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THE FEASIBILITY OF USING SIPHONS FOR DEGASSING WATER

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INTRODUCTION

Supersaturation of dissolved gases in water supplies of fish hatcheries has been a problem for many years (Marsh and Gorham 1904). Recently, elaborate and expensive electro-mechanical aeration systems have been employed to lower the dissolved nitrogen levels to acceptable concentrations. Hatcheries such as Dworshak (U.S. Fish and Wildlife Service) on the Clearwater River in Idaho; Blue Creek (Washington State Department of Game) on the Cowlitz River; and South Santiam (Oregon Department of Fish and Wildlife) on the South Santiam River have been constructed with permanent degassing equipment installed to reduce intermittently high supersaturation levels in either well or river water.

Many systems currently in use, however, do not readily lower saturation to acceptable levels, i.e., below 105% (Wood 1968)[1/]. In addition, they are subject to mechanical failure and human error. To overcome these inherent problems is costly; consequently, simple alternative solutions to the supersaturation problem are needed.

The U.S. Army Corps of Engineers (CofE) is intermittently faced with problems of water supersaturated with nitrogen or atmospheric gas at CofE operated dams or from water supply sources selected for use at CofE-funded fish hatcheries. The latest potential problem is related to the use of water from the tailrace of Lost Creek Dam (Rogue River, Oregon) for a hatchery, although this new dam was designed to eliminate the problem of supersaturation. The CofE, therefore, needed to consider various methods of degassing this water.

1/ Wood, J. W. 1968. Diseases of Pacific salmon; their prevention and treatment. Wash. Dep. Fish., Hatchery Div., Olympia, 73 p.

The CofE issued a contract to the National Marine Fisheries Service to conduct the study of siphons as degassing devices. The specific objectives were to determine: (1) general degassing efficiency that can be obtained with siphons, (2) siphon-design parameters of most importance to the degassing efficiency, and (3) general problems associated with the operation of siphons. Findings are described in this report.

PRINCIPLES OF SIPHON OPERATION

The use of a siphon for degassing water provides a distinct advantage over standard degassing methods now in use because standard methods are made to operate at atmospheric pressure. As a general principle, the higher the saturation value above 100%, the more readily gas can be removed from solution. Therefore, as saturation values are lowered and approach 110%, degassing efficiency of standard methods is markedly reduced.[2/] A siphon overcomes this problem by subjecting the column of water to a significantly lower pressure. This has the effect of raising the saturation value--thus increasing degassing efficiency.

As shown in Figure 1, a vacuum head of 16.7 feet doubles the saturation value (100 to 200%) and an additional increase of only 8.4 feet (to 25.1 feet of vacuum head) doubles the saturation value again (200 to 400%). Above 25 feet of vacuum head, 4.2 feet of additional vacuum will elevate saturation values from 400 to 800%. Degassing methods of any kind should be many times more efficient at these high levels of supersaturation.

2/ Subsequent to completion of the study a method of degassing using coke rings was tested and appears to be of considerable merit for degassing large water volumes down to a safe level of saturation. (Owsley, David E. Aug. 1977. U.S. Fish Wildl. Serv., Dworshak Hatchery, Orofino,Idaho.)

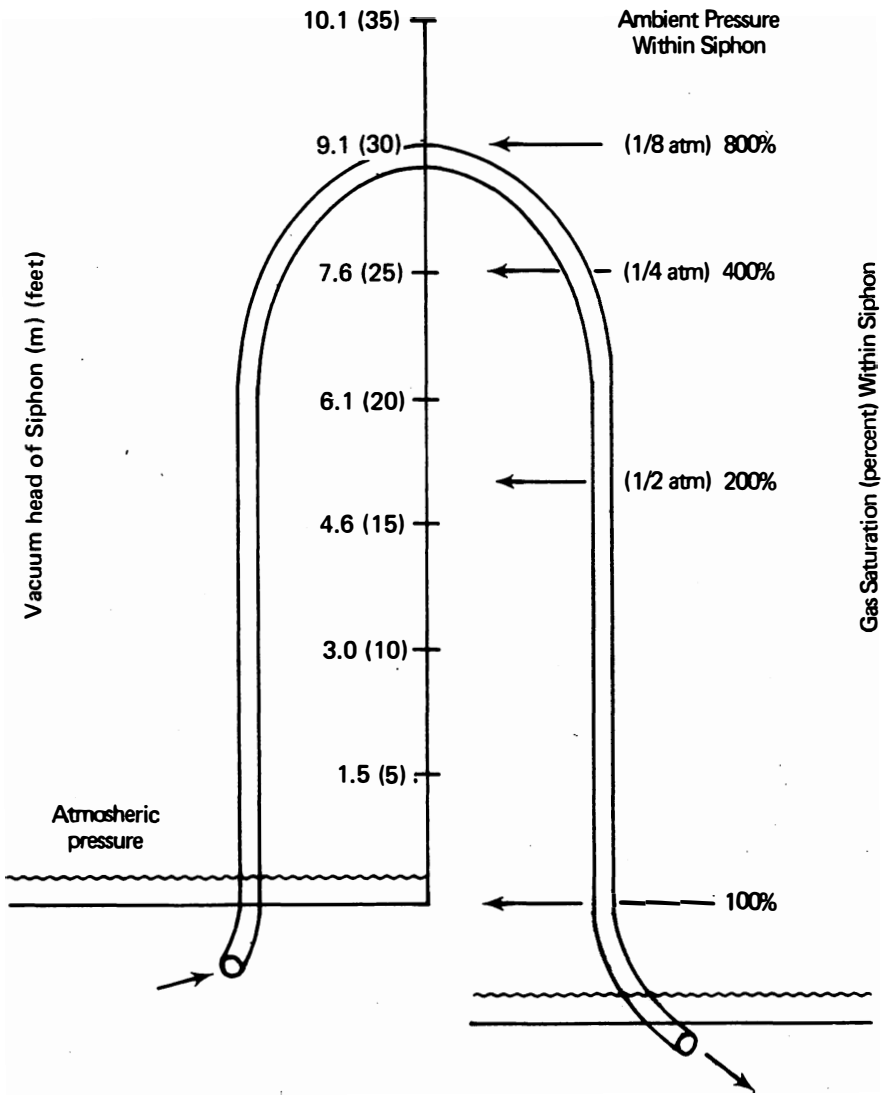


Figure 1.--Effect of vacuum head on saturation value (atmospheric gases dissolved in water) within a siphon.

The rate of degassing of a siphon of a given design depends upon several factors: (1) the total gas content of the water entering the siphon intake; (2) the vacuum head of the siphon, which determines the maximum percent supersaturation; (3) the time of passage of the water through the apex (the area of reduced pressure within the siphon); and (4) the turbulence of the water as it passes through the region of reduced pressure.

Degassing efficiency is not constant throughout the apex of a siphon; i.e., as gas is released from the water, the saturation level is reduced, and the rate of degassing decreases. This is in keeping with the general principle that the higher the gas content, the more readily gas can be removed.

METHODS AND PROCEDURES

Available equipment was adapted for general tests to determine the feasibility of degassing water by means of siphons. A schematic illustration of the physical setup used is given in Figure 2.

In the tests conducted, the following factors were varied:

(1) Vacuum head (difference in elevation between supply reservoir water surface and the apex of the siphon).

(2) Static head (elevation difference from supply reservoir to discharge point of siphon).

(3) Length of siphon apex.

(4) Turbulence (as affected by water velocity, roughness of boundary layers, etc.).

(5) Gas content of water supply.

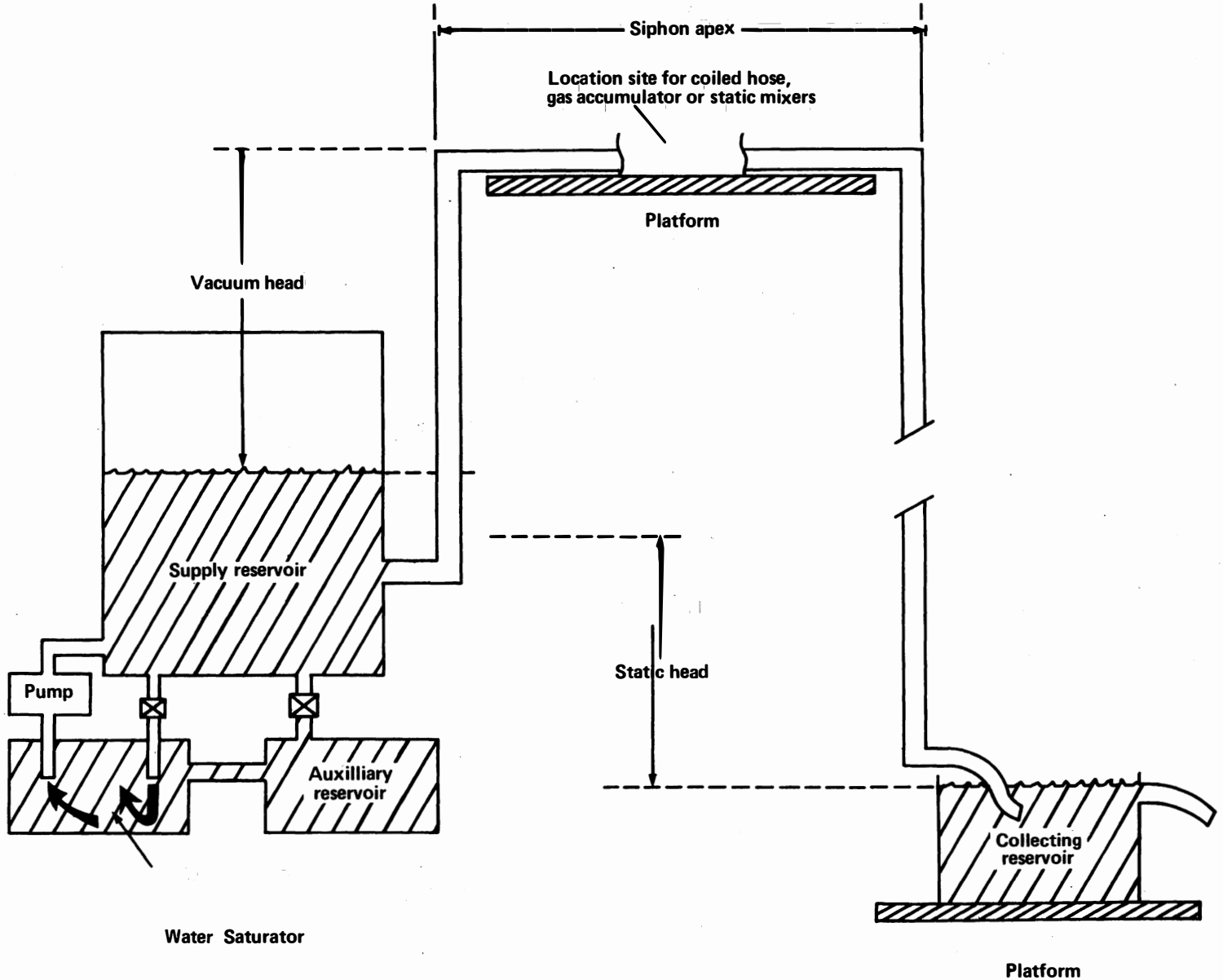
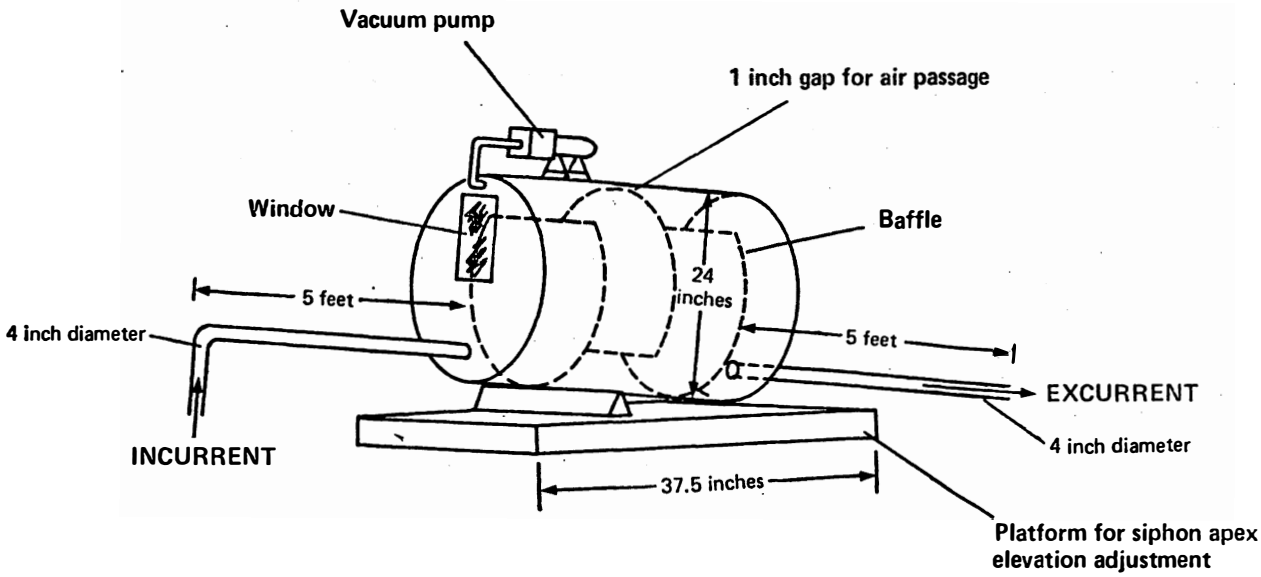


Figure 2.--Schematic illustration of equipment used in siphon study.

Prior to beginning a test, water in the supply reservoir was recirculated through a saturator and an auxiliary reservoir until all the water reached the desired level of gas saturation. During the test, water from the auxiliary reservoir was pumped into the supply reservoir to maintain a constant water level.

Siphons 100 to 200 feet long with apexes between 10 and 115 feet in length were tested. The apex of the siphon was on a platform that could be raised or lowered to produce various vacuum heads. When the length of the apex of the siphon exceeded 15 feet, the hose was coiled on the platform. The receiving reservoir also rested on a platform that could be raised or lowered to vary the static head.

Water velocity and turbulence were varied by using 2-, 4-, and 6-inch inside diameter (i.d.) hoses at different vacuum heads (the smaller the diameter of the hose and the greater the head, the greater the water velocity and turbulence). In some tests, the water velocity was insufficient to strip out the free gas as it formed, and the siphon would airlock. This was solved by installing a gas accumulator and vacuum pump at the apex of the siphon (Figure 3). The length of the 4-inch i.d. hose at the apex was restricted to 15 feet when the gas accumulator was used. The volume of water in the apex of the hose together with that in the gas accumulator was calculated to equal the water volume in 115 feet of 4-inch i.d. hose. We tested the assumption that use of the accumulator would allow reduction of the apex length without reducing degassing efficiency.



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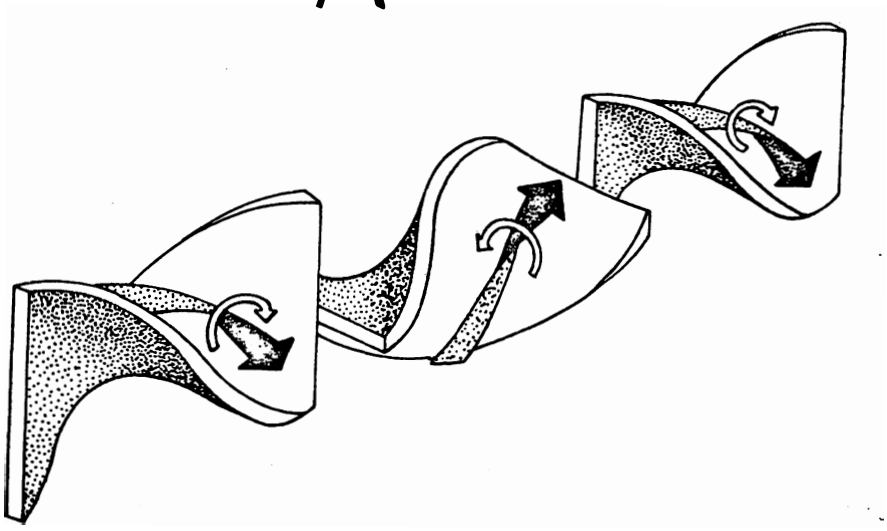

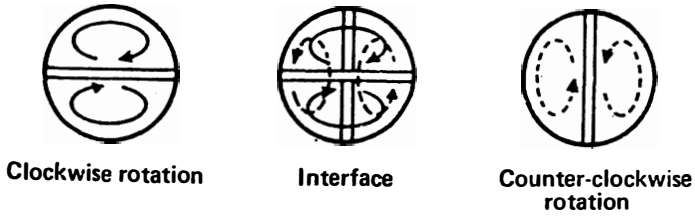

B

Figure 3.--Design of gas accumulator (A), and a short section of a static mixer with the outer shell cut away showing direction and rotation of water flow (B).

Finally, because turbulence was found to be an important factor in degassing efficiency, we tested two static mixers designed to increase the turbulence associated with a given water velocity. The mixers (by Kenics Corp. North Andover, Mass.[3/] described by Fisette and Chen 1975) were each 42 inches in length (Figure 3). They were placed in series at the apex of the siphon with equal lengths of hose between the first and second mixer and after the second mixer to create a siphon with an apex 15 feet long.

Each siphon test was run for 10 min. Water samples for dissolved gas analysis were taken simultaneously from the supply and collection reservoirs at the 5th, 8th, and 10th min. of operation. The average of these values was used for analysis. Water samples from the supply reservoir were taken below the water surface with a Van Dorn bottle, while water from the collection reservoir was taken by means of surgical tubing inserted about 1 foot below water level. Water temperature was measured before and after individual tests and ranged from 9.7 to 13.1^{o}C throughout the tests.

In some of the tests, we measured water velocity of the discharge of the siphon. This was calculated after determining the length of time required to fill a 53-gallon drum. Velocity as well as exposure time of the water to the siphon apex were computed. For those tests in which water velocity was not measured, we used the static head and siphon design to estimate velocity by referring to flow measurements made with similar siphons and static heads.

3/ References to trade name(s) do not imply endorsement of commercial product(s) by the National Marine Fisheries Service, NOAA.

Analysis of water samples for dissolved nitrogen was done with a gas chromatograph as described by Swinnerton, et al. 1962. The instrument was calibrated by measurements made with an Arthur H. Thomas modification of the Van Slyke-Neill manometric blood gas analyzer (Van Slyke and Neill 1924). The Alsterburg modified Winkler method was used to calibrate the gas chromatograph for determination of the dissolved oxygen levels (American Public Health Association 1971). Percentage saturation figures for both dissolved oxygen and dissolved nitrogen values were calculated from tables by Weiss (1970).

RESULTS

Because this was a feasibility study limited to determine the: (1) general degassing efficiency of a siphon, (2) siphon design parameters of most importance, and (3) general problems associated with siphon operation, the results do not lend themselves to derivation of specific formulas for siphon design or operation. However, the results do meet the basic objectives; demonstrate that siphons are effective in degassing water; and indicate that further, more sophisticated research should be conducted to refine and further develop the data generated.

Siphons tested in this study did an effective job of degassing water. As expected, degassing efficiency of various siphon designs depended on gas content of the water, vacuum head, turbulence, and length of the siphon apex (time of exposure of the water). Test results are graphically portrayed in Figures 4 to 10. Caution must be exercised regarding use of Figures 5 to 10, however. These figures are presented to show how degassing efficiency of siphons is influenced by various siphon design parameters. For this purpose, only two data points are necessary; however, the resulting graphs imply that rate of degassing is linear. But, we know this is not true because the rate of degassing decreases as gas content decreases.

Only a limited amount of data were obtained that demonstrates the lack of linearity (Figure 4). Figure 4 presents data showing the nonlinearity of the degassing rate for a specific set of siphon parameters. We find these data conform to the following formula:

$$Y = 113.612 - 5.685 \ln X$$

where, Y is percent saturation at standard pressure and X is time of exposure in seconds. The two constants, 113.612 and 5.685, are obtained from our test data. Clearly, a change in any single siphon parameter will result in a change in the degassing rate and, therefore, the formula.

The degassing efficiency of an unmodified hose-siphon is graphically demonstrated in Figure 5 which depicts a decrease in saturation from 114 to 87% in about 30 sec. This decrease occurred within a 200-foot length of 2-inch i.d. hose with 115 feet of the hose maintained at a 20-foot vacuum head at the apex.

The effect of increased vacuum head on degassing efficiency is illustrated in Figure 6. A 2-inch i.d. siphon, 115 feet long with 15 feet at the apex, reduced gas saturation 1.5% with 18-foot vacuum head and 8% with a 28-foot vacuum head. Exposure time at the apex was less than 3 sec.

Increasing turbulence enhances degassing efficiency. This is achieved by either reducing the diameter of the siphon, increasing water velocity within the same size siphon, or by the addition of static mixers. Results of tests with different diameter siphons implied that greater efficiency could be achieved with the 2-inch i.d. hose than the 4-inch i.d. hose (Figure 7).

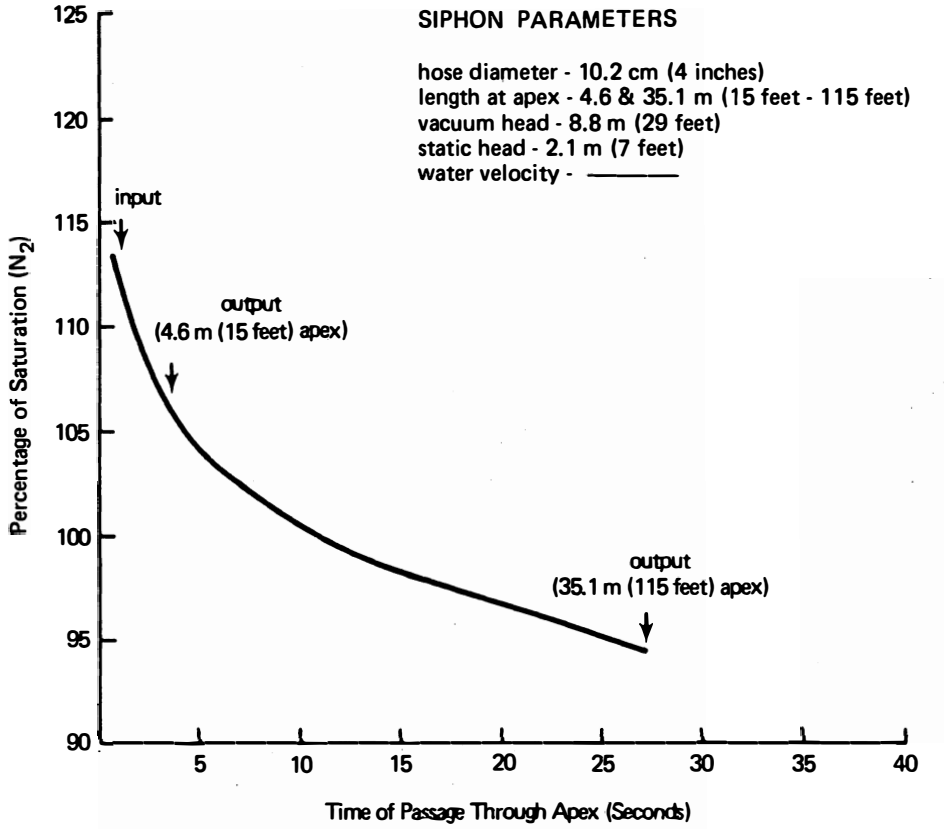

Figure 4.--Nonlinear rate of degassing: illustrated by change in N_2 concentration over time from two tests which were identical except for hose length at the apex (15' and 115') which produced two different times of exposure. The resultant curve may be expressed by $Y = 113.612 - 5.685 \ln X$ where Y is % of saturation N_2 and X is time of exposure.

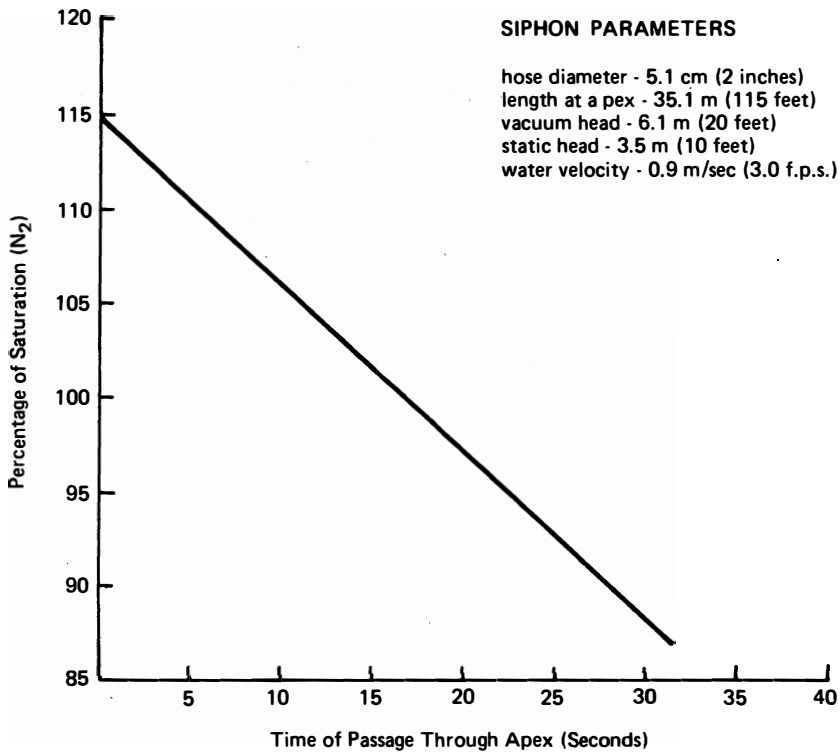

Figure 5.--Gas saturation can be easily reduced below 100% with unmodified hose siphon.

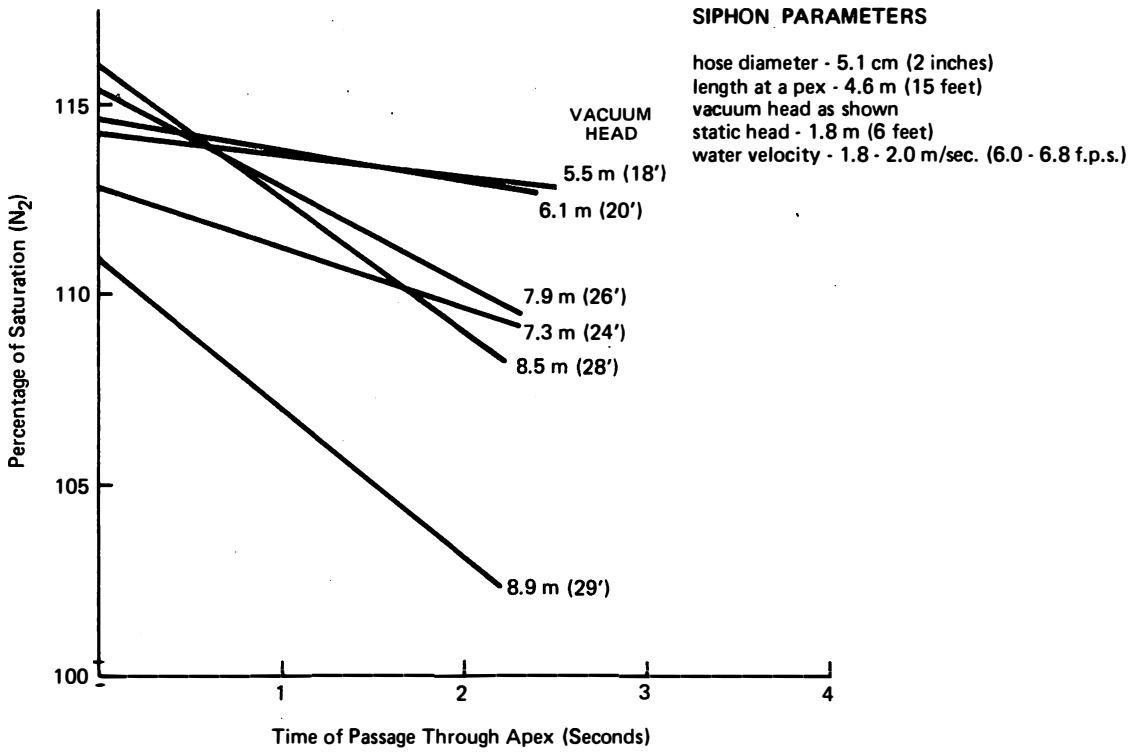

Figure 6.--Test series showing effect of varying vacuum head on degassing efficiency.

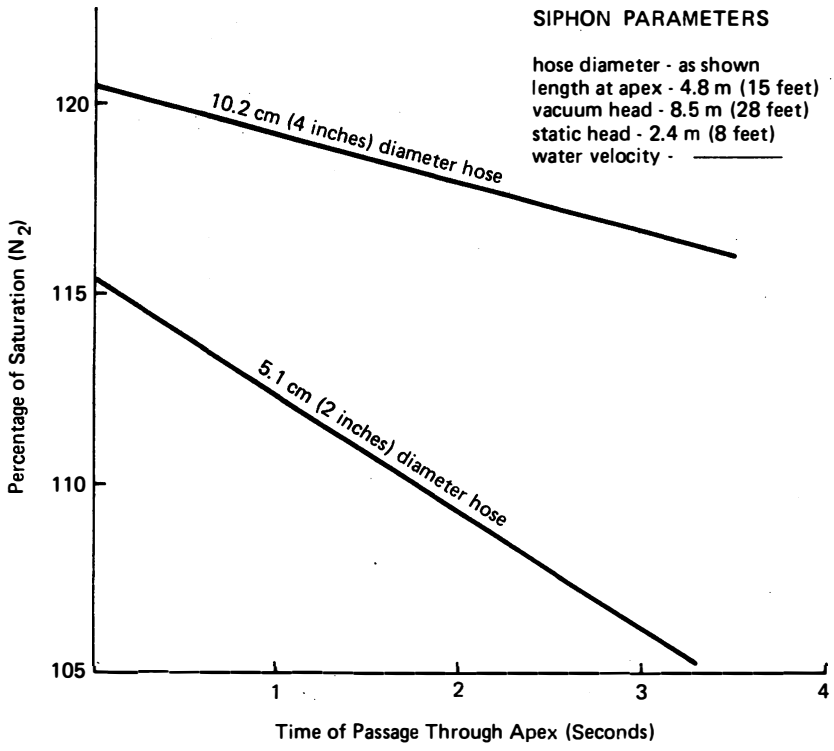

Figure 7.--Greater reduction of dissolved gas with smaller diameter hose implies that turbulence is an important factor in degassing efficiency.

At water velocities of 6.3 fps, a 4-inch i.d. siphon with a 115-foot apex and 28-foot vacuum head reduced the N_2 level from 124 to 95% of saturation in 18 sec (Figure 8). The same siphon at water velocities of 4.4 fps only reduced N_2 from 121 to 107% in that time. It required an additional 6 sec to reduce the N_2 to the normal 100% saturated level.

Static mixers in a 15-foot long apex lowered gas content from 112 to 90% in less than 5 sec, whereas the 4-inch i.d. siphon with 115 feet of coiled hose at the apex required 31 sec to lower gas content from 111 to 94% (Figure 9). Furthermore, these results were achieved with the relatively low water velocity of 3.2 fps. It appears from this series of tests that turbulence is more important to degassing efficiency than time of exposure.

In several tests, the siphon air locked and broke (Appendix Figure 1). This occurred at relatively low water velocities. Presumably the velocities must be sufficient to strip out the free gas as fast as it forms to prevent the gas from accumulating. This was corrected by installation of the gas accumulator.

We tested the assumption that a gas accumulator could be used to shorten the siphon apex without sacrificing degassing efficiency. Using 4-inch i.d. hoses, efficiency of a 10-foot long apex with a gas accumulator was compared with an unmodified siphon having a 115-foot long apex (the same internal volume at the apex as the 9.8 cu. ft. accumulator plus 10 feet of 4-inch i.d. hose). The test showed that a gas accumulator can be used to shorten a siphon apex without an appreciable change in degassing efficiency (Figure 10).

Average N_2 values for all tests are presented in Appendix Figure 1 and individual dissolved gas measurements and velocity measurements (converted to exposure time at the apex of the siphon) can be found in Appendix Tables 1 to 11.

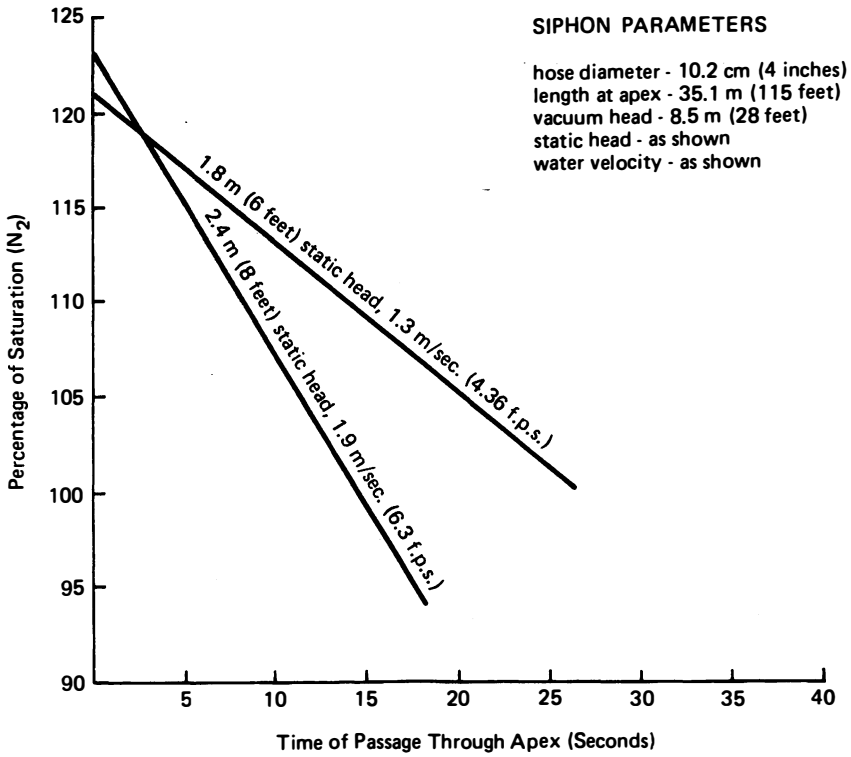

Figure 8.--Greater reduction of dissolved gas with higher velocities (increased turbulence) illustrates the importance of turbulence.

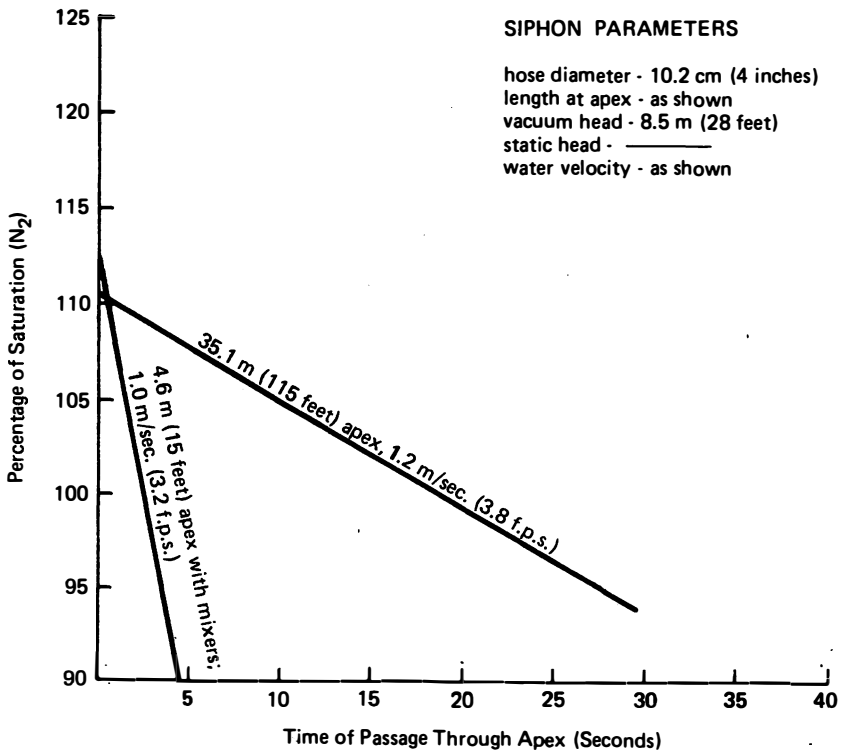

Figure 9.--Use of static mixers in siphon apex to create turbulence significantly increases degassing efficiency.

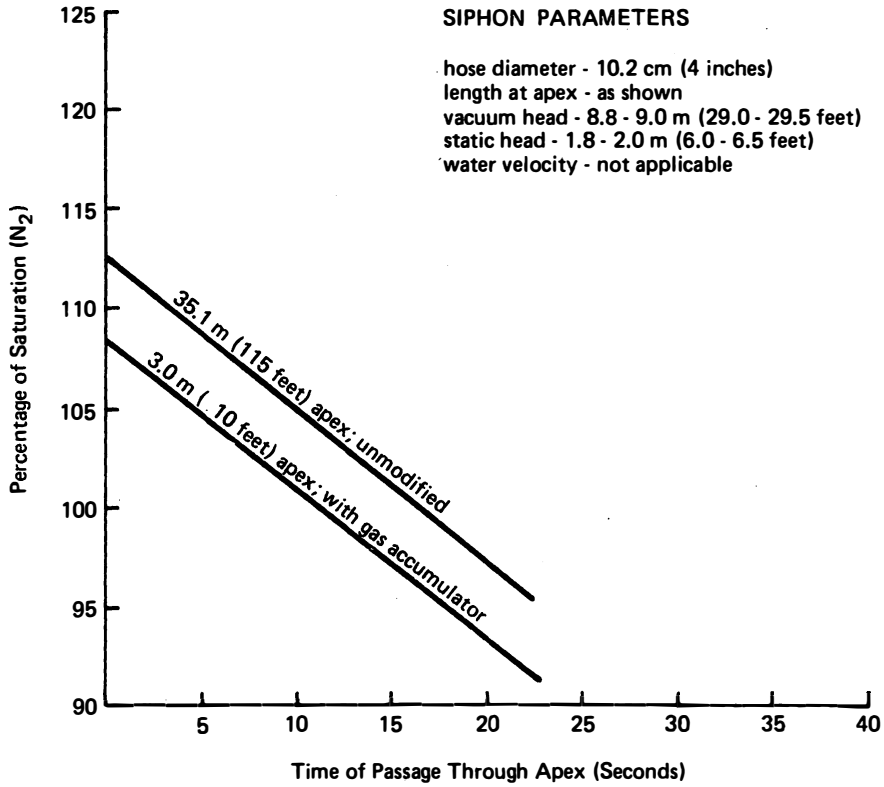

Figure 10.--Use of gas accumulator allowed apex length to be shortened without reducing degassing efficiency.

DISCUSSION AND RECOMMENDATIONS

The intent of this feasibility study was to generate data of sufficient reliability to enable researchers to: (1) draw general conclusions regarding the efficacy of siphons for degassing water and (2) to identify the most important variables for the process. We believe the data generated by this brief study have achieved these goals but caution the reader against using the data for designing siphons to achieve a specific level of degassing efficiency. For this purpose, we strongly recommend a more elaborate and more carefully conducted series of tests.

To provide a means of predicting the degassing efficiency of siphons of a given design, a general formula should be derived. Such a formula might take into account the following factors:

1. Total gas content of the water above 100% saturation at standard pressure, i.e., the input level.
2. Total gas content of the water above 100% saturation for the pressure at the apex of the siphon, i. e., vacuum head.
3. The Reynolds number (King 1954) of the conduit at the apex, or a suitable substitute associated with a special device used to increase turbulence.
4. Travel time of the water through the apex.

The empirical determination of the accurate degassing efficiency of various devices for increasing turbulence was beyond the scope of this study. Until such studies are completed, a general formula for use in designing prototype siphons cannot be derived.

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APPENDIX

Table 1. 2" i.d. siphon with 15 feet of 2" i.d. hose at the apex (supersaturated water source).

2. 2" i.d. siphon with 115 feet of 2" i.d. hose at the apex (supersaturated water source).

3. 4" i.d. siphon with 15 feet of 4" i.d. hose at the apex (supersaturated water source).

4. 4" i.d. siphon with 115 feet of coiled 4" i.d. hose at the apex (water source near normal saturation).

5. 4" i.d. siphon with 115 feet of 4" i.d. hose at apex (supersaturated water source).

6. 4" siphon with 65 feet of coiled 4" i.d. hose at the apex and 50 feet of coiled 4" i.d. hose about 10 feet above the discharge end (water source near normal saturation).

7. 4" i.d. siphon with 2-42" static mixers plus 96" of 4" i.d. hose at the apex (water source near normal saturation).

8. 4" i.d. siphon with 2-42" long x 4" i.d. static mixers plus 96" of 4" i.d. hose at the apex (supersaturated water source).

9. 4" i.d. siphon with reservoir tank (9.8 cu. ft.) at the apex (water source near normal saturation).

10. 4" i.d. siphon with reservoir tank (9.8 cu. ft.) at the apex (supersaturated water source).

11. 6" i.d. siphon with 10 feet of 6" i.d. pipe at the apex (water source varied from near normal to supersaturated condition).

Figure 1. Average degassing (% of saturation N_2) for 2", 4", and 6" i.d. siphons at various vacuum and static heads with various gas concentrations from the reservoir.

Appendix Table 1.--2" i.d. siphon with 15 feet of 2" i.d. hose at the apex (supersaturated water source).

Vacuum head (Ft. of water negative)	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration 2/ time at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average difference 1/	Reservoir sample	Discharge sample	Average difference 1/	
		1	96.2	90.7		112.4	103.2		
29	7	4	--	92.5	4.9	--	104.0	8.7	3.3
		6	96.2	90.7		111.0	101.9		
		1	97.1	90.7		111.7	103.3		
29	6	4	--	90.7	5.9	--	101.2	8.6	---
		6	96.2	90.7		110.3	102.6		
		1	96.2	91.6		110.3	104.0		
29	5	4	--	91.6	4.1	--	103.2	7.3	2.2
		6	95.3	91.6		110.3	101.9		
		1	98.7	92.3		117.7	105.1		
28	8	4	--	93.2	5.6	--	106.5	9.5	
		6	97.8	92.3		112.8	105.8		
		1	98.7	92.3		117.7	108.6		
28	6	4	--	92.3	5.6	--	107.9	7.8	2.2
		6	97.8	93.2		114.2	107.9		
		1	98.1	88.8		113.7	102.6		
26	10	4	--	87.9	8.6	--	101.9	10.3	---
		6	96.2	88.8		111.7	102.6		
		1	99.9	95.3		117.9	113.0		
26	8	4	--	94.4	4.0	--	111.7	4.9	---
		6	98.1	95.3		115.8	111.0		
		1	96.9	95.0		114.9	110.7		
26	6	4	--	94.1	2.9	--	108.6	5.9	2.3
		6	97.8	94.1		115.6	108.6		
		1	96.2	90.7		113.0	105.4		
24	10	4	--	91.6	5.2	--	104.7	8.1	3.2
		6	96.2	90.7		113.0	104.7		

Appendix Table 1.--Continued

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation: Reservoir sample	Oxygen: Discharge sample	Oxygen: Average difference 1/	Nitrogen % of saturation: Reservoir sample	Nitrogen: Discharge sample	Nitrogen: Average difference	Duration time at the apex of siphon (sec.) 2/
		1	99.6	98.7		112.1	109.3		
24	6	4	--	98.7	1.2	--	109.3	3.7	2.4
		6	99.6	97.8		113.5	108.6		
		1	99.6	98.7		112.8	110.0		
24	4	4	--	98.6	0.9	--	110.0	2.8	---
		6	99.6	98.7		112.8	110.0		
		1	102.2	99.4		117.4	114.0		
20	8	4	--	100.4	2.1	--	114.0	2.7	2.2
		6	102.2	100.4		116.1	114.0		
		1	99.4	99.4		113.3	112.6		
20	6	4	--	99.4	0.9	--	112.6	2.1	2.4
		6	101.3	99.4		116.1	112.6		
		1	103.1	102.2		117.4	116.7		
18	10	4	--	99.4	2.6	--	112.6	3.2	2.8
		6	104.1	101.3		118.8	115.4		
		1	101.5	99.6		114.9	111.4		
18	8	4	--	100.6	0.3	--	112.8	0.9	---
		6	99.6	100.6		112.1	113.5		
		1	100.6	101.5		113.5	114.7		
18	6	4	--	100.6	0.3	--	112.1	1.5	2.5
		6	100.6	99.6		114.9	111.4		
		1	100.6	99.6		114.9	111.4		
18	4	4	--	99.6	0.4	--	112.8	0.9	---
		6	98.7	98.7		110.7	111.4		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

Appendix Table 2.--2" i.d. siphon with 115 feet of 2" i.d. hose at the apex (supersaturated water source).

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration time at the apex of siphon (sec.) 2/
			Reservoir sample	Discharge sample	Average difference 1/	Reservoir sample	Discharge sample	Average difference 1/	
28	8	1	--	--	*	--	--	*	--
28	6	1	--	--	*	--	--	*	--
26	8	1	--	*	*	--	*	*	
26	6	1	--	--	*	--	--	*	--
24	8	1	105.9	70.6	35.3	116.2	70.6	45.6	--
		4	--	--	*	--	--	*	
24	6	1	--	*	*	--	*	*	
		1	105.6	85.4		116.5	88.1		
20	10	4	--	84.5	19.7	--	86.7	27.2	31.3
		6	102.8	83.6		112.3	86.7		
		1	106.3	81.6		116.2	84.4		
20	8	4	--	81.6	24.8	--	83.0	32.2	50.4
		6	107.2	82.5		115.6	83.7		
		1	104.2	83.2		115.3	86.3		
20	6	4	--	83.2	21.9	--	85.6	29.8	60.5
		6	106.0	83.2		116.0	85.6		
20	6	1	103.6	72.4	31.2	114.9	74.7	40.2	--
		4	--	*	*	--	*	*	
		1	108.8	87.8		120.9	93.2		
18	8	4	--	87.8	21.0	--	92.5	28.2	22.8
		6	108.8	87.8		120.9	92.5		
		1	107.7	87.5		119.5	91.7		
18	6	4	--	86.6	21.3	--	91.7	28.1	47.9
		6	108.7	86.6		118.8	89.6		
		1	107.7	84.7		118.8	85.5		
18	4	4	--	78.3	26.5	--	77.8	37.3	16.4
		6	108.7	82.0		118.8	81.3		
		7	--	*	*	--	*	*	

* Siphon airlocked and water ceased flowing.

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

Appendix Table 3.--4" i.d. siphon with 15 feet of 4" i.d. hose at the apex (supersaturated water source).

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration time at the apex of siphon (sec.) 2/
			Reservoir sample	Discharge sample	Average difference 1/	Reservoir sample	Discharge sample	Average difference 1/	
		1	96.2	90.8		113.9	107.7		
29	7	4	95.3	90.8	5.4	113.2	105.6	7.1	--
		6	97.1	90.8		113.9	106.3		
		1	96.4	90.9		111.3	105.8		
29	6	4	94.6	90.9	4.6	110.0	103.8	5.7	2.9
		6	--	90.9		--	105.2		
		1	100.8	93.5		119.3	113.2		
29	5	4	99.0	91.7	7.3	118.7	111.1	6.8	2.9
		6	99.0	91.6		117.3	110.4		
		1	97.8	94.6		121.5	116.7		
28	8	4	--	93.2	4.1	--	116.0	4.3	--
		6	97.8	93.2		119.5	116.0		
		1	100.5	95.9		126.4	121.5		
28	6	4	98.7	95.0	3.4	123.0	120.2	3.5	--
		6	97.8	95.9		120.9	118.1		
		1	94.9	93.1		121.2	117.8		
26	10	4	94.9	92.1	3.1	121.2	117.1	4.3	--
		6	94.9	90.3		121.2	115.7		
		1	96.8	95.0		117.4	114.6		
26	8	4	97.8	94.1	2.7	118.1	--	3.5	--
		6	--	--		--	114.0		
		1	104.0	103.1		--	120.5		
24	10	4	--	100.3	0.9	125.3	118.5	6.1	--
		6	--	100.3		--	118.5		
		1	94.9	92.1	2.8	121.2	117.1	4.1	
		1	105.1	95.0		116.0	114.6		
24	8	4	--	95.0	10.1	--	112.6	2.7	
		6	105.1	95.0		116.0	112.6		
		1	94.9	92.1	2.8	119.1	114.3	4.8	

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

Appendix Table 4.--4" i.d. siphon with 115 feet of coiled 4" i.d. hose at the apex (water source near normal saturation).

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average 1/ difference	Nitrogen % of saturation Reservoir sample	Discharge sample	Average 1/ difference	Duration 2/ time at the apex of siphon (sec.)
29	7	1	95.1	81.5	12.7	98.6	86.2	11.9	---
		4	95.1	82.4		98.6	87.6		
		6	94.2	82.4		98.6	86.2		
29	5	1	95.1	86.9	8.8	101.6	93.2	8.8	---
		4	--	86.9		--	92.8		
		6	96.9	87.8		102.4	93.6		
29	4	1	94.2	90.5	4.9	101.1	95.3	5.4	36.6
		4	96.0	87.8		100.6	95.7		
		6	95.1	92.3		100.7	95.3		
29	3	1	94.2	81.5	12.7	100.3	82.7	17.6	50.2
		4	--	*	*	--	*	*	
28	6	1	93.3	86.0	7.0	102.0	92.8	8.8	29.9
		4	95.1	87.8		100.7	93.6		
		6	95.1	88.7		100.3	93.2		
28	4	1	93.3	89.6	1.6	100.3	96.5	5.1	37.4
		4	--	89.6		--	94.9		
		6	94.2	92.3		101.1	95.3		
28	4	1	92.3	87.6	4.7	100.0	94.4	5.7	---
		4	91.4	85.7		100.8	94.8		
		6	91.4	87.6		100.4	94.8		
28	3	1	93.3	89.6	4.1	102.0	96.5	6.4	43.9
		4	--	86.0		101.1	91.5		
		6	92.3	90.5		101.1	97.0		
28	3	1	91.4	87.6	4.8	100.4	95.6	4.8	---

Appendix Table 4.--Continued

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration 2/ time at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average 1/ difference	Reservoir sample	Discharge sample	Average 1/ difference	
26	4	1	--	93.7		--	99.3		
		4	98.3	94.6	3.2	104.5	99.3	5.5	26.1
		6	97.3	95.5		104.5	98.8		
26	3	1	87.4	83.3		100.7	95.7		
		4	86.5	82.9	3.9	99.9	94.9	5.1	---
		6	88.3	83.8		99.5	94.1		
26	2	1	88.3	76.6	11.7	99.5	87.4	12.1	
		4		*	*		*	*	
24	6	1	93.1	92.1		97.5	96.0		
		4	95.8	92.1	2.1	99.2	95.6	2.5	26.5
		6	--	92.8		--	96.0		
24	4	1	94.9	93.7		98.4	95.6		
		4	95.8	92.8	1.8	97.5	96.0	2.4	32.6
		6	94.0	92.8		97.9	95.1		
24	3	1	95.8	92.1		98.8	95.6		
		4	95.8	91.3	4.6	99.7	94.7	3.5	---
		6	95.8	90.3		97.9	95.6		
24	2	1	98.5	92.1		99.7	95.6		
		4	95.8	90.3	7.2	99.2	94.3	5.7	---
		6	--	87.6		--	91.3		
20	6	1	93.7	93.8		99.7	99.2		
		4	94.6	93.8	0.8	98.8	98.6	0.4	26.1
		6	94.6	92.8		98.4	97.9		

Appendix Table 4.--Continued.

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Nitrogen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Duration 2/ time at the apex of siphon (sec.)
		1	95.8	93.8		99.2	98.6		
20	4	4	--	93.7	2.1	--	99.0	0.3	31.0
		6	95.8	93.7		98.8	98.6		
		1	93.3	92.4		100.1	98.4		
20	3	4	93.3	92.8	0.8	99.3	99.7	0.3	39.9
		6	93.3	92.4		98.4	98.8		
		1	93.4	89.7		97.0	93.3		
20	2	4	95.1	88.8	5.8	97.5	91.6	5.3	---
		6	--	87.0		--	91.1		

*Siphon airlocked and water ceased flowing

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

Appendix Table 5.—4" i.d. siphon with 115 feet of 4" i.d. hose at apex (supersaturated water source).

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration time at the apex of siphon (sec.) 2/
			Reservoir sample	Discharge sample	Average difference 1/	Reservoir sample	Discharge sample	Average difference 1/	
		1	102.8	88.5		113.0	93.5		
29	7	4	101.9	86.7	14.7	111.7	92.1	17.2	---
		6	102.8	88.2		113.1	93.8		
		1	104.6	89.4		115.7	96.2		
29	6	4	--	91.1	13.9	--	96.9	18.5	---
		6	103.7	90.3		113.7	95.6		
		1	104.6	90.3		111.7	95.6		
29	5	4	102.8	90.3	13.6	110.3	95.6	15.8	---
		6	102.8	88.9		109.0	92.2		
		1	109.9	90.3		129.1	105.4		
28	8	4	109.0	89.4	18.4	125.7	104.1	22.3	---
		6	106.3	90.3		122.4	100.7		
		1	107.1	81.9		121.0	87.1		
28	8	4	--	80.3	24.9	--	87.1	32.1	---
		6	105.2	81.3		117.4	87.1		
		1	94.4	83.1		107.0	91.2		
28	8	4	--	81.7	13.4	--	89.2	18.3	---
		6	96.2	80.8		108.4	87.8		
28	8	1	104.0	83.9	20.1	123.9	96.8	27.2	---
		4	---	---		---	---		
		1	92.6	84.0		106.3	95.3		
28	7	4	94.4	83.5	9.8	107.0	95.3	12.8	---
		6	93.5	83.5		107.0	91.2		
		1	105.4	90.3		120.3	99.3		
28	6	4	106.3	90.3	15.4	122.3	101.3	20.8	---
		6	105.4	90.3		120.3	100.0		

Appendix Table 5.—Continued.

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation: Reservoir sample	Oxygen: Discharge sample	Oxygen: Average difference 1/	Nitrogen % of saturation: Reservoir sample	Nitrogen: Discharge sample	Nitrogen: Average difference 1/	Duration time at the apex of siphon (sec.) 2/
		1	--	85.3		--	92.8		
28	5	4	97.1	85.3	11.8	110.7	94.8	16.6	---
		6	97.1	85.3		110.7	94.8		
		1	97.1	85.9		109.1	95.3		
26	8	4	--	86.2	10.1	--	95.3	12.9	---
		6	95.3	86.2		107.0	94.7		
		1	101.6	84.9		112.1	92.0		
26	8	4	--	84.9	15.6	--	92.0	19.2	---
		6	100.1	85.8		110.6	92.7		
		1	103.5	88.1		121.0	102.4		
26	8	4	103.5	86.2	16.4	121.0	100.3	20.2	---
		6	101.7	85.3		119.6	98.3		
		1	95.3	90.5		108.4	101.5		
26	7	4	95.3	89.0	5.5	108.4	99.4	8.5	---
		6	94.4	89.0		109.1	99.4		
		1	99.1	92.7		109.2	101.0		
26	6	4	100.1	92.7	7.1	107.5	100.1	7.8	26.1
		6	100.1	92.7		107.1	99.3		
		1	100.1	90.6		111.4	96.3		
24	8	4		90.6	9.5	--	96.3	14.3	---
		6	100.1	90.6		109.9	96.3		
		1	100.8	91.9		117.5	105.2		
24	8	4	101.7	90.8	9.9	119.6	104.3	14.0	---
		6	100.8	90.8		117.5	103.1		
24	4	1	99.9	89.0	10.9	115.4	99.7	15.7	---
		4	99.0			114.8			
		6	98.0	---	*	112.0	---	*	

*Siphon airlocked and water ceased flowing.

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

Appendix Table 6.--4" siphon with 65 feet of coiled 4" i.d. hose at the apex and 50 feet of coiled 4" i.d. hose about 10 feet above the discharge end (water source near normal saturation).

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration[2/] time at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average[1/] difference	Reservoir sample	Discharge sample	Average[1/] difference	
29	7	1	94.2	91.8	3.1	102.7	98.1	4.7	14.1
		4	94.2	91.6		102.1	98.7		
		6	94.2	89.8		102.7	96.6		
29	6	1	94.2[3/]	89.8	4.1	102.5[3/]	96.7	5.8	14.8
		4		89.8			96.7		
		6		90.7			96.7		
29	5	1	95.1	89.8	4.4	103.4	96.1	6.4	16.1
		4	94.2	90.7		101.4	96.1		
		6	94.2	89.8		102.7	96.1		
29	4	1	93.3	90.7	3,2	100.3	96.1	4.9	18.4
		4	93.3	90.7		100.7	96.1		
		6	94.2	89.8		100.1	94.1		
28	8	1	92.2	91.6	1.4	101.4	98.7	2.2	12.5
		4	--	91.3		--	98.5		
		6	92.2	89.6		100.7	98.4		
28	7	1	92.2	90.5	1.4	100.7	98.1	3.5	13.5
		4	--	91.3		--	95.4		
		6	92.2	90.5		101.4	98.1		
28	6	1	92.2	90.5	2.0	101.4	96.7	3.7	16.1
		4	--	89.6		--	97.4		
		6	92.2	90.5		100.7	98.0		
28	5	1	93.1	91.3	1.9	102.1	97.2	5.3	17.5
		4	--	90.5		--	97.4		
		6	92.2	90.5		100.7	98.0		

Appendix Table 6.—Continued.

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Nitrogen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Duration time at the apex of siphon (sec.) 2/
26	8	1	94.0	89.6	4.1	100.7	97.4	3.5	13.5
		4	--	88.7		--	97.4		
		6	92.2	88.7		100.7	96.7		
26	7	1	93.1	88.7	5.0	100.1	98.0	3.7	13.5
		4	--	86.9		--	97.4		
		6	93.1	88.7		101.4	97.4		
26	6	1	94.0	90.5	3.1	100.7	96.7	4.0	16.1
		4	--	90.5		--	97.4		
		6	93.1	90.5		100.7	96.0		
26	5	1	92.2	90.5	2.6	99.4	97.4	2.2	16.9
		4	--	90.5		--	98.7		
		6	94.0	90.5		100.7	97.4		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ Estimated value interpolated from measurements made before and after test.

Appendix Table 7.—4" i.d. siphon with 2-42" static mixers plus 96" of 4" i.d. hose at the apex [3/] (water source near normal saturation).

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average [1/] difference	Nitrogen % of saturation Reservoir sample	Discharge sample	Average [1/] difference	Duration [2/] time at the apex of siphon (sec.)
		1	97.4	90.0		102.4	92.1		
26	8	4	--	87.4	9.1	--	91.4	10.5	3.8
		6	97.4	87.4		102.4	92.1		
		1	95.5	91.0		100.3	100.3		
26	6	4	--	90.0	5.9	--	92.1	6.2	---
		6	96.5	89.2		101.7	92.1		
		1	96.5	91.0		101.7	95.5		
24	8	4	--	92.0	5.2	--	96.9	6.0	3.4
		6	96.5	91.0		101.7	94.8		
		1	95.5	92.8		101.7	94.8		
24	6	4	--	92.8	2.7	--	95.5	6.2	4.0
		6	95.5	92.8		101.7	96.2		
		1	98.3	92.0		105.2	99.0		
22	10	4	--	92.8	5.0	--	99.0	5.0	4.5
		6	97.4	93.7		102.4	98.3		
		1	98.3	94.6		104.5	99.0		
22	8	4	--	95.5	3.2	--	99.0	4.1	---
		6	97.4	93.7		101.7	99.0		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ Materials used were 4" i.d. hose with 4" i.d. P.V.C. counter current static mixers manufactured by Kenics Corporation.

Appendix Table 8.--4" i.d. siphon with 2-42" long x 4" i.d. static mixers plus 96" of 4" i.d. hose at the apex (supersaturated water source).[3/]

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration time[2/] at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average difference[1/]	Reservoir sample	Discharge sample	Average difference[1/]	
29	7	1	---	---	*	---	---	*	---
29	6	1	---	---	*	---	---	*	---
29	5	1	---	---	*	---	---	*	---
		1	101.9	---		114.0	---		
28	8	4	--	84.6	16.4	--	90.0	22.7	4.8
		6	100.1	84.6		111.3	90.0		
28	6	1	---	---	*	---	---	*	---
		1	99.2	86.4		109.3	92.1		
26	10	4	--	87.4	12.4	108.6	92.8	16.3	3.9
		6	99.2	86.4		107.9	92.1		
		1	108.7	99.4		119.7	104.4		
26	8	4	--	101.3	8.2	--	107.2	14.4	---
		6	107.8	99.4		119.7	104.4		
26	6	1	--	*	--	--	*	--	---
		1	98.3	92.0		107.2	100.3		
24	10	4	--	92.0	6.3	107.2	100.3	7.3	3.1
		6	98.3	92.0		107.2	99.0		
		1	108.7	101.3		120.4	109.3		
24	8	4	--	102.2	6.8	--	111.3	9.3	---
		6	108.7	102.2		119.7	112.0		
		1	108.7	99.4		116.2	103.7		
24	6	4	--	100.4	7.7	--	105.1	10.6	---
		6	106.9	100.4		114.8	105.8		

Appendix Table 8.--Continued.

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation: Reservoir sample	Discharge sample	Average 1/ difference	Nitrogen % of saturation: Reservoir sample	Discharge sample	Average 1/ difference	Duration 2/ time at the apex of siphon (sec.)
		1	105.0	100.4		113.4	105.8		
22	10	4	--	99.4	4.4	--	105.9	7.2	---
		6	103.2	99.4		112.7	105.9		
		1	111.5	106.9		126.7	118.3		
22	8	4	--	108.7	3.7	--	118.3	7.4	3.8
		6	109.7	105.0		123.2	116.2		
		1	105.9	103.2		115.5	108.6		
22	6	4	--	102.2	3.9	--	110.0	5.9	4.5
		6	106.9	102.2		114.8	109.3		

* Siphon airlocked and water ceased to flow.

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ Materials used were a 4" i.d. hose with 4" i.d. P.V.C. counter current static mixers manufactured by Kenics Corporation.

Appendix Table 9.--4" i.d. siphon with gas accumulator (9.8 cu. ft.) at the apex[3/] (water source near normal saturation).

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration [2/] time at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average [1/] difference	Reservoir sample	Discharge sample	Average [1/] difference	
		1	94.4	91.7		103.1	99.7		
29	5	4	--	86.2	6.7	--	94.1	7.4	22.4
		6	94.4	85.2		103.1	93.4		
		1	95.5	91.8		106.1	101.2		
26	8	4	--	91.8	3.2	--	101.9	4.0	18.1
		6	96.4	94.6		106.1	103.3		
		1	95.5	94.6		105.4	102.6		
26	6	4	--	94.6	5.6	--	102.6	3.1	21.1
		6	96.4	93.7		106.1	102.6		
		1	96.4	96.4		105.4	104.0		
24	6	4	--	97.3	3.2	--	104.7	0.8	21.6
		6	95.5	96.4		104.7	104.0		
		1	96.2	96.2		104.5	104.5		
22	6	4	--	98.1	-1.1	--	103.8	0.5	21.3
		6	95.3	96.2		105.2	104.5		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ Materials used were 4" i.d. hose and a cylindrical reservoir (24" i.d. x 37.5" long) with an attached vacuum pump for expelling gas and a window for observing water depth and turbulence.

Appendix Table 10.--4" i.d. siphon with gas accumulator (9.8 cu. ft.) at the apex [3] (supersaturated water source).

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average [1] difference	Nitrogen % of saturation Reservoir sample	Discharge sample	Average [1] difference	Duration [2] time at the apex of siphon (sec.)
29.5	6.5	1	97.6	81.2	16.4	108.8	91.6	17.2	22.7
		1	103.6	84.3		117.6	97.6		
29	7	4	--	84.3	18.2	--	96.9	19.7	---
		6	102.7	86.2		117.0	98.3		
		1	104.7	86.3		120.7	101.9		
29	6	4	--	85.4	18.2	--	100.6	19.9	---
		6	103.6	86.3		120.0	99.9		
		1	114.6	97.7		127.7	109.9		
29	5	4	--	92.2	19.7	--	102.0	20.2	22.4
		6	112.8	92.2		122.4	102.7		
		1	101.3	89.4		113.6	101.2		
28	8	4	--	90.3	10.9	--	101.9	11.1	---
		6	100.4	90.3		112.9	103.3		
		1	101.5	93.2		116.0	106.4		
28	6	4	--	93.2	8.0	--	107.0	9.8	---
		6	101.5	94.1		116.7	106.4		
		1	109.2	98.1		122.1	110.3		
26	10	4	--	95.3	13.1	--	106.8	14.1	18.8
		6	108.2	93.4		120.7	104.7		
		1	106.8	94.6		113.2	100.7		
26	8	4	--	95.5	10.6	--	102.0	11.6	18.1
		6	104.2	94.6		113.2	102.0		
		1	106.8	97.2		115.9	104.7		
26	6	4	--	96.4	9.2	--	103.4	12.1	21.1
		6	105.0	96.4		115.9	103.4		

Appendix Table 10.--Continued.

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Oxygen % of saturation Discharge sample	Oxygen % of saturation Average difference 1/	Nitrogen % of saturation Reservoir sample	Nitrogen % of saturation Discharge sample	Nitrogen % of saturation Average difference 1/	Duration 2/ time at the apex of siphon (sec.)
		1	97.6	95.8		110.9	106.1		
26	4	4	--	95.8	2.1	--	106.7	4.6	---
		6	97.6	94.9		110.9	106.1		
		1	105.5	98.1		117.2	107.5		
24	10	4	--	98.1	8.0	--	106.8	9.9	17.1
		6	103.6	93.4		115.8	105.4		
		1	100.6	95.0		109.3	102.4		
24	8	4	--	93.2	6.2	--	101.0	7.1	17.7
		6	98.7	92.3		107.9	101.0		
		1	107.6	99.0		117.2	107.3		
24	6	4	--	97.2	9.4	--	105.3	11.4	21.6
		6	106.8	97.2		117.2	104.7		
		1	103.3	95.9		114.9	105.8		
22	10	4	--	95.9	6.3	--	105.8	9.3	16.6
		6	102.4	97.8		114.9	105.2		
		1	101.5	95.9		111.4	104.5		
22	8	4	--	95.9	5.2	--	104.5	5.9	18.4
		6	100.6	95.9		109.3	104.5		
		1	109.4	103.3		121.1	109.9		
22	6	4	--	100.7	6.9	--	110.6	10.0	21.3
		6	107.6	100.7		117.8	108.0		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ Materials used were a 4" i.d. hose and a cylindrical reservoir (24" i.d. x 37.5" long) with a vacuum pump attached.

Appendix Table 11.--6" i.d. siphon with 10 feet of 6" i.d. pipe at the apex (water source varied from near normal to supersaturated condition)[3/].

Vacuum head (Ft. of water pressure)	Static head	Time (minutes after stabilized)	Oxygen % of saturation			Nitrogen % of saturation			Duration[2/] time at the apex of siphon (sec.)
			Reservoir sample	Discharge sample	Average[1/] difference	Reservoir sample	Discharge sample	Average[1/] difference	
30.5	3.0	0.5	100.1	95.0	5.1	104.5	102.6	1.9	---
30.0	3.5	0.5	100.1	95.0	5.1	104.5	102.6	1.9	---
29.5	4.0	0.5	100.1	95.0	5.1	104.5	102.6	1.9	---
29	6.5	1	--	88.8		--	102.1		
		4	101.4	86.2	13.7	116.2	99.6	15.4	1.5
		6	--	88.0		--	100.8		
29	6.5	1		88.8		--	100.1		
		4	98.1	88.0	10.4	112.3	100.2	11.9	---
		6	--	86.2		--	100.8		
29	4.5	1	--	95.8	4.3	--	105.2	1.3	---
		6	100.1	95.8		105.2	102.6		
28.5	7.0	1	--	89.6		--	103.4		
		4	105.7	88.0	16.9	123.3	102.8	20.2	---
		6	--			--			
28.5	5.0	1	--	95.8		--	105.8		
		4	102.7	95.8	6.6	111.0	105.2	5.4	---
		6	--	96.7		--	105.8		
28.0	7.5	1	105.7	89.6	16.1	123.3	102.8	20.5	---
28.0	5.5	1	--	96.7		--	109.1		
		4	104.4	96.7	7.7	116.9	109.1	8.2	1.3
		6	--	96.7		--	107.8		
27.5	8.0	1	--	93.8		--	113.0		
		4	105.7	92.1	13.0	123.3	111.8	11.8	---
		6	--	92.1		--	109.8		

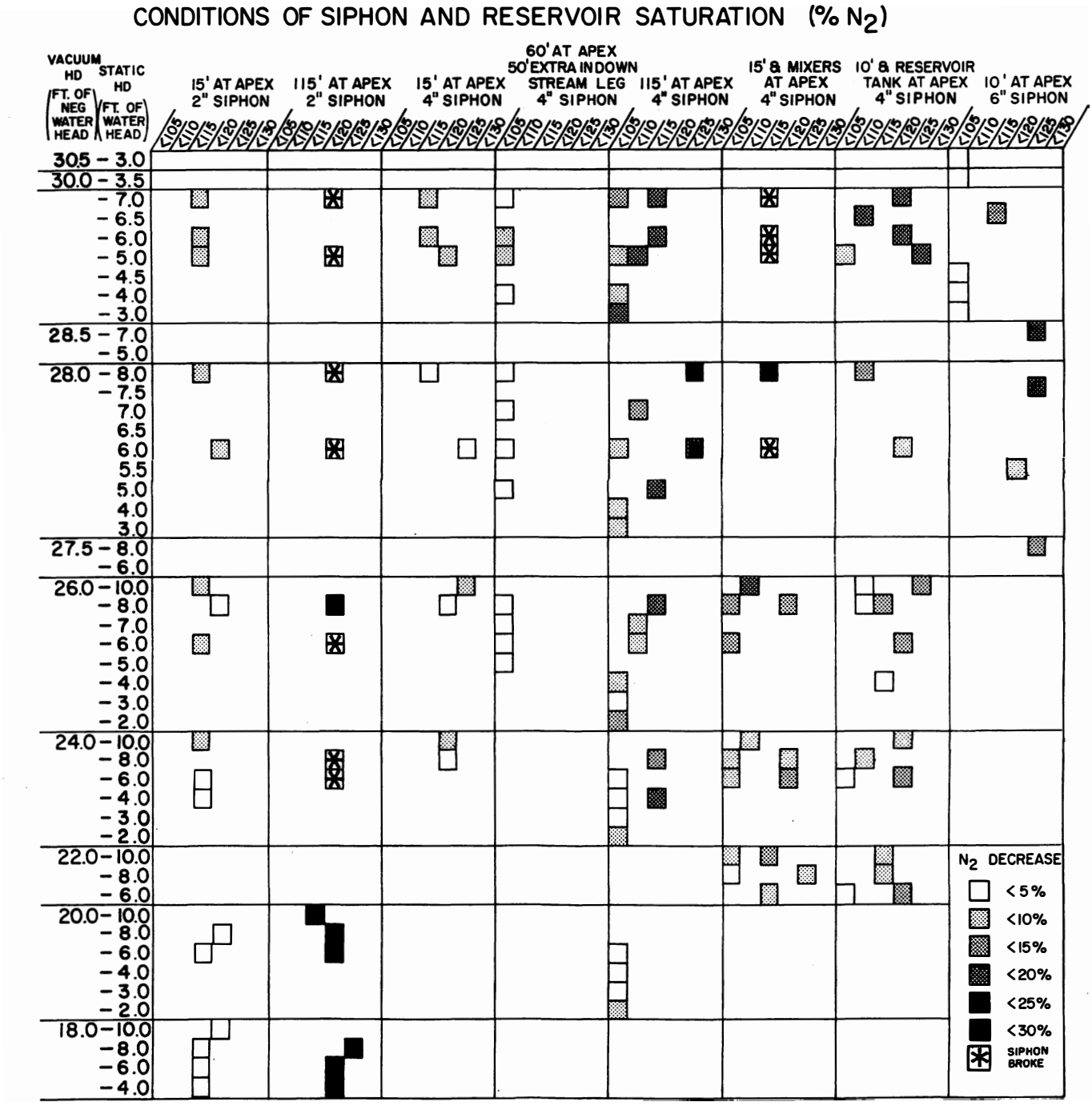
Appendix Table 11.--Continued.

Vacuum head (Ft. of water	Static head pressure)	Time (minutes after stabilized)	Oxygen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Nitrogen % of saturation Reservoir sample	Discharge sample	Average difference 1/	Duration time at the apex of siphon (sec.) 2/
		1	--	101.8		--	118.2		
27.5	6.0	4	111.2	99.8	11.1	126.6	113.0	11.9	---
		6	--	99.2		--	113.0		

1/ Differences are calculated from averages of reservoir samples minus average of discharge sample.

2/ Times calculated from velocity measurements.

3/ 6" i.d. pipe smooth inner surface.



Appendix Figure 1.--Average degassing (% of saturation N_2) for 2", 4", and 6" i.d. siphons at various vacuum and static heads with various gas concentrations from the reservoir.