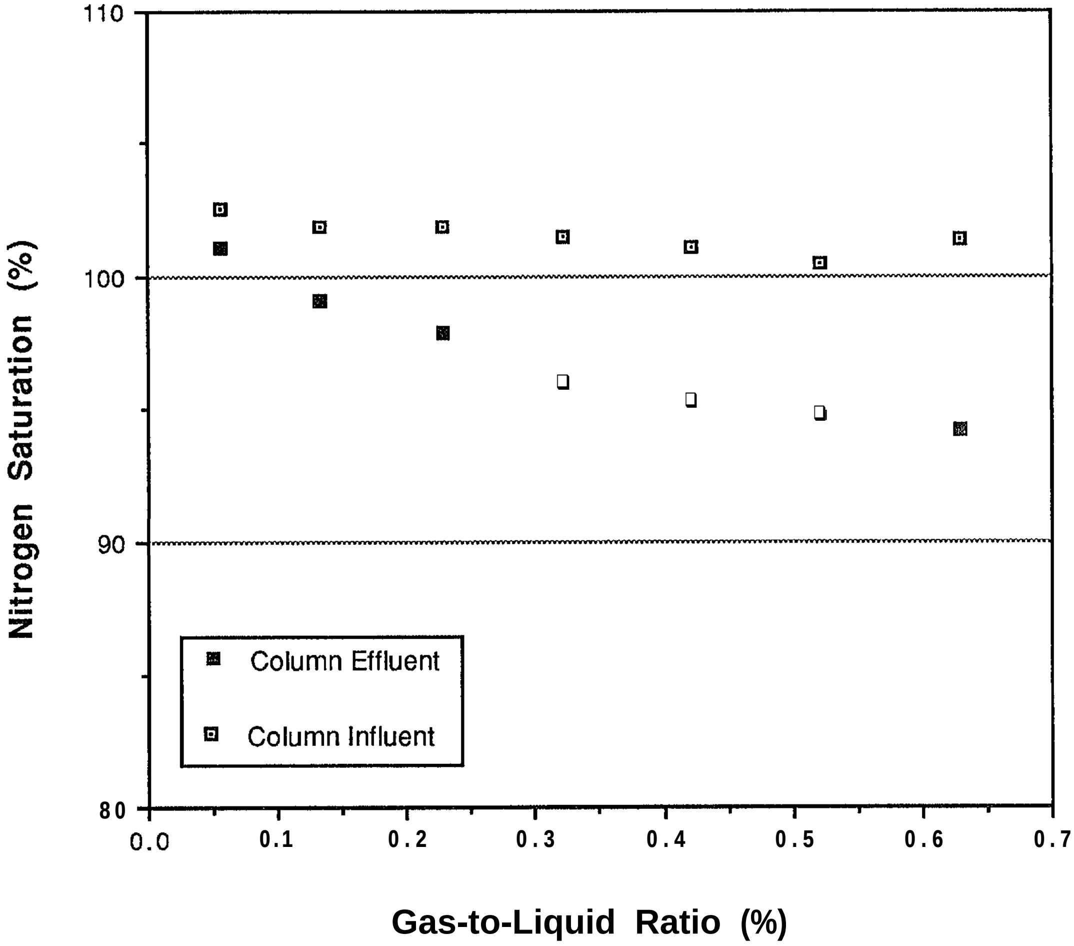


Figure 17 Influent and Effluent Nitrogen Saturation as a Function of Gas-to-Liquid Ratio - 30 Inch Column

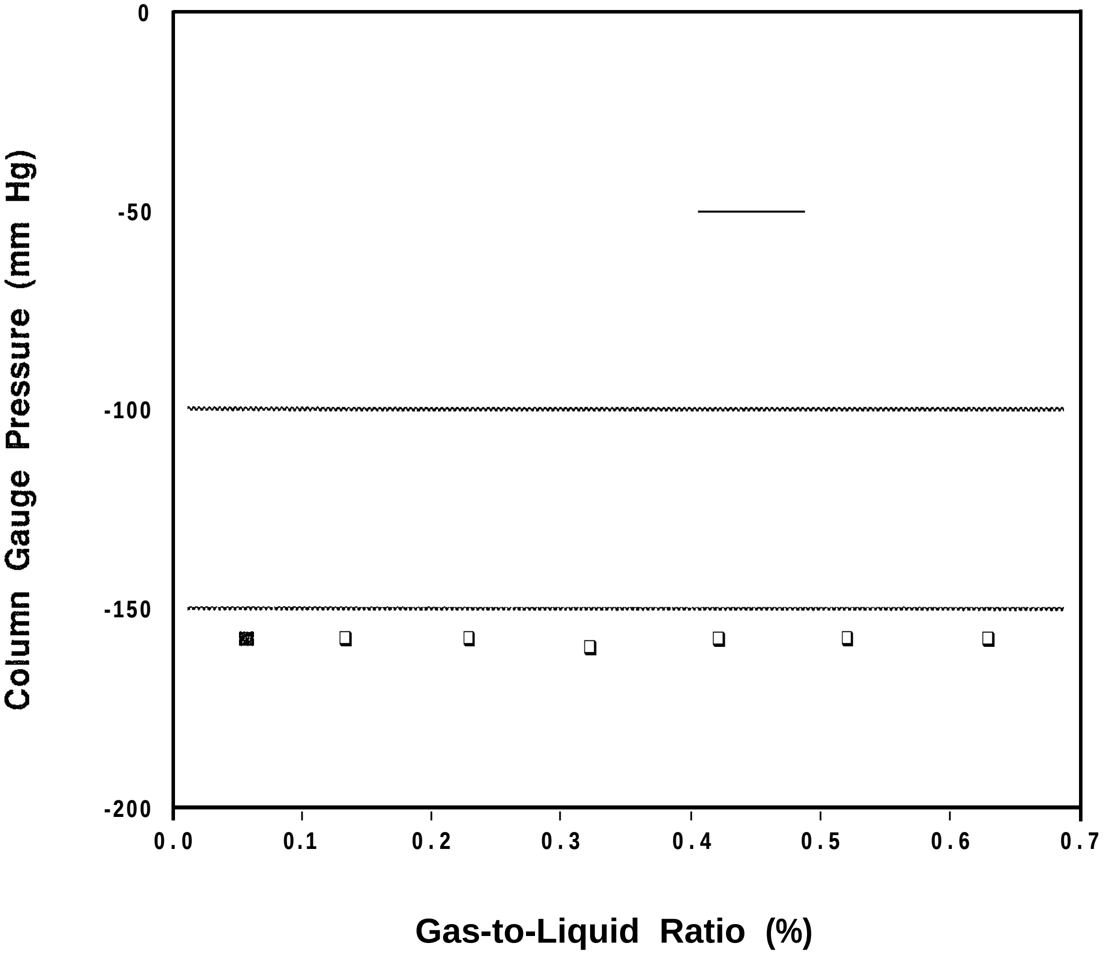


Figure 18 Gauge Pressure on Top of Column as a Function of Gas-to-Liquid Ratio - 30 Inch Column

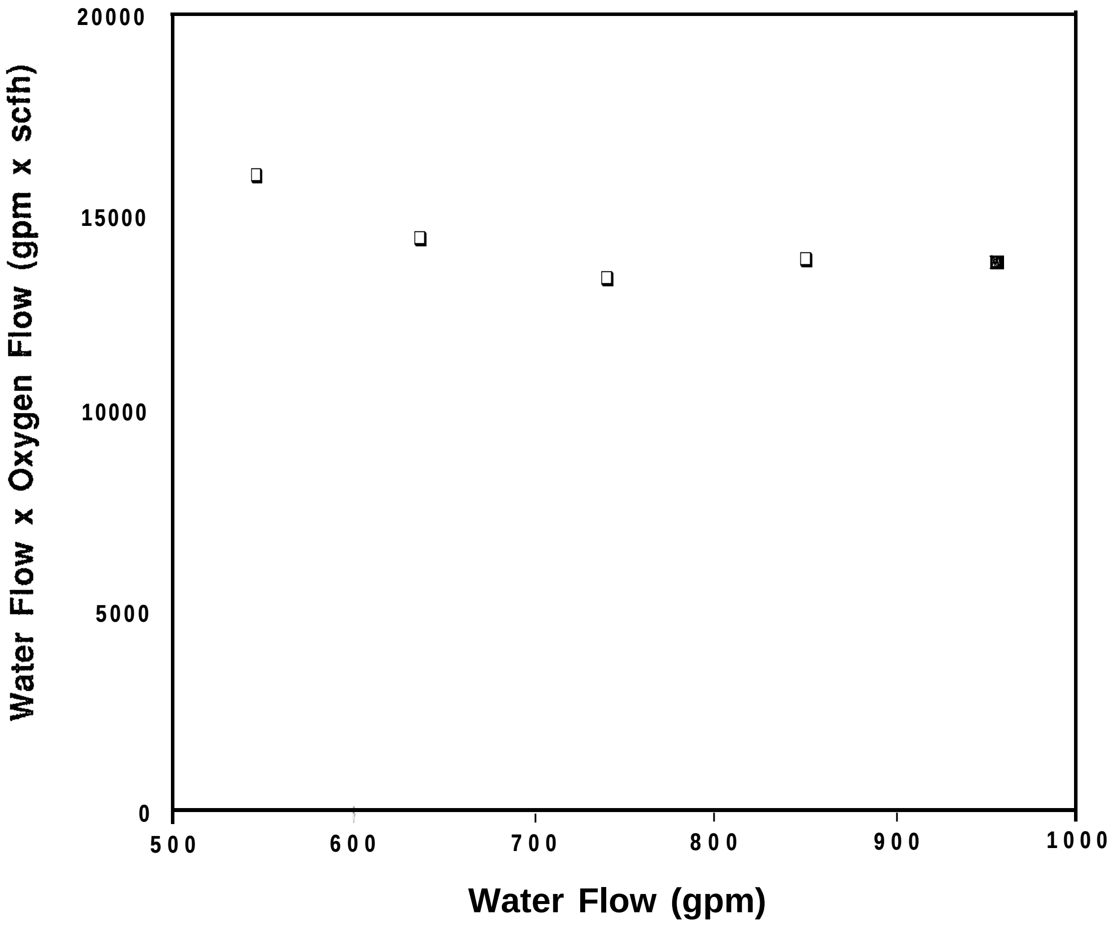


Figure 19 The Product of Water Flow x Gas Flow as a Function of Water Flow in Test 4 - 30 Inch Column

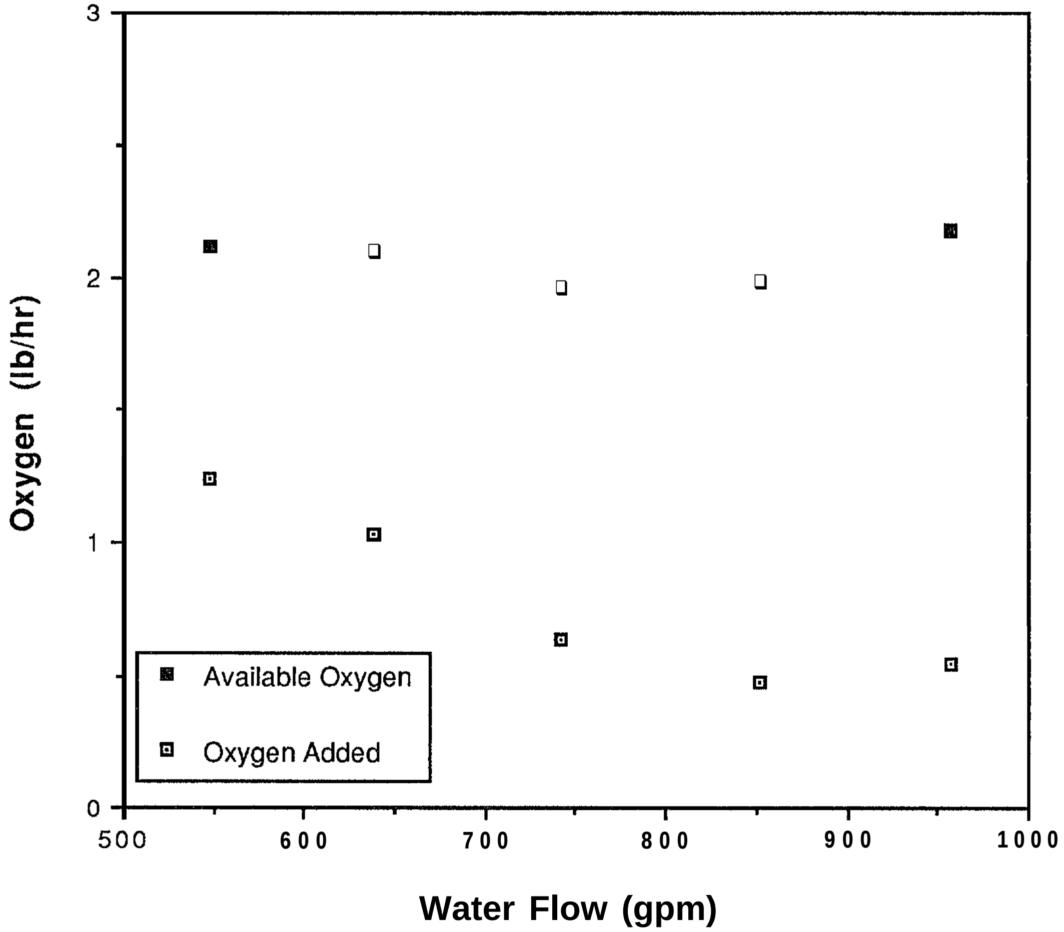


Figure 20 Oxygen Transfer Rate and Available Oxygen (based on an effluent criteria of 7 mg/l) as a Function of Water Flow Rate in Test 4 - 30 Inch Column

Discussion

This section discusses the performance evaluation of Williamette *Hatchery Oxygen Transfer Columns* and compares their performance to those used by the Michigan Department of Natural Resources. All of the figures presented in this section have been placed at the end of this discussion section. Performance data is discussed in terms of hydraulic loading expressed in terms of water flow/column cross sectional area (gpm/fta).

ADO

One of the major advantages of a pure oxygen system is the ability to adjust the effluent DO concentration by changing the gas flowrate or gas-to-liquid (G/L) ratio. This allows regulation of the amount of oxygen supplied to the rearing units to meet a diel or seasonal variation in oxygen consumption.

Both column sizes show a linear increase in ADO as a function of G/L ratio (Figures 3 and 12) as is common with pure oxygen systems (Colt and Watten, 1988). At the design loadings, the performance for the 24 inch column was significantly better than the 30 inch column.

Compared to the Michigan columns (see Appendix B for detailed information), the 24 inch *Williamette Hatchery Oxygen Transfer Columns* produced ADOS comparable to similarly loaded Michigan columns (Figure 22). In general the 30 inch *Williamette Hatchery Oxygen Transfer Columns* produced lower ADOS at a given G/L ratio than the Michigan columns (Figure 22).

Absorption Efficiency

The most commonly used performance measure is absorption efficiency (the percent of oxygen transferred into the water). While a high absorption efficiency reduces oxygen costs, high levels of gas supersaturation in the influent water may limit the maximum absorption efficiency.

Over most of the G/L range tested, the absorption efficiency of the 24 inch column was greater than the 30 inch column (Figure 23). Typically in pure oxygen columns, the absorption efficiency decreases with increasing ADOS or G/L ratios (Colt & Watten, 1988, Westers et al., In Press). The 30 inch *Williamette Hatchery Oxygen Transfer Columns* showed the characteristic decrease in absorption efficiency with increasing G/L ratio. The 24 inch *Williamette Hatchery Oxygen Transfer Columns* showed an initial increase then a slow decrease in absorption efficiency with increasing G/L ratio. This may be a characteristic of the column configuration or due to inaccuracies in gas flow or dissolved oxygen measurements at low oxygen flows. For example, at the lowest G/L ratio tested with the 24 inch column, the change in partial pressure read from the Common Sensing unit was only 2 mm Hg. An increase in partial pressure of 1 mm Hg would increase the absorption efficiency from 22.5% to 33.74 %.

The absorption efficiency for the 24 inch columns throughout the range of loadings tested were significantly higher than the Michigan pure oxygen transfer column (Figure 24). The absorption efficiency for the 30 inch *Williamette Hatchery Oxygen Transfer Column* was similar to the Michigan columns (Figure 24).

The regression equations between absorption efficiency, ADO, and G/L are equal to:

24 Inch Columns

$\text{ADO} = 0.189 + 6.43 * (\text{G/L})$ $\quad r^2 = 0.988$

$\text{AE} = 66.2 - 2.73 * (\text{ADO})$ $\quad r^2 = 0.917$

30 Inch Columns

$ADO = 0.289 + 4.41 * (G/L)$ $r^2 = 0.981$

$AE = 55.3 - 6.76 * (ADO)$ $r^2 = 0.951$

The AE vs ADO regression equation for the 24 inch column did not use the first three data points.

Oxygen Transfer Rate

The oxygen transfer rate is the total amount of oxygen transferred into the water and is typically expressed in lb/hour. At a given column size, the oxygen transfer rate was highest at the highest water flow rate (Figures 6 and 15). This is a direct result of a relatively constant absorption efficiency and the higher water flowrates. The maximum observed oxygen transfer rates and available oxygen for the two columns at the design hydraulic loading rate are approximately equal to:

Size	Oxygen Transfer Rate (lb/hour)	Available Oxygen (lb/hour)
24	1.7	2.7
30	1.1	2.5

The reduced water flow tests (Figures 11 and 20) showed that increasing the G/L ratio could compensate for reduced water flow, but at increased oxygen gas costs.

The effluent DO criteria has a major effect on the design and operation of pure oxygen systems. The available oxygen is significantly larger than the oxygen transfer rate. The available oxygen is based on the amount of oxygen that can be removed before the raceway effluent drops to a given DO concentration (typically 6-7 mg/l) and therefore depends both on the oxygen in the influent water and the amount of pure oxygen transferred into the water. If this hatchery is operated with the existing dissolved oxygen criteria equal to the influent DO, then the oxygen consumption must be limited to the oxygen transfer rate. If the dissolved oxygen criteria is based on an absolute mass concentration in mg/l, then the oxygen consumption in the raceway can be increased to the available oxygen value.

Effluent ΔP

Gas supersaturation problems can be produced in salmonid hatcheries by APs in the range of 40 to 80 mm Hg. Pure oxygen systems can either increase or decrease the effluent AP from the unit, depending on column pressure and operating conditions (Colt and Watten, 1988).

The 24 inch column actually increased the AP, while the 30 inch column decreased the AP. The effluent AP from the 24 inch column was typically in the range of 18-26 mm Hg and did not appear to depend on the G/L ratio. Gas bubble trauma (gas bubble disease) should not be a problem at these BPS, but it would be prudent to carefully monitor APs.

Effluent Nitrogen Saturation

At a given AP, the biological impact of gas supersaturation is reduced if the nitrogen gas pressure is lowered. The Michigan columns were in fact initially designed to remove nitrogen gas from well waters. Typically, the effluent nitrogen saturation decreases with increasing G/L ratio (Colt and Watten, 1988).

The effluent nitrogen saturation values were typically less than 100 % and decreased with increasing G/L ratio (Figures 8 and 17). The 24 inch column was more efficient in removing nitrogen.

Column Pressure

The column pressure has a direct impact on the saturation concentration of oxygen within the column, and therefore, the rate of oxygen transfer. Low column pressures (i.e., a vacuum) tend to reduce oxygen transfer into the water but increase the rate of nitrogen transfer from the water. It is important to note that column pressure inside the column is not constant, but varies from the measured value at the top to approximately local barometric pressure at the discharge.

The column pressure measured at the top of the column was less than the local barometric pressure (i.e., a vacuum) and depended strongly on hydraulic loading rate and to a less degree on the G/L ratio. When compared with the Michigan Column data (Westers et al., In Press), the column pressures for the Williamette Hatchery *Oxygen Transfer Columns* were significantly lower (Figure 25). This may be related to the reduced diameter of the discharge pipe in the *Williamette Hatchery Oxygen Transfer Columns.* As the hydraulic loading rate was increased, the vacuum in the 24 in column increased (Figure 25). For the 30 inch column, the vacuum initially increased and then remained constant at the two highest loading rates (Figure 25).

Overall Performance Evaluation

The performance of the *Williamette Hatchery Oxygen Transfer Columns* is similar or superior to the Michigan type columns. The performance of packed columns is largely independent of hydraulic loading rate (Hackney and Colt, 1982). Whereas, both the performance of the *Williamette Hatchery Oxygen Transfer Columns* and the Michigan columns (Westers et al., In Press) are very sensitive to hydraulic loading rate. It is important to note that the *Williamette Hatchery Oxygen Transfer Columns* (and Michigan columns) are actually a type of low pressure downflow bubble aerator (DPBA) unit (Speece et al., 1971). Due to the vacuum produced by the constriction of the effluent piping, the Williamette columns are 40-80 % filled with water and a significant amount of the total gas transfer occurs in the water-bubble mixture.

The small diameter of the discharge pipe is probably responsible for the lower column pressure and some of the reduced performance. A high velocity in the discharge pipe will increase the discharge of gas from the column and increase the column vacuum.

Influent Dissolved Gas Levels

Influent dissolved gas concentrations can significantly impact column performance (Colt and Watten, 1989); significant seasonal variations may exist in small streams (Bouck, 1984). The collection of information on the daily and seasonal variation of dissolved gases at the Williamette Hatchery should be strongly encouraged as it will be very useful in further design work for oxygen supplementation.

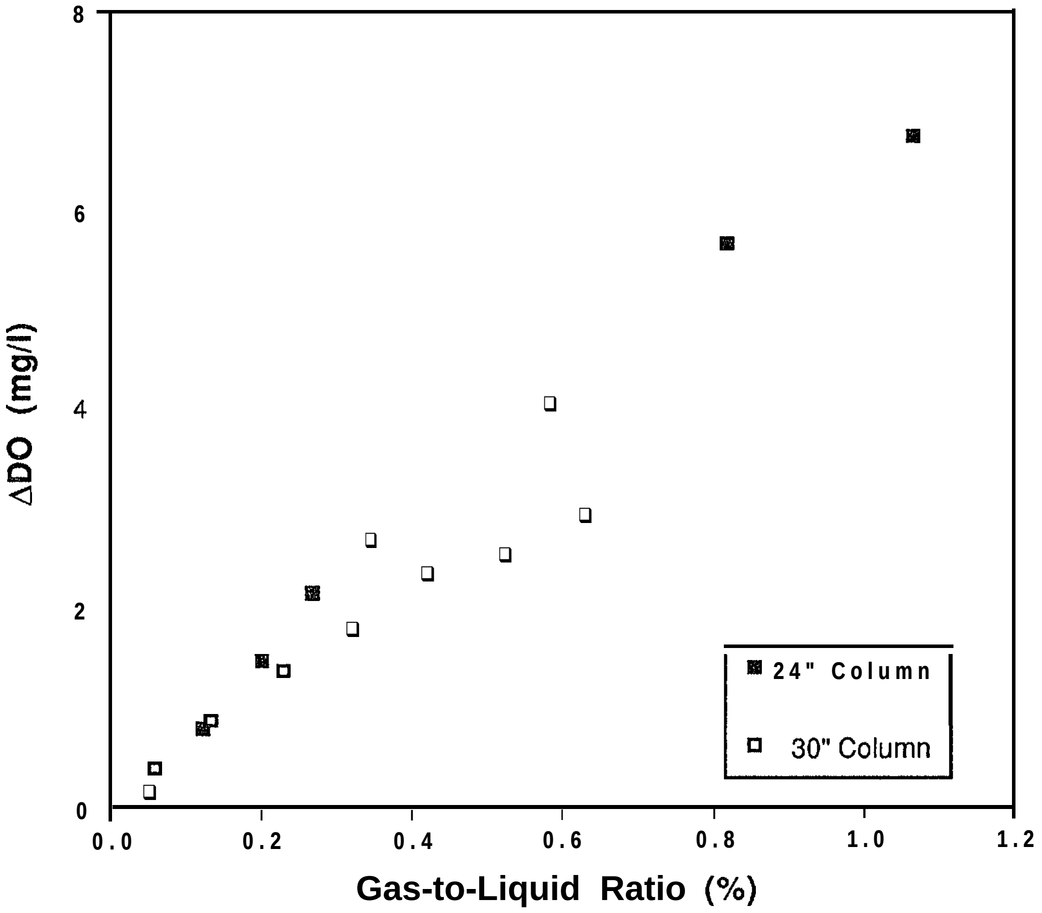


Figure 21 The Change in Dissolved Oxygen (ADO) as a Function of Gas-to-Liquid Ratio and Column Size

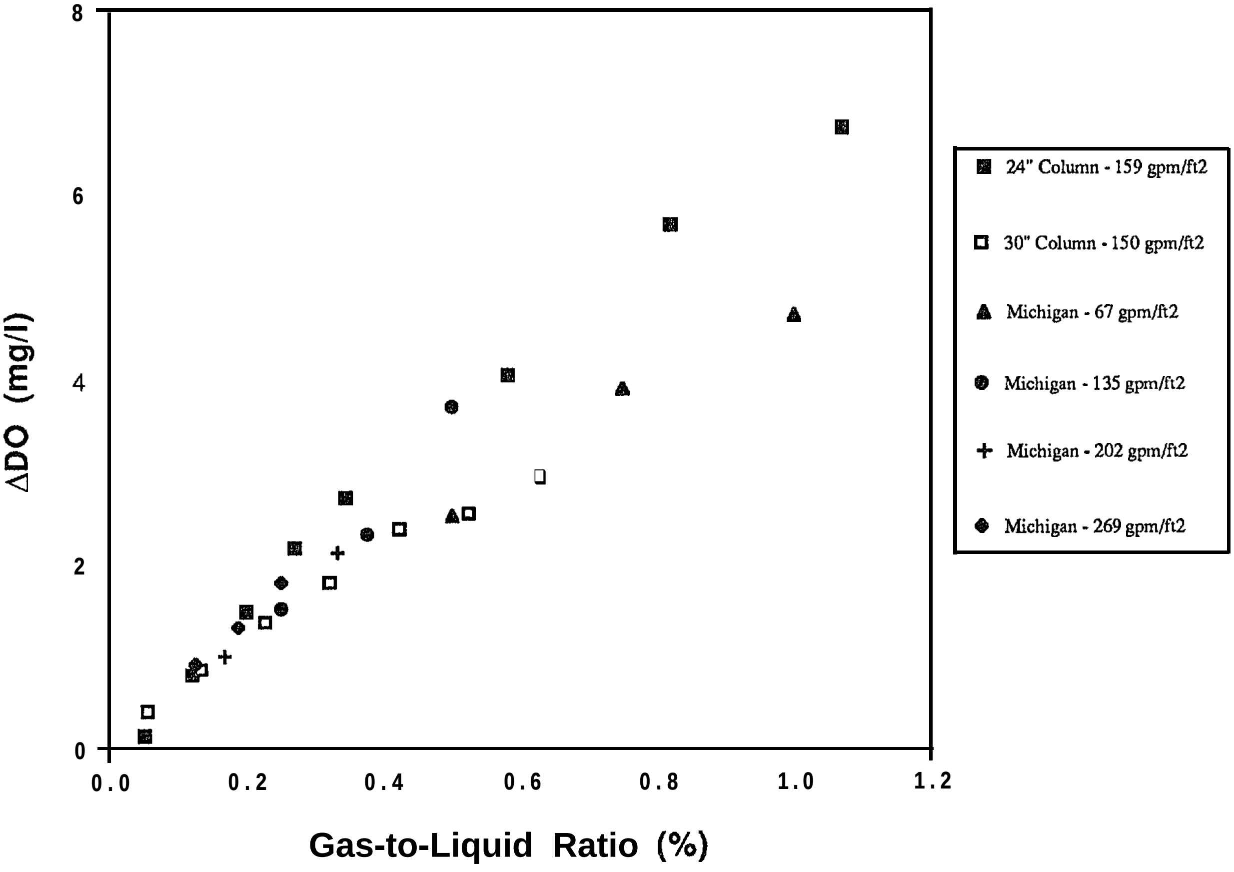


Figure 22 Comparison of the Change in Dissolved Oxygen (ADO) at Williamette Hatchery with Michigan Pure Oxygen Columns (Westers et al., In Press)

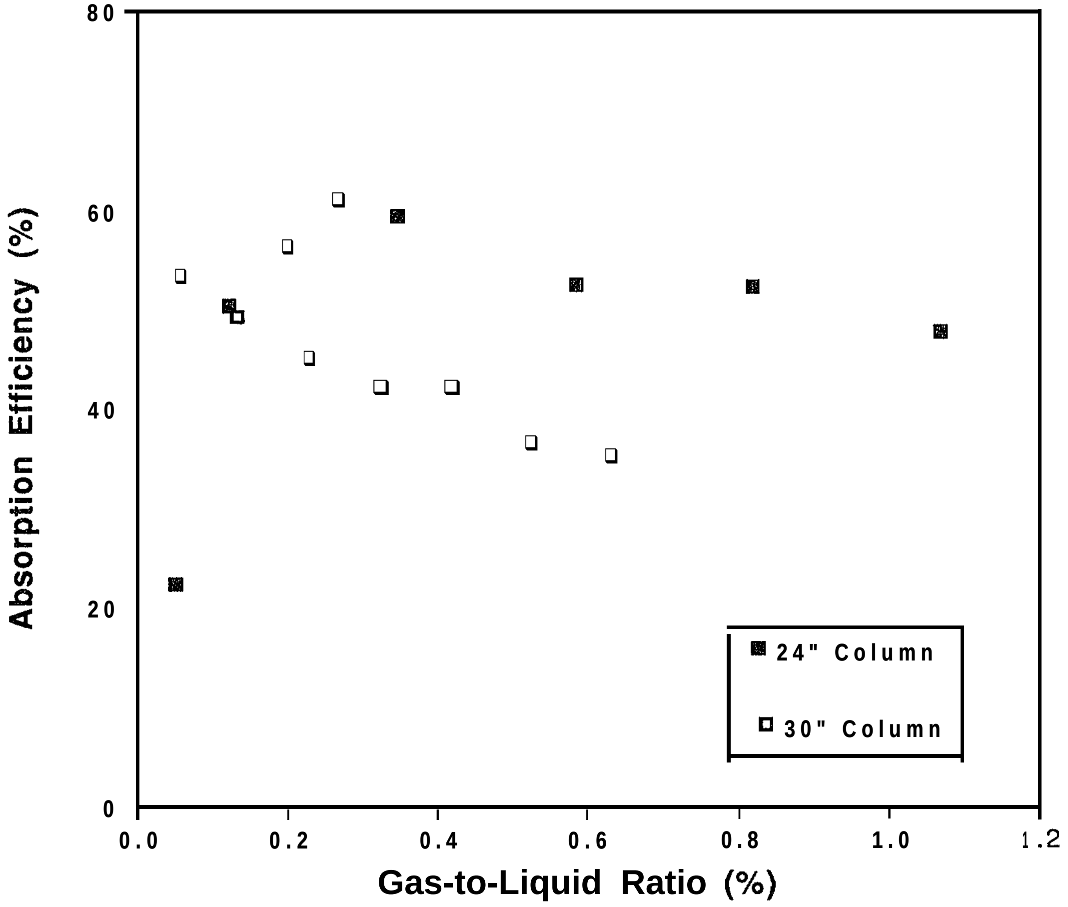


Figure 23 Absorption Efficiency as a Function of Gas-to-Liquid Ratio and Column Size

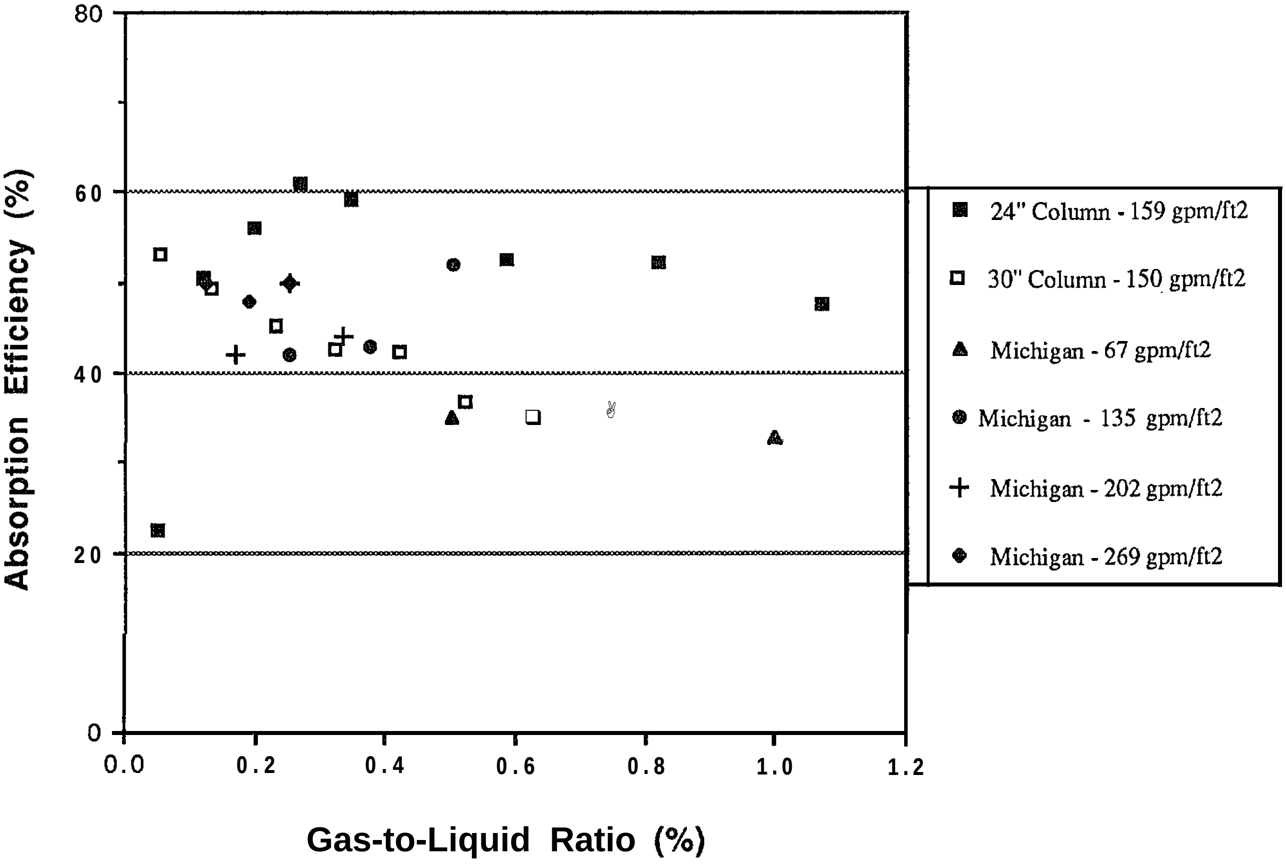


Figure 24 Comparison of Absorption Efficiency at Williamette Hatchery with Michigan Pure Oxygen Columns (Westers et al, In Press)

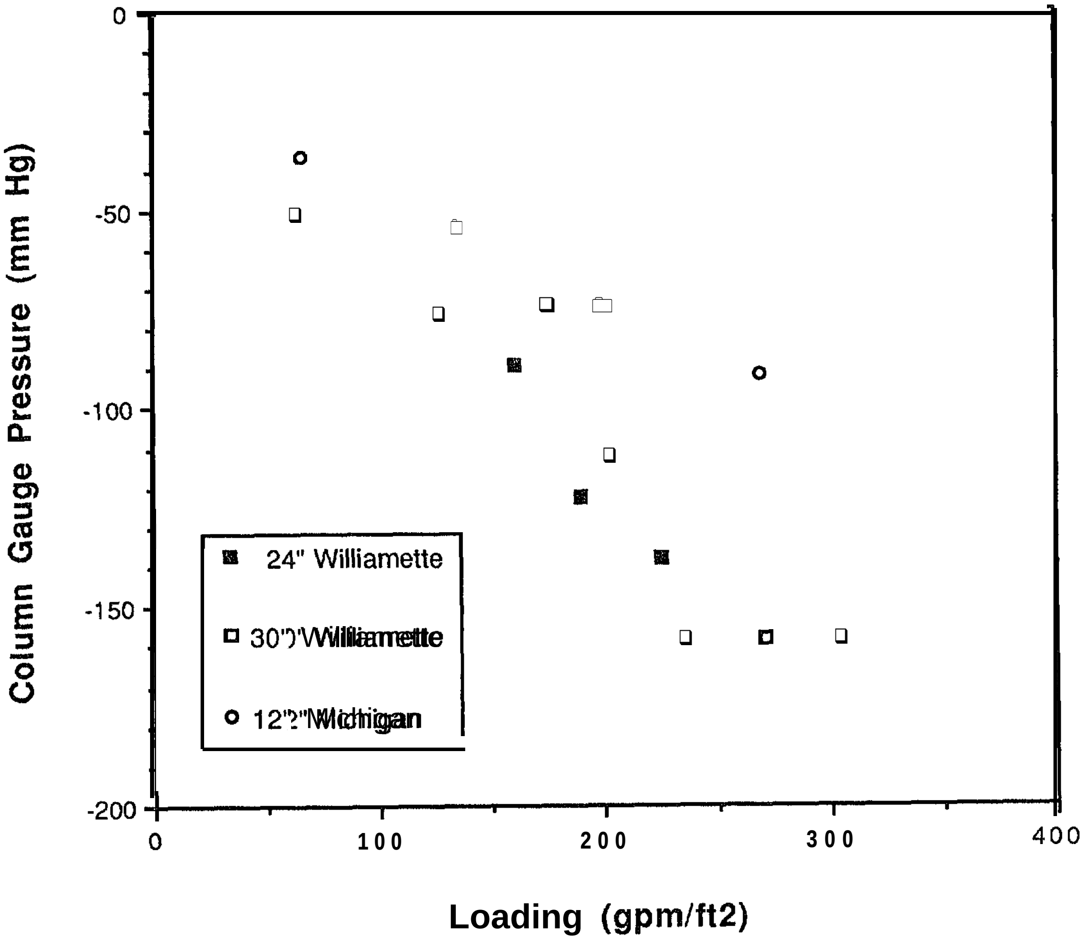


Figure 25 Effect of Hydraulic Loading on Column Pressure (based on Westers et al., In Press and the 24 inch column at Williamette)

Conclusions and Recommendations

The performance of the pure oxygen columns at the Williamette Hatchery was tested during May, 1990. The columns used at the Williamette Hatchery are based on similar units used by the Michigan Department of Natural Resources.

Performance Evaluation

The absorption efficiency of the 24 and 30 inch *Williamette Hatchery Oxygen Transfer Columns* ranged from 30 to 60%, which is comparable to published information on the Michigan columns. In general, the performance of the 24 inch column was superior to that of the 30 inch column or the Michigan columns. The geometry and internal construction *of* the *Williamette Hatchery Oxygen Transfer Columns* differ from the Michigan columns in several important *ways.*

The performance of the LHO systems appears promising and the purchase and testing of a full-sized unit is highly recommended. Additional testing of the prototype unit is probably not warranted unless additional hardware is installed.

Impact of Absorption Efficiency on Annual Oxygen Costs

The yearly oxygen demand for the Williamette Hatchery oxygen supplementation project is estimated to be 31,713 lb. Based on a oxygen purity of 99.6% and oxygen costs of \$0.40/100 **ft^3,** the yearly cost of oxygen is estimated below for various absorption efficiencies:

Absorption Efficiency (%)	Annual Oxygen Cost ($)	Decrease in Oxygen cost ($)
100	1526	170
90	1696	339
75	2035	1018
50	3053	3053
25	6106	----

Increasing the absorption efficiency from 50 to 75% would decrease oxygen costs of the present project by only approximately $1018/year, which is small compared to the annual project cost. The pure oxygen system at Williamette is designed for experimental purposes, therefore the existing system is adequate.

Additional Experimental Work

While oxygen is not a major cost in the present experimental system, it will be much more critical in full-scale applications. It was necessary to build separate columns for this experiment, but a centralized system may be more cost-effective in larger applications.

There is considerable interest in the use of the Michigan type column in the Pacific Northwest and better definition of their operating characteristics or improvement in their performance would be useful to hatchery operations. In addition, there are a number of other oxygen transfer system that may have potential in the Pacific Northwest.

The following additional experimental work is recommended:

(1) Test the impact of changing the diameter of the effluent piping. It may be desirable to test several different effluent pipe diameters.

Because of the sensitivity of the column performance on hydraulic loading, the modified column should be tested over a wide range of water flows.

(2) Test other oxygen transfer options such as the LHO, low-head spray systems with nozzles, low-head downflow bubble contact aerators, or direct injection of oxygen into the supply pipeline.

Acknowledgments

I would like to thank Tom Herbst, Bob Sohler, Joe Sheahan, and all the other hatchery personnel at the Williamette Hatchery for their help during testing.

Refereraces

Boersen, G. and J. Chesney. 1987. Pages 17-24 in Papers on the use of supplemental oxygen to increase hatchery rearing capacity in the Pacific Northwest, Bonneville Power Administration, Portland, Oregon.

Bouck, G. R. 1984. Annual variation of gas supersaturation in four spring-fed Oregon streams. Progressive Fish-Culturist, 46:139-l 40.

Clesceri, L. S., A. E. Greenberg, and R. R. Trussell. (editors). 1989. Standard methods for the examination of water and wastewater. 17th edition, American Public Health Association, Washington D.C.

Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure. American Fisheries Society Special Publication No. 14.

Colt, J. and B. Watten. 1988. Application of pure oxygen in fish Culture. Aquacultural Engineering 7:397-441.

FishPro, Inc. 1989. Williamette Hatchery Oxygen Supplementation. Project Drawing.

Gowan, R. 1987. Use of supplemental oxygen to rear chinook in seawater. Pages 35-39 in Papers on the use of supplemental oxygen to increase hatchery rearing capacity in the Pacific Northwest, Bonneville Power Administration, Portland, Oregon.

Hackney, G. E. and J. E. Colt. 1982. The performance and design of packed column aeration systems for aquaculture. Aquacultural Engineering, 1:275-295.

Severson, R. F., J. L. Stark, and L. M. Poole. 1987. Use of oxygen to commercially rear coho salmon. Pages 25-34 in Papers on the use of supplemental oxygen to increase hatchery rearing capacity in the Pacific Northwest, Bonneville Power Administration, Portland, Oregon.

Speece, R. E., M. Madrid, and K. Needham. Downflow Bubble Contact Aeration. Journal of the Sanitary Engineering Division, ASCE, 97:433-441.

Watten, B., J. Colt, and C. Boyd. In Press. Modeling the effect of dissolved nitrogen and carbon dioxide on the performance of pure oxygen absorption systems. American Fisheries Society Symposium Number 8.

Westers, H. V. Bennett, and J. Copeland. 1987. Michigan's Experience with Supplemental Oxygen in Salmonid Rearing. Pages 12-16 in Papers on the use of supplemental oxygen to increase hatchery rearing capacity in the Pacific Northwest, Bonneville Power Administration, Portland, Oregon.

Westers, H., G. Boersen, and V. Bennett. In Press. Design and Operation of Sealed Columns to Remove Nitrogen and Add Oxygen. Proceedings of the Fisheries Bioengineering Symposium, American Fisheries Symposium Series Number 8.

Appendix A Experimental Data From The Williamette Hatchery

Table A-l Data for 24 inch Column at Design Hydraulic Loading (159 gpm/ft^2)

Rotameter Reading	Gas Flowrate (dh Oxygen)	Gas Flowrato (scfh Oxygen)	Q/L (%)	Column Press. (inches of Hg)	Air Temp. (F)	AE (%)	Available DO (lb/hr)	DO Added (lb/hr)	ΔDO (mg/l)	Water Flow (gpm)
13	2.04	2.01	0.05%	4.2	61	22.49%	1.10	0.04	0.15	510
25	4.95	4.90	0.1%	4.1	56	50.39%	1.21	0.20	0.60	506
36	7.90	7.89	0.20%	3.6	60	56.19%	1.35	0.36	1.47	495
48	10.64	10.64	0.27%	3.5	61	61.05%	1.52	0.54	2.16	504
56	13.67	13.69	0 34%	3.4	61	60.37%	1.64	0.66	2.70	503
00	23.33	23.46	0.66%	3.2	61	62.66%	1.90	1.01	4.05	501
119	32.69	32.61	082%	3.1	65	52.36%	2.39	1.41	5.66	499
147	43.04	43.16	107%	3.1	66	47.66%	2.69	1.60	6.73	503

Rotsmeter Reading	Column-out Barometric Pres. (mm Hg)	Column-out Temperature (C)	Column-out PPoxygen (mm Hg)	Column-out DOout (mg/l)	Column-out ΔP (mm Hg)	Column-out Pwa (mm Hg)	Column-out Nitrogen (%)
13	733	0.3	156	11.30	16	6.76	102.61%
26	734	0.4	162	11.76	20	6.64	101.77%
36	734	9.6	172	12.45	23	6.96	100.54%
48	734	0.9	161	13.02	25	9.14	99.31%
66	734	10.1	169	13.53	26	9.26	98.09%
90	734	10.4	210	14.93	23	9.46	93.89%
119	734	10 2	232	16.67	23	9.32	90.05%
147	734	10.1	247	17.66	21	9.26	67.09%

Rotameter Reading	Column-in Barometric Pres. (mm Hg)	Column-h Temperature (C)	Column-in PPoxygen (mm Hg)	Column-h DOin (mg/l)	Column-h ΔP (mm Hg)	Column-In Pwa (mm Hg)	Column-in Nitrogen (%)
13	733	9.3	153	11.16	7	6.76	101.04%
25	734	9.7	152	10.96	3	9.02	100.54%
36	734	9.7	152	10.96	6	9.02	101.07%
46	734	10.2	152	10.66	5	0.32	100.66%
66	734	10.3	152	10.63	4	9.30	100.70%
90	734	10.1	152	10.66	3	9.26	100.53%
119	734	10.0	152	10.01	6	9.20	101.41%
147	734	10.1	153	10.95	14	9.26	102.26%

Table A-2 Data for 24 inch Column at Reduced Water Flows

Rotameter Reading	Gas Flowrate (cfh Oxygen)	Gas Flowrate (sdh Oxygen)	WL (%)	Column Press. (inches of Hg)	Air Temp. (F)	AE (%)	Available 0 0 (lb/hr)	DO Added (lb/hr)	ΔDO (mg/l)	Water Flow (gpm)
148	43.45	44.77	2.79%	2.0	61	29.17%	1.48	1.07	10.74	200
73	18.11	16.24	0.67%	3.0	66	62.70%	1.76	0.04	4.71	400
60	14.49	14.37	0.36%	3.6	70	58.54%	1.76	0.69	2.75	604
50	11.42	11.14	0.23%	4.6	61	66.67%	1.97	0.79	2.66	598
43	0.56	9.19	0.16%	5.4	62	79.61%	1.05	0.6	1.7	706

Rotameter Reading	Column-out Barometric Pres (mm Hg)	Column-out Temperature (C)	Column-out PPoxygen (mm Hg)	Column-out DOout (mg/l)	Column-out ΔP (mm Hg)	Column-out Pwa (mm Hg)	Column-out Nitrogen (%)
148	736	9.2	296	21.76	8	0.72	76.09%
73	736	6.5	214	15.90	23	a.32	03.33%
60	736	6.2	188	14.06	16	8.16	96.96%
50	736	9.2	186	13.59	17	a.72	97.14%
43	736	9.4	172	12.51	4	8.84	97.31%

Rotameter Reading	Column-in Barometric Pres (mm Hg)	Column-in Temperature (C)	Column-In PPoxygen (mm Hg)	Column-h DOin (mg/l)	Column-In ΔP (mm Hg)	Column-in Pwa (mm Hg)	Column-in Nitrogen (%)
148	736	9.2	161	11.04	5	a.72	101.15%
73	736	a.9	152	11.10	5	8.54	100.98%
60	735	a.4	152	11.32	a	a.26	101.47%
50	736	9.3	150	10.94	6	a.70	101.32%
43	736	9.5	149	10.81	6	8.90	101.66%

Table A-3 Data for 30 inch Columns at Design Hydraulic Loading (150 gpm/ft^2)

Rotameter Reading	Gas Flowrate (cfh Oxygen)	Gas Flowrate (scfh Oxygen)	WL (%)	Column Press. (inches of Hg)	Air Temp. (F)	AE (%)	Available 0 0 (lb/hr)	DO Added (lb/hr)	ΔDO (mg/l)	Water Flow (gpm)
20	3.58	3.32	0.06%	6.2	81	53.25%	1.27	0.15	0.39	751
39	8.61	7.96	0.13%	6.2	85	49.30%	1.45	0.32	0.06	749
60	14.40	13.72	0.23%	6.2	60	46.20%	1.57	0.51	1.36	749
60	20.15	19.03	0.32%	6.3	59	42.68%	2.30	0.67	1.60	739
100	26.45	24.93	0.42%	6.2	64	42.31%	2.43	0.67	2.35	736
120	33.03	31.00	0.52%	6.2	68	36.74%	2.48	0.94	2.53	740
139	39.79	37.34	063%	6.2	67	35.26%	2.49	1.08	2.93	740

Rotameter Reading	Column-out Barometric Pres. (mm Hg)	Column-out Temperature (C)	Column-out PPoxygen (mm Hg)	Column-out DOout (mg/l)	Column-out ΔP (mm Hg)	Column-out Pwa (mm Hg)	Column-out Nitrogen (%)
20	736	11.9	151	10.38	6	10.44	101.05%
39	735	12.4	160	10.88	3	10.79	00.12%
60	735	12.2	164	11 20	0	10.85	97.90%
80	733	8.0	176	13.23	1	6.04	06.00%
100	734	8.1	181	13.57	2	8 09	96.34%
120	734	a.4	184	13.70	2	6.26	94.81%
139	733	8.8	186	13.72	1	8.40	94.24%

Rotameter Reading	Column-in Barometric Pres. (mm Hg)	Column-in Temperature (C)	Column-in PPoxygen (mm Hg)	Column-in DOin (mg/l)	Column-in ΔP (mm Hg)	Column-h Pwa (mm Hg)	Column-in Nitrogen (%)
20	735	12.1	146	10.00	9	10.58	102.62%
39	735	12.3	147	10.02	6	10.72	101.91%
60	735	12.5	145	9.84	4	10.66	101.91%
80	734	8.0	152	11.43	a	8.04	101.45%
100	734	8.2	150	11.22	4	6.15	101.10%
120	733	a.4	150	11.17	1	6.26	100.53%
139	732	9.0	147	10.70	3	8.60	101.36%

Table A-4 Data for 30 inch Column at Reduced Water Flows

Rotameter Reading	Gas Flowrate (cfh Oxygen)	Gas Flowrate (scfm Oxygen:	WL (%)	Column Press. (Inches of Hg)	Air Temp. (F)	A5 (%)	Available DO (lb/hr)	DO Added (lb/hr)	ΔDO (mg/l)	Water Flow (gpm)
					74					
63	15.37	14.34	0 1 %	6.2	71	46.06%	2.16	0.54	1.14	967
70	17.30	16.17	0.24%	6.2		35.64%	1.06	0.46	1.12	652
77	10.24	17.96	0.30%	6.2	71	42.69%	1.96	0.63	1.71	742
90	23.33	22.57	0.44%	4.4	76	65.57%	2.10	1.03	3.23	636
109	20.30	29.12	0.66%	2.6	81	61.61%	2.12	1.24	4.51	546

Rotsmeter Reading	Column-out Barometric Pres. (mm Hg)	Column-out Temperature (C)	Column-out PPoxygen (mm Hg)	Column-out DOout (mg/l)	Column-out ΔP (mm Hg)	Column-out Pwa (mm Hg)	Column-out Nitrogen (%)
63	733	10.5	163	11.56	10	9.51	00.70%
70	732	10.2	163	11.64	8	0.32	00.41%
77	732	0.7	170	12.26	2	0.02	07.14%
90	733	10.0	103	13.57	30	0.77	96.03%
109	733	11.0	210	14.73	10	9.84	03.13%

Rotameter Reading	Column-in Barometric Pres. (mm Hg)	Column-h Temperature (C)	Column-in PPoxygen (mm Hg)	Column-in DOin (mg/l)	Column-in ΔP (mm Hg)	Column-in Pwa (mm Hg)	Column-in Nitrogen (%)
63	733	10.5	147	10.43	10	9.51	102.60%
70	732	10.1	147	10.52	12	9.26	102.91%
77	732	0.0	147	10.57	11	9.14	102.74%
90	733	10.9	147	10.33	1	0.77	101.00%
100	733	11.1	146	10.22	8	9.9	102.40%

Table A-5 Data for LHO System

Rotameter Reading	Gas Flowrate (dh Oxygen)	Gas Flowrate (scfh Oxygen)	WL (%)	Column Press. (Inches of Hg)	Air Temp. (F)	AE (%)	Available DO (lb/hr)	DO Added (lb/hr)	ΔDO (mg/l)	Water Flow (gpm)
10	0.5	0.53	0.61%	0	60	61.37%	0.0491	0.0260	4.94	10.9
10	0.5	0.53	0.61%	0	60	41.85%	0.0406	0.0164	3.37	10.9
10	05	0.53	0.61%	0	60	27.90%	0.0344	0.0122	2.24	10.9

Rotameter Reading	Column-out Barometric Pres. (mm Hg)	Column-out Temperature (C)	Column-out PPoxygen (mm Hg)	Column-out DO (mg/l)	Column-out ΔP (mm Hg)	Column-out Pwa (mm Hg)	Column-out Nitrogen (%)
10	732	a.2	214	16.01	13	8.15	91.41%
10	732	6.2	103	14.44	9	8.15	94.36%
10	732	6.2	178	13.32	10	8.15	97.18%

Rotameter Reading	Column-in Barometric Pres. (mm Hg)	Column-in Temperature (C)	Column-in PPoxygen (mm Hg)	Column-h DOIn (mg/l)	Column-in ΔP (mm Hg)	Column-In Pwa (mm Hg)	Column-In Nitrogen (%)
10	732	6.2	146	11.07	6	6.15	102.07%
10	732	a.2	146	11.07	6	6.15	102.07%
10	732	6.2	146	11.07	8	8.15	102.07%

Appendix B Data On The Michigan Columns

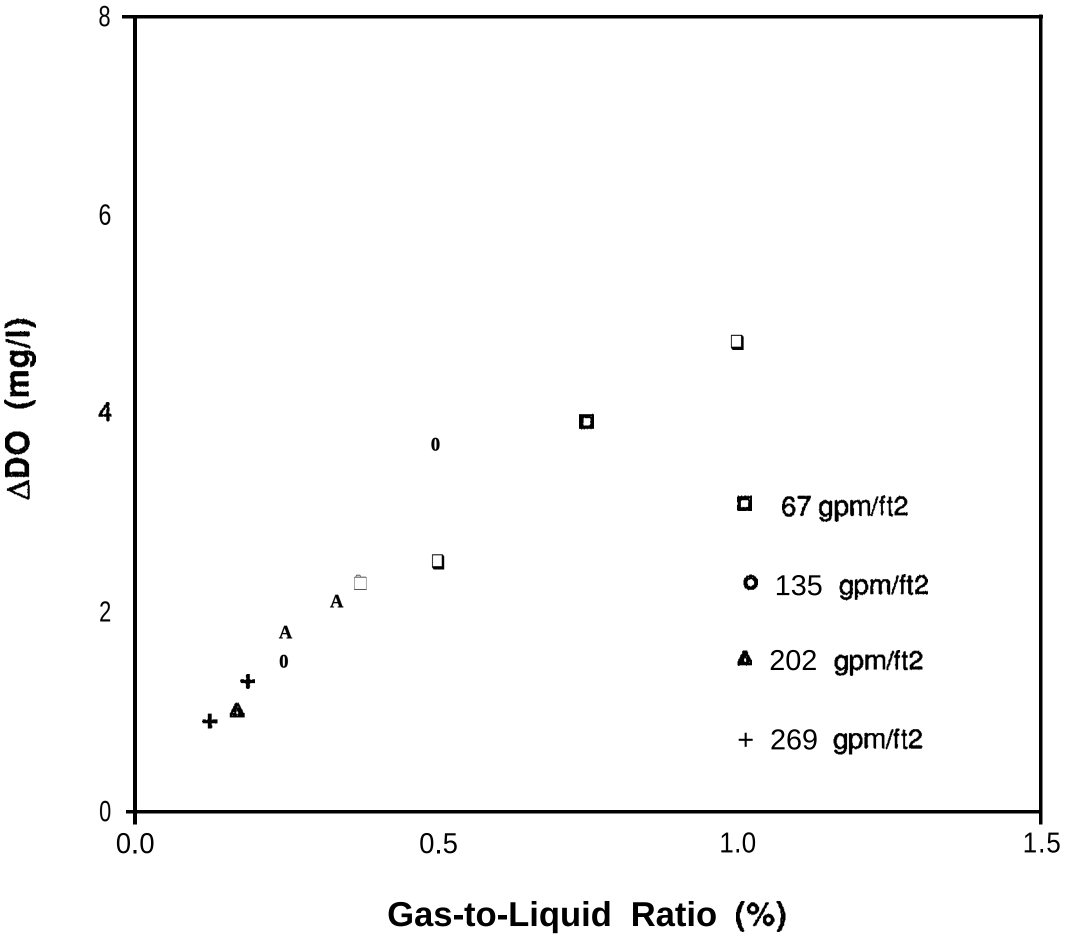


Figure B-l The Change in Dissolved Oxygen (ADO) as a Function of Gas-to-Liquid Ratio and Hydraulic Loading Rate - 12 Inch Column (Westers et al., In Press)

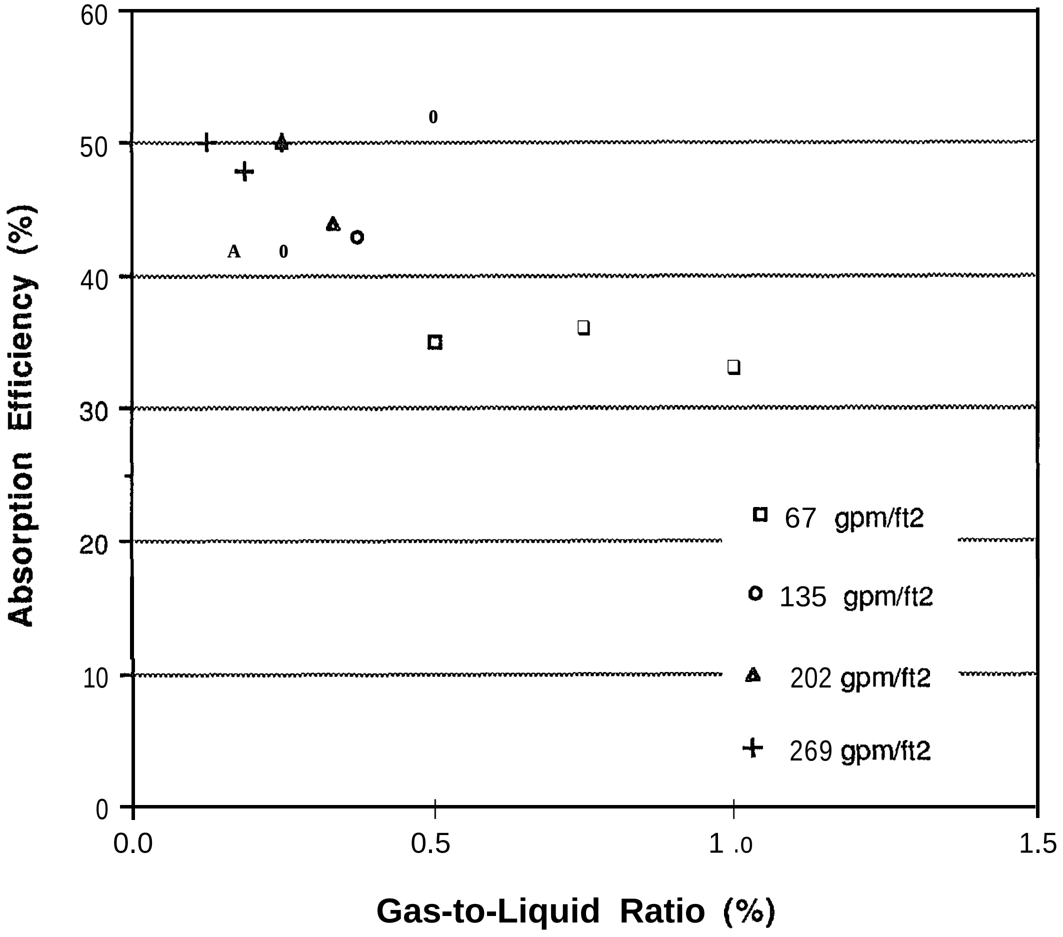


Figure B-2 Absorption Efficiency as a Function of Gas-to-Liquid Ratio and Hydraulic Loading Rate - 12 Inch Column (Westers et al., In Press)

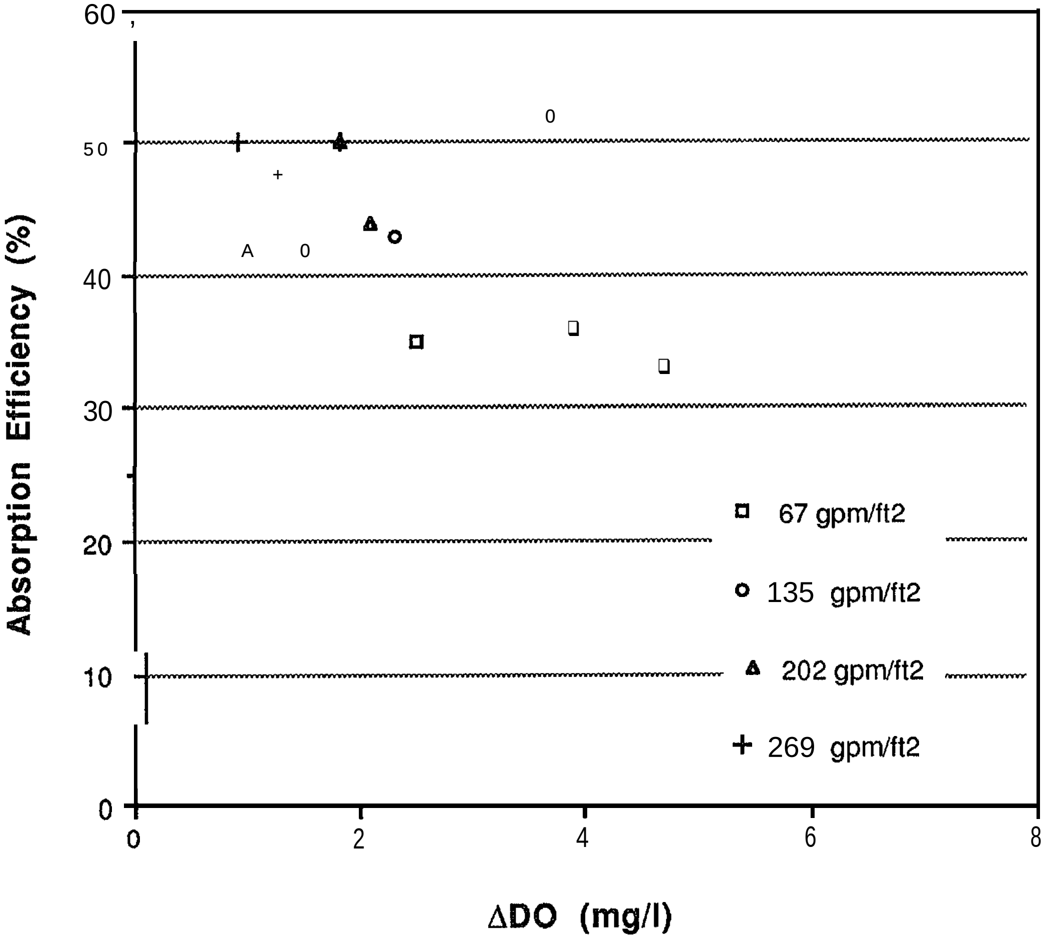


Figure B-3 Absorption Efficiency as a Function of **ADO** and Hydraulic Loading Rate - 12 Inch Column (Westers et al., In Press)