DEPARTMENT OF
FISHERIES AND
OCEANS

AERATION METHODS FOR SALMONID HATCHERY WATER SUPPLIES

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1. INTRODUCTION

Frequently groundwater and occasionally surface waters must be aerated to meet hatchery water quality requirements. This report outlines the design principles, applications, and performance characteristics of several aeration techniques. The report is not a design manual but is intended to help the engineer select and specify appropriate aeration equipment, or alternatively, choose an appropriate concept for an "in house" design.

Section 2 discusses the objectives of the most common gas transfer processes. Section 3 presents a brief review of the basic principles of aeration and how they apply to the design and testing of aeration equipment. Section 4 describes the characteristics, advantages, disadvantages, and applications of various types of aerators. The final section discusses problems with design, selection, and specification of aeration equipment.

The seriousness of each of the potential problems noted depends on the particular aeration equipment application. In other words, what might be a serious disadvantage in one instance may be minor or non-existant in another. It is, therefore, up to the design engineer to analyze the comments in the report as they pertain to the specific situation.

2. IMPROVEMENTS IN WATER QUALITY ACHIEVED BY AERATION

2.1 Addition of Dissolved Oxygen

To assure a high degree of safety, a level of 98% saturation is required for incubation (Protection Level A) (SIGMA, 1979). Rearing and holding requirements are less stringent, however, the carrying capacity of a rearing pond (weight of fish per unit flow) is seriously constrained when dissolved oxygen levels are about 60% saturation (Protection Level B). Therefore, even small increases in dissolved oxygen levels can significantly increase the carrying capacity. For example, a water supply at 90% saturation would have about twice the carrying capacity of a water supply at 75% saturation. Therefore, a typical objective of aeration would be to achieve 95-100% saturation. The 98% saturation level required for incubation may not be a practical goal with some types of aerators. If this type of aerator is preferred for the particular application then aeration costs must be weighed against the risks of lower oxygen levels and the loss of carrying capacity in order to establish a practical objective.

2.2 Oxidation of Iron

The objective of iron removal from groundwater by aeration and filtration is to achieve a total iron concentration of less than about 0.3 mg/L. The more complete the oxidation, the greater the chance a treatment system would have of attaining this goal.

Oxidation of iron by aeration is generally preferable to chemical oxidation because of the risk of accidents. The oxygenation reaction can be expressed by:

$$2\,Fe^{++} + \tfrac{1}{2}\,O_2 + 5H_2O \;=\; 2\,Fe(OH)_{3(s)} + 4H^+ \quad (1)$$

(log K = 5.8, 25^{o}C) (Fair et al, 1968)

0.14 mg/L of dissolved oxygen is needed to oxidize 1 mg/L of ferrous iron. The reaction constant predicts that at the pH of most natural waters the ferrous iron is unstable and the reaction will go virtually to completion. Although this reaction is thermodynamically correct, pH and other factors affect the rate of the reaction and considerable retention time may be necessary.

2.3 Reduction in Total Gas Pressure

Gas bubble disease has been observed in alevins at total gas pressures of less than 105 percent (SIGMA, 1979). As the design value should be lower than the suggested criteria of 105% to allow for fluctuations in aerator performance, it is therefore suggested that aeration equipment be designed to reduce the total gas pressure below 103 percent. This level should provide protection for the most sensitive life stages and provide a safety factor for larger fish. Levels of approximately 103 percent are feasible with aeration towers or mechanical surface aerators.

2.4 Removal of Carbon Dioxide

Carbon dioxide is very soluble in water and concentrations in the order of 100 mg/L in groundwater are not uncommon. However, because the partial pressure of carbon dioxide in the atmosphere is low (about 0.00033 atm) the saturation value is less than 2 mg/L at normal water temperatures.

Exposure of water droplets to air for 2 seconds ordinarily lowers the carbon dioxide concentrations by 70 to 80%. Removal efficiencies as high as 90% are possible (Fair et al, 1968). Aeration is efficient at removal of carbon dioxide down to about 10 mg/L, a concentration within the acceptable range for fish culture. Good ventilation is required to prevent a build up of asphyxiating concentrations of carbon dioxide and to promote rapid release of the gas.

Removal of carbon dioxide increases the pH. For example, if a water contained a bicarbonate alkalinity of about 50 mg/L as $CaCO_3$ at a temperature of 10^oC, a reduction in the carbon dioxide concentration from 100 mg/L to 10 mg/L would increase the pH from about 6.1 to about 7.1.

2.5 Removal of Hydrogen Sulphide

The removal of hydrogen sulphide is complicated by several factors. First, the removal process must be very complete as no more than 2 ug/L should remain in the water.

Second, the solubility of hydrogen sulphide is very high (more than twice as high as CO_2) and very low partial pressures of hydrogen sulphide in an aeration device could result in lethal concentrations in the water. In other words, good ventilation is extremely important.

Third, as removal of carbon dioxide increases the pH, hydrogen sulphide dissociates to form the sulphides HS^- and S^- which cannot be removed by aeration.

Fourth, oxygen introduced by aeration can react with hydrogen sulphide to produce elemental sulphur, which then can be removed by coagulation and filtration (Fair et al, 1968).

Fifth, hydrogen sulphide is an explosive and extremely toxic gas to humans.

2.6 Removal of Methane

Methane can be present in well waters. It has a low solubility (similar to that of oxygen) and does not react with water. Because it is not present in the atmosphere it is readily removed by aeration. Good ventilation is required to prevent accumulation of explosive mixtures.

2.7 Removal of Ammonia

The quantity of undissociated ammonia (dissolved ammonia gas) is primarily a function of pH and temperature. Only at a pH in the range of 10.8 to 11.5 is removal of ammonia by aeration possible (Figure 1). The ammonia stripping process consists of (1) raising the pH, generally with the addition of lime, and (2) utilizing a well ventilated aeration device. The application of the process to water supply treatment is severely limited by the cost of pH adjustment and sensitivity to temperature variations. For applications in cold weather where a high degree of removal is required the stripping process will generally not be adequate (EPA, 1975).

3. BASIC PRINCIPLES OF AERATION

3.1 General

There are two parameters that govern the design of aeration equipment: 1) gas solubility and 2) the rate of gas transfer. Gas solubility dictates maximum (or minimum) levels that are attainable; the rate of gas transfer dictates the practicality of reaching the desired levels. Both parameters must be considered carefully in aeration design and therefore are briefly discussed below.

3.2 Gas Solubility

Henry's law states that the quantity of dissolved gas in a liquid is directly proportional to the partial pressure of the gas in the atmosphere in contact with the liquid; i.e.:

$$C_S = K_S P \qquad (2)$$

C_S - saturation concentration of gas in liquid (mL/L)

K_S - coefficient of absorption (mL/L)

P - partial pressure (molar fraction of total pressure in atmospheres)

The stability of a dissolved gas is changed when either the absorbtion coefficient or the partial pressure is altered.

The main factor affecting the absorption coefficient is temperature, however, the concentration of ionic impurities also affects the solubility. Brackish water values can be obtained by multiplying the solubility or the absorption coefficient for freshwater by approximately $\left[1-(\bar{s} \times 10^{-5})\right]$, where $\bar{s}$ is the salinity of the water expressed in mg/L as chlorides (Weber, 1972). Absorption coefficients (Table I) are derived empirically and presented in a number of engineering handbooks.

TABLE I

ABSORPTION COEFFICIENTS OF COMMON GASES IN WATER (Fair et al, 1968)

Gas	MOL. WT.	Density @ $0^{o}C$ and 1 atm mg/mL	Absorption Coefficients (mL/L) @ 1 atm $0^{o}C$	$10^{o}C$	$20^{o}C$	$30^{o}C$	Molecular Percentage In Dry Air [1]
O_2	32.00	1.429	49.3	38.4	31.4	26.7	20.95%
N_2	28.01	1.251	23.0	18.5	15.5	13.6	78.08%
CO_2	44.01	1.977	1,710	1,190	878	665	0.03%
H_2S	34.08	1.539	4,690	3,520	2,670	-	-
NH_3	17.03	0.7710	1,300	910	711	-	-

[1] Dry air also contains 0.93% Argon

The partial pressure is defined to be the molar fraction of the total gas pressure. The partial pressure varies with the dry composition of the gas stream at standard temperature and pressure and with factors such as barometric pressure, hydrostatic pressure and water vapour pressure. Higher altitude reduces partial pressure and, therefore, solubility according to the ratio of observed to standard pressure. The approximate change in pressure with altitude is 1% for every 82 metres (270 feet) of elevation. Hydrostatic pressure increases partial pressure and solubility by approximately 10% for every metre of depth. Water vapour pressure decreases partial pressure by reducing the total pressure exerted by all other gases. Values for water vapour pressure are given in Table II.

Appendix I contains an example calculation of gas solubility and similar calculations can be done for any gas. Solubility of oxygen in freshwater at different temperatures is given by Table III. Solubility of both oxygen and nitrogen is shown graphically in Figure 2.

The above discussion and data has a direct effect on the design of aeration equipment. For example, the relatively high absorption coefficients of carbon dioxide and hydrogen sulphide would indicate that to strip these gases high ventilation rates are required to reduce

TABLE II

SATURATED WATER VAPOUR PRESSURE IN RELATION TO WATER TEMPERATURE

(at 760 mm Hg air pressure) (Davis, 1975)

Temperature (^{o}C)	Saturated Water Vapour Pressure (mm Hg)	Temperature (^{o}C)	Saturated Water Vapour Pressure (mm Hg)
-5	3.0	16	13.6
-4	3.4	17	14.5
-3	3.7	18	15.5
-2	4.0	19	16.5
-1	4.3	20	17.5
0	4.6		
		21	18.6
1	4.9	22	19.8
2	5.3	23	21.0
3	5.7	24	22.4
4	6.1	25	23.7
5	6.5		
		26	25.2
6	7.0	27	26.7
7	7.5	28	28.3
8	8.0	29	30.0
9	8.6	30	31.8
10	9.2		
11	9.8		
12	10.5		
13	11.2		
14	12.0		
15	12.8		

TABLE III

SOLUBILITY OF OXYGEN IN FRESH WATER VS. WATER TEMPERATURE

(Atmosphere Contains 20.9% Oxygen at a Pressure of 760 mm Hg including water vapour pressure) (Davis, 1975)

Temp (C)	mg/L = P.P.M.	Temp (C)	mg/L
0	14.62	16	9.95
1	14.23	17	9.74
2	13.84	18	9.54
3	13.48	19	9.35
4	13.13	20	9.17
5	12.80		
		21	8.99
6	12.48	22	8.83
7	12.17	23	8.68
8	11.87	24	8.53
9	11.59	25	8.38
10	11.33		
		26	8.22
11	11.08	27	8.07
12	10.83	28	7.92
13	10.60	29	7.77
14	10.37	30	7.63
15	10.15		

their partial pressures so that re-absorption does not occur. Conversely, to solubilize oxygen, high partial pressures are desirable to overcome the relatively low absorption coefficient. Methods of performing both of these functions are included in Section 4.

3.3 The Rate of Gas Transfer

The rate of gas transfer is proportional to its degree of undersaturation (or supersaturation) in the absorbing liquid multiplied by a constant. This relationship can be expressed as:

$$\frac{dc}{dt} = K \frac{A}{V} (C_s - C_t) \quad (3)$$

$\frac{dc}{dt}$	-	change in concentration of the dissolved gas with time
K	-	gas transfer coefficient
$\frac{A}{V}$	-	area of gas-liquid interface per unit volume of liquid
C_s	-	saturation concentration
C_t	-	concentration at time t

The "driving force" for transfer is the magnitude of $C_s - C_t$. For example, if the oxygen deficit ($C_s - C_t$) is very small, as in a typical fish hatchery application, conventional aeration will be very inefficient. An advantage can be gained if the saturation concentration can be increased by pressure, thereby increasing the oxygen deficit. However, supersaturation must be prevented.

The gas transfer coefficient K is dependent on the rate of molecular diffusion through thin gas and liquid films at the air-water interface. For gases of fairly low solubility (i.e. O_2, N_2 and CO_2) transfer through the liquid film is the rate limiting step. Because increased temperature and turbulence reduces the liquid film thickness, K increases and gas transfer is promoted. For gases of intermediate solubility in water (i.e. H_2S) the effect of both liquid and gas films remain important. Therefore, both the gas and liquid must be stirred or agitated to reduce film thickness and promote gas transfer (increase K).

The gas transfer coefficient for different gases is different under identical transfer conditions. Of major importance is the relative rates of transfer of oxygen and nitrogen especially if air is being introduced at greater than atmospheric pressure. For example, assume that a water supply has identical initial partial saturation levels of oxygen and nitrogen and that hydrostatic pressure is used to achieve oxygen saturation. Nitrogen could become supersaturated if the gas transfer coefficient for nitrogen was greater than that of oxygen.

Gas transfer literature examined in this study gave conflicting information as to the relative transfer rates of the two gases. Weber (1972) concluded that "film theory and penetration theory give results which indicate that the mass transfer coefficient is proportional to the liquid diffusivity raised to a power between 0.5 and 1.0". Tsivoglou et al (1965) showed experimentally that the relative diffusion rates of two gases were inversely proportional to their molecular diameters.

If the molecular diameters of oxygen and nitrogen are taken to be 2.41 Å and 2.19 Å, respectively, then nitrogen would have a rate of diffusion 1.1 times that of oxygen. Thus, nitrogen would be expected to have a gas transfer coefficient (K) between about 1.05 and 1.1 that of oxygen. Weber (1972) reports experimental results which gave a K for nitrogen that was 1.05 times that for oxygen.

In a discussion of dissolved nitrogen changes in a U-tube, Speece, (1970) states that the gas transfer coefficient of nitrogen is approximately 0.83 that for oxygen. A few dissolved gas measurements of water in a full scale U-tube tend to support this concept (Section 4.3.4). Because of the importance of preventing supersaturation the relative transfer rates of oxygen and nitrogen should be clarified before installing a pressure saturation device.

Equation (3) integrates to:

$$C_t = C_s - (C_s - C_o)\, e^{-K \frac{A}{V} t} \qquad (4)$$

C_o - initial dissolved gas concentration

Equation (4) shows, for example, that to obtain a high dissolved oxygen concentration, C_t, both $\frac{A}{V}$ and time, t, must be large as well as K.

The relationship between the air-water interface surface area exposed per unit volume, $\frac{A}{V}$, and time, t, is of particular value in understanding aerator performance. For example, waterfall or spray aerators create a high area to volume ratio through the production of fine drops or thin films of water. However, the exposure time of water to the air may be short. Similarly, diffused aeration systems are more efficient if bubbles are small(and therefore have a large surface area for a given volume of air)and if they are retained in the liquid for as long a time as possible. Because of differences in exposure time and $\frac{A}{V}$, two identical aerators in tanks of different geometry can have very different transfer characteristics.

Stripping of supersaturated gases follows equation (3) except that transfer is in the opposite direction from absorption. Because the saturation value of a gas is influenced by its partial pressure in the air in contact with the water, ventilation is an important consideration in gas stripping devices. An increase in partial pressure of the gas in air would increase the saturation value and, therefore, would reduce the rate of gas release. Additionally, consideration of solubility shows that the increased saturation value would be the minimum concentration in the water that could be achieved. For example, diffused air in a tank is probably not a satisfactory method of removing hydrogen sulphide because the partial pressure of hydrogen sulphide in the bubbles leaving the tank could cause a saturation concentration in the water in excess of recommended concentrations. A device using larger air to water ratios would be more suitable.

3.4 Practical Consideration of Factors Affecting Aerator Performance

For a specific test of a gas transfer device the overall transfer coefficient, $K\frac{A}{V}$, is constant. For oxygen transfer, $K\frac{A}{V}$ is usually known as KLa in units of time^{-1}. Surface, diffused, and eductor type aeration equipment is usually tested in pure water at 20^{o}C by the non-steady state test (APHA-AWWA, 1976). An aeration device is placed in a tank stripped of dissolved oxygen. The aerator is turned on and the increase in dissolved oxygen of the water is measured with respect to time. KLa is calculated from a rearrangement of equation (4):

$$KLa = \frac{\ln (C_s - C_o) - \ln (C_s - C_t)}{t - t_o} \qquad (5)$$

KLa varies with temperature approximately according to equation (6):

$$(KLa)_T = (KLa)_{20} \times 1.024^{T-20} \qquad (6)$$

A single KLa value from an aeration test is reproducible within about 10% (APHA-AWWA, 1976), however, performance tests of identical full scale equipment tested in the shop and field can vary by up to 30% (Stukenburg et al, 1977).

Manufacturers usually express the results of aeration tests in terms of weight of oxygen tranferred per hour per unit of power at 20^{o}C and at a dissolved oxygen deficit of 9.17 mg/L. This can be calculated by:

$$KgO_{2/KW-hr} = (KLa)_{20}(hr^{-1}) \times \frac{9.17\ mg/L}{10^6} \times vol.\ (m^3) \times 998\ kg/m^3 \div KW \qquad (7)$$

OR

$$lbsO_2/HP\text{-}hr = (KLa)_{20}(hr^{-1}) \times \frac{9.17\ mg/L}{10^6} \times vol.\ (gal) \times 8.34\ lbs/gal \div HP \quad (8)$$

(Eckenfelder and Ford, 1970)

9.17 is the saturation concentration @ 20^{o}C and 760 mm Hg atmospheric pressure.

The efficiency of diffused air systems is often expressed as the quantity of oxygen transferred to the liquid as a percentage of the quantity of oxygen delivered to the tank. To compare diffused air systems with other aerator types an approximate conversion is:

Percent Transfer x (0.09 to 0.12) = $KgO_{2/KW\text{-}hr}$

or

Percent Transfer x (0.15 to 0.20) = $lbs\text{-}O_{2/HP\text{-}hr}$

The conversion factor depends on the mechanical efficiency of the blower and on friction losses.

It is very important to estimate the transfer efficiency under field conditions as opposed to direct application of the manufacturer's performance data. The transfer efficiency can be adjusted for the field oxygen deficit and for the temperature according to the equation:

$$N = No \frac{Cs - Cl}{C_{20}} 1.024^{T-20} \quad (9) \quad \text{(Eckenfelder, 1966)}$$

N - $KgO_{2/KW\text{-}hr}$ field conditions

No - $KgO_{2/\ KW\text{-}hr}$ at 20^{o}C and an oxygen deficit of 9.17 mg/L

Cs - field value of dissolved oxygen saturation concentration

Cl - field value of liquid dissolved oxygen concentration

T - temperature ^{o}C

For example, a surface aerator rated at No = 1.8 $KgO_{2/KW\text{-}hr}$ (3 $lbsO_{2/HP\text{-}hr}$) operating at $7^{o}C$ and producing 90% saturation could have a field performance of approximately:

$$N = (1.8\ KgO_{2/KW\text{-}hr})\ \frac{12.17\ mg/L - 10.95\ mg/L}{9.17\ mg/L}\ (1.024^{7-20})$$

$$N = 0.18\ KgO_{2/KW\text{-}hr}(0.3\ lbsO_{2/HP\text{-}hr})$$

Tank geometry and flow patterns and surface active materials, if present in the water, should also be considered, however, this example is sufficient to demonstrate the loss of performance that can be expected under field conditions.

4. APPLICATIONS OF AERATION EQUIPMENT

4.1 General

Aerators can be classified into two groups; first, those which create the gas transfer interface by forming droplets or thin water films through air; and, second, those which create the gas transfer interface by forming bubbles in water. Equipment from the first group utilizes a large volume of air compared to the volume of water. Equipment from the second group, however, utilizes a relatively small volume of air compared to the volume of water. Generally, if gases are to be stripped from water, equipment from the first group should be used. If absorption of oxygen is the major goal, equipment from the second group can be used. There are exceptions to these guidelines which are described in the discussions of specific types of equipment.

The main characteristics to consider when selecting an aeration system are:

1. Suitability for accomplishing desired water quality goals (the goals and some of the factors affecting various aeration processes have been discussed in Section 2)

2. Cost and Availability - some "off the shelf" equipment may be cheaper than custom engineered equipment but may be less efficient and more expensive in the long term or visa versa.

3. Power source used - gravity, pumps, blowers, mechanical agitators, or a combination of these.

4. Climatic Considerations - mainly icing problems
   - some aerators may modify water temperature either favourably or unfavourably.

5. Energy Consumption Efficiency - efficiency may be unimportant if gravity head is available but very important if electricity must be generated in a remote location.

6. Reliability - reliability can be achieved by using very simple gravity operated devices. Alternatively mechanical systems could be flexibly designed and standby equipment provided to allow for failure of individual components.

7. Controllability or "turndown" - raw water quality may perodically change so that less gas transfer is required. The device should be capable of a reduction in gas transfer without loss of energy consumption efficiency.

8. Prevention of Supersaturation - aerators operating at higher than atmospheric pressure achieve dissolved oxygen saturation but can also produce supersaturation. Equipment of this type requires a reliable control system. On the other hand, aeration equipment which operates at atmospheric pressure provides a safety factor against accidental supersaturation (caused by air entrainment into pipelines or pumps).

9. Noise - some types of blowers are extremely noisy and often require a separate insulated building.

10. Maintenance - devices susceptible to clogging or fouling should be avoided as periodic shut downs for chemical treatments may not be feasible.

The following sections describe the main characteristics of several types of aerators. Where possible, design information and/or operational experience is described briefly.

4.2 Waterfall and Spray Aerators

Some of the devices in this category are shown in Figure 3. We will specifically discuss aeration towers and mechanical surface aerators. Some other types are mentioned briefly.

4.2.1 Aeration Towers

Description

These devices are tower-like structures filled with a series of perforated trays or media such as Raschig rings, wooden slats etc. Water cascading downward creates a large gas transfer surface area by creating thin water films and droplets. It is essential that aeration towers are well ventilated to effectively remove released gases. A high volume, low pressure fan can be used to force or induce a counter current air draft through the tower when high ventilation rates are required.

Application

Aeration towers are most suitable for removal of high concentrations of carbon dioxide and/or hydrogen sulphide. Oxygen can be transferred effectively to oxidize iron, and near saturation concentrations of oxygen can be achieved relatively easily. There is no danger of supersaturation from this type of device. Aeration towers are also suitable for reduction of supersaturation of nitrogen.

Advantages

Aeration tower advantages include simplicity of operation and a small space requirement. Equipment is available from several manufacturers or, alternatively, an aeration tower can be designed "in house" based on appropriate existing installations or on-site testing.

Disadvantages

First, control over the aeration rate is difficult. Changes in raw water quality, i.e. a decrease in dissolved oxygen in the raw water could not easily be handled. Second, the device is similar to a cooling tower and a reduced water flow passing through the tower in winter could lose excessive heat. Third, slimes, algae, iron bacteria and insect larvae can grow in aeration towers. Plugging in the top of the tower could cause uneven water distribution and produce poor gas transfer efficiency. Growths could be controlled with chlorine or copper sulphate, however, shutdown of the affected equipment would require that standby equipment be provided. Fourth, corrosion must be considered in aeration tower design. Stainless steel, aluminum, rot-resistant woods, concrete, fiberglass and plastics are examples of durable materials used.

Operating Characteristics

a) Municipal Water Treatment Practice

Multiple tray aerators are commonly used in municipal water supply treatment. From three to nine trays are generally used and spacing between trays may vary from 30 to 76 cm (12 to 30 inches). The tray area required is approximately 1.77 m^2 (19 ft^2) for 1000 L/min (264 US gpm) (AWWA, 1969).

Carbon dioxide removal by multiple tray aerators can be approximated by an empirical equation:

$$C_n = C_o 10^{-kn} \qquad \text{(AWWA, 1969)}$$

n - the number of trays
C_0 - raw water concentration of carbon dioxide
C_n - concentration after n trays
k - usually varies from 0.12 to 0.16

k is dependent on temperature and characteristics of the aerator and can be obtained from the equipment manufacturer. Typical multiple tray aerators for CO_2 removal are described in Table IV.

TABLE IV

TYPICAL MULTIPLE TRAY AERATORS (AWWA, 1969)

Installation	Design Capacity mgd	Area of Trays sq.ft.	Type and Size of Media	No. of Trays Including Distribution Pan	Vertical Distance Between Pans in.	Housing	Space Per Million Gallons Per Day Capacity sq ft.	Operating Results		
								Flow mgd	CO_2 ppm Raw	CO_2 ppm Aerated
Naples, Fla.[1]	1.1	81	2-in. coke	4	18	outside	74	.67	28	4
Wichita, Kan.[2]	48	986	2-in. coke	5	18	inside	21	30	21	7.9
Owensboro, Ky.[3]	10	280	coke	6	14	outside	28	5.4	34	8
Columbia, Mo.[4]	3	160	none	5	18		53			
Marshall, Mo.[5]	2	80	none	6	18	inside	40	1.03	28	10
Memphis, Tenn.[6]										
Allen Sta	30	896	3-in.-6 in. coke	10	15½	inside	30	10.5	96	3.2
Sheehan Sta.	30	690	coke	6	16	inside	23	22.6	38	10

1. Removal of hydrogen sulfide and carbon dioxide.
2. Removal of carbon dioxide; has forced draft ventilation at rate of 29,500 cfm.
3. Removal of carbon dioxide.
4. Removal of hydrogen sulfide; outdoors with roof and screen sides.
5. Removal of carbon dioxide; has forced draft ventilation at rate of 2,000 cfm.
6. Removal of carbon dioxide; natural ventilation through open walls.

The percent saturation of dissolved oxygen that can be practically achieved in tray aerators has not been extensively reported in the literature. A study of the oxygenation characteristics of a tray type aerator found that a well water at less than 1 mg/L dissolved oxygen could be increased to 90% saturation with 10 trays at a spacing of about 15 cm (6 inches)(Wheaton, 1977). The flow rate per tray area was not reported.

b) Abbottsford Hatchery Aeration Tower

At the Provincial Fish and Wildlife Trout hatchery at Abbottsford, B.C. an aeration tower is an integral part of the water recycle system in the rearing section of the hatchery. The aeration tower is approximately 4.6 m (15 feet) high, and has a cross sectional area of about 4 m^2 (43 ft^2). The tower packing consists of wooden slats and natural ventilation is provided through openings in the walls. A combined flow of 3180 L/min (700 Igpm) of 10% groundwater and 90% recycle water is piped to the aeration tower. The influent to the aeration tower contains about 5 to 7 mg/L of dissolved oxygen at 15^oC. The effluent from the aeration tower contains about 10 mg/L dissolved oxygen (95 to 100% saturation) (R. McMillan, Assistant Supervisor, Fraser Valley Trout Hatchery, pers. comm.).

Using a rough estimate for pumping efficiency and friction losses the efficiency of the Abbottsford aeration tower is about 0.24 KgO_2/KW-hr (0.4 lbs O_2/H.P.-hr). The tower cross sectional area required per 1000 L/min is 1.26 m^2.

Excessive levels of dissolved nitrogen have been noted at the Abbottsford hatchery. The aeration system apparently reduces supersaturation to below problem concentrations (R. McMillan, pers. comm.).

c) Washington State Department of Fisheries Aeration Towers

Groundwater supplies for fish hatcheries in Washington commonly have dissolved nitrogen supersaturation and low dissolved oxygen levels.

The Washington State Department of Fisheries has developed a natural draft aeration tower utilizing aluminum screens as the tower media. The performance of the George Adams Hatchery aeration tower has been monitored. The tower is 4 m (13 feet) high, 1.8 m (6 feet) in diameter and contains 12 screens at a 30 cm (12 inch) spacing. Influent water is 107 to 108 percent saturated with dissolved nitrogen but only 20 to 30 percent saturated with dissolved oxygen. At a flow of 17,000 L/min (10 cubic feet per second) and a temperature of 9^{o}C the effluent from the tower is 102% saturated with dissolved nitrogen and 97 percent saturated with dissolved oxygen (L. Peck, Wash. State Dept. of Fisheries, Olympia, Wash., pers. comm.).

Using a rough estimate for pumping efficiency and neglecting friction the efficiency of the George Adams aeration tower would be approximately 0.6 KgO_2/KW-hr (1.0 lbs O_2/HP-hr).

The tower cross-sectional area required per 1000 L/min is 0.15 m^2.

d) Dworshak Hatchery Packed Columns

Engineering staff at Dworshak National Fish Hatchery, Idaho, have conducted tests on packed towers and columns to remove excessive levels of nitrogen. It was found that placing of packing (plastic Norton rings) in a perforated tray type aerator significantly improved nitrogen gas removal.

A packed column degasser suitable for nitrogen removal from small flows of 38 to 568 L/min (10 to 150 US gpm) per column has been developed. The degasser consists of a 1.5 m (five foot) long section of pipe filled with 1.4 m (four and a half feet) of 3.8 cm (1½ inch) plastic Norton Rings. The column is vertically mounted about 7 to 10 cm above the clearwell. Inlet water delivered to the top of the column entrains air and percolates down through the packing. A typical performance test on a 25 cm (10 inch) diameter column with a flow of 660 L/min (175 USgpm) reduced nitrogen supersaturation from 129% to 102% at 17^{o}C (Owsley, 1977, 1978).

The cross-sectional area required per 1000 L/min is approximately 0.08 m^2, significantly less than the other aeration towers described.

e) Commercially Available Packed Towers

One manufacturer was queried on the cost and performance of a packed tower to remove CO_2 and add O_2 to 10,200 L/min (2,700 US gpm) of well water that contained zero dissolved oxygen. The unit suggested was approximately 6 m (20 feet) high and 3 m square (10 feet square), packed with Raschig rings and equipped with a 1.5 horsepower induced draft fan. The manufacturer suggested that carbon dioxide would be effectively reduced from 100 mg/L to less than about 10 mg/L and dissolved oxygen increased to near 100% saturation. The bare equipment cost of the unit was $33,000.

4.2.2 Mechanical Surface Aerators

Description

Mechanical surface aerators are propeller pumps, turbines, rotors, brushes or paddles that violently agitate the surface of a body of water (Figure 3). The aerator rapidly changes the air-water interface by creating a spray of droplets or flow of air-entrained liquid which creates turbulence and mixing throughout the tank. Some bubbles are entrained down into the tank, however, most of the gas transfer usually occurs near the surface of the water.

Application

Surface aerators are suitable for stripping of nitrogen and carbon dioxide and for absorption of oxygen. Oxygenation of iron could be assisted by the retention time provided in the aeration tank. Surface aerators could possibly be used for hydrogen sulphide removal, however, this may not be feasible due to ventilation and safety requirements if the aeration tank is housed. Surface aerators cannot cause a significant degree of supersaturation.

Advantages

An advantage of surface aerators is that aeration can be easily controlled. The energy used by the motor depends on the speed of rotation and the degree of submergence of the turbine or rotor. The submergence can be controlled by raising or lowering the rotor or by increasing or decreasing the water level in the tank. Floating propellor pump aerators can be controlled by introducing air into the pump intake.

Another advantage of surface aerators is that they are not subject to clogging or biological fouling.

Surface aerators may be readily obtained from several manufacturers in sizes from 1 to 100 horsepower and can be powered by electric or gasoline motors.

Disadvantages

A disadvantage of surface aerators is their tendency to ice in cold weather. For most localities in British Columbia housing and appropriate ventilation would be required.

Another disadvantage of surface aerators is the requirement for a relatively large tank. For floating surface aerators the maximum power to volume ratio is about 0.1 KW per m^3 (0.5 HP per 1000 US gal). Any further increase in power would result in surging and instability (R. Weiss, Peabody Welles, Roscoe, Illinois). Tanks must also be larger than the impingement area of the spray. Tankage may, however, be required to allow retention time for complete oxidation of iron,

To allow for periodic maintenance and breakdowns standby units should be provided. If several units are used standby equipment would not be a major cost.

Operating Characteristics

The efficiency of oxygen transfer of surface aerators is commonly about 1.8 $K_gO_{2/KW\text{-}hr}$ (3 lbs $O_{2/HP\text{-}hr}$) at standard conditions. As shown in Section 3.4 actual field performance can be drastically reduced when an attempt is made to approach saturation. Figure 4 shows how energy requirements can increase as the treated water approaches saturation. 85% to perhaps 95% saturation appears to be the upper limit that can be practically achieved.

Tank geometry affects efficiency of mechanical surface aerators. Kormanik, 1976, found that aerators became more efficient as the power to surface area ratio was increased. Varying the depth of the tank from 5.5 to 3.7 m (18 to 12 feet) did not affect efficiency as much as reducing the surface area. The largest power to surface area ratio tested was 0.38 KW/m^2 (4.7 H.P. per 100 ft^2) (75 H.P. aerator in a 40 ft by 40 ft x 12 ft deep tank). An application of surface aerators to obtain oxygen levels near saturation would probably be at the upper limit of power to tank size. Where several surface aerators are installed in the same basin performance of an aerator may be affected by the flow patterns created by adjacent aerators. Several instances of poor field performance compared to shop tests could have been the result of this factor (Stukenburg and Wahbeh, 1978).

The circulation pattern in a surface aerated aeration tank is important in determining aeration efficiency when desired effluent quality is near saturation. Completely mixed flow is the "worst case" assumption (example in Section 3.4). One manufacturer advised that power requirements calculated with equation (9) could be more realistically estimated by use of the log mean average of the inlet and outlet oxygen deficits rather than just use of the outlet oxygen deficit (R. Weiss, Peabody Welles, Roscoe Ill., pers. comm.) (Figure 4).

It would appear to be an advantage to design a tank so that plug flow was achieved as closely as possible. One method could be to introduce the raw water directly to the aerator to maximize the oxygen deficit during the most intense agitation. Another method could be to install several aerators in a long plug flow basin.

Surface aerators have been used at Dworshak National Fish Hatchery in Idaho to reduce both nitrogen and oxygen supersaturation (115-130%) caused by water spillage at Dworshak Dam. Twelve 22 KW (30 HP) surface aerators are supported on steel bridges in a 1353 m^3 (357,000 US gal) concrete tank. The aeration basin treats a flow of 140,000 L/min (37,000 US gpm) at a power to tank volume ratio of 0.2 KW/m^3 (1 HP per 1000 US gal). The water level is maintained by a weir to provide a depth for best aerator efficiency. With all twelve aerators operating nitrogen supersaturation was reduced from 122% to 101% (Wold, 1973). Because the water is repumped and heated following the aeration tank, a second degasification step is necessary prior to use in the hatchery (Owsley, 1977).

4.2.3 Other Types of Spray and Waterfall Aerators

Nozzle spray aerators direct the water upward vertically or at an angle breaking up the water into small drops. Spray aerators, which are essentially fountains, can be aesthetically attractive. However, spray aerators appear to be impractical in B.C. because they have a large space requirement and must be housed in cold climates.

Where gravity head is available numerous types of devices can be used to aerate water. This could take the form of a series of weirs (Wheaton, 1977), splashboards or paddlewheels (Chesness and Stephens, 1971). These devices may not be suitable for primary aeration because of icing or other considerations but could be useful as reaeration devices within the hatchery.

4.3 Bubble Aerators

Figures 5, 6 and 7 show a few types of bubble aerators. We will specifically discuss diffusers, aspirators and eductors, submerged turbines, U-tubes, and pure oxygen devices.

4.3.1 Diffusers

Description

Diffused aeration utilizes compressed air to discharge bubbles into a tank of water. The diffuser can consist of perforated pipes, nylon socks, porous plastic tubes, stone tubes, or various sparger devices. The major factors affecting efficiency of oxygen transfer are bubble size (surface area of air-water interface), depth of the tank and flow pattern within the tank. As described by equations (3) and (4) it is desirable to achieve a large interfacial surface area, a large oxygen deficit and a long bubble retention time.

Application

Diffusers are suitable for increasing dissolved oxygen and possibly for stripping of carbon dioxide providing that a high transfer rate is achieved at the surface of the tank. As shown in Appendix II and Figure 8 this type of device is not recommended for stripping hydrogen sulphide. The "Swedish Degasser", a shallow tank diffuser device with an extremely high air flow rate has been used for nitrogen removal.

Supersaturation is theoretically possible with diffused aeration in a deep tank and must be controlled by reducing the air flow or utilization of a shallow tank.

One possible application of diffused air would be to operate a low head air lift pump accomplishing aeration at the same time. This type of equipment has been used in a hatchery water recycling experiment at the Pacific Biological Station, Nanaimo (R. Brett, pers. comm.).

Advantages

Diffused aeration systems are not subject to icing or freezing problems and can be installed outside in cold climates without excessive heat loss.

Disadvantages

Efficiency of oxygen transfer is generally low, from 3% to 12% (about 0.3 KgO_2/KW-hr to about 1.1 KgO_2/KW-hr) at standard conditions (Weber, 1972). Efforts to increase oxygen transfer increase costs. For example, a fine bubble diffuser system (producing very small bubbles) requires filtered air to prevent clogging. Similarly, an increase in depth of the tank increases the air compression head required and blower horsepower, and the cost of the tank.

Fine bubble diffusers can become fouled with slimes and growths which can reduce performance and require periodic cleaning. Coarse bubble diffusers are not as easily affected but efficiency is sacrificed.

Operating Characteristics

Diffused aeration has been extensively applied to the activated sludge process. Most design variables, i.e. diffuser type, depth, tank geometry, and air flow rates have been investigated and reported on with respect to solids handling and mixing as well as gas transfer. No literature was found during this study on existing applications of diffused air to achieve saturation of oxygen.

Oxygen transfer rates of a diffuser in a 8.2 m (27 foot) deep bubble column were 96% (Jackson et al, 1975). An economic comparison of deep tank aeration and conventional aeration for wastewater treatment showed both capital and operating cost savings with an optimum tank depth of 9 to 12 m (30 to 40 feet) (Edwards et al, 1975). This type of system may be applicable to achieve oxygen saturation, however, it does not appear to be as advantageous as the related U-tube concept discussed in Section 4.3.4.

A nitrogen degasser device, designed in Sweden, has been used at the Craig Brook National Fish Hatchery, Maine, (Dennison and Marchysyn, 1973) and at the Dworshak Hatchery, Idaho, (Owsley, 1977). The degasser is essentially a shallow tank diffuser utilizing a very high air flow to water flow rate ratio, about 25:1. A 15 cm (6 inch) layer of water is passed over a perforated aluminum or stainless steel plate. Air is forced up through the perforations at a high rate creating extreme turbulence in the water. A unit designed for a water flow rate of 1140 L/min (300 US gpm) utilizes an air flow rate of 28300 L/min (1000 cfm) discharging through a perforated plate 1.5 m (4.8 feet) long by 0.9 m (3.0 feet) wide with 1.6 mm (1/16 inch) perforations at 2.5 cm (1 inch) centers.

Nitrogen supersaturation can be reduced to acceptable levels with this device, however, Owsley (1977) found that the performance of the unit decreases with increasing flow rate and that performance was not always consistent.

4.3.2 Aspirators and Eductors

Description

Aspirators and eductors depend on the motive force obtained from the head developed by gravity or a pump to draw air into a venturi device. The air is rapidly entrained by the water, intimately mixed and then discharged from the device into a vessel. Three types are shown in Figures 5 and 6. As with diffused air systems oxygen transfer efficiency increases with increasing depth and hydrostatic pressure. Design considerations often require that air be delivered to the venturi under pressure which requires the addition of a blower.

Mixing in the tank and tank surface renewal is promoted by the jet action of the discharge. The retention time of bubbles can be prolonged by careful design of tank geometry.

Application

Aspirators and eductors are suitable for oxygen transfer and possibly for stripping of carbon dioxide providing that a high transfer rate is achieved at the surface of the tank. Because the acceptable concentration of hydrogen sulphide is very low this type of device is not recommended for stripping hydrogen sulphide (Appendix II and Figure 8). Relatively efficient oxygenation to saturation is possible with tanks deeper than about 10 feet, however, supersaturation must be controlled.

Advantages

In general, aspirators or eductors run by a gravity water source are very reliable and have low maintenance requirements. Control of aeration is possible either through reduction in the number of units or by controlling the air flow to the venturi. Some types are installed within a tank and these are not subject to freezing or icing and, therefore, no building is required. Most types are not subject to clogging or biological fouling. A number of aspirators and eductors are manufactured commercially, however, other types are simply constructed of common materials.

Disadvantages

Aspirators installed in shallow tanks are not as efficient at oxygen transfer as deep tank eductors with a pressurized air supply. Power requirements for most types of shallow tank applications would likely be very similar to surface aerators (Figure 4). However, use of a blower to improve efficiency has a number of disadvantages. First, the reliability of the system is reduced and provision of standby equipment and power would be required. Second, economical control of an air supply from some types of blowers is difficult. In deep tanks supersaturation is possible and accurate control of aeration would be mandatory. Third, positive displacement blowers are extremely noisy and often require insulation or a separate building.

Operating Characteristics

a) Quinsam Hatchery, B.C.

Quinsam Hatchery, near Campbell River, B.C., has an aeration system utilizing the aspirators shown in Figure 5. Approximately 68,000 L/min (15,000Igpm) of 8-11^{o}C spring water with an inlet dissolved oxygen content of 89 percent saturation is aerated to increase the dissolved oxygen to about 96 percent saturation (McLean and Spicer, 1978). At an average operating pressure of 11.8 psi and assuming a typical pump efficiency the field operating efficiency of the system is approximately 0.03 KgO_2/KW-hr (0.05 $lbsO_2$/HP-hr).

A river water source which is slightly supersaturated with dissolved oxygen is also aerated. Supersaturation of dissolved oxygen is reduced from about 105 percent to about 100 percent saturation (McLean and Spicer, 1978).

b) Dworshak Hatchery, Idaho

Aspirators based on the same design (Burrows and Combs, 1968) are used at the Dworshak Hatchery, Idaho. The oxygen content of water is increased to between 90 and 100 percent saturation with the aspirators, however an operating pressure of 20 psi is required rather than the recommended 10 psi. At this higher pressure the aspirators cause nitrogen supersaturation of over 108 percent (Owsley, 1977).

c) A PVC Aspirator

Scott, (1972) tested a different type of venturi in a laboratory test, (Figure 6). The gas transfer rate of this device was found to be significantly greater than an air stone diffuser and a spray aerator.

d) Thompson Hatchery, Michigan

The Michigan State Department of Natural Resources has recently installed (winter, 1978) a Penberthy Jet aeration system at their Thompson Hatchery at Thompson, Michigan. A typical aeration tank designed to oxygenate 9080 L/min (2400 US gpm) of 10.6^{o}C well water is 3.7 m (12 feet) wide by 6.1 m (20 feet) long by 4.6 m (15 feet) deep. A 9.4 horsepower submersible pump recirculates the water through a jet eductor supplied with up to 9200 L/min (325 cfm) of air from positive displacement blowers (Figure 6). Inlet dissolved oxygen is about 5 mg/L (45% sat.) and the tank was designed to raise the dissolved oxygen to 10 mg/L (90% sat.). After only a short time in operation is was found that the aeration tank effluent was supersaturated. Extensive mortality resulted from gas bubble disease. Subsequent throttling of the discharge valve from the blowers has adjusted aeration so that excessive supersaturation is prevented. The air requirements to prevent supersaturation, the levels of supersaturation achieved, and the transfer efficiency of the system have not yet been documented.

One well water source for the Thompson Hatchery contains 0.5 mg/L of hydrogen sulphide. After passing through the jet aeration tank the hydrogen sulphide is not detectable in the water (by sense of smell). (The odour threshold level for hydrogen sulphide is less than 0.1 ug/L APHA - AWWA, 1976). Good ventilation and rapid renewal of the air water interface at the surface of the tank is evidently sufficient to remove the hydrogen sulphide. Another well water source contains 10 mg/L of hydrogen sulphide. An aeration tower effectively removes the hydrogen sulphide from this water.

The discharge from Thompson Hatchery jet aeration tank is carefully baffled so that no bubbles are carried through to the hatchery. There was concern that carry over of bubbles would impair the swimming ability of small fish (Doug Morgan, Michigan State Dept. of Nat. Res., Engineering Division, pers. comm.).

Under standard conditions the manufacturer's claim that the Penberthy jet aeration system can transfer up to 3 to 3.6 KgO_2/KW-hr (5 to 6 $lbsO_2$/HP-hr). An increase in depth of the tank allows higher efficiencies (Figure 9). As with surface aeration an attempt should be made to establish a flow pattern as close to plug flow as possible. Production of an oxygen saturated water with this device is a relatively recent application and further experimentation and testing appears to be required to achieve an efficient, reliable, and easily controllable system.

e) Cowlitz Trout Hatchery, Washington - "Multicone Aerator" Tests

The "Multicone Aerator" is a gravity flow device which utilizes several aspirators ("cones") to introduce air into the water. The aspirators are vertically mounted in 3 sequential stages separated by redistribution bowls. A typical 3 stage unit designed for a water flow rate of 6800

L/min (1800 US gpm) would be about 2 m (6.5 feet) high and about 1.5 m (5 feet) in diameter. Constructed of cast aluminum the unit would have a shipping weight of 794 Kg (1750 lbs). The budget price (1979) for a 6800 L/min unit was quoted to be $20,000 (H. Mitchell, Sales Manager, Infilco Degremont, Montreal).

Kramer, Chin and Mayo (1971) tested the oxygen addition and nitrogen removal capability of Infilco Degremont's "Multicone Aerator" at the Cowlitz Trout Hatchery in Washington. At a water flow rate of about 1500 L/min (400 US gpm) and a water temperature of about 12^{o}C an 8500 L/min (2250 US gpm) capacity unit increased the dissolved oxygen concentration of a well water from 50% to 85% saturation. At a similar flow rate and temperature the same unit increased the dissolved oxygen saturation of another well water from 85% to 95% saturation. In previous tests the Multicone Aerator was reported to have effectively reduced nitrogen supersaturation from about 120% to acceptable levels (Kramer, Chin and Mayo, 1971).

4.3.3 Submerged Turbines

Description

Turbine aeration units disperse compressed air by the shearing and pumping action of a rotating impeller (Figure 6). The major difference between diffused air and submerged turbine aeration is that tank mixing can be independently controlled by varying the power input to the turbine.

Application

The submerged turbine is suitable for oxygen transfer and possibly for carbon dioxide removal if a high transfer rate is achieved at the surface of the tank. Supersaturation is possible and could be controlled by reducing the air flow.

Advantages

The submerged turbine may be capable of relatively efficient oxygen transfer to saturation if a deep tank is used. The device would be more tolerable of icing conditions than surface aerators, however, housing might be required in severe climates.

Disadvantages

As with compressed air jet aeration, the submerged turbine is dependent on both a mechanical pump and a blower, thereby increasing maintenance, reducing reliability and increasing noise levels.

Operating Characteristics

The optimum oxygenation efficiency occurs when the power split between the turbine and blower horsepower is near a 1:1 ratio. The transfer efficiency of turbine aeration units at standard conditions will vary from 1 to 1.8 KgO_2/KW-hr (1.6 to 2.9 $lbsO_2$/HP-hr) (Eckenfelder, 1966). Further testing and experimentation is required to predict the efficiency in producing an oxygen saturated water.

4.3.4 U-Tubes

Description

The name U-tube is derived from the configuration of the water flow (Figure 7). Flow is directed down to the bottom of a chamber 3 to 18 m (10 to 60 feet) deep and then is directed back to the surface. Air bubbles are introduced at the inlet by a diffuser, a venturi or by a free falling cascade. Downward water velocities exceed the buoyant velocity of the bubbles and carry the bubbles to the bottom of the chamber and back to the surface.

As the bubbles descend hydrostatic head pressurizes the bubbles and increases the partial pressure of oxygen. The saturation concentration of dissolved oxygen is increased and, therefore, the driving force for gas transfer is increased. It is possible to saturate or supersaturate water with dissolved oxygen with one pass through a U-tube.

The operating characteristics, design, and application to hatchery water treatment have been described by Speece et al, 1969, Speece and Orosco, 1970 and Speece, 1969. Speece has shown U-tube aeration to be a highly efficient method of introducing oxygen when saturation levels are required.

Application

U-tubes are most suitable for oxygenating water where the percent saturation of dissolved nitrogen is less than or equal to the percent saturation of dissolved oxygen and where there is little or no requirement for stripping of dissolved gases. Use of a degasification step to remove dissolved nitrogen, hydrogen sulphide, and/or carbon dioxide prior to use of the U-tube would expand its range of application.

Advantages

The U-tube has numerous advantages for fish hatchery installations.

1) The U-tube can efficiently saturate water with oxygen with as little as 1/10th the energy required by conventional aeration.
2) Gravity head can be utilized as the sole source of power and only about 1.5 to 3 m (5 to 10 feet) is required. Air can be introduced by a venturi or by a cascade type inlet.
3) The U-tube would not be affected by normal growths of nuisance organisms and would require little maintenance.
4) Climatic considerations are of little significance. A small building over the U-tube is all that would be required.

5) Because air is introduced near the surface only low pressure air is required allowing the use of venturis or less noisy centrifugal blowers.

6) Both capital and operating costs of the U-tube could be considerably less than other aeration schemes.

Disadvantages

The major disadvantage of the U-tube is that its application is limited to oxygenating those well waters with low concentrations of nitrogen, carbon dioxide, and hydrogen sulphide. Use of a degasifier in conjunction with the U-tube would significantly increase the cost of the system. Another disadvantage is the necessity to prevent supersaturation. Control over aeration and supersaturation can be achieved, however, this may be difficult if dissolved oxygen and dissolved nitrogen vary periodically. A considerable amount of research and custom engineering may be required to produce a reliable and easily controllable system.

Operating Characteristics

The main U-tube design variables are:

1) air-water ratio
2) dissolved oxygen concentration in the inlet
3) depth of the U-tube
4) water velocity through the U-tube

Speece, 1969, presents a table of the air-water ratio and U-tube depth required to achieve 100% saturation of oxygen (Table V). Water velocities are usually in the range of 1.5 to 2.4 m/sec (5 to 8 feet per second) for efficient gas transfer.

TABLE V

AIR WATER RATIO (IN PERCENT) REQUIRED FOR OXYGEN SATURATION

BY A U-TUBE (Speece, 1969)

Inlet Dissolved Oxygen (% Saturated)	U-Tube Depth (feet) 20	30	40	50	60
0	-	23	18	15	13
20	-	20	16	13	11
40	-	18	14	12	10
60	22	14	11	9	8
80	14	9	8	7	5

If the U-tube requires 1 m (3 feet) of head to increase the dissolved oxygen from 60% to 100% saturation, the oxygen transfer efficiency would be about 1.5 KgO_2/KW-hr (2.5 $lbsO_2$/HP-hr) compared to less than about 0.24 KgO_2/KW-hr (0.4 $lbsO_2$/HP-hr) for a conventional aeration system (Speece, 1969).

Supersaturation of U-tube effluent can be controlled by three main methods:

1) Reduce the air water ratio by controlling the air supply to the U-tube. This could be accomplished by valving the air delivery line or venturis.

2) Reduce the depth of the U-tubes. For example, a lab study indicated that one particular 3 m (10 foot) deep U-tube system was capable of a maximum supersaturation of about 106% (Speece, 1969). However, for reduced depths several U-tubes in series may be required to oxygenate the water.

3) Bypass the U-tube, mix a portion of the undersaturated water with supersaturated water, and adjust the flow to achieve saturation.

The Mescalero National Fish Hatchery, Mescalero, New Mexico has a cascade inlet 12 m (40 foot) deep U-tube designed to oxygenate 1500 L/min (400 US gpm) of 12.8^{o}C spring water. The spring water is about 72% saturated with oxygen and about 72% saturated with nitrogen. After passing through the U-tube the water is about 120% saturated with oxygen and about 101% saturated with nitrogen (McElwain and Olson, 1968). (This would tend to support the concept that nitrogen transfer rates are somewhat less than oxygen transfer rates). However, gas bubble disease occurred and it was necessary to construct a bypass system that would allow adjustment of the dissolved oxygen saturation from 120% to 100% (Speece, 1969). Gas bubble disease, (a gas bubble behind the eye of a fish) occurred at a total gas pressure of about 105% (McElwain and Olson, 1968).

Another type of serious gas bubble problem was encountered when the total gas pressure was near or slightly less than 100%. Minute bubbles tended to accumulate on debris particles, including food. Small fish (swim up to 3 weeks feeding) ingested the bubbles when eating and the bubbles tended to collect in the bend of the stomach. The flotation effect of the trapped air eventually impaired the swimming ability of the fish and these fish died within 3 to 24 hours. Large fish took in bubbles but were able to pass the air bubbles out of their systems along with fecal material (McElwain and Olson, 1968).

The current hatchery manager advised that the U-Tube system was not presently being used due to supersaturation control problems. Insufficient gravity head is available to easily control the bypass system (Mr. Chase, pers. comm.). The cascade type inlet also does not allow control over the air water ratio and probably compounds the difficulty of controlling supersaturation.

4.3.5 Pure Oxygen Systems

Description

Pure oxygen can be used instead of air in diffused aeration systems or in special devices designed to achieve high transfer efficiencies (about 50 to near 100 percent).

One such device oxygenates only a portion of the flow but introduces oxygen under pressure. The oxygen supersaturated stream is then mixed with the main raw water stream (Union Carbide "Lindox" process).

Another efficient pure oxygen device is the downflow bubble contact aerator (Speece et al, 1971) (Figure 7). This device provides for the passage of water downward through an open-bottomed, expanding cross section hood containing bubbles of pure oxygen. The inlet velocity at the top of the hood is highest and is designed to be greater than the buoyant velocity of the bubbles. The exit velocity at the bottom of the hood is designed to be less than the buoyant velocity of the bubbles. Therefore, the bubbles are trapped inside the hood, and close to 100% transfer can be achieved.

Application

Pure oxygen systems could be suitable for achieving an oxygen saturated water supply. The downflow bubble contactor could also be used to strip nitrogen and carbon dioxide if a sufficient quantity of bubbles are allowed to escape from the bottom of the hood. However, oxygen absorption efficiency would decrease as the volume of "air" escaping increased. Pure oxygen systems may be useful in pilot hatchery or water treatment studies, or as emergency or back up systems to other equipment.

Advantages

Pure oxygen systems could have a relatively low capital cost and can easily saturate a water supply with oxygen. Supersaturation of oxygen has less effect on total gas pressure than has nitrogen (SIGMA, 1979), therefore, control of oxygen supersaturation is not as difficult as with diffused air systems. In fact, nitrogen can be stripped without use of a degasifier. Pure oxygen systems are flexible and could be set up on a small scale for pilot hatchery operation with a minimum requirement for electrical power and tankage.

Disadvantages

Commercial oxygen is relatively expensive and transportation costs to a remote location may be a significant fraction of the cost. On-site oxygen generating plants are not economical if oxygen requirements are less than about 20 tons of oxygen per day. Therefore, hatcheries would be supplied by a bulk tank supply. An example calculation of pure oxygen costs is included in Appendix III.

The downflow bubble contactor utilizing pure oxygen is a recently developed concept and has not been extensively applied. Custom engineering and further studies would likely be required.

Operating Characteristics

Downflow bubble contact aerator studies have indicated that 80% to 90% oxygen absorption efficiency can be achieved when oxygen is injected at an air to water ratio of 0.5%. Oxygen transfer economy appears to be about 2.4 KgO_2/KW-hr (4 $lbsO_2$/HP-hr). However, this performance is not greatly affected by an attempt to saturate the water (Speece, 1971).

5. DISCUSSION

5.1 General

A number of engineering considerations for various types of aeration equipment are outlined in Table VI. As a general guideline waterfall or spray aerators are best suited for addition of oxygen and for removal of dissolved gases such as carbon dioxide, hydrogen sulphide, nitrogen and methane. Bubble type aerators are mainly useful for addition of oxygen.

5.2 Selection, Specification, and Testing of Commercially Available Aerators

Selection of Aeration Equipment

Most of the commercially manufactured aeration equipment is designed for municipal water and wastewater treatment. The engineer should be aware of the purpose the equipment was designed for and should make sure that equipment meets the specific needs of fish culture. For example, a type of aeration tower that is normally used for carbon dioxide removal may not increase the dissolved oxygen levels sufficiently. Another example is the need for tankage. Mechanical surface aerators may not be appropriate unless tankage is required to increase retention time.

Specification of Aeration Equipment Performance

The engineer should specify the inlet and outlet concentration of dissolved gases and the allowable power requirement or, alternatively, the transfer efficiency economy. If aeration requirements are variable the engineer should specify the degree of "turndown" of the system desired. If supersaturation is a potential problem the method of control should be specified. Spray and mist control from mechanical surface aerators and noise levels at a given distance from blowers can be specified.

TABLE VI ENGINEERING CONSIDERATIONS OF WATER SUPPLY AERATION EQUIPMENT

AERATOR TYPE	MAJOR APPLICATION	POSSIBLE APPLICATION	DESIGN CONSTRAINTS	SPECIAL DESIGN CONSIDERATIONS	PILOT TESTING	PERFORMANCE SPECIFICATIONS	STANDBY EQUIPMENT	MAINTENANCE
AERATION TOWERS	CO_2 removal O_2 addition N_2 removal H_2S removal Oxygenation of iron CH_4 removal		- height of tower limited by loss of performance due to poor distribution of air and water in tower - flow rate of water per unit tower cross-sectional area limited by loss in performance due to poor droplet formation and reduction in air-water interface - H_2S stripping can be constrained by maximum air flow rate	- cooling of water - corrosion - insect screens - icing - cleaning procedure	- combined H_2S and CO_2 removal requires pilot testing. - removal of high N_2 concentrations may require pilot testing	- some manufacturers are willing to meet performance specifications - "in house" design may be suitable if problem is straight forward and performance data is available	- depends on loss in performance due to mechanical breakdown - if biological fouling is expected shut down may be required (ie. iron bacteria)	- pumps, fans, motors - cleaning - biological fouling - precipitates
MECHANICAL SURFACE AERATORS	O_2 addition CO_2 removal N_2 removal Oxygenation of iron	H_2S removal (not if aeration basin is housed)	- power to tank volume ratio limited by surging of power demand of aerator - large tank required - icing in cold climates	- ventilation if housed - method of controlling turndown - cooling of water - design of tank to maximize efficiency - utilization of retention time	- not usually required	- specify performance, manufacturer requires knowledge of aeration tank geometry - "in house" designs not recommended	- require at least one standby unit	- motors, impellers or rotors
DIFFUSERS	O_2 addition Oxygenation of iron	CO_2 removal	- depth of tank increases blower costs - production of fine bubbles requires air filtration - efficiency of oxygen transfer low - large tank required	- control of supersaturation - design of tank for optimum bubble retention time - baffling of tank outlet to prevent bubbles from entering hatchery water system, ("carry-over") - noise control/blowers	- may be required for oxygenation of iron and/or CO_2 removal	- specify perfomance, manufacturer requires knowledge of aeration tank geometry	- standby blower capacity required	- blowers - fine bubble diffusers require cleaning due to particulates in air supply and biological fouling
ASPIRATORS AND EDUCTORS	O_2 addition CO_2 removal Oxygenation of iron		- depth of air introduction for aspirators is limited to a few feet without use of compressed air - depth of air introduction for "jet" aeration increases blower costs - large tank required	- control of supersaturation - design of tank for optimum transfer efficiency, plug flow and long bubble retention time - baffling of tank outlet to prevent bubble "carry-over" - noise control/blowers - utilization of retention time	- may be required for oxygenation of iron and/or CO_2 removal - "in house" designed aspirators - performance tests would be required if situation is significantly different from previous installations	- specify perfomance, manufacturer will probably choose tank geometry - "in house" designs may be suitable if performance is satisfactory	- standby pumps and blowers required	- pumps, blowers

AERATOR TYPE	MAJOR APPLICATION	POSSIBLE APPLICATION	DESIGN CONSTRAINTS	SPECIAL DESIGN CONSIDERATIONS	PILOT TESTING	PERFORMANCE SPECIFICATIONS	STANDBY EQUIPMENT	MAINTENANCE
SUBMERGED TURBINES	O_2 addition Oxygenation of Iron	CO_2 removal	- large tank required	- control of super-saturation - baffling of tank outlet to prevent bubble "carry-over" - utilization of retention time	- may be required for oxygenation of iron and/or CO_2 removal	- specify performance, manufacturers would probably recommend the aeration tank geometry - "in house" design not recommended	- blowers - at least one spare motor for turbine units	- blowers, motors, impellers
U-TUBES	O_2 addition	Oxygenation of iron (if retention time provided)	- dissolved nitrogen percent saturation should be less than or equal to dissolved oxygen percent saturation in raw water - water velocity through the U-tube must be between approximately 5 to 8 feet per sec. - diameter of excavation and ground conditions	- control of super-saturation - baffling of U-tube outlet to prevent bubble "carry over" - bubble injection method	- required to test control system and performance	- "in house" design required	- standby pumps and blowers (as required)	- pumps, blowers
PURE OXYGEN SYSTEMS	O_2 addition	Oxygenation of iron (if retention provided) N_2 - removal CO_2 - removal	- commercial oxygen costs - a high transfer efficiency should be achieved	- method of oxygen introduction, a wide variation in techniques is possible	- required if "in house" design used	- specify performance - "in-house" design may be suitable	- as required	- as required

Performance Testing

Aeration is a complex process that is difficult to model or simulate by shop tests (Maise, 1970) (Stukenburg and Wahbeh, 1978). However, laboratory studies may be necessary to develop the aerator design, especially with removal of hydrogen sulphide (Fair et al, 1968). Stukenburg et al, 1977 report that of sixteen different site tests of newly installed aeration systems they witnessed only seven systems that met performance expectations satisfactorily. Several of the systems required major field modification of the equipment before they performed adequately.

In situations where there could be significant difference between shop performance and field performance, field tests should be conducted by the manufacturer as a part of the supply contract.

5.3 "In House" Designs

Custom designed aeration equipment used at existing hatcheries may be suitable for application to gas transfer problems at new hatcheries. Prior to the adoption of these designs, however, it should be determined that differences in the two applications will not impair performance. Should uncertainty remain, pilot testing is recommended. Alternatively, the equipment can be designed for easy modification or for addition of extra units at a reasonable cost.

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APPENDICES

APPENDIX I

CALCULATION OF GAS SOLUBILITY

To calculate the carbon dioxide saturation value at $10^{o}C$ and 760 mm Hg in distilled water:

a) from Table I - Ks = 1190 $mL/_{L}$

b) dry air normally contains 0.033% of carbon dioxide by volume

c) the vapour pressure at $10^{o}C$ is 9.2 mm Hg in saturated air (Table II)

d) the partial pressure of carbon dioxide is

$$0.00033\ (760-9.2) = 0.\ 248 \text{ mm Hg, or } \frac{0.248}{760} = 3.26 \times 10^{-4} \text{ atm.}$$

e) the volume concentration of carbon dioxide from Henry's Law is:

$$1190\ mL/_{L} \times \frac{0.248}{760} = 0.388\ mL/_{L}$$

f) 1 mole of an ideal gas at $0^{o}C$ and 760 mm Hg occupies a volume Vo, where:

$$V_{o} = 22412\ mL/_{g\text{-mole}}$$

at $10^{o}C$:

$$V = \frac{T}{To}\ \frac{Po}{P\text{-}Pw}\ V_{o} = \frac{(283)}{(273)}\ \frac{(760)}{(760-9.2)}\ 22412 = 23518\ mL/_{g\text{-mole}}$$

g) 1 mL of carbon dioxide at $10^{o}C$ and 760 mm Hg weighs:

$$44g/_{mole} \div 23518\ mL/_{g\text{-mole}} \times 1000\ mg/_{g} = 1.87\ mg/_{mL}$$

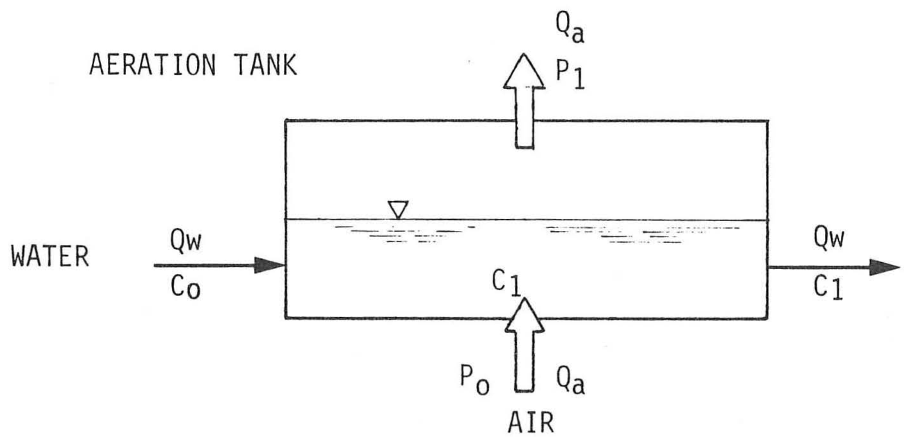
h) the weight concentration of carbon dioxide at saturation is:

$$0.388\ mL/_{L} \times 1.87\ mg/_{mL} = 0.73\ mg/_{L}\ CO_2$$

This calculation assumes that the gas behaves like an ideal gas. Results may be a few percent in error from experimentally determined values.

SIMPLIFIED CALCULATION OF CO_2 OR H_2S GAS STRIPPING BY DIFFUSED AIR SYSTEMS

1. DEFINITION SKETCH



Qw = water flow L/min

Qa = air flow L/min

A_{wr} = air water ratio

$= \dfrac{Qa}{Qw}$

C_o = gas conc. mL/$_L$

C_1 = gas conc. mL/$_L$

P_o = partial pressure of gas in air supply

P_1 = partial pressure of gas in air leaving tank

2. ASSUMPTIONS

a) Volume of air entering tank = volume of air leaving tank.

b) Equilibrium is reached - partial pressure of gas in bubbles leaving tank is in equilibrium with the concentration of gas in solution.

c) Partial pressure at surface of tank = partial pressure in bubbles (ventilation is restricted).

d) Tank is completely mixed and is at concentration C_1.

3. RELATIONSHIPS BETWEEN VARIABLES

a) Henry's Law

$$P_1 = \frac{C_1}{K} \qquad (1)$$

K - absorption coefficient $mL/_L$

Md- moles/L of ideal gas @ the specified temperature and pressure (molar density)

b) Air Quantity Balance

Moles of gas coming in = $P_o \times M_d \times Q_a$ = $moles/_{min}$

Moles of gas going out = $P_1 \times M_d \times Q_a$ = $moles/_{min}$

Moles of gas removed from water:

$$P_1 M_d Q_a - P_o M_d Q_a = (P_1 - P_o) M_d Q_a$$

c) Water Quantity Balance

Moles of gas coming in = $C_o \; mL/_L \times Q_w \; L/_{min} \times M_d \; moles/_L$

$$\times \frac{L}{1000 \text{ mL}} = \text{moles/min}$$

$$= \frac{C_o Q_w M_d}{1000} \; moles/_{min}$$

Moles of gas going out = $\frac{C_1 Q_w M_d}{1000} \; moles/_{min}$

d) <u>Air and Water Quantity Balance</u>

Moles of gas removed from water = difference between moles coming in and moles going out of tank.

$$(P_1-P_o)\ Q_a = (C_o-C_1)\ \frac{Q_w}{1000} \qquad (2)$$

$$\frac{Q_a}{Q_w} = A_{wr} = \frac{(C_o-C_1)}{(P_1-P_o)\ 1000} \qquad (3)$$

e) <u>Combine Henry's Law and Air Water Balance</u>, (1) and (3), and rearrange to get:

$$C_o = A_{wr}\ 1000\ \left(\frac{C_1}{K_s}-P_o\right) + C_1 \qquad (4)$$

f) <u>Percent Removal (R)</u>

$$R = \frac{C_o-C_1}{C_o} \qquad (5)$$

To calculate percent removal of a gas:

1) Choose the desired effluent concentration C_1.

2) Choose the air water ratio for the device A_{wr}.

3) Calculate influent concentration from equation (4).

4) Calculate percent removal from equation (5).

For example: Calculate percent removal of CO_2 with an air water ratio of 0.25.

1) Choose 10 $mg/_L$ as the desired carbon dioxide concentration in the effluent

- at $10^{o}C$ and 760 mm Hg the density of CO_2 is 1.87 $mg/_{mL}$

(see Appendix IA, step (g))

- therefore $C_1 = \dfrac{10 mg/_L}{1.87\ mg/_{mL}} = 5.35\ mL/_L$

2) Choose an air water ratio of 0.25.

3) $C_o = (0.25)(1000)(\dfrac{5.35}{1190} - 0.00033) + 5.35 = 6.39\ mL/_L$

4) Percent Removal $R = \dfrac{6.39 - 5.35}{6.39} \times 100 = 16\%$ (as in figure 8)

Note: This calculation ignores the effects of ventilation of the water surface. It therefore underestimates the removal of gases if there is significant ventilation.

For example, the Thompson Hatchery in Michigan achieved 99 percent removal (or greater) of a low concentration of hydrogen sulphide with their outdoor jet aeration tank (air water ratio 1.0). On site experimentation appears to be the best method of predicting gas removal by diffusion.

APPENDIX III

COMMERCIAL OXYGEN COSTS FOR A HATCHERY WATER SUPPLY

a) Given:

Flow rate = 3000 gpm.

Raise D.O. from 0 $mg/_L$ to 11.3 $mg/_L$ (100% saturation at 10^oC).

Hatchery is 100 miles from Vancouver.

b) Oxygen Required:

$$3000 \text{ gpm} \times 8.36 \text{ lbs}/_{gal} \times \frac{11.3 \text{ ppm}}{10^6} \times 43200 \text{ min}/_{mth} \times \frac{1}{2000 \text{ lbs}/_{ton}}$$

$= 6.12 \text{ tons}/_{month}$

@ 50% transfer efficiency = $12.24 \text{ tons}/_{month}$

@ 24,160 ft^3 O_2 $gas/_{ton}$ = 296,000 $ft^3/_{month}$

c) Oxygen Cost:

Product cost $\$0.95/_{100\ ft^3}$ x 296,000 = $\$2812/_{month}$

Transport cost $\$0.08/_{100\ ft^3}$ for each 25 miles over a 50 mile radius

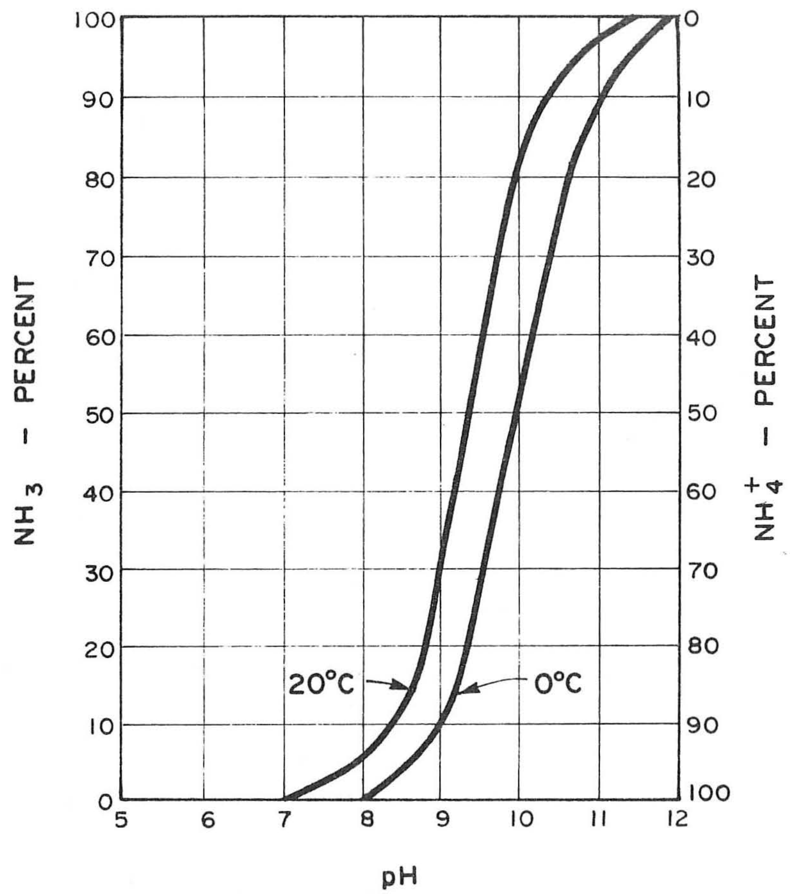
$\frac{\$.08}{100}$ x 2 x 296,000 = $\$\ 474/_{month}$

Container rental cost per month = $\$\ 775/_{month}$

Oxygen Cost $\$4061/_{month}$

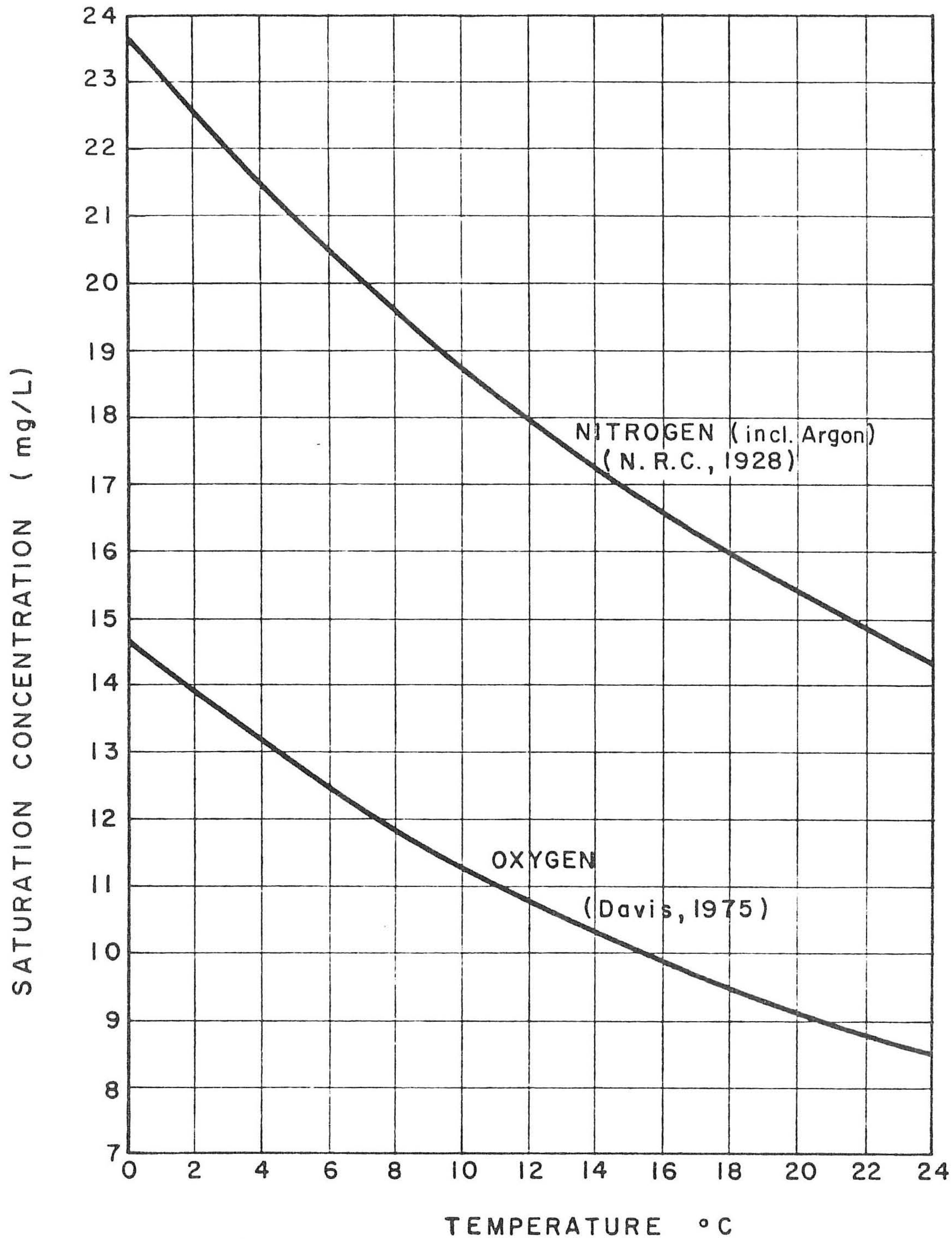
Oxygen Cost Per Year = \$50,000

Note: Oxygen costs vary with amount used, becoming more expensive per unit volume as volume used decreases.



EFFECTS OF pH AND TEMPERATURE ON DISTRIBUTION OF AMMONIA AND AMMONIUM ION IN WATER

FIGURE 1

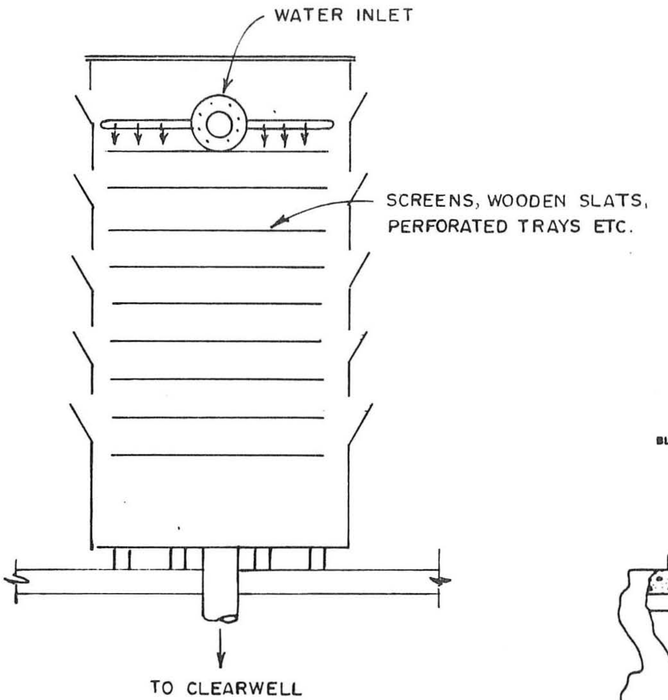


NOTE

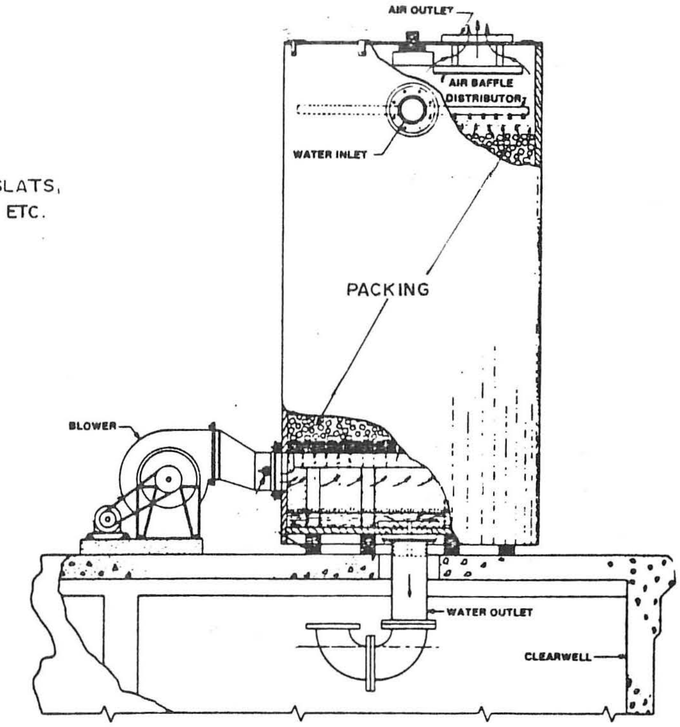
CONCENTRATION AT 100 % SATURATION IN FRESHWATER
AT 760 mm Hg ATMOSPHERIC PRESSURE

NITROGEN AND OXYGEN SATURATION CONCENTRATION VS. TEMPERATURE

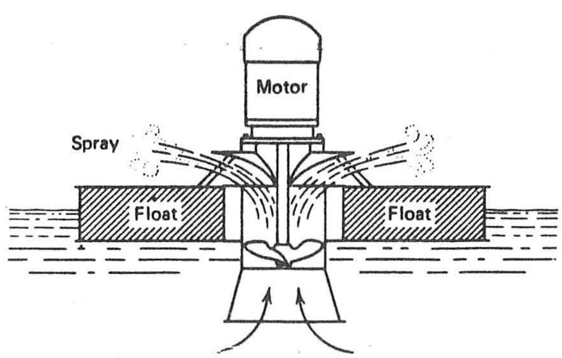
FIGURE 2



NATURAL DRAFT AERATION TOWER



FORCED DRAFT PACKED TOWER

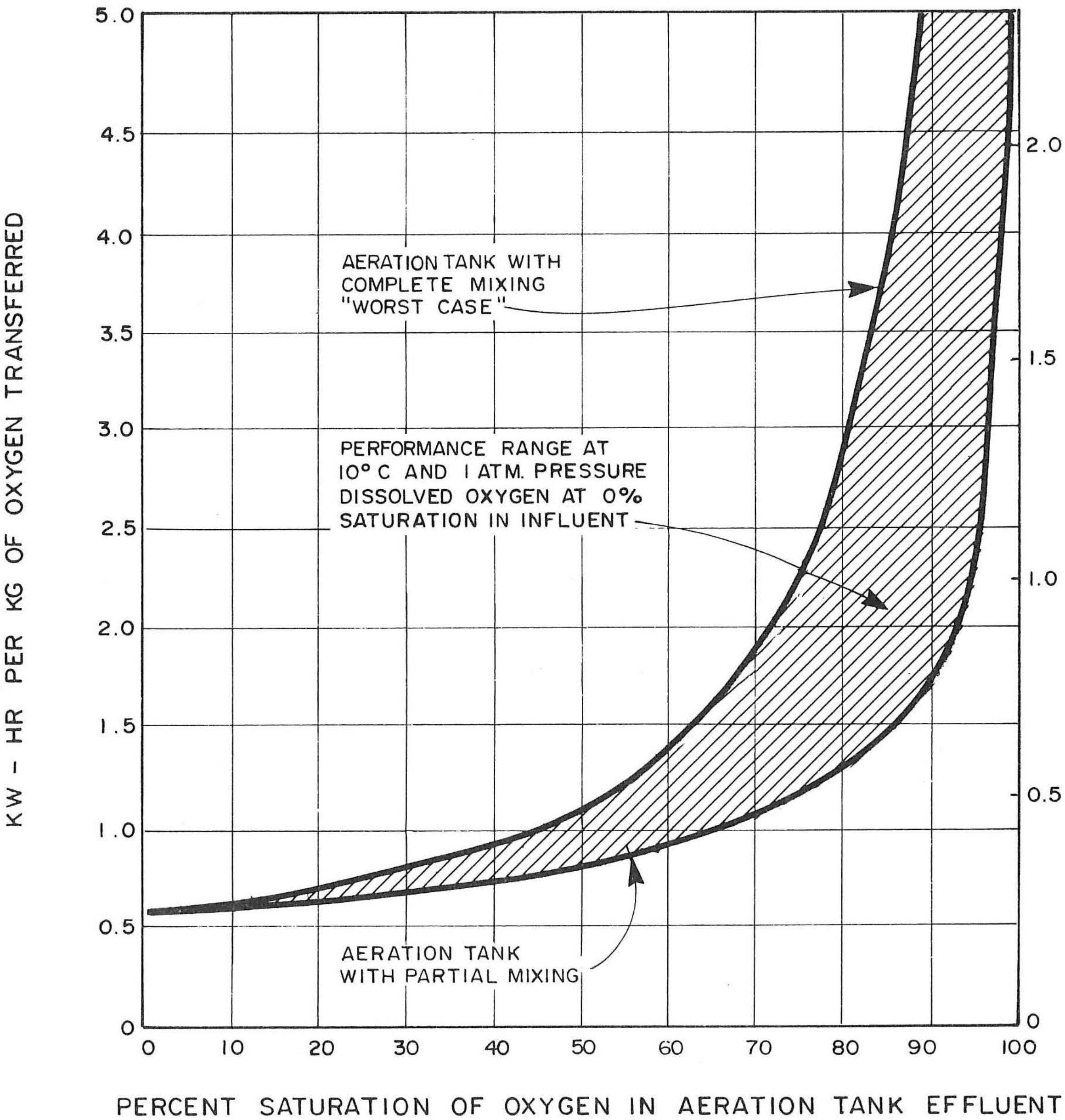


SURFACE AERATOR

AERATION TOWERS AND

A MECHANICAL SURFACE AERATOR

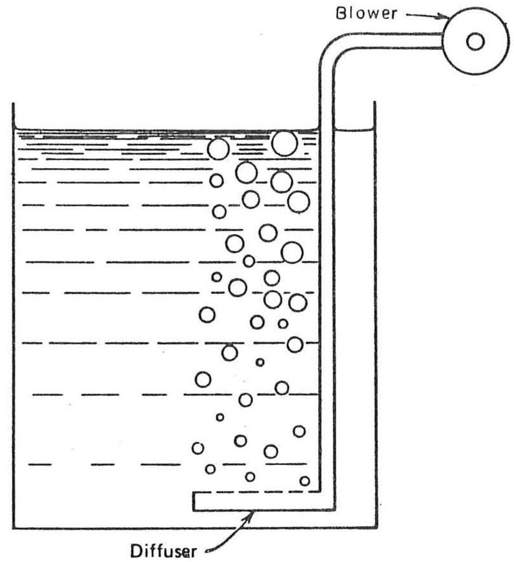
FIGURE 3



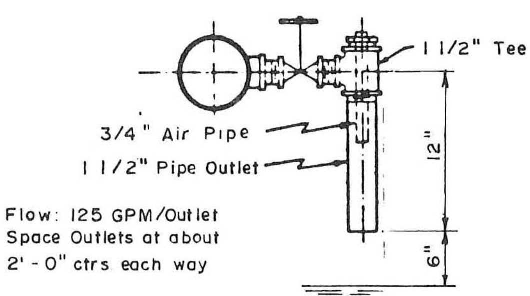
NOTE:
AERATOR CAPABLE OF TRANSFERRING 1.64 kg O_2 / kw - hr AT 20° C, 1 ATM. PRESSURE AND AN OXYGEN DEFICIT OF 9.17 mg / L

ESTIMATED PERFORMANCE RANGE OF A MECHANICAL SURFACE AERATOR

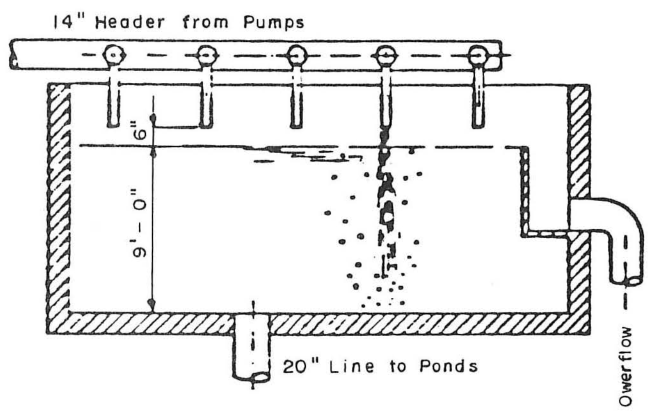
FIGURE 4



DIFFUSER AERATOR



DETAIL OF ASPIRATOR

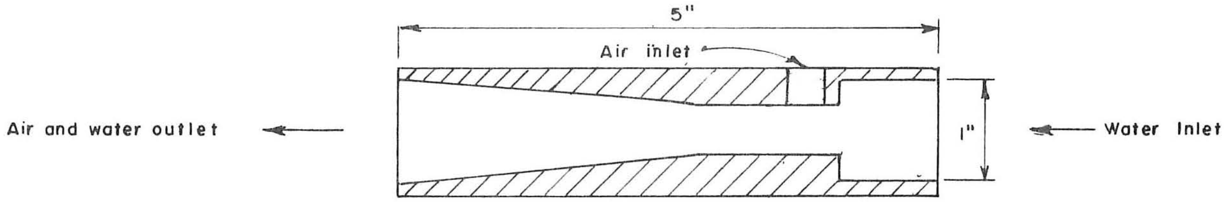


AERATION TANK

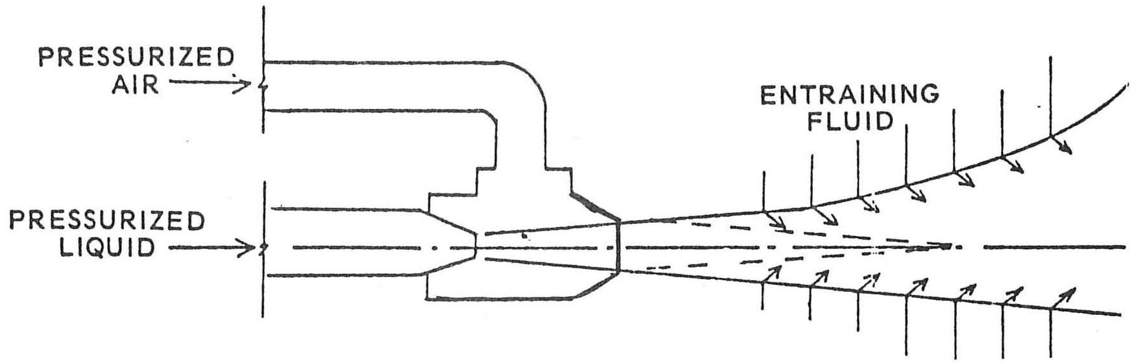
ASPIRATORS SIMILAR TO THOSE
AT QUINSAM HATCHERY,
CAMPBELL RIVER, B.C.
(Burrows and Combs, 1968)

DIFFUSER AERATOR AND
ASPIRATOR

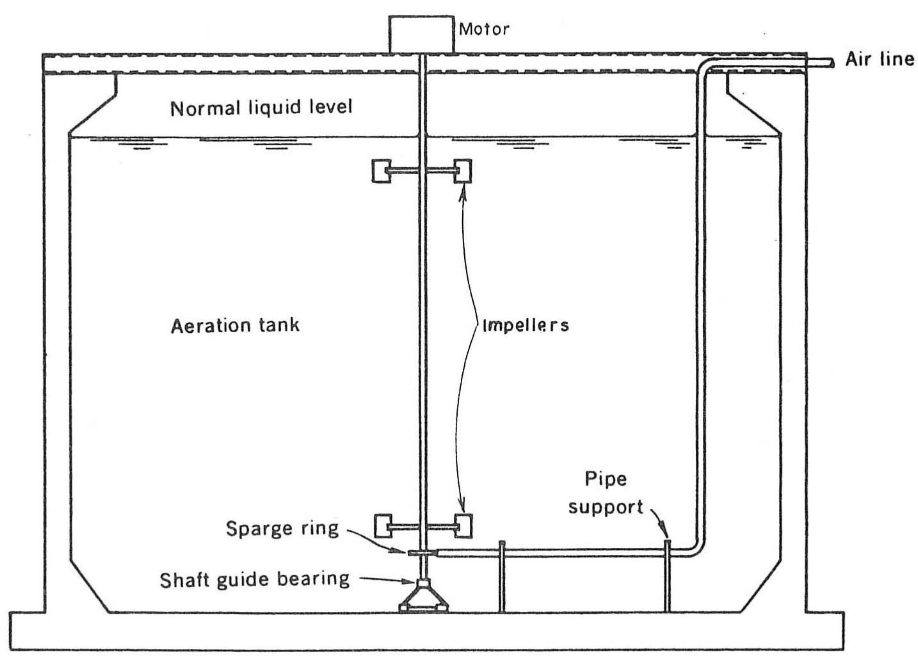
FIGURE 5



POLYVINYL CHLORIDE ASPIRATOR
(Scott, 1972)



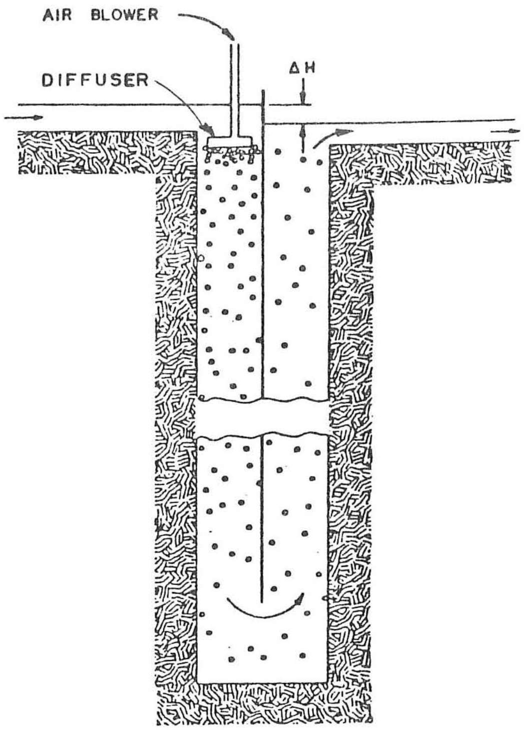
JET AERATOR



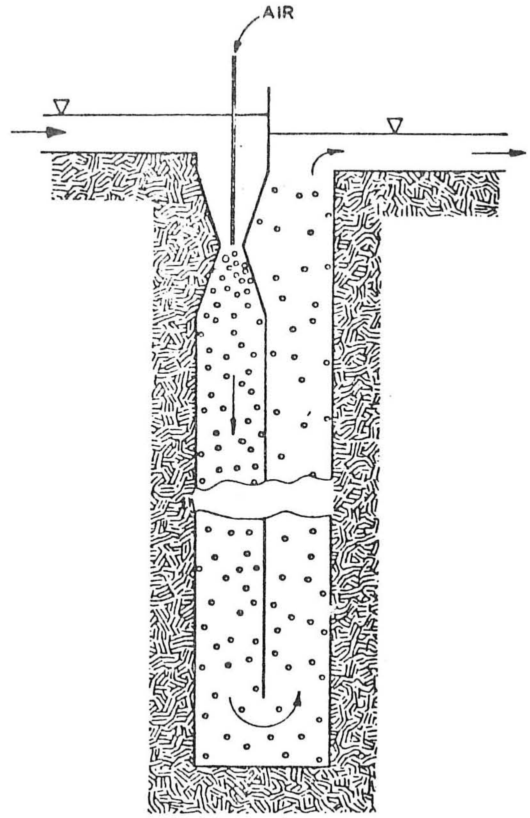
SUBMERGED TURBINE AERATOR

ASPIRATOR, JET AERATOR AND SUBMERGED TURBINE AERATOR

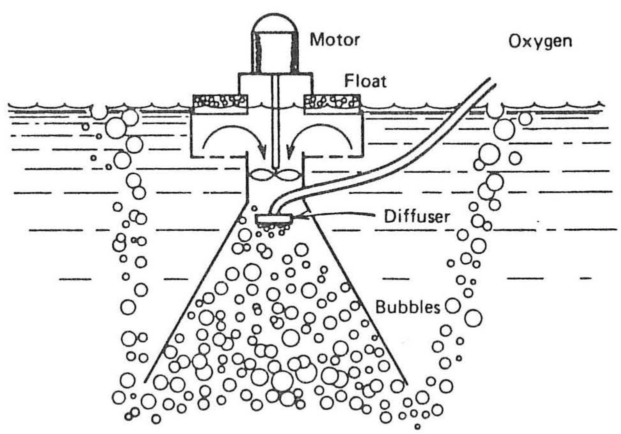
FIGURE 6



U-TUBE WITH DIFFUSER TYPE INTAKE



U-TUBE WITH VENTURI TYPE INTAKE

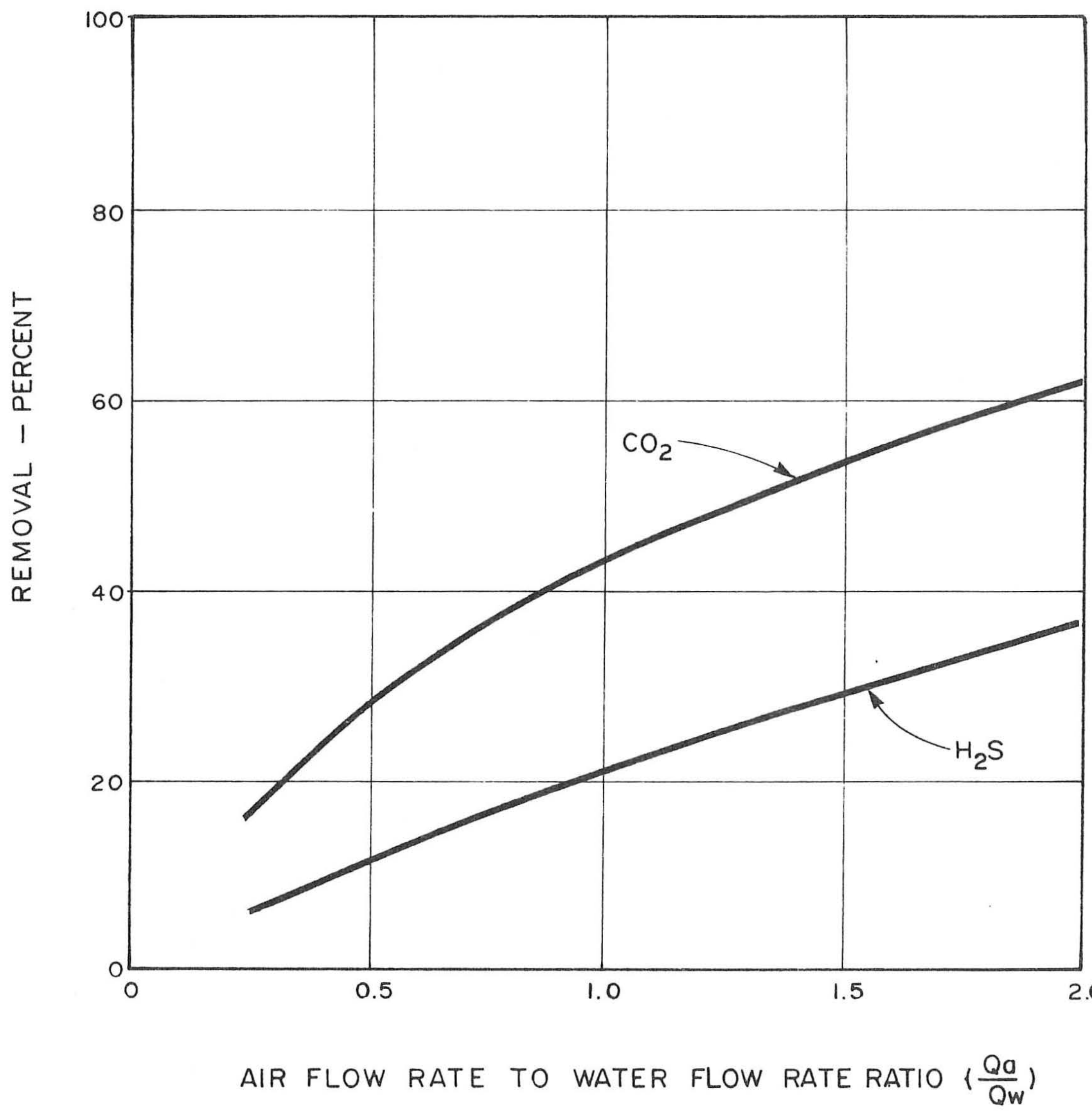


DOWNFLOW BUBBLE CONTACT AERATOR

U – TUBE AERATOR AND

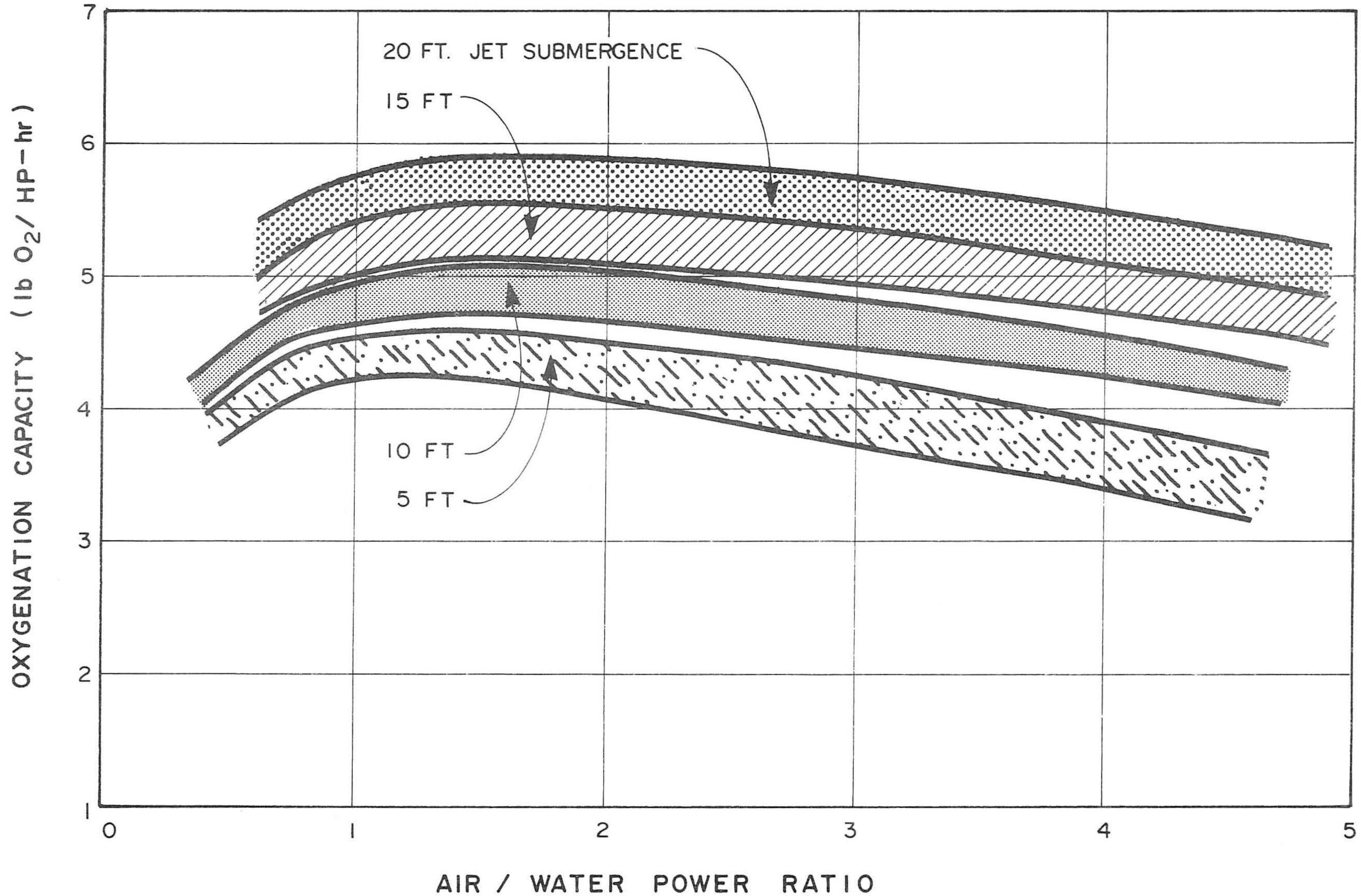
DOWNFLOW BUBBLE CONTACT AERATOR

FIGURE 7



ESTIMATE OF CO_2 AND H_2S
REMOVAL BY DIFFUSED AIR SYSTEMS
(NEGLECTING WATER SURFACE VENTILATION)

FIGURE 8



OXYGENATION CAPACITY AT VARIOUS
AIR/WATER POWER RATIOS FOR A JET AERATOR
(Huang and Mandt, 1973)

FIGURE 9