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U. S. ENVIRONMENTAL PROTECTION AGENCY
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by

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INTRODUCTION

The Arctic Environmental Research Laboratory (AERL) constructed an experimental aerated lagoon as part of a pilot facility at Eielson Air Force Base, Alaska, in 1968. The lagoon was 16 ft wide by 12 ft deep by 82 ft long and divided into six cells. Perforated tubing (Hinde Engineering Co., Highland Park, Illinois) was used originally for aeration. The tubing is 5/8 inch OD with short slits cut every 1-1/2 inches on the top and a lead keel on the bottom to keep it submerged.

Because of clogging problems encountered with the perforated tubing in the experimental lagoon, and similar experiences reported by others, the lagoon was modified in January 1970, by replacing the perforated tubing with Aer-O-Flo (Aer-O-Flo Corporation, Florence, Kentucky) non-clog diffusers. This was done to determine the feasibility of using coarse bubble or non-clog diffusers in aerated lagoons. The Aer-O-Flo diffuser consists of a cap which rests on a 1/8-inch pipe orifice (see detail of Figure 3). When air is flowing the cap is forced up about 1/16 inch and air flows under the cap and theoretically up through the small holes in the cap. When air is shut off the cap falls back against the orifice and prevents solids from backing up in the system.

The lagoon was operated for 2 years with no problems which could be associated with these diffusers. Because of the success with the Aer-O-Flo diffusers in the pilot facility, it was decided they should be demonstrated in a full scale lagoon. This led to an agreement with the Army in the summer of 1971 which allowed AERL to modify part of the waste treatment lagoon at Ft. Greely.

The Ft. Greely lagoon has two principal cells which can be operated in series or in parallel. Each cell is separated into two smaller cells by a baffle which extends to about 1 foot below the water surface. Each principal cell 200 ft by 200 ft at the base and the operating depth is 10 feet. Aeration is provided by perforated tubing.

One-half of the lagoon was modified as shown in Figure 1. Two clusters of Chicago Pump Shearfusers (Chicago Pump, FMC Corp., Chicago, Illinois) (Figure 2) were installed in one cell. Shearfusers consist of a box about 7-1/2 inches square with a 1-inch air injection orifice entering the side. As the air rises in the box, water is pulled in through a hole in the other side and the resulting shearing action causes the air to break up into smaller bubbles. Aer-O-Flo diffuser clusters (Figure 3) were installed in the second cell.

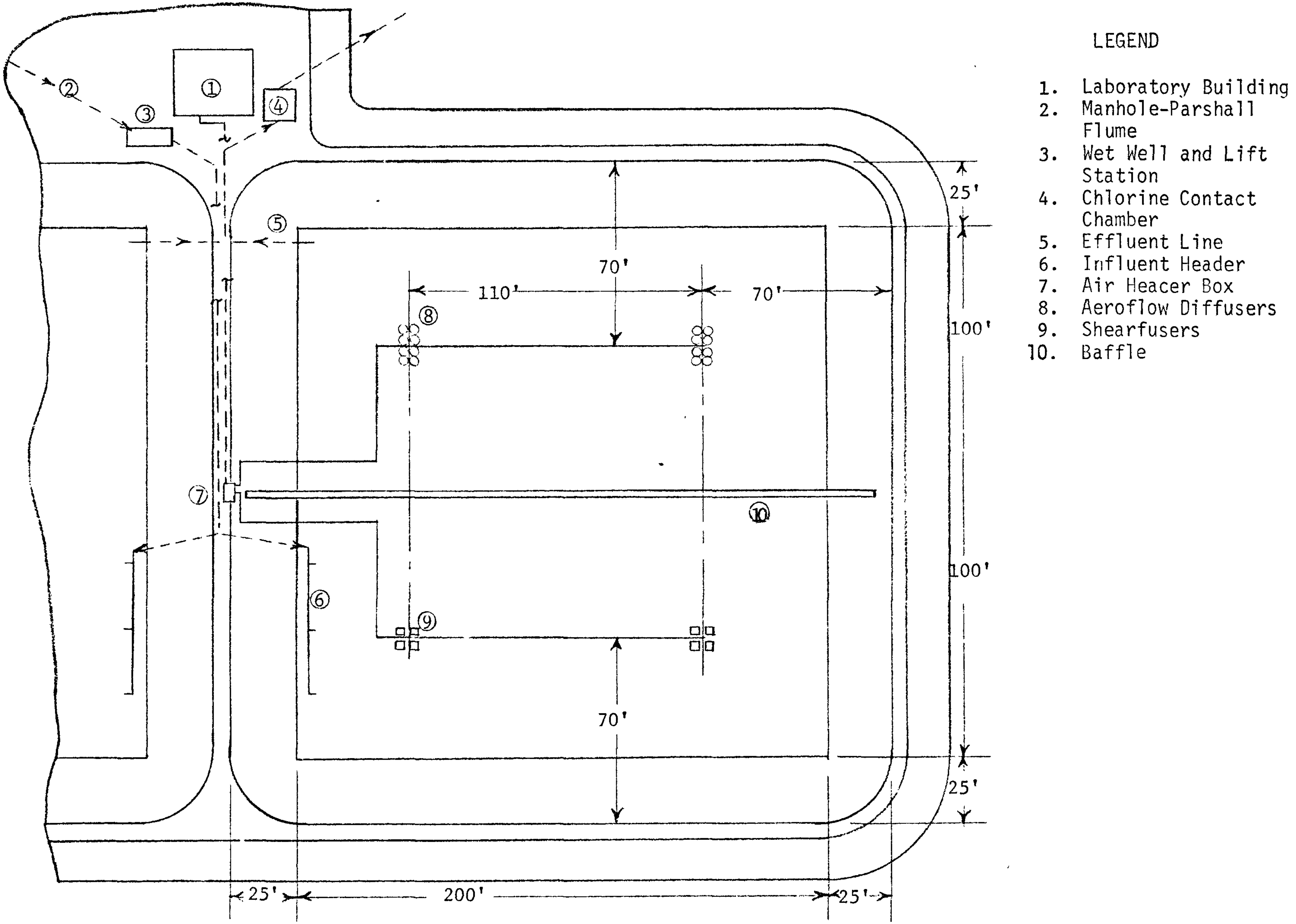

Figure 1. FT. GREELY AERATED LAGOON MODIFICATIONS

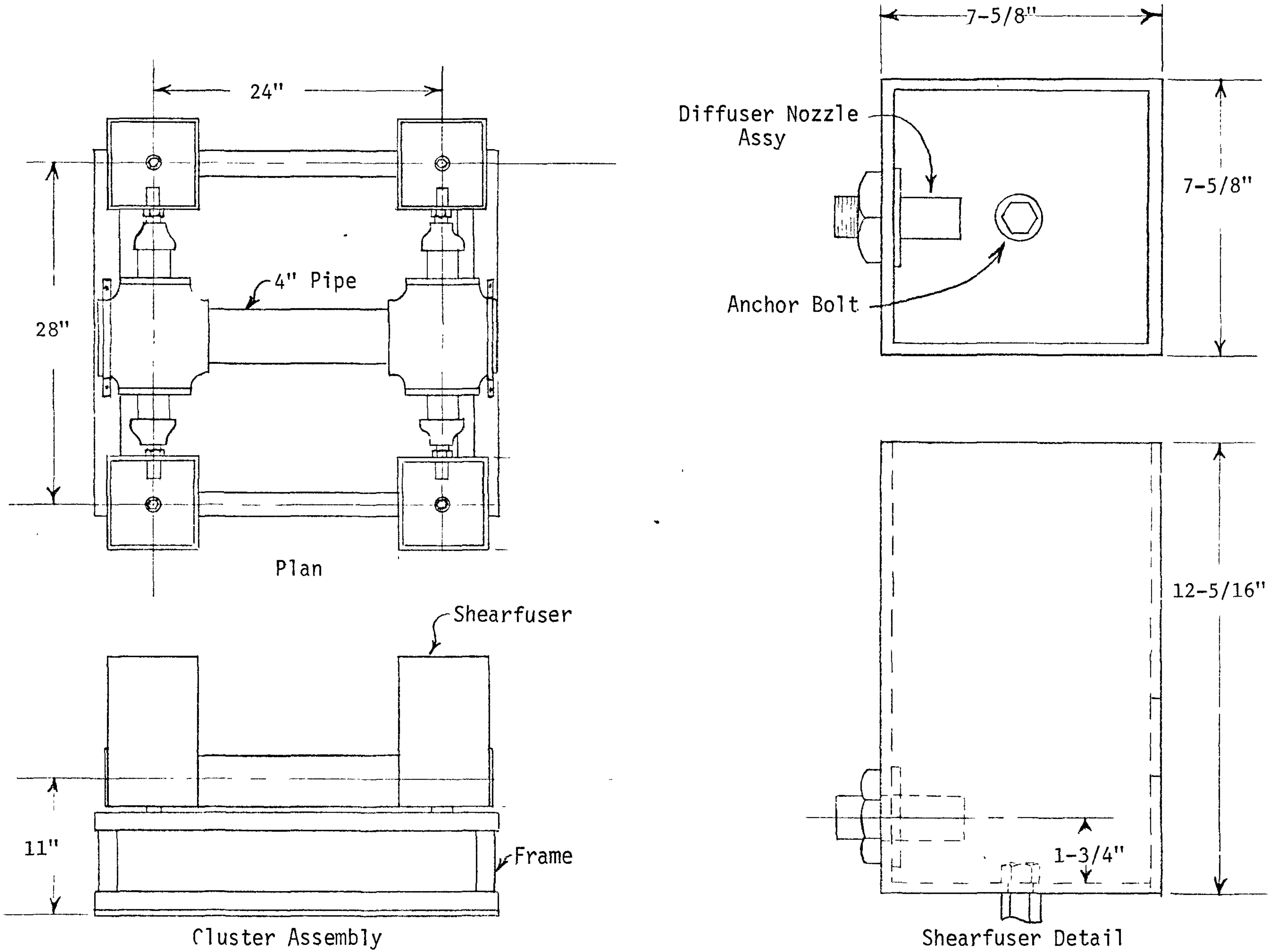

Figure 2. CHICAGO PUMP SHEARFUSER ASSEMBLY

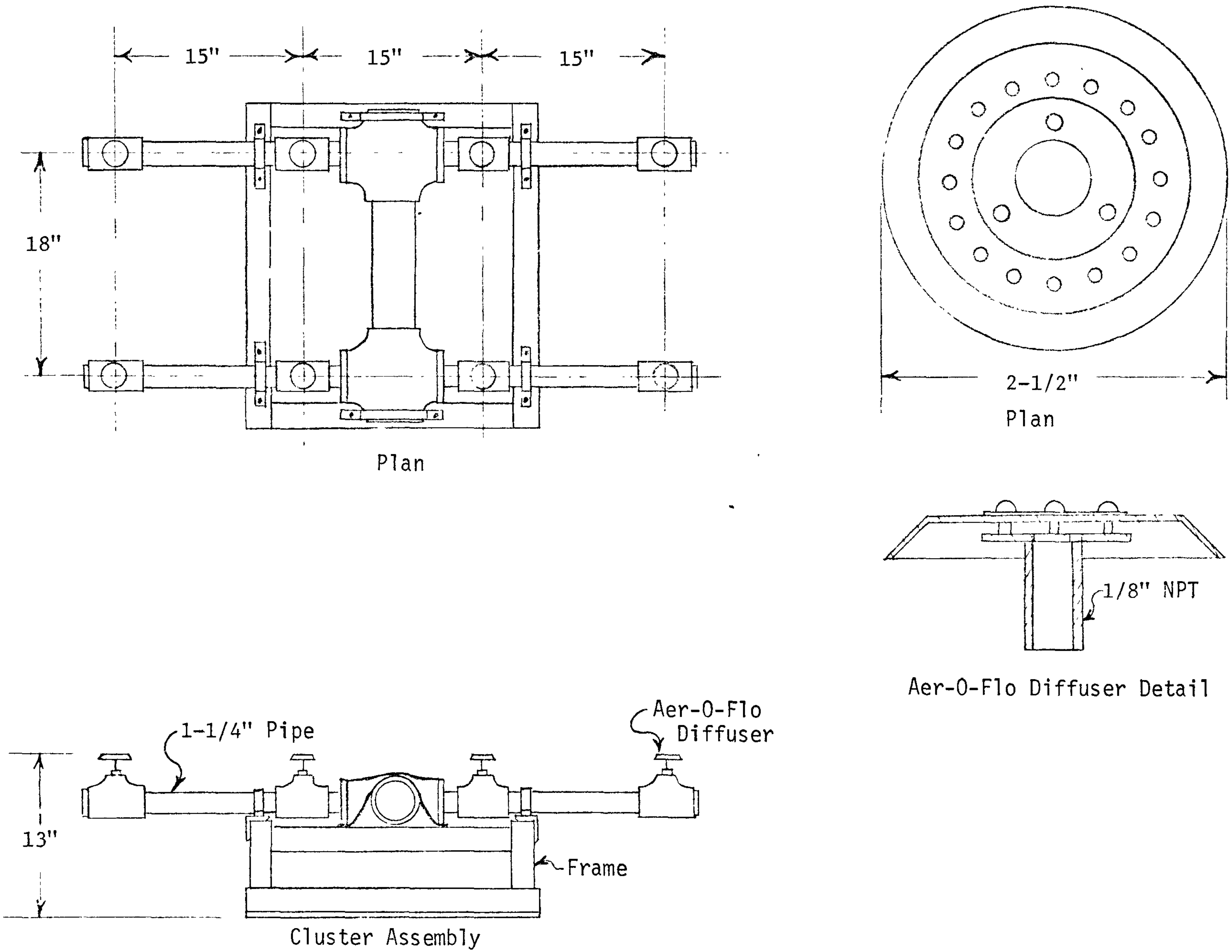

Figure 3. AER-O-FLO DIFFUSER ASSEMBLY

LAGOON PERFORMANCE

The two principal cells of the lagoon were operated in paralled and monitored over the 1971-1972 winter. Table 1 presents a summary of the performance of the lagoon through this period. Nearly all of the influent samples were collected using a composit sampler; however, some problems were encountered with the collection equipment due to large solid particles fouling the line. All effluent samples were grab.

The difference in detention times was due to an imbalance of flow to the two sides. BOD removals for both sides appear to be typical of a cold region aerated lagoon with removals of 81 percent and 82 percent, respectively, for detention times of 25 and 38 days.

Figure 4 gives further information on the perforated tubing aerator performance. Lagoon dissolved oxygen (D.O.) levels, taken between 10:00 AM and 1:00 PM on the dates indicated, were obtained with a YSI D.O. meter (Model 54) and probe. Air flow data was obtained through the use of a venturi meter on the coarse bubble side, and this value was subtracted from the total blower output for the fine bubble side.

Some of the variability of the data is due to clogging problems encountered with the perforated tubing. That is, as the tubing began clogging, more air was diverted to the coarse bubble aerator side to reduce the discharge pressure of the compressors. The trend begain in December or January. Although the discharge pressures ranged around 9 psi in May, the air flow through the perforated tubing was so low that the lagoon went anaerobic. The tubing was cleaned with HCl gas around the first of June. The cleaning plus algal activity accounts for the high D.O. levels in June. Air flow data was not obtained in early July.

TABLE 1

FT. GREELY WINTER DATA SUMMARY

November 1971 through May 1972

	Influent[1]	Coarse Bubble Diffuser[1]	Fine Bubble Diffuser[2]
Detention Time (Days)	---	25	38
Loading (#BOD/day/1000 ft^3)	---	0.45	0.30
BOD	182	35	33
Percent Removal		81	82
COD	343	118	114
Percent Removal		66	67
SS	153	39	36
Percent Removal		74	76

1 - Average of 10 samples

2 - Average of 9 samples

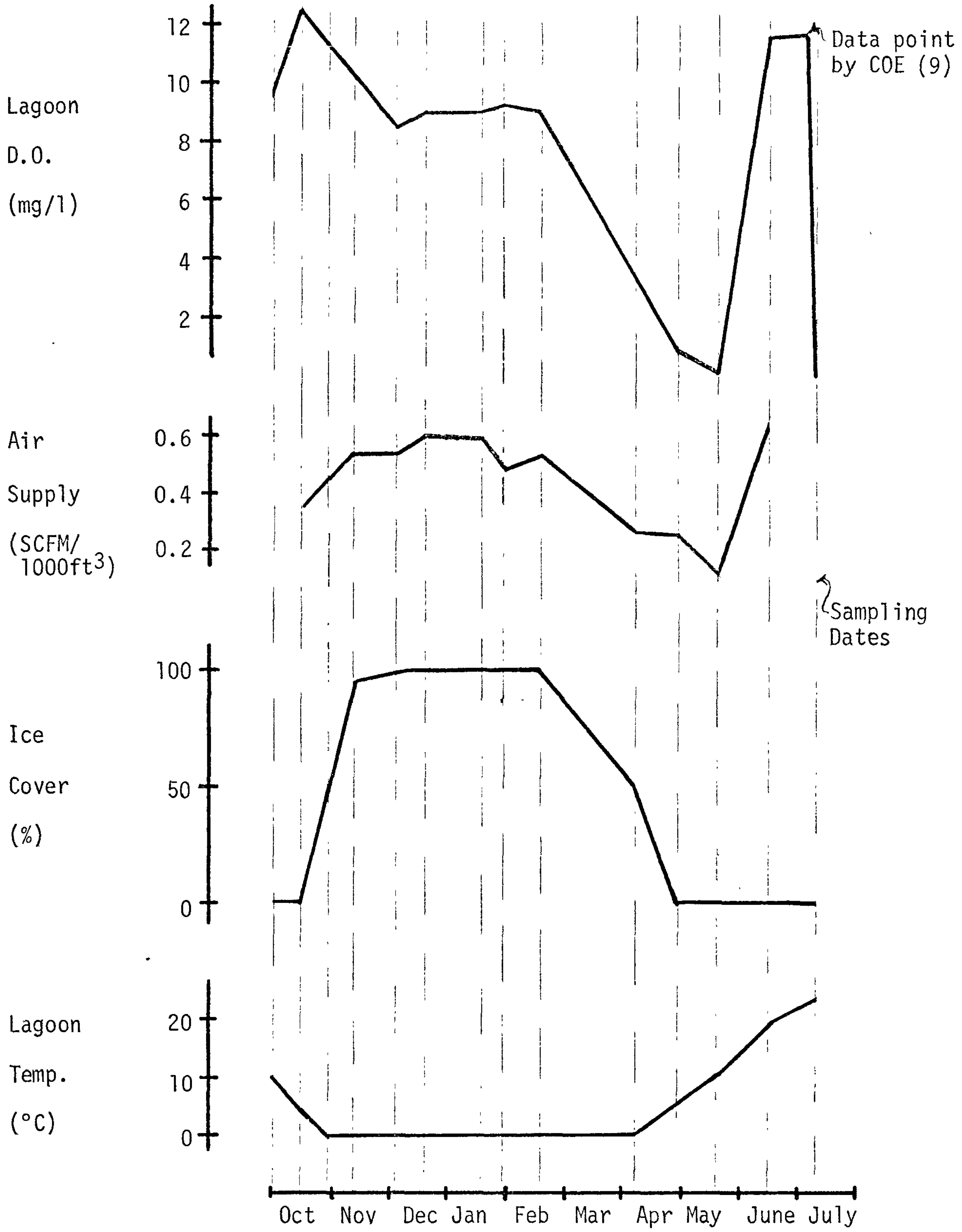

Figure 4. FT. GREELY FINE BUBBLE AERATOR

The low D.O. which occurred in July was not due to low air flow but was due to bottom sludge turnover. This turnover is caused by heavy sludge layers which undergo increasing anaerobic action as the temperature increases until the resulting gas production causes the sludge to rise and release sulfides. The result is a drastic decline in algae and a great increase in D.O. uptake which reduces the lagoon D.O. level to 0. This lasts for a few days at which time the D.O. level begins to increase again. This phenomenon usually occurs once each year after spring breakup in an aerated lagoon in which sludge accumulates with little decomposition over the winter months.

Figure 5 presents the same information for the coarse bubble diffuser side. The lagoon temperature and ice cover was about the same except the ice did not reach 100 percent. The air flow increased during the period of clogging of the perforated tubing until the cleaning in June. Most of the air was diverted to the fine bubble aerator side after the cleaning for an oxygen transfer test; however, the algae had created supersaturated conditions and the attempt was abandoned. The low D.O. point in early June was again due to the sludge turnover phenomena.

Some questions have been raised concerning ice fog generation by the coarse bubble diffusers. Visual observation indicated open water over all four clusters throughout the winter period. These open areas tended to shrink as the air temperature decreased and would almost ice over completely above the Aer-O-Flo clusters at -40°F. The open area above the Shearfuser cluster near the influent always maintained a larger open area, shrinking to about 25 feet in diameter at -40°F. Significant ice fog generation seemed to occur only over this cluster. No ice fog blanket was ever observed around the lagoon as the ice fog that was formed was either not enough to become a nuisance or dissipated rapidly. It should be noted that the influent

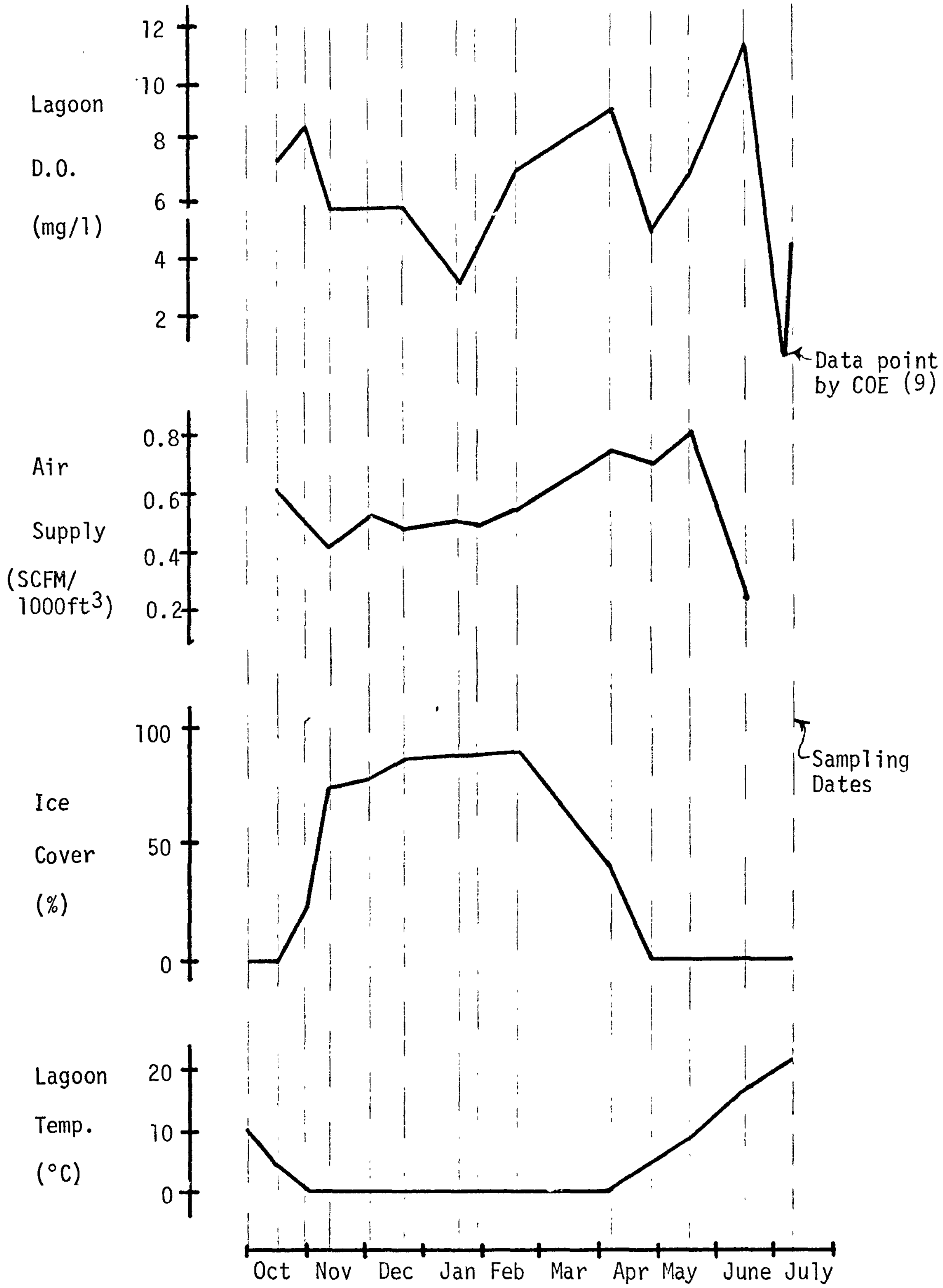

Figure 5. FT. GREELY COARSE BUBBLE AERATOR

sewage temperatures to this lagoon range around 20°C even in winter and that lower influent temperatures would reduce ice fog generation. During the colder period of the year the perforated tubing side of the lagoon was completely ice covered and no ice fog was observed.

Ice fog generation could be reduced by providing more diffuser clusters which would increase the spacing between diffusers. The increased spacing would reduce agitation over the diffusers which would increase the ice cover, thereby reducing the ice fog generation. The diffuser efficiencies would not be affected as transfer rates are independent of diffuser spacing, provided the spacing is sufficient to minimize interfering bubble patterns (6). Increased spacing may provide an improvement over the very close coarse bubble diffuser arrangement of the Ft. Greely clusters which may have resulted in an interfering bubble pattern.

OXYGEN TRANSFER STUDIES

The oxygen transfer equation is as follows:

$$\frac{dc}{dt} = \alpha K_L a(\beta C_s - C) - r$$

$\frac{dc}{dt}$ Change in concentration (mg/l/hr). For steady state conditions: $dc/dt = 0$.

$K_L a$ = Oxygen Transfer Coefficient (hr^{-1}).

α = Ratio of $K_L a$ of lagoon contents to $K_L a$ of tapwater.

C_s = Oxygen saturation concentration (mg/l).

C = Oxygen concentration in liquid (mg/l).

β = Ratio of C_s in liquid to C_s in tapwater.

r = Oxygen Demand Rate (mg/l/hr).

The $K_L a$ value is the overall oxygen transfer coefficient and can be used for rating aerators. C_s-C represents the driving force in the transfer of oxygen into the liquid.

When using the $K_L a$ coefficient, it must be remembered that the constant applies only to a given aeration system (1,8). The value of the constant will be influenced by tank geometry and diffuser type. Air flow rates also affect the $K_L a$ value. For a constant oxygen uptake rate, as the air flow rate is increased, the D.O. level in the liquid increases, which in turn reduces the driving force and increases the $K_L a$ value.

It should also be remembered that the efficiency of aerators is related to the oxygen uptake rate in the reacting liquid. That is, under steady state conditions, the amount of oxygen transferred cannot be greater than that utilized in the liquid, and the aerator effeciency will decrease with increasing D.O. levels.

The K_La value is influenced by temperature which may be accounted for through the Arrhenius temperature correction equation as follows:

$$K_La\ (T) = K_La(20)\theta^{T-20}$$

θ = Temperature Coefficient

T = Temperature, °C

A value of 1.02 was used in adjusting the K_La values obtained in these studies (5).

In order to compare the performance of the coarse and fine bubble aerators, oxygen transfer studies were conducted at the Ft. Greely lagoon.

K_La values were calculated from the oxygen transfer equation for steady state conditions. Values of 0.85 and 0.9 were used for α and β respectively, for all the tests. Cs was found from the following equation (7):

$$Cs = Cw\ \left(\frac{P_b}{29} + \frac{O_t}{42}\right)$$

Cw = Oxygen saturation concentration at the actual barometric pressure.

P_b = psia at the aerator depth.

O_t = percent oxygen in the air leaving the tank

D.O. uptake samples were obtained at mid-depth from the three docks on each half of the lagoon and the values reported are an average of the three samples.

D.O. uptakes were determined by bringing samples into a laboratory building, shaking the samples for aeration, placing the samples in BOD bottles, placing the BOD bottles in a water bath at the same temperature as the lagoon, and reading the D.O.'s with a YSI D.O. meter (Model 54) and YSI BOD probe (Model 542A). This procedure was accomplished as quickly as possible, usually within a few minutes. The bottles were agitated periodically during the D.O. uptake period. The uptake for May 18 was adjusted for algae production and bottom sludge demand. Algae production was determined by hanging light and dark BOD bottles in the lagoon as per Camp (2). Bottom sludge demand was determined by means of a bottom sludge respirometer (3). The higher D.O. uptakes for the coarse bubble diffusers are a result of the higher influent flow to that side as mentioned previously.

D.O. levels in the lagoon were also determined with a YSI meter and probe. D.O.'s were measured at various points throughout the lagoon at the beginning of the sampling season and found to be reasonably uniform. Thereafter, D.O.'s were determined from the three docks on each half of the lagoon and the D.O. levels reported are an average of these.

Table 2 presents the oxygen transfer data collected and is grouped by type of aerator. Also shown is one data point for a lagoon serving the Northway, Alaska, FAA station which at that time had air gun aerators (Aero-Hydraulics Corp., Montreal, Canada). The last data point is taken from the literature and represents an evaluation of an air gun installation at Brampton, Ontario (12). Air gun aerators are designed for use in deeper lagoons (15 feet) and consist of a tube with a chamber at the bottom. Air is pumped into the chamber and builds up until released by a siphoning effect through a tube in one large bubble. Water is drawn into the tube and a pumping action occurs. The units are designed to provide mixing as well as oxgenation.

TABLE 2

OXYGEN TRANSFER DATA

Aerator	Date	Liquid Temp. °C	Ice Cover %	D.O. Level mg/l	D.O. Uptake mg/l/hr	Air Supply SCFM/ 1000 ft^3	O_2 Transfer Efficiency %	K_La Value		lb. O_2 Transfer / hp-hr
								Calculated	Adjusted to 20°C	
Ft. Greely Coarse Bubble	Feb 18	<0.5	90	6.9	0.34	0.54	3.8	0.064	0.094	1.42
	Apr 6	<0.5	40	9.1	0.23	0.76	1.9	0.054	0.079	0.69
	Apr 28	5.2	0	5.2	0.30	0.70	2.7	0.049	0.066	0.99
	May 18	10.5	0	7.0	0.46	0.81	3.7	0.14	0.17	1.32
	Nov 30	1.0	30	3.8	0.42	0.73	3.5	0.049	0.071	1.27
	Dec 22	1.0	70	0.7	0.34	0.52	4.0	0.030	0.044	1.69
Ft. Greely Fine Bubble	Feb 18	<0.5	100	9.1	0.21	0.52	2.5	0.047	0.069	0.53
	Apr 6	<0.5	50	3.2	0.17	0.27	4.1	0.019	0.028	1.04
	Apr 28	5.2	0	1.0	0.18	0.26	4.4	0.019	0.025	0.93
Northway Air Gun	May 23	8	0	5.0	0.37	1.29	1.7	0.070	0.088	0.71
Brampton Air Gun (Thon, 1964)		14.8	0	3.6	0.43	1.03	2.6	0.064	0.073	0.72

Mixing over the center baffle was too great to permit separate evaluation of the two types of non-clog aerators at Ft. Greely. As a result, the diffusers performance has been lumped together for evaluation. This should not detract substantially from the results as any difference between the two coarse bubble aerators will be small compared to that between the coarse bubble and fine bubble aerators.

The progressive drop in D.O. levels for the fine bubble diffuser is a result of the clogging mentioned previously. Data for the fine bubble aerator was not obtained on May 18 because the lagoon had gone anaerobic at that time. Data for November and December was not obtained because the fine bubble diffusers had been renovated during the summer by manually punching larger holes in the tubing which changed the diffuser characteristics.

Based on the O_2 transfer efficiencies for comparable lagoon D.O. levels, the coarse bubble diffuser efficiencies appear to be 75-90 percent of those for the fine bubble diffuser. An important point to note, however, is that although the fine bubble diffuser efficiencies are generally higher, the pounds of oxygen transferred per hp-hr are lower due to the higher compressor discharge pressures associated with the clogged tubing. The low O_2/hp-hr values would indicated that although the fine bubble diffuser is more efficient in oxygen transfer, it is not necessarily more economical because of the power requirements.

Figure 6 presents a plot of the K_La value at 20°C times the aeration basin volume per diffuser ($K_La \cdot V$) vs. the air flow rate per diffuser (SCFM/diffuser). The coarse bubble diffusers were evaluated as shearfusers. This was done because, situated in the first cell where the oxygen demand was greatest, the shearfuser received the major portion of the total air flow. Each Aer-O-Flow diffuser cluster was considered as one shearfuser which made a total of 10 shearfusers for the calculations.

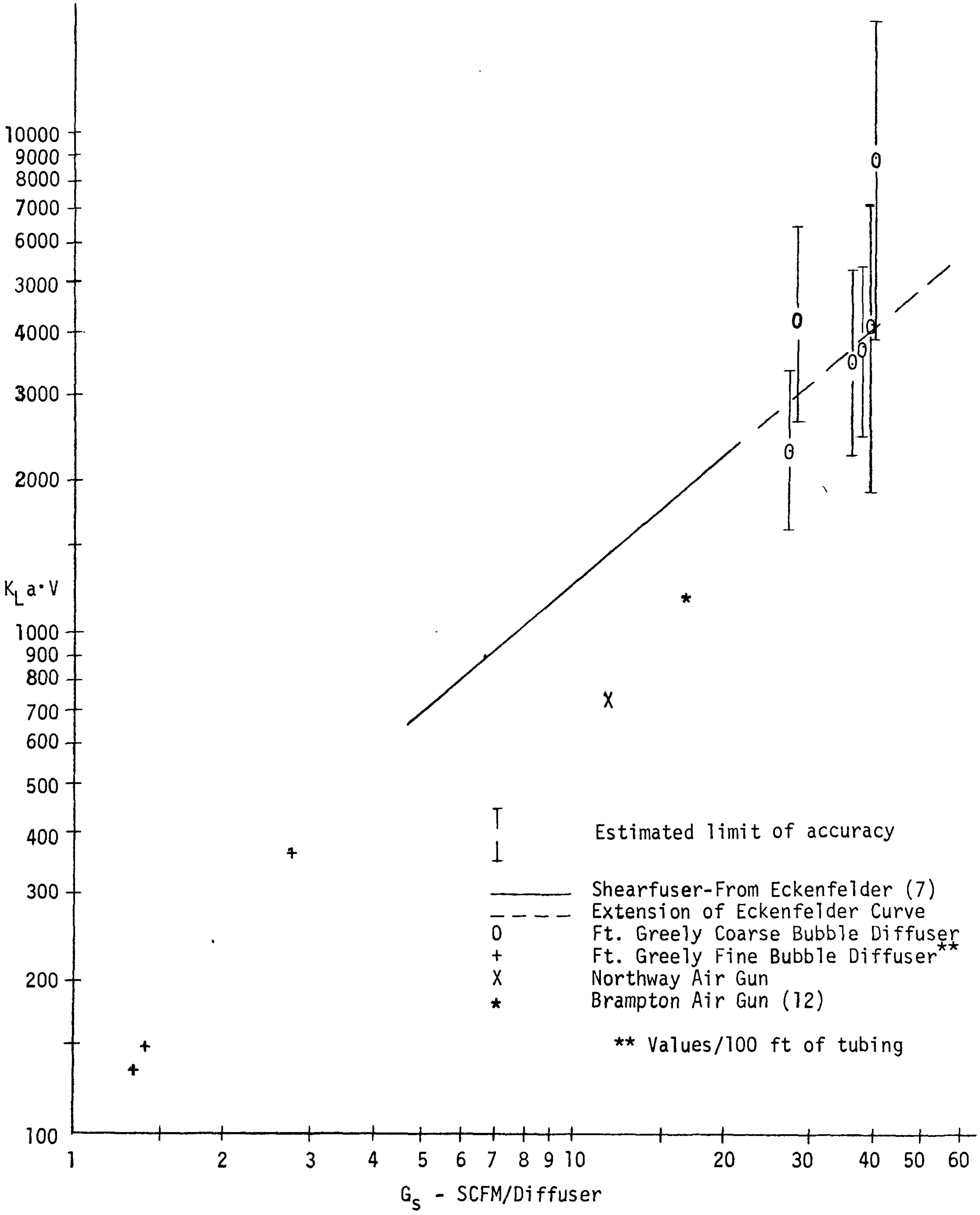

FIGURE 6

OXYGEN TRANSFER CHRACTERISTICS FOR DIFFUSERS IN AERATED LAGOONS

The solid line shown was obtained from the literature and relates the K_La value for a certain diffuser and tank configuration to the tank volume per diffuser. The curve is based on data obtained in a tank 24 ft. long by 4 ft wide by 15 ft deep, using the shearfuser diffuser. Other curves for similar coarse bubble diffusers were shown but are not presented here.

Because of the variability of the shearfuser data obtained at Ft. Greely, maximum and minimum values of K_La based on possible errors in procedures and equipment were calculated and a range of $K_La \cdot V$ values plotted as shown. The accuracies used in the calculation were as follows:

C = ±0.5 mg/l - Standard Methods (11) indicates an accuracy of ±0.1; however, ±0.5 was used because of the slow instrument response due to the cold conditions during the studies.

r_γ = ±15 percent - Sawyer (10) indicates the BOD test accurately is considered to be 5 percent. The 15 percent value was used to account for sampling error.

β = ±0.05

α = ±0.01

The uppermost point shown represents the data for May 18 which is probably the most questionable because of the need to account for algae D.O. production and bottom sludge demand. The algae D.O. and bottom sludge demand values were varied by +50 percent and -50 percent for the error calculations.

Based on the plot of data in Figure 6, it would appear that the $K_La \cdot V$ vs. air flow data that has been published may be used for coarse bubble diffuser oxygen transfer determinations for aerated lagoons. This data should be used with caution, however, as the published data is based on much smaller aeration basin volumes per diffuser. At the larger basin volumes per diffuser the slope of the curve may be somewhat different and not reflected in the limited data presented here.

Data points for the fine bubble and air gun diffusers shown in Figure 6 should be considered as providing approximate information only because of the limited number of points and the possible scatter as reflected in the shearfuser data.

CONCLUSIONS AND RECOMMENDATIONS

The results of these studies indicate that, although the fine bubble diffuser is 10-25 percent more efficient in oxygen transfer than the coarse bubble diffuser, it is not more economical. Power requirements in terms of lb. O_2 transferred/hp-hr are higher because of the restricted diffuser openings which require higher blower discharge pressures. Maintenance requirements are also higher because of clogging in the tubing which requires periodic cleaning. The clogging also results in higher compressor maintenance due to increased discharge pressures.

Regarding lagoon design with coarse bubble diffusers, it is suggested that published $K_La \cdot V$ vs. air flow/diffuser data may be used. A certain amount of caution should be exercised, however. Although the Ft. Greely coarse bubble diffuser data presented here indicated the published curve could be extended for use in aerated lagoon design, the scatter prevented defining a slope for the extended curve.

In areas where ice fog is a problem, consideration should be given to using a large number of clusters (less aerators per cluster) which would provide more space between the diffusers. This increased spacing would reduce the generation of ice fog as the percent of ice cover would increase with lower agitation above the aerator clusters. Spreading out the diffusers would not reduce the oxygen transfer efficiencies and may provide an improvement over the Ft. Greely cluster arrangement.

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