

Measuring the impact of a 3-hp blower assist on the aeration efficiency of a 50-hp aspirating aerator

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The blower retrofit proved to be an inexpensive way of increasing aeration efficiency by 40%.

After considering various options for increasing the oxygen-transfer capacity of the mill's aerated stabilization basin (ASB), the supplier installed a 3-hp blower on several propeller-driven aspirating aerators. The retrofit was designed to increase air flow through the aerator, with the objective of increasing the rate of oxygen transfer and the amount of oxygen transferred per unit of energy. Oxygen-transfer performance with and without blower assist was determined by an off-gas analysis procedure wherein the oxygen content of ambient air is compared with that of off gas emerging from the lagoon surface.

Original aeration system

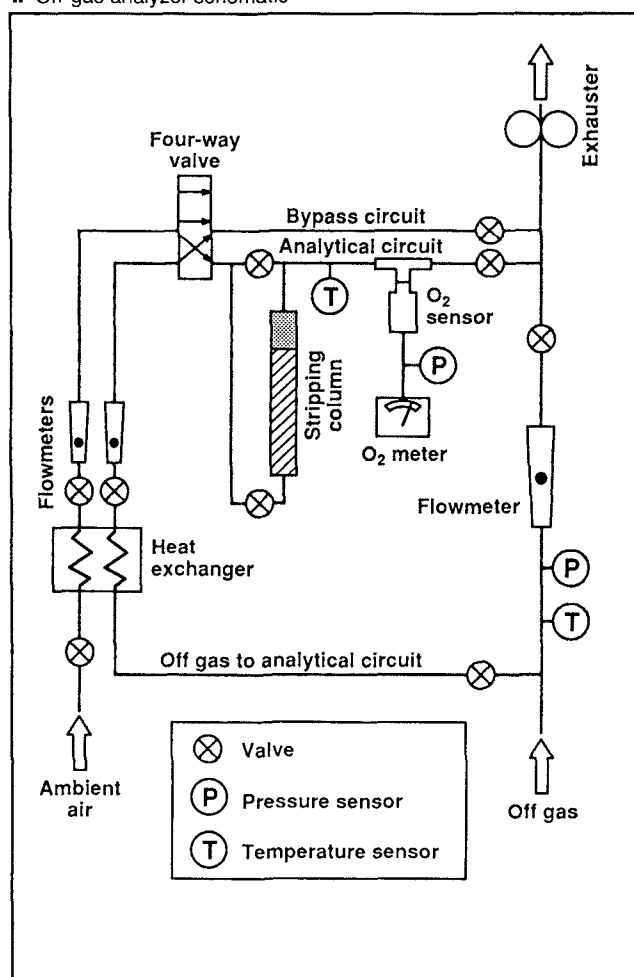
The ASB, brought on line in 1969, is a rectangular earthen basin measuring 853 ft in length, 656 ft in width, and 12 ft in depth. A covered anaerobic basin with approximately half this volume precedes the ASB and delivers an average influent flow of about 4 million gal/day.

Initially, the ASB was equipped with 12 floating, 50-hp, slow-speed aerators, for a total 600 hp of mixing and aeration. Several years later, aeration capacity was doubled to 1200 hp by adding six floating, 100-hp, slow-speed aerators. As the aerators aged, maintenance problems gradually increased. By 1982, it was obvious that the aerators were nearing the end of their useful lives and would need to be replaced. Sludge buildup in the ASB was becoming a problem.

Slow-speed aerators are more expensive than high-speed aerators. While the high-speed aerators are reliable, the slow-speed unit is clearly a better mixing device. In October 1984, the mill purchased and installed four 50-hp aspirating aerators. These units consist of a motor mounted atop a hollow shaft. Air enters the shaft through

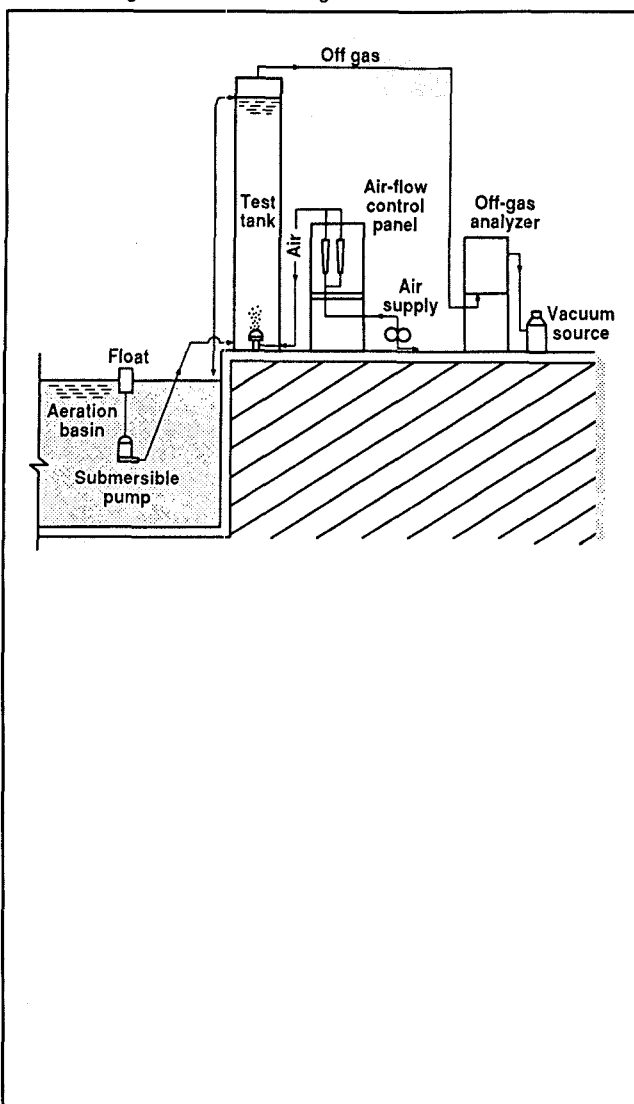
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1. Off-gas analyzer schematic

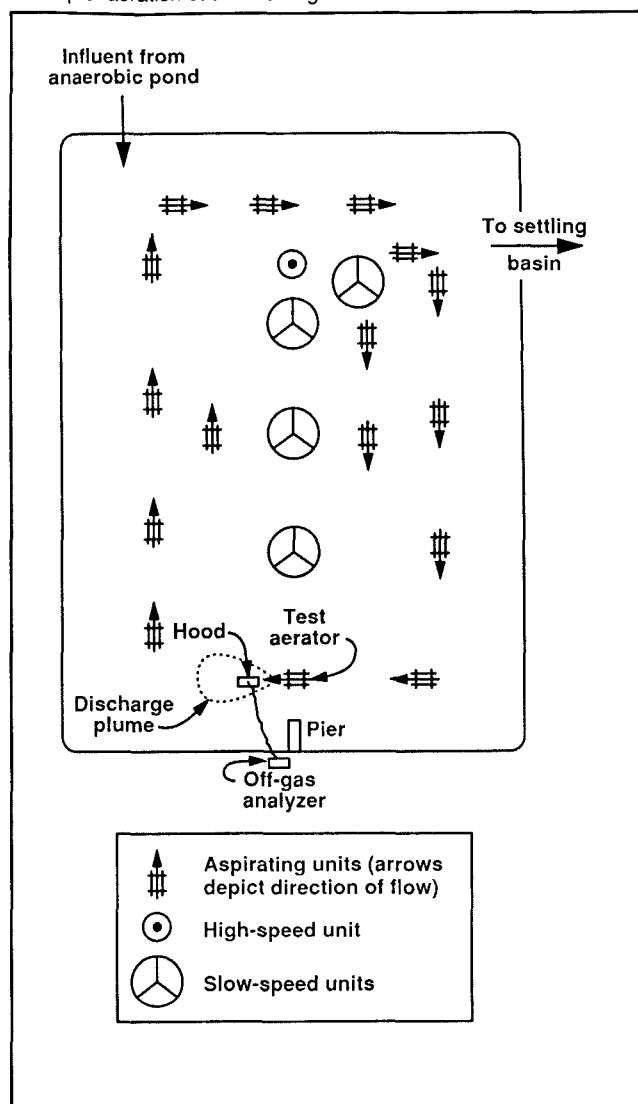


an intake port just beneath the motor and is forced out through the submerged end by a propeller pump. In June 1985, four 100-hp units were procured. In September 1985, six more 50-hp aspirating aerators were placed in service.

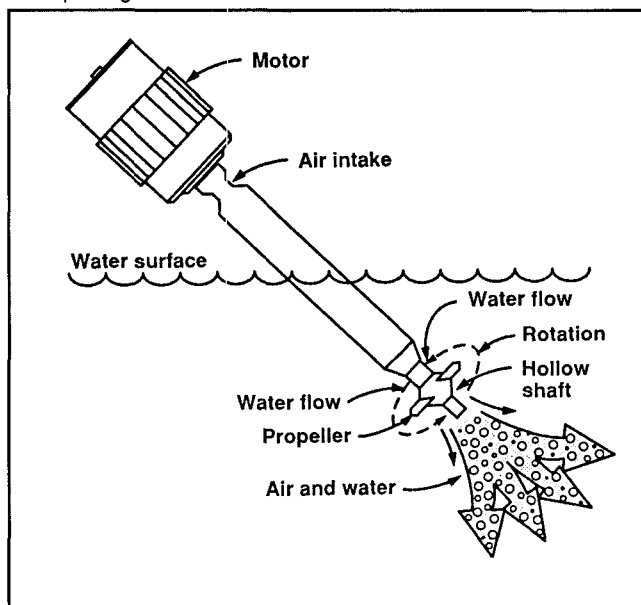
2. Test configuration for estimating α factor



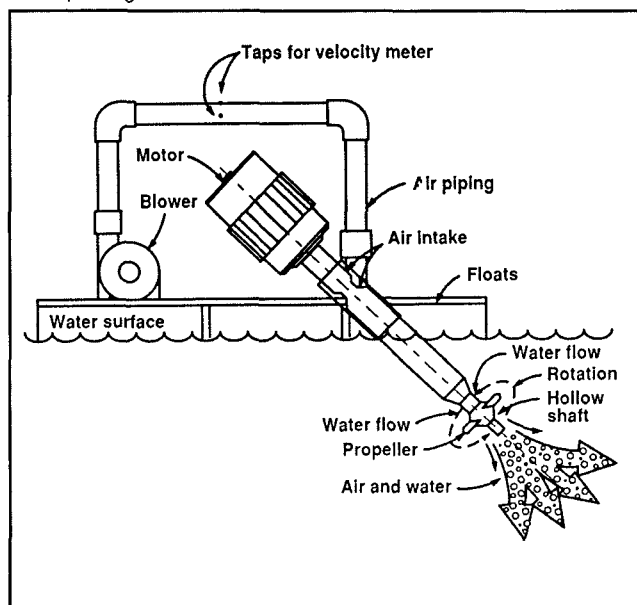
3. Map of aeration basin showing test site and location of aerators



4. Aspirating aerator without blower



5. Aspirating aerator with blower



Since that time, two additional 50-hp units have been procured. Substantial solids resuspension was experienced over a period of 18 months as the aspirating aerators were installed or moved, as reported by Gardner and Winslow (1).

The mill's remaining slow-speed units will ultimately fail, and there is always the possibility that the system's oxygen demand will increase. In either case, it was clear that the mill needed to develop contingency plans for increasing the system's oxygen-transfer capacity. One economically attractive option was to attempt to increase the oxygen-transfer capacity of the aspirating aerators by retrofitting them with blowers. If this approach proved to be effective, it could postpone or possibly eliminate the need to purchase additional aeration equipment.

The rate and efficiency of oxygen transfer were measured with and without blower assist. Calculations were based on data obtained using the off-gas analysis procedure as well as by measuring the flow of air to the aerator. At the time the analysis was carried out (late January 1990 and again in early May), four or five slow-speed floating aerators were operational along with one high-speed unit. The mill's 16 aspirating aerators also were in operation.

Test procedure

Off-gas analysis

A Mark V off-gas analyzer (Ewing Engineering Co.) was used to measure the gas-phase oxygen-transfer efficiency and off-gas flow rates. The analyzer was equipped with a stripping column to remove carbon dioxide and water vapor and included an oxygen sensor, as seen in Fig. 1. The history, theoretical development, and application of the technology is described in the literature (2-4). Introduced in July 1981, the hardware and procedure have gained wide acceptance in the diffused-aeration industry. In a recently completed \$1.2-million, three-year EPA study of fine-pore diffused-aeration systems in the United States (5), every major investigator used off-gas analysis as the primary method of measuring oxygen-transfer efficiency.

Simply stated, the off-gas analyzer compares the partial pressure of oxygen in dried ambient air with that of the off gas emerging from the surface of the aeration basin. Carbon dioxide and water vapor are removed from all samples in the analyzer's stripping column. Using the millivolt outputs observed for both off gas (M_{og}) and ambient (reference) air (M_r) from the gas-phase oxygen meter, a direct measure of the actual oxygen-transfer efficiency (OTE) under prevailing field conditions is easily computed using Eq. 1.

$$OTE = 1 - [Y_e(1 - Y_i)]/[Y_i(1 - Y_e)] \quad (1)$$

where

OTE = oxygen transfer efficiency [fraction of oxygen in inlet gas (ambient air) transferred to liquid]

Y_i = mole fraction of oxygen in inlet gas

= 0.2095 for dried ambient air

Y_e = mole fraction of oxygen in dried, carbon-dioxide-free off gas

$$= Y_i(M_{og}/M_r)$$

Off gas was collected beneath a 4-ft $\times$ 8-ft wooden capture hood constructed by mill staff. Gas from the pond surface was captured beneath the floating hood and transported to the analyzer by vacuum through a flexible 1.5-in.-diam. crushproof hose. Flow rate to the analyzer is controlled by a throttling valve located between the hood and the vacuum source. By adjusting the flow rate, the pressure beneath the off-gas collection hood can be controlled to within ± 0.1 in. water gauge of existing ambient pressure. At this equilibrium condition, the rate of off-gas flow at this position and the rate of withdrawal are the same. The rate of flow is then obtained by taking readings from one of two variable-area glass rotameters installed in the analyzer.

The standard oxygen-transfer efficiency under process conditions can be calculated by measuring the concentration of dissolved oxygen (DO) in the liquid at the sampling location, the temperature of the mixed liquor, and local barometric pressure. Standard conditions are zero DO, mixed-liquor temperature of 20°C, and pressure of 1 atm (29.92 in. Hg). These are the same conditions as those used to report test data in clean water. The ratio of standard oxygen-transfer efficiency in process water ($SOTE_{pw}$) to that in clean water ($SOTE_{cw}$) is termed the α factor.

Calculating the alpha factor

In many cases, the $SOTE_{cw}$ for a given diffused aeration system is known. In these instances, α factor can be calculated using Eq. 2.

$$\alpha = SOTE_{pw}/SOTE_{cw} \quad (2)$$

However, the clean-water oxygen-transfer performance of the 50-hp aspirating aerator—with or without blower assist—is not reliably known. To evaluate the performance of this unit under standardized conditions, it is necessary to estimate clean-water performance from process-water tests.

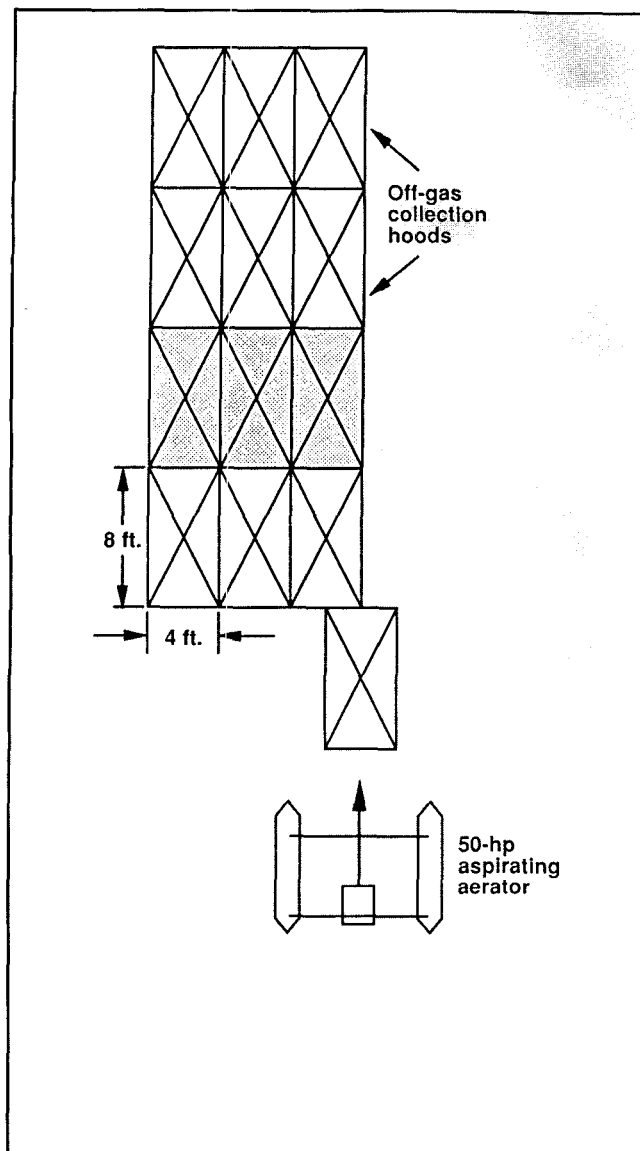
$SOTE_{cw}$ can be estimated by rearranging Eq. 2 as shown in Eq. 3.

$$SOTE_{cw} = SOTE_{pw}/\alpha \quad (3)$$

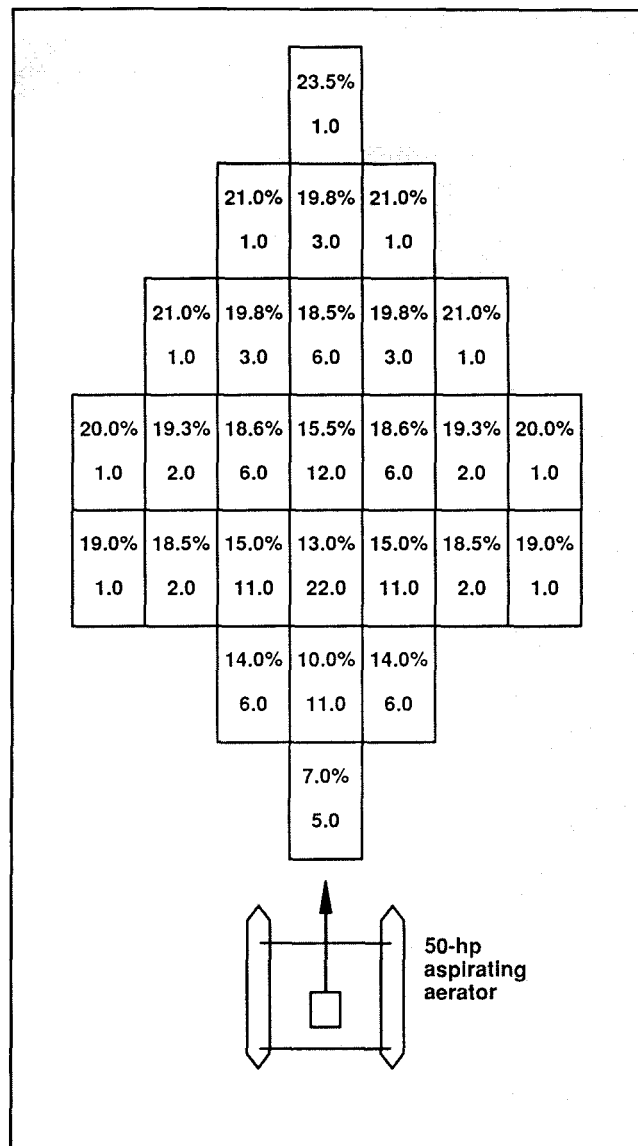
To estimate the α factor, a steady-state aeration test was conducted in a columnar tank (2.5 ft in diameter by 11 ft high) using a porous ceramic diffuser (4, 6). On the basis of visual observations, particularly with regard to the apparent bubble sizes in the discharge plume from the aspirating aerator, it was decided to use a fine-pore diffuser to estimate the α factor. This approach, if anything, yields an α factor on the low side and therefore may somewhat overestimate the clean-water efficiency obtained from Eq. 3.

Figure 2 illustrates the hardware configuration used in the test designed to estimate the α factor. Lagoon liquor was pumped through the column, and $SOTE_{pw}$ was determined. The test diffuser had also been previously tested several times in a similar column using tap water, so the $SOTE_{cw}$ value at the same air flow rate was known.

6. Typical hood placement for sampling off gas in the aerator's symmetrical discharge plume



7. Overall results for aspirator without blower ($SOTE_{pw} = 15.3\%$, off-gas flow = 128 std. ft^3/min). Each box represents the position of the 4-ft $\times$ 8-ft capture hood over the aerator's discharge plume. The top number within each box is the $SOTE_{pw}$ at that position, and the bottom number is the corresponding off-gas flow in units of standard cubic feet per minute.



The ratio of $SOTE_{pw}$ to $SOTE_{cw}$ in the column is an estimate of the α factor for the full-scale system.

Current aeration system

Figure 3 is a map of the ASB showing the position of equipment at the time the tests were conducted. There were four slow-speed floating aerators in service along with one high-speed surface unit and sixteen aspirating aerators with propeller pumps. The test unit is located near the bottom of Fig. 3, just above the pier.

The test aerator was a 50-hp aerator with a 3-hp blower.

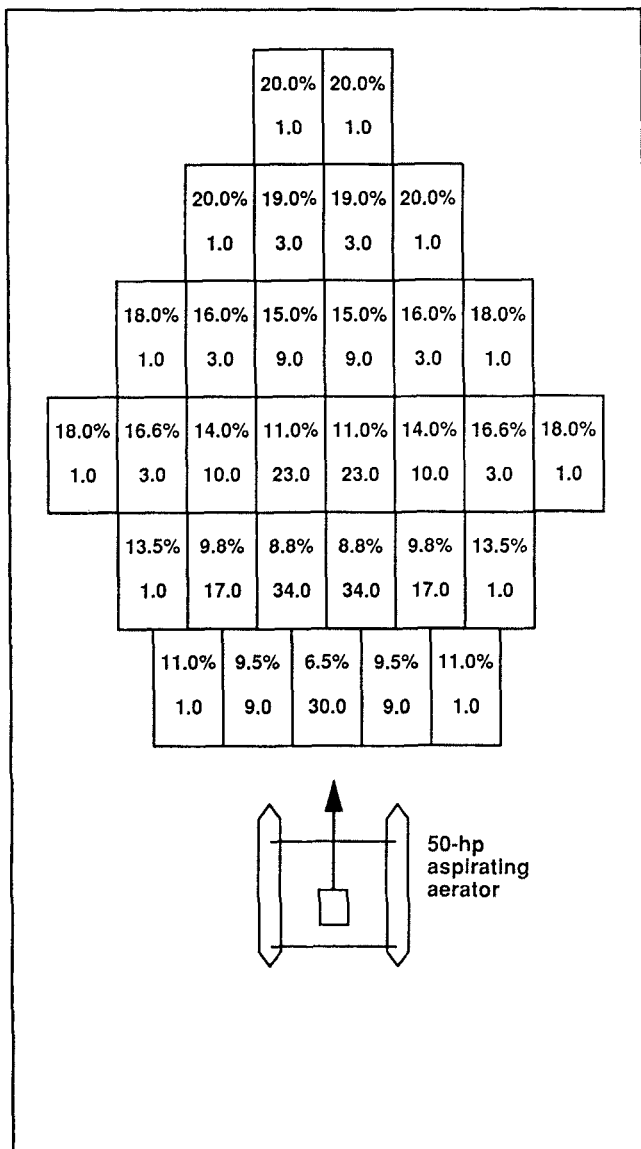
Figure 4 shows the aerator as typically applied, without the blower. Figure 5 depicts the aerator with the blower and associated piping. When the blower is operating, air under a slight pressure is forced through the intake ports.

Tests were carried out with and without blower assist. The aerator was operated without blower assist by disconnecting the 8-in. PVC (polyvinyl chloride) piping from the motor housing at the blower discharge. With the piping removed, all air flow is drawn through the open pipe to the inlet ports on the hollow shaft. Air flow to the aerator with and without blower assist was estimated from data provided by a thermal mass flowmeter installed in the transfer piping, as seen in Fig. 5.

Test procedure

The full-scale field test involved positioning the capture hood at various locations above the aerator's discharge plume. The hood was fastened in place by tying it to fixed objects with four lines. Because of time and physical

8. Overall results for aspirator with blower ($SOTE_{pw} = 10.8\%$, off-gas flow = 264 std. ft³/min). Each box represents the position of the 4-ft × 8-ft capture hood over the aerator's discharge plume. The top number within each box is the $SOTE_{pw}$ at that position, and the bottom number is the corresponding off-gas flow in units of standard cubic feet per minute.



constraints, only about half of the discharge plume was sampled on any given day. Considering the general symmetry with regard to the axis of the aspirating aerator, these data were combined to estimate performance over the entire discharge plume. **Figure 6** indicates one of the sampling plans employed during the test program.

The off-gas analyzer was located on the pier. DO concentration was measured with a YSI DO probe and meter, with the probe held in place adjacent to the hood. The submersible pump, used to transfer lagoon liquor to the test column on shore, was secured to the frame of the floating aerator on the inlet side of the unit about 4 ft below the water surface.

Results and discussion

The results of this investigation are summarized and presented in **Table I** and in **Figs. 7 and 8**. The first five rows of data in **Table I** are the results obtained on the five test dates shown. The last two rows present an overall summary of results with and without the blower in operation.

Data were collected under two test conditions: with the blower and without the blower. Results obtained under the two conditions were then compared based on similar collection sampling plans. These data were averaged and combined to develop an idealized pattern for $SOTE_{pw}$ conditions and off-gas flow rate for each sampling location. **Figures 7 and 8** present a spatial map of the results. Inside each hood placement is listed the $SOTE_{pw}$ as a percentage and the off-gas flow from that location in units of standard cubic feet per minute.

These figures indicate that the areas directly downstream from the aerator have the highest gas capture rates and the lowest $SOTE_{pw}$ values. In general, the $SOTE_{pw}$ increases the further one gets from the aerator, either downstream or from the axis of the aerator. This observation is reasonable, since the further away from the aerator that the gas bubbles exit the liquid surface, the longer they have been in contact with the liquid. The greater contact time results in increased oxygen transfer. Also, since smaller bubbles are less buoyant than larger ones, they tend to be carried further away from the aerator by currents before reaching the water surface. The combination of greater interfacial area and longer contact times promotes additional gas-phase oxygen transfer.

Figures 7 and 8 demonstrate the unique advantage of the off-gas method to provide detailed spatial profiles of flow and OTE distribution over the discharge plume of the aerator. To estimate the overall oxygen-transfer efficiency of the aerator, it is necessary to weigh the OTE on the basis of gas rate. In other words, more emphasis needs to be given to an area with a higher off-gas flow rate than an area with a low rate. The mean weighted average $SOTE_{pw}$ is computed using Eq. 4.

$$\text{Mean weighted average } SOTE_{pw} = \frac{\sum(\text{flow rate} \times \text{OTE})}{\sum \text{flow rate}} \quad (4)$$

The overall mean weighted average for each condition is listed in the third column in **Table I**. The measured off-gas flow is the total gas captured by the collection hood.

In addition to measuring air flow by off-gas capture, a Series 440 air-velocity meter (Kurz Instruments) was also used. The meter utilizes a constant-temperature thermal anemometer sensor to measure standard velocity (25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the moving air stream as it passes over the heated sensor. The sensing probe was inserted into the 8-in. PVC pipe between the blower and the inlet ports of the aspirating aerator to obtain a velocity profile both horizontally and vertically at 1-in. intervals across the inside diameter. The air flows by this technique are listed under the column headed "Estimated flow by velocity meter."

Of the two air measurements, the off-gas readings are probably somewhat low, while the meter readings are somewhat high. If the sampling plan were expanded, more

I. Test results for five trials and overall results obtained with blower on and off

Test date	Condition	Mean weighted avg. $SOTE_{pw}$	Measured off-gas flow, std. ft^3/min	Est. flow by vel. meter, std. ft^3/min	Calculated power, hp	Field transfer rate, lb/h		Field aeration efficiency, lb/hp·h		Est. α	Est. clean-water transfer rate, lb/h		Est. clean-water aeration efficiency, lb/hp·h	
						Off gas	Meter	Off gas	Meter		Off gas	Meter	Off gas	Meter
1/31/90	Blower on	0.1133	216.6	385	48.0	25.5	45.4	0.53	0.95	0.56	45.5	81.1	0.95	1.69
2/1/90	No blower	0.1460	121.9	180	44.2	18.5	27.4	0.42	0.62	0.56	33.0	48.9	0.75	1.11
2/2/90	Blower on	0.1095	245.8	385	48.0	28.0	43.9	0.58	0.91	0.56	50.0	78.4	1.04	1.63
5/8/90	Blower on	0.1031	174.2	385	48.0	18.7	41.3	0.39	0.86	0.56	33.4	73.8	0.70	1.54
5/9/90	No blower	0.1440	130.5	180	47.2	19.6	27.0	0.42	0.57	0.56	35.0	48.2	0.42	1.02
Overall	No blower	0.1530	128.0	180	45.0	20.4	28.7	0.45	0.64	0.56	36.4	51.2	0.80	1.14
Overall	Blower on	0.1080	264.0	385	48.0	29.7	43.3	0.61	0.90	0.56	53.0	77.3	1.10	1.61

gas would be captured. However, with the blower running, a significant air leak was obvious at the seal between the PVC piping and the hollow shaft (probably 10–50 std. ft^3/min). As a result of this discrepancy, both transfer rate and aeration efficiency were calculated on the basis of off-gas flow as well as velocity measurements.

Power consumption of the test aerator was calculated from measured voltage and amperage data when operating with and without the blower. On the basis of the steady-state column testing, α factor was estimated to be about 0.56. The oxygen uptake rate averaged about 6 mg/L/h.

The field transfer rate was calculated using Eq. 5.

$$\text{Field transfer rate} = SOTE_{pw} \times \text{flow} \times 0.075 \times 0.2313 \times 60 \quad (5)$$

where

$SOTE_{pw}$ = standard oxygen-transfer efficiency in process water, calculated as a decimal rather than a percentage

flow = measured off-gas flow or estimated air flow to aerator, std. ft^3/min

0.075 = weight of air per cubic foot at standard conditions

0.2313 = weight fraction of oxygen in ambient air

60 = conversion from minutes to hours

The clean-water transfer rate was estimated by dividing the field transfer rate by the α value obtained in the steady-state column test. The field and estimated clean-water aeration efficiencies were determined by dividing the transfer rates by the calculated power draw. Because of the inherent difficulties in reliably measuring the appropriate α for this equipment, questions still exist regarding the aerator's true clean-water aeration efficiency. The relative performance with and without blower assist, however, does not depend on α and is considered quite reliable.

Comparing the overall data with and without the blower, it is apparent that the blower increased the oxygen-transfer rate (lb/h) by approximately 50% and aeration efficiency (lb/hp·h) by about 40%. The incremental improvement in transfer rate and efficiency is almost the

same regardless of whether the measured off-gas flow or the estimated air delivery from the velocity meter are used. Averaging the results obtained using the off-gas capture and velocity meter indicate an apparent clean-water aeration efficiency of 0.97 lb/hp·h without the blower and 1.35 lb/hp·h with the blower. These results suggest significant oxygen-transfer improvements can be obtained very economically by retrofitting the remaining aspirating aerators with blowers.

Summary

Off-gas test procedures were successfully applied to measure the process-water oxygen-transfer performance of a 50-hp aspirating propeller-pump aerator with and without blower assist. The results indicate an oxygen-transfer rate improvement of about 50% and an aeration-efficiency improvement of about 40% with the use of a 3-hp blower assist. The estimated aeration efficiency of the aspirating aerator in clean water is approximately 1.0 lb O_2 /hp·h with the blower. □

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