WATER TREATMENT, AERATION

1. Introduction

One of the important characteristics of wastewater is the presence of countless diversity of biological life forms. Most of these life forms utilize oxygen in one form or another. When they use free molecular oxygen they are known as aerobic life forms. When the life forms use chemically bound oxygen they are called as anaerobic life forms. Anaerobic life forms breakdown complex organic matter into simpler forms of organic compounds and chemicals resulting in odor and public-health problems (1). Aerobic life forms are most desired because the end products of their biological action are water and carbon dioxide (2,3). They use molecular oxygen to biochemically metabolize the organic material present resulting in an odorless environment. In wastewater systems some of the oxygen consumption could be due to chemical reactions such as converting hydrogen sulfide (H_2S) to H_2SO_4, free-metal ions (iron, manganese) to their oxides, known as Chemical Oxygen Demand (COD). The combined values of these oxygen requirements are known as the Biochemical Oxygen Demand or the BOD. In any event to treat the waste in wastewater much oxygen has to be transferred into the water (4).

The most common application in the field of wastewater treatment system is to dissolve enough oxygen to maintain and aerobic condition. Water when exposed to air, attempts to reach an equilibrium concentration of dissolved oxygen (DO). Sufficient oxygen to meet the biochemical oxygen demand of an aerobic waste treatment system does not enter water through the normal surface area. Because of the low solubility and diffusion at the gas–liquid interface, oxygen transfer is limited. To transfer or to dissolve large quantities of oxygen that are needed, additional interface must be created. Either air or oxygen can be introduced into the liquid, or the liquid in the form of droplets can be exposed to the atmosphere.

Oxygen transfer may be defied as the process by which oxygen is transferred from gas to liquid phase. Bubbling air under water is the oldest and at times one of the preferred method of aeration.

However, dispersing the bubbles and mixing the transferred oxygen uniformly throughout the wastewater volume is a limiting factor in the use of air bubblers.

2. Oxygen Solubility

The solubility of gas in water follows the principles of Henry's gas law. The dissolution of oxygen is no exception and is affected by temperature, atmospheric pressure, the presence of other dissolved or undissolved material such as organics, fats and oils, and concentration of oxygen in the air. Oxygen is slightly soluble in water and the solubility of oxygen is inversely proportional to the water temperature and at a given temperature, directly proportional to the partial pressure of the oxygen, directly in contact with the water. At equilibrium, the concentration of gas dissolved in a liquid is the function of the partial pressure of the gas adjacent to the liquid. This relationship is give by Henry's law (eq. 1):

$$P_g = Hx_g \tag{1}$$

Where, P_g is the partial pressure of gas, (atm), (the partial pressure of oxygen in air is about 21% by volume at sea level. The volume decreases at higher altitude). H is the Henry's law constant, x_g is equilibrium mole fraction of dissolved gas. Henry's law constant is a function of the type of the gas, temperature, and constituent of the liquid.

The dissolved matter in the water lowers oxygen solubility. At 20°C at sea level (1 atm), the equilibrium concentration of dissolved oxygen in clean water (tap water) is 9.17 mg/L and in chlorine free water at is 9.09 mg/L and in seawater at is 7.42 mg/L (4). A point to remember is that the solubility of atmospheric oxygen is much less in domestic wastewater than distilled water.

3. Diffusion

Though the solubility follows Henry's gas law, the driving force by which the gas overcomes the resistance generated by the surface film is the difference in the concentration of the diffusing gas. After overcoming the barrier of the liquid surface, the molecular diffusion of a gas into a liquid is determined by the characteristics of the gas and the liquid, the temperature of the liquid, the concentration deficit, hydraulically induced turbulence, thermal- and wind-induced circulation, and molecular diffusion.

The process of gas diffusion into the liquid through the water surface may be expressed by Fick's law.

$$\frac{dC}{dt} = K_L a(C_s - C) \tag{2}$$

where:

dC/dt is the rate of change in concentration of gas in solution, mg/L · s
$K_L a$ = overall mass transfer coefficient, s^{-1}
C_s = saturation concentration of gas in solution, mg/L
C = actual concentration of gas in solution, mg/L

3.1. The Two-Film Theory.

For the last 90 years, several talented and dedicated engineers have tried to explain the gas transfer mechanism involved with oxygen transfer in the water (5,6). W. E. Adeney and H. G. Becker came up with one of the best analyses of gas absorption process in water: the two film theory. In this model, the theory is that there two films exist at the gas–liquid interface, as shown in (Fig. 1). The two films, one liquid and one gas, provide the resistance to the diffusion of gas molecules between the bulk-liquid and

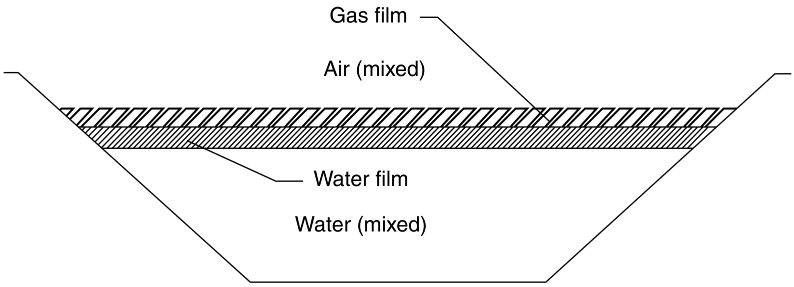

Fig. 1. Schematic representation of the two films at the air–water interface.

bulk gaseous phases. For the migration of the gas molecules from the gas phase to the liquid phase, slightly soluble gases encounter the primary resistance to migrate from the liquid film, and highly soluble gases encounter the primary resistance from the gaseous films.

The two-film theory is based on a physical model in which two films exist at the gas–liquid interfaces shown in Fig. 2.

In wastewater treatment systems, the rate of gas transfer is proportional to the difference between the existing concentration and the equilibrium concentration of the gas in solution.

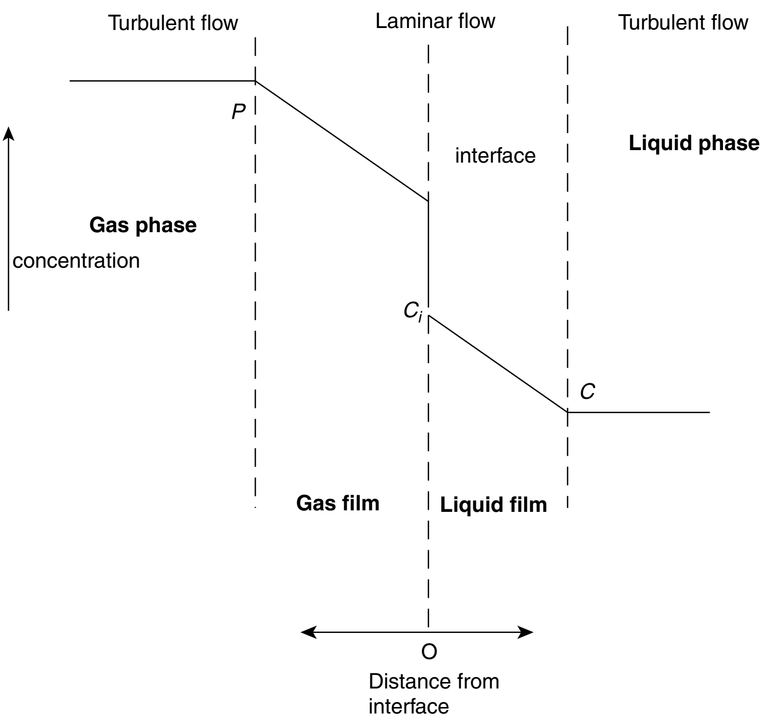

Fig. 2. Simplified sketch for two-film theory of gas transfer. Adopted from Ref. 7.

This relationship is represented below:

$$\frac{dm}{dt} = K_g \cdot A(C_s - C) \tag{3}$$

Where:

$\frac{dm}{dt}$ = rate of mass transfer
K_g = coefficient of diffusion for gas
A = area through which gas is diffusing
C_s = saturation concentration of gas in solution, mg/L
C = concentration of gas in solution, mg/L

Aerators are evaluated on the basis of the quantity of oxygen transferred per unit of air introduced to the water for equivalent conditions (temperature, chemical composition of the water, the depth at which the air is introduced, or the bubble contact time, etc).

$$dm/dt = V\, dc/dt \tag{4}$$

Equation 3 can be written as:

$$dC/dt = K_g \cdot A/V(C_s - C) \tag{5}$$

In practice $K_g \cdot (A/V)$ can be replaced by a proportionality factor that is related to existing conditions of exposure as $\mathrm{K_La}$ (Fick's Law).

So the equation can be rewritten as:

$$dC/dt = K_L a(C_s - C) \tag{6}$$

Where:

dC/dt = change in concentration, mg/L
$\mathrm{K_La}$ = overall mass-transfer coefficient
C_s = saturation concentration of gas in solution mg/L
C = concentration of gas in solution, mg/L

The effect of the resistance exhibited either or by both films, at the liquid-gas interface which exists per unit volume of fluid is represented by K_La. To a given amount of air introduced to a liquid system, the available surface area through which gas diffusion can take place is inversely proportional to the bubble size. So it can be generalized to some extent that the value of K_La increases as the bubble size decreases.

Creating turbulence in water enhances the efficiency of gas transfer. Turbulence created by aerators reduces the thickness of the liquid film and promotes oxygen transfer and dispersion of dissolved gas once the diffusion of the gas into the liquid is achieved. Where air bubbles are used, because of the lifting effect and drag by the viscous fluid, they promote turbulence and circulation of the liquid. In this respect, aerators should not only supply enough oxygen for treatment, but also should provide adequate mixing to prevent solid separation of the mixed liquor suspended solids (MLSS), from the bulk liquid. At least the mixing level should keep the biological floc completely mixed with BOD and oxygen to effectively treat the waste in the wastewater. Generally speaking the average horizontal mixing velocity of the wastewater should be maintained at approximately 0.4 fps (0.1 m/s) to prevent solids deposition (8).

The value of the K_La is temperature dependent and increases with temperature.

This effect is often expressed as:

$$(K_La)_T = (K_La)_{20}\mathrm{X}(\Theta)^{\mathrm{T}-20} \tag{7}$$

Where:

$(K_La)_T$ = value of the oxygen transfer coefficient at operating temperature
$(K_La)_{20}$ = value of oxygen transfer coefficient at 20°C
Θ = temperature correction factor (usually 1.024)
T = operating temperature of the water, °C

Normally, the oxygen transfer coefficient is calculated in clean water and then corrected for wastewater, because of many variables involved. Sawyer and Lynch (9), studied the influence of various detergents on K_La. They found that by adding 15 mg/L of detergent to water lowered the value of K_La by 40%. King (10) reported that the saturation value of oxygen in domestic wastewater is about 95% of the distilled water. He also found that the transfer coefficient values of fresh wastewater can be 26–46% of the freshwater.

In wastewater treatment systems, oxygen is used to degrade the substrate to produce the high energy compound required for cell synthesis and for respiration. In treatment systems with long cell residence time, the oxygen required for cell maintenance can be the same as for the substrate metabolism. It is recommended to maintain a minimum residual Dissolved Oxygen (DO) level of 0.5 to 2.0 mg/L in reactor basin at all times to prevent oxygen deficiencies from odor production and the rate of substrate removal. Several "rules of thumb", for determining oxygen requirements were developed. One pound of oxygen per pound of carbonaceous BOD_5 removed has been used for many years. For diffused air aeration systems 0.5 to 2.0 ft^3 air/gal wastewater (3.7–15 m^3) was considered adequate in the past. Later, 500 to 900 ft^3 air/lb BOD_5 (30–55 m^3/kg BOD_5) was used. "The Ten State Standard" (Health and Education Service 1971) recommended 1000 ft^3 air/lb BOD_5 removed (60 m^3 air/kg BOD_5) to be used. For extended air treatment system, the air supplied may up to 2,000 ft^3 air/lb BOD_5 (125 m^3 air/kg BOD_5) removed, so as to supply enough oxygen for endogenous respiration and an anticipated occurrence of nitrification. It should be noted that these rules of thumb are considered as a conservative in that the air supplied will provide enough mixing of the biological solids. Eckenfelder and O'Connor (11) formulated a simple equation of oxygen requirement as follows. Pound of O_2 supplied/d=A (lb BOD_5 removed/d)+B (lb MLSS in aeration tank).

Where A=oxygen required for BOD_5, synthesis and B=oxygen required for endogenous respiration. They found that A=0.48 mg O^2/mg BOD_5 removed and

$B = 0.08$ mg O^2/mg solids in the reactor. However, tests conduced by others came up with different values (12).

From these studies the following conclusions were drawn.

1. As the substrate removal increases, oxygen demand will increase.
2. As the cell residence time increases, the oxygen requirement increases.
3. As the cell mass increases oxygen demand increases, cell degradation increases.

When the hydraulic detention time is decreased and the substrate removal rate remains constant, higher amount of oxygen will have to be supplied. This is due to the increased amount of sludge return rate to maintain the same effluent quality.

In addition, if nitrification is planned additional oxygen should be supplied over the BOD_5 oxygen demand. When nitrification occurs, the oxygen demand will be at the rate of 4.6 lb of oxygen/lb of $NH_4{-}N$ satisfied.

4. Aerators

Over the past 100 years, treating wastewaters through biological oxidation has drawn the attention of several very talented engineers. Always the preference has been through aerobic treatment. Although anaerobic treatments were employed, the odor problem and fear of disease are the drawbacks. Angus Smith (11) introduced oxygen by blowing air under wastewater to effectively bring about the removal or to satisfy the BOD_5 in the wastewater success. This was followed by several engineers of that time who treated and recovered the water, one of the most important natural resources. However, experimental results were not completely satisfactory. By 1910, it was found that returning some of the suspended solids back to the fresh wastewater along with aeration, the treatment efficiency significantly improved and found wide spread application throughout the Western world. By 1923, the importance of oxygen and mixing of the sludge growth were considered vital for BOD_5 removal and cleaning up of the wastewater. To achieve this, mechanical aerators were considered as a part of the wastewater treatment system.

Aerators may be divided into two basic groups: (*1*) ecto-type aerators and (*2*) endo-type aerators.

4.1. Ecto Type Aerators. Ecto type aerators are devices which oxygenate or aerate the water from outside the water surface. They are also known as surface aerators such as splashers, rotor or brush type aerators, rotating discs, cascade aerators, bio-discs, fountains etc.

Surface aerators are designed to throw the water up into the air. During this process the air born water is broken into smaller droplets, thus creating a large surface interfacial area. Oxygen in the air is transferred into the oxygen-deficient water drops. In the mean time some of the gases from the water drops are also exchanged into the atmosphere.

There is also a secondary aeration and mixing effect in these types of aerator. When the air born aerated droplets impact on the surface of the water, they in turn entrap some atmospheric air and further oxygen transfer occurs at the water surface. There is a tendency with these aerators to re-aerate the same volume of water and the water in the deeper layers may not get oxygenated and mixed. To over come this, some surface aerators are equipped with draft tubes. The draft tube could reach to the deeper layers of the water. Even with the draft tube, there is a tendency for these aerators to develop cells around the aerators where the water is supersaturated with oxygen and in between zones of low oxygen and dead zones where solids accumulation could be possible. With surface aerators, there is some cooling effect because of evaporation and aerosol misting can occur. The wind could carry an aerosol mist to the neighboring properties. Due to these potential problems, these type of aerators are not appreciated in populated areas. However, some brush aerators install covers over their rotors to prevent too much cooling and ice formation in colder regions and aerosol formation. Some of the surface aerators seems to create large amount of foam, which can be blown around by strong wind. Some of the examples of the Ecto Type aerators are discussed below.

Surface Aerators (Splashers). Surface aerators may be fixed or movable. The fixed types are permanently mounted to the floor or the aeration tanks with steel support structures or mounted from concrete support platforms. Disadvantages in having permanently mounted surface aerators are many, but the main ones are (*1*) That they need heavy equipment to move them in place and to service them; (*2*) They are not practical when there is more than a 6 in. water level fluctuation.

The movable types are mounted on to a flotation system. The floats could be foam filled steel or corrosion resistant stainless steel or PVC shells (Fig. 3**f**).

The advantages are that they can be installed in any pond or tank where the water level fluctuation is normal. Movable aerators are very simple in design. They may be available is sizes from 1 hp to 100 hp. They consist of a submerged or partially submerged impeller that are attached to the motor directly or through an extended shaft. The impellers are fabricated from steel, cast iron, noncorrosive alloy such as stainless steel and synthetic materials. The impellers are used to agitate the water vigorously, entraining air in the wastewater thereby creating a large air-water interface that enhances the dissolution of oxygen. In some designs the impellers are enclosed in a tube and the water is drawn upwards and deflected with baffles to create very fine bubbles. The bubbles exchange oxygen on their way in the air. The droplet impacts on the water surface creating displacement currents and mixes the aerated water with the oxygen deficient water. The surface aerators may be classified according to the speed in which the impellers are rotated, as low speed and high speed. In low-speed surface aerators, the impeller is driven with a reduction gear by an electric motor. The motor or the gearbox is usually mounted on to a platform that is supported either by piers extending to the bottom of the tank (Fig. 3**a**) or by beams that span the tank. In high-speed surface aerators, the impeller is coupled directly to the rotating electric motor shaft. High-speed surface aerators are always mounted on floats. Surface aerators are considered by some engineers to be not well suited to some treatment systems, such as plug flow systems. However, these aerators are generally well adapted to many basin geometries, especially in large basins and lagoons where large amounts of power can be used. In some instances these surface aerators are favored because they end to handle increased loading levels with higher oxygen uptake values.

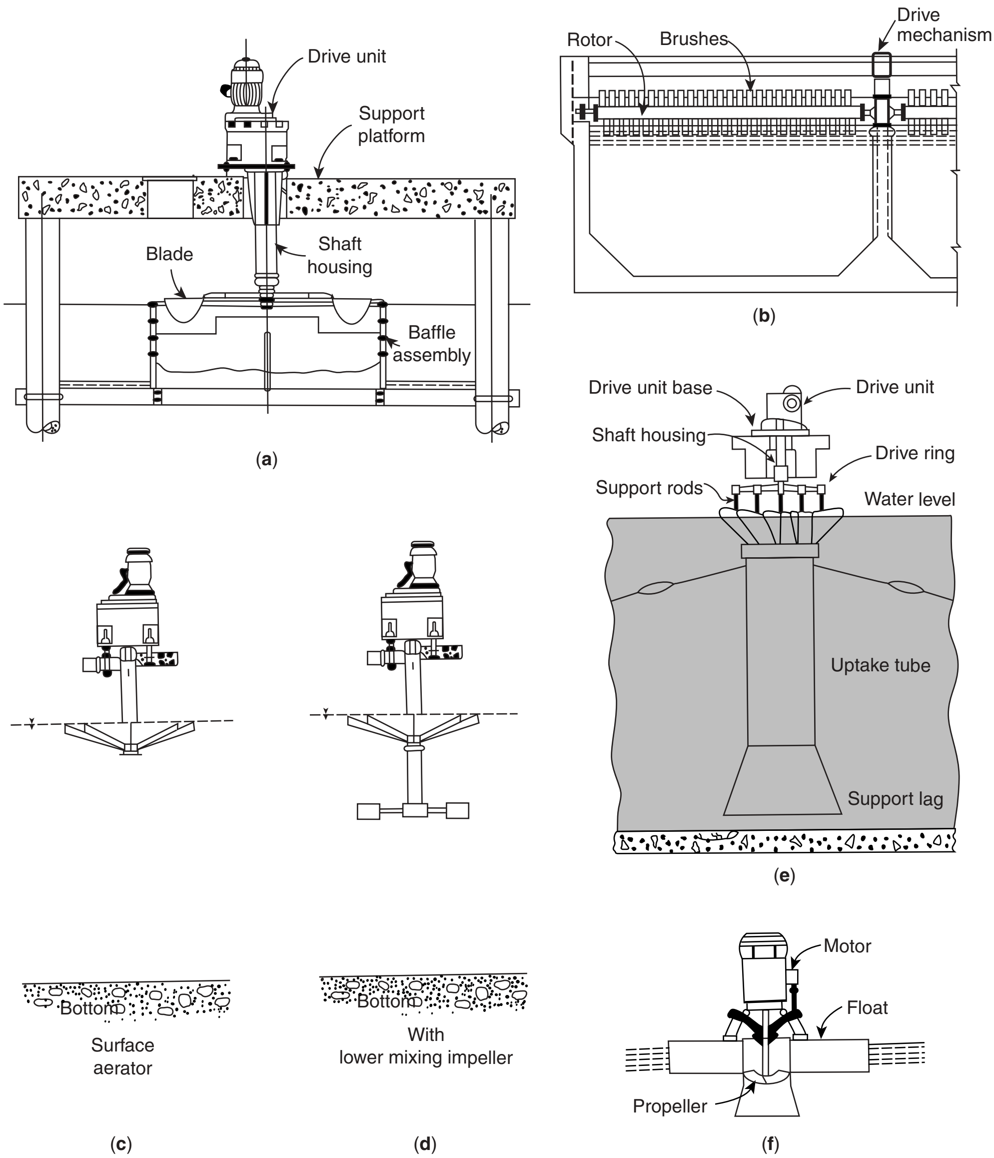

Fig. 3. Ecto type aerators. Surface aerators (mechanical aerators): (**a**) permanently mounted surface aerator; (**b**) brush aerator; (**c**) typical surface aerator; (**d**) surface aerator with axillary impeller; (**e**) surface aerator with a draft tube; (**f**) floating surface aerator.

As mentioned before the fixed surface aerators are quite sensitive to depth of impeller submergence. An increase in impeller submergence results in increased fluid pumpage and power use and can decrease gear box life expectance when the overloading persists. To have a successful and long term satisfactory installation, it is important that each application is properly evaluated before specifying a particular type of surface aerators (Fig. 3**c**).

Providing draft tubes ensure the mixing by bringing up the liquid and solids from the bottom layers. The draft tubes are used when the basin is deeper than 15 to 30 ft (4.5 to 9.0 m). Draft tubes are also recommended when the mixing in the basin becomes an issue (Fig. 3**e**).

An alternative to using draft tube is to install an auxiliary lower mixing impeller. These auxiliary lower impellers will improve the mixing of the lower layers of the basin at a higher power usage (Fig. 3**d**). The surface aerators may be mounted either from bridge or from platforms. The design of the platform should be adequate to handle the torque and vibration developed by the aerators. When mounted from abridge, the bridge should be designed to withstand at least four times a torque and impeller side load anticipated. The location of the surface aerator in the tank is a function of the configuration of the impeller. Radial flow impeller aerators are generally located 0.5 to 0.7 times the impeller diameter above the tank bottom. If axial flow impeller aerators are designed, the aerators shall be located 0.6 to 0.65 of the tank depth, measured from the water surface (8).

Low Speed Surface Aerators. Low speed surface aerators have a much better oxygen transfer efficiency compared to coarse bubble diffused air type aerators. The low speed surface aerators normally operated at 20 to 100 rpm. The low speed aerators are usually smaller power units. These units also use gear box to reduce the impeller speed from the motor. The gear box transmission unit on the low-speed aerator is a very critical item. A service factor of 2.0 or higher is recommended by the American Gear Manufacturers Association, in order to achieve mechanical durability. For example, without this service factor, if two low-speed surface aerators with different impeller speed were to be installed in a tank, the shock waves created by the two aerators or deflection from the wall may cause an overload of the gear drive.

The low-speed surface aerators may come in several different forms (Fig. 3). They are available in normal power increments up to 150 hp (110 kW). Most of the low-speed aerator designs use an impeller operating just about the water level. The submergence of the impeller may be adjusted to control the power out put and oxygen transfer efficiency of the unit. This could be accomplished by adjusting the weir for seasonal loading fluctuation. The low-speed surface aerators also come in two speed units. Depending on the load or oxygen demand the speed can be changed at the gear box. The impeller on the unit may be as large as 12 ft (3.6 m) in diameter and operate at a top speed of 15 to 20 fps (6 m/s) impeller peripheral velocity.

The oxygen transfer efficiency of the low-speed surface aerator is still not very clear. Although, high transfer values have been claimed, the actual values range form 2.0 to 4.5 lb/hp-h (0.3 to 0.8 kg/kW · h) (8).

High Speed Surface Aerators. High speed surface aerators are of limited use in activated sludge systems. There are some concerns regarding the disruption of the activated sludge floc, possibly making it more difficult for the floc to settle. However, they have been used primarily in lagoons and stabilization ponds. High speed aerators are not good mixers and with limited in oxygen transfer efficiency (8). The pumping capacity of the unit is much lower than the low speed surface aerators (Fig. 3). They also come in standard motor power increments up to 150 hp (95 kW).

Kessener Brush Aerators. The Kessener brush aerators, originated in Europe, are used to provide both aeration and circulation in oxidation ditches (16). However, they also come in float-mounted brush aerators, and can be operated in open water applications such as fish ponds, lakes, and lagoons. Their use in fish ponds are wide spread, where a single portable unit can be attached to a tractor power takeoff and employed to aerate several fish ponds. The brush aerators are horizontally mounted on the water surface. They are made up of a cylinder with several rows of steel vanes attached perpendicular to the cylinder. The cylinder is rotated rapidly by the motor. The blades pick up water, break them in to smaller bubbles, and create turbulence at the water surface. The oxygenated water is moved away from the brush in a horizontal direction.

The oxygen transfer efficiency of the brush aerators is approximately 2.5 to 3.5 lb O_2/hp-h (0.4 to 0.6 kg/kW). The transfer efficiency of the brush aerators are not affected by the depth of submergence of the rotor. A deeper the submergence of the rotor will increase the oxygen transfer slightly, but will require more power and essentially the oxygen transferred will remain the same. The rotors are made in various sizes up to maximum of about 25 ft. Two rotors with one common electric motor arranged end to end could aerate a ditch 50 ft in width (Fig. 3**b**).

Spray Aerators. In spray aerators, water is sprayed into the air through nozzles, as in fountains. The water can be collected and sprayed back in a closed loop. Oxygen transfer occurs when the water is pumped up into the air and when the water hits the hard floor and scatters in to finer bubbles (Fig. 4**a**).

Waterfall Aerators and Cascade Aerators. Waterfall and cascade aerators are of very limited use. Generally they are used to enhance the aesthetics of small garden ponds. In the water fall and cascade aerators, water is pumped up to a higher elevation spread out and allowed to flow in a thin sheet over a series of cascades or other obstruction to create turbulence so as to create new air–water interface surface area. During this process atmospheric oxygen is absorbed and mixed on its way down. Normally, the water is collected at the bottom and pumped up in a closed loop and the process is repeated (Fig. 4**b**).

4.2. Endo-Aerators. As described before, endo aerators oxygenate the water by pumping air under water. There are several types available in

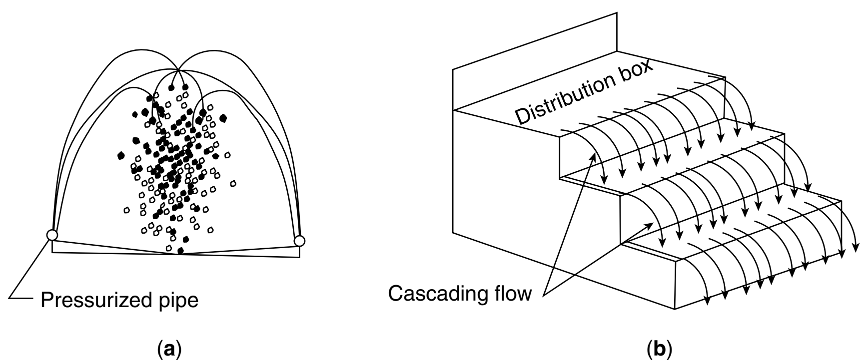

Fig. 4. Ecto type aerators. (**a**) Spray aerator; (**b**) waterfall and cascade aerator.

the market. Only three distinct groups are described here. They are diffused-air, jet air and aspirated air aerators.

Diffused-Air Aeration Systems. The diffused-air aeration system is one of the oldest ways of aerating wastewater treatment systems. All diffused aeration systems introduce air under the water through diffusers. Air blower packages are used to supply the required amount of air. The blowers be sized to overcome the water head and provide enough volume or air to satisfy the oxygen requirement and maintain an aerobic condition in the tank at all times. In diffused aeration, it was found that oxygen transferred at the time of bubble formation and after the bubble leaves the diffuser. The bulk of the transfer occurs after the bubble has left the diffuser, since there is a liner increase in transfer efficiency verses depth (17). Factors affecting oxygen transfer are (*1*) bubble size; (*2*) diffuser air flow rate; (*3*) diffuser placement; and (*4*) mixing the air with surrounding medium. The diffusers are designed to produce fine, medium, and coarse bubbles. The engineers design the treatment tanks depending on the type of the bubble sizes to be used. Naturally the tank depth dictates the appropriate diffused-air aeration system. Oxygen transfer is a function of mass transfer across the gas–liquid interface. For a given volume of air, an increase in bubble size will decrease the amount of surface area for gas-liquid interface essentially, if the bubble size is doubled, then the interfacial area is halved. Other factors such as surface tension that tend to break up large bubbles are important, but the concept of smaller bubbles having larger interfacial area and better gas exchange efficiency still stands. Diffusers are made with different materials to produce the desired bubble sizes.

Fine Bubble Diffusers. Fine bubble diffusers come in three kinds: tube diffusers; plate diffusers; and dome diffusers. Mostly they are made of ceramically bonded grains of fused crystalline aluminum oxide or vitreous silicate-bonded grain of pure silica or resin-bonded grains of pure silica. Transfer efficiency of up to 7.5 lb O_2/hp-h has been reported (8). Medium bubble diffusers are made of Saran or woven-fabric sock or sleeves wrapped around plastic or ceramic diffuser tubes (Fig. 5**e**, **f**, **h**). The two types of diffusers are on the market are plate and tube diffusers and dome diffusers.

Diffuser Tubes and Plate Diffusers. The plate diffusers and diffuser tubes are made of fine ceramic and fused silica. They are arranged on headers over the length of the tank. The tube diffusers are screwed into air manifold, which may run the length of the tank close to the bottom along one side of the tank, or short manifolds. Headers may be mounted on movable drop pipes. Fine bubble diffuser systems produces fine to medium size bubbles. But it is important to have swing-lifts and individual valves for each header to service a section of the aeration system. With movable drop pipes, it is possible to raise a header out of the water without interrupting the process or draining the tank for servicing the diffuser tubes (Fig. 5**c**, **g**).

Dome Diffusers. The dome diffusers consist of porous dome 7 in. (17.8-cm) in diameter, made out of an aluminum oxide material. The aluminum oxide material is compressed to a dome shape to ensure uniform permeability and to produce a flow of fine air bubbles about 0.08 in. (2 mm) in diameter. The upward movement of the bubbles induce gentle upward mixing pattern and keep the light biological solids in suspension. The domes are mounted on a

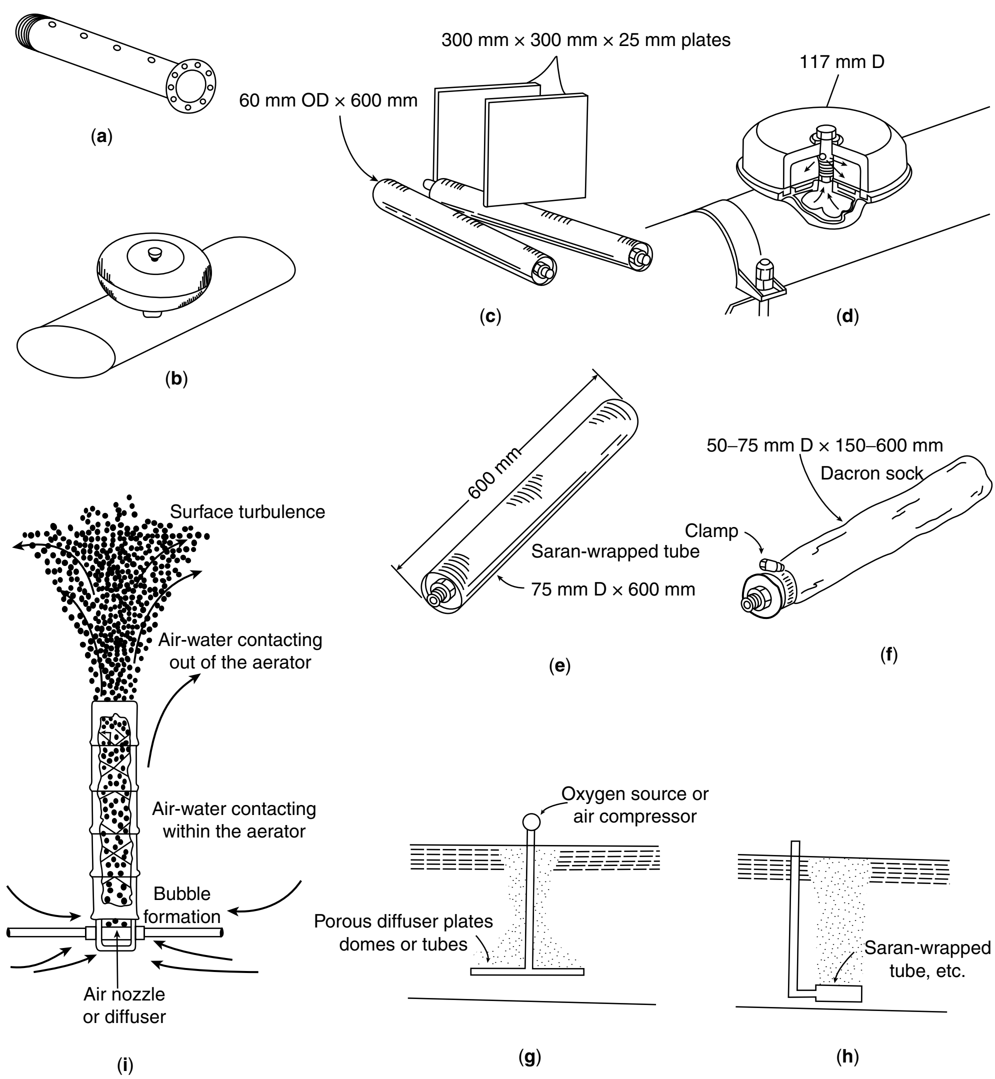

Fig. 5. Endo type aerators, diffused-air aerators. (**a**) Diffuser tube (medium and fine bubble); (**b**) bubble cap (coarse bubbles); (**c**) ceramic tubes and plates; (**d**) dome diffuser (fine bubbles); (**e**) Saran wrapped fine bubble tubes; (**f**) fine bubble diffuser socks; (**g**) and **h**) fine bubble diffuser installed; (**i**) Polcon tubes.

network of poly(vinyl chloride) air piping which runs the length of the aeration tank (Fig. 5**a**). The lateral pipe spacing and the dome diffuser spacing range from 12 to 30 in. (300 to 760 mm), depending on the process requirement. The piping is attached to the floor at 5-ft (1.58 m) intervals by poly(vinyl chloride) floor fixtures and adjustable saddles. A single corrosion resistant tubular bolt is used as a structural fastener, air inlet, and control orifice. With dome diffusers, the inlet air should be clean, free of dust particles, oils and grease, since they may clog the diffuser pores. Use of impregnated or dry type air filters in series before the blower is very common. Pre-coated bag filters and electrostatic filters have also been used. However, diffusers with slightly bigger orifices could ease the dust problem for some extent.

Coarse Bubble Diffusers. Coarse bubble diffusers are much popular because they greatly reduce the servicing requirements. These diffusers generally produce a medium-to-coarse bubble and correspondingly with a lower oxygen transfer efficiency. There are several kinds of coarse bubble diffusers on the market. Only a few are covered here.

Diffuser Tubes. Diffuser Tubes are made out of long PVC tubing with holes drilled on the sides. The holes are progressively larger away from the air source. Control valves are provided at the air source to control the amount of air provided to the tubes. The valves provide a uniform amount of air to each tubes (Fig. 5**a**).

Bubble Caps. Bubble caps are made of nonporous material such as cast iron, stainless steel or heavy plastic. They are attached to headers through specially designed anchoring fixtures. The fixtures serve as sir supply orifices and adjust the amount of air to the caps (Fig. 5**b**).

Polcon Tubes or Tubular Diffusers. Polcon Tubes are some what different from diffused-air aerators. In these units, a 12 to 18 in. diameter tube is equipped with an inserted of twisted auger shaped plate. The tube is mounted to a lateral air supply pipe and bolted to the floor vertically. The height could range from 4 to 8 ft. The air is released at the bottom, where provisions are made for water intake. The air–water mixture raises up through the tubes in a torturous pathway. The transfer efficiency is expected to vary with the basin geometry and depth. The units are very poor mixers and the tubes have to be installed very close together and/or other mechanical means of mixing is required (Fig. 5**h**).

Jet Air Diffuser Aerators. Jet air diffusers have been on the market for some time. In this aerator a water-air chamber is equipped with one or more jet nozzles. The air and wastewater are pumped into a chamber and ejected at high pressure. The pressure buildup in the air–water chamber increases the partial pressure and enhances the oxygen transfer rate. The velocity of the discharged plume and raising air bubbles provide mixing. The efficiency of the jet-air aerators depends on the submergence of the jet and other previously mentioned conditions. Oxygen transfer rates were reported between 2.5 to 5.0 lb O_2/hp-h (0.4 to 0.8 kg/kW). From the amount of air pumped, the reported transfer rate indicates 37%, however, it generally ranges from 10 to 15% (8). It is possible for the nozzle to get clogged by trash and fibrous material. To prevent this problem, it is recommended that the influent wastewater should be filtered or pretreated before entering the aeration tanks with jet-air aerators (Fig. 6**e**).

Aspirating Aerators. Aspirating aerators were developed in Germany around 1965. The design is very simple. A hollow shaft with few holes above the water surface is directly coupled to a motor shaft above the water surface. A screw propeller is attached to the other end of the hollow shaft. A draft tube is place to surround the hollow shaft. In the German version the hollow shaft is rigidly attached to the motor shaft and cantilevered. In the U.S. version, the hollow shaft is attached to the motor shaft through a fled coupling or U-joint. In these designs, the hollow rotating shaft is supported under the water with a water lubricated ware surface or a mechanical bearing. Two types of aspirating

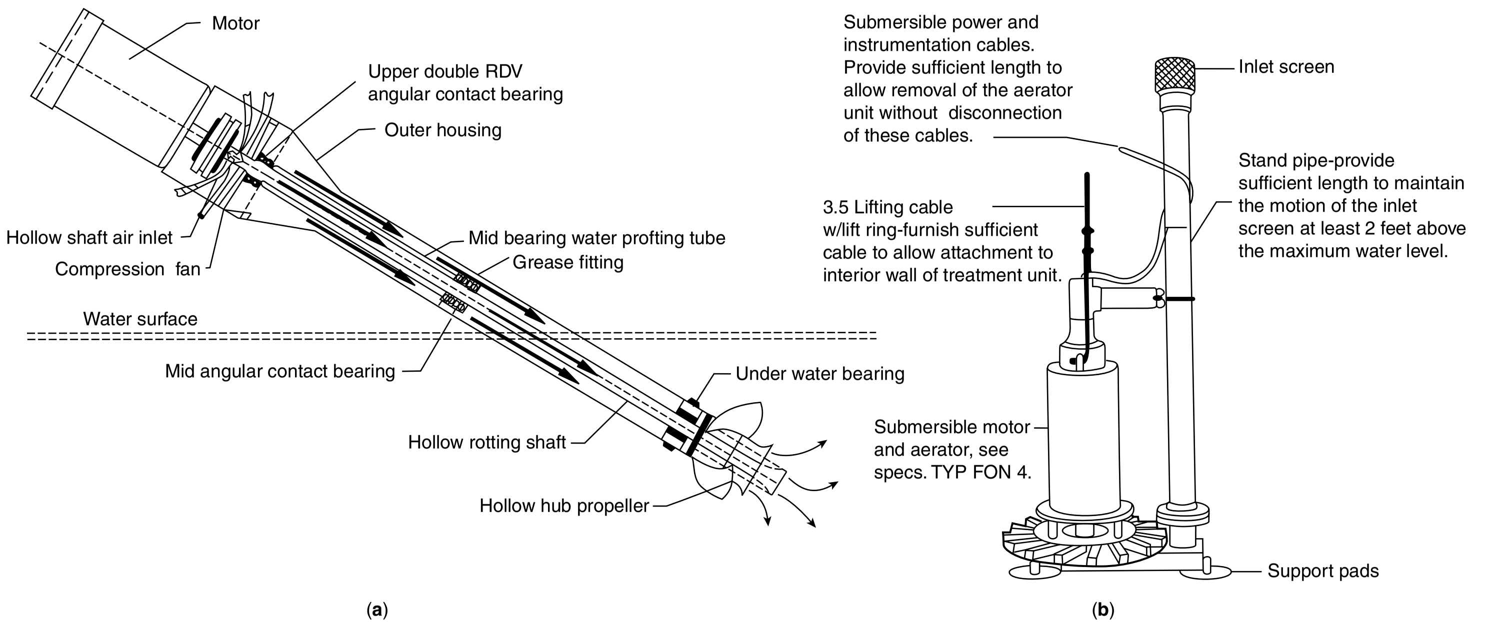

Fig. 6. Endo type aerators and aspirating aerators. (**a**) Compressed-aspirating aerators with three bearings; (**b**) Submersible aspirating aerator; (**c**) Aspirating aerator with an U-Joint; (**d**) Compressed-aspirating aerator with two bearings; (**e**) Jet aerator with single nozzle.

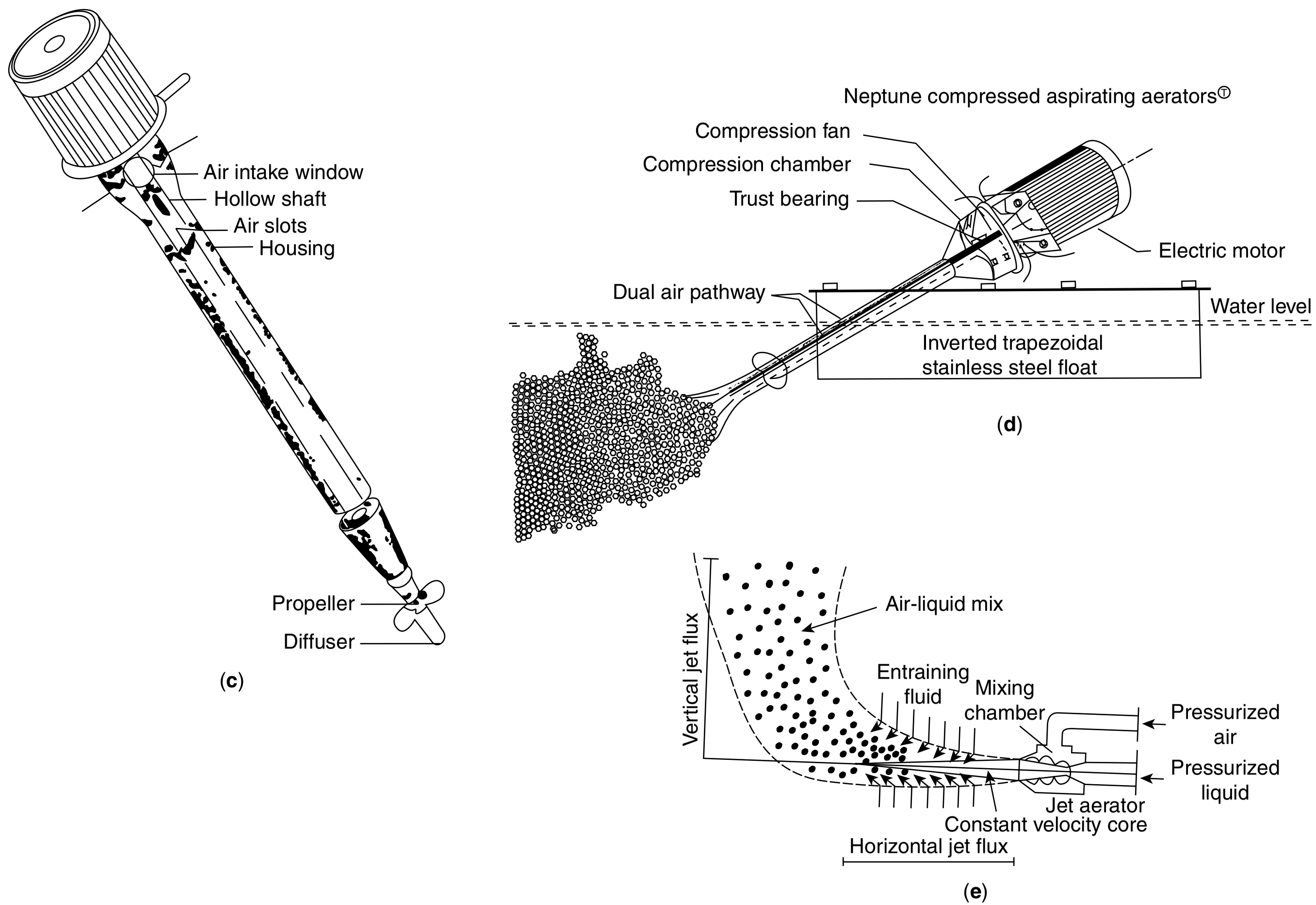

Fig. 6. (*Continued*)

aerators are on the market, the subsurface and the submersible aspirating aerators.

Subsurface Aspirating Aerators. There are two distinct models are available.

Propeller Driven Aspirating Aerators. These aerators come with hollow rotating shaft or with solid shaft. Both fit the same description as that of the German design. With a couple of exceptions they all use one or two bearings to support the rotating shaft above and under the water surface. Since 1975 several models have been introduced in the market. One design uses a three hollow prong pod like diffuser others use tubular diffusers (Fig. 6**c**). These aerators are mounted at an angle of about 25 to 30° to the water surface, when the motor is energized, the shaft and the propeller are rotated. The rotating propeller displaces the water and moves it forward away. This creates a partial vacuum in front of the propeller. Atmospheric air rushes through the holes in the hollow shaft or through the draft tube and hollow hub propeller to fill the vacuum under water. Because of the severe turbulence created by the propeller, the air is sheared in to fine to medium size bubbles and carried away for long distances from the propeller (about 25–75 ft). For the air to reach the water, the aspirating force has to strong enough to overcome the water head and the frictional head lose generated at the draft tube and the rotating shaft walls. The volume of the air flow is inversely proportional to depth of propeller submergence, and directly proportional to the aspiration force. The oxygen transfer rates for subsurface aspirating aerator range from 0.8 to 2.8 lb O_2/hp · h. When bigger hp units are required, it is a common practice, just to change the propeller and the shaft with a bigger motor. These changes may be cheaper for the manufacturers, but the customer usually gets the short end of the deal, because the bigger units do not deliver the required oxygen. The author had the opportunity to test several 7.5 hp aspirating aerators and compared them with 50 hp aspirating aerators and found that the oxygen transfer rate ranged from 2.5 lb to 0.8 lb O_2/hp-h, respectively. Under these conditions, it would be advantageous for the customer to install three to 15-hp aspirating aerators in instead of one 50-hp aerator. However, propeller driven aspirating aerators move the water horizontally and bring about a complete mixing of the basin or lagoon with lower energy requirement than other aerators. It was found that the subsurface aspirating aerators require only 0.07 hp to completely mix 1000 ft^3 of water (16). Because these subsurface aspirating aerators develop a horizontal flow pattern like open channel flow water, depth is not a limiting factor.

Compressed Aspiration Aerators. Most of the tests the author conducted and the results were considered intradepartmental and were not published. However, it has become evident that using the aspiration force developed by the propeller alone to bring down air under water is limited and cannot be enhanced further without some additional design improvement. Studying the test results of these aerators the following points became evident. (*1*) The air flow is proportional to the pressure above the water surface. (*2*) By increasing the static pressure above the water surface, one can overcome a portion or all of the head lose and increase the air flow. (*3*) The frictional loss will be negligible after reaching a critical air flow to surface area ratio. (*4*) Whether the air flow is internal or external, the frictional loss is lower when surface is dynamic, such as rotating shafts.

With this background and the technical know-how compressed-aspirating aerator technology was evolved. In compressed-aspiration both compression and aspiration (suction of air) occurs simultaneously. The draft tube is modified to accommodate a compression chamber above the water surface. A compression fan is attached to the rotating shaft in the compression chamber. The air flows through and around a hollow a rotating shaft. After testing several types of compression fans, it was found that a turbo fan with radial type impellers is more efficient in compressing air. Since the fan works under negative pressure along with aspiration, no extra energy is needed to operate the compression fan. By installing the compression fan, the amount of air supplied is about 20–30% more than the aerators designed with propeller aspiration alone. Compressed-aspirating aerator was patented and introduced by American Aerators, Inc., under the trade name Neptune Compressed-Aspirating Aerators (Fig. 6**c**, **d**). After the introduction of Neptune, several companies have introduced a few versions of compressed aspirating aerators. One company has included an extra blower package and another an overhead blower system. Independent test data on these designs are very sketchy and not available.

Submersible Aspirating Aerators. Submerged aspirating aerators were originally used in Germany, by Frings Co., to aerate and mix vinegar in fermentation tanks. The same design with some minor modification was introduced to aerate wastewater systems. Among several others it is also manufactured by American Aerators, Inc. It is a unique concept in submerged aerators. It uses a specially designed star-shaped rotor impeller below the water surface. The rotor is sandwiched between two steel circular plates called the stators. The hollow rotor connects with the atmosphere above the water surface through an air inlet tube. The advancing side of the star-shaped impeller is flat and the opposite sides of the leading edges are opened to let air under the water surface. When the rotor impeller is rotated at high speed under the water surface, the leading edge of the impeller generates pressure drop. To fill this pressure drop, atmospheric air rushes under the water surface through the air inlet tube and the hollow rotor. The rotor impeller mixes the air with the wastewater and ejects them out through horizontal vanes sandwiched between the stator plates with force. The force of the air water mixture create sever turbulence under water and creates a complete mix of the whole basin. The oxygen, the bio-mass, and the water is brought together into and intimate contact with one another. The aeration and mixing action brings about a complete biological degradation of the waste in the wastewater (Fig. 6**b**).

A BOD removal efficiency of more than 90% has been reported in activated sludge systems and deep lagoon-type treatment systems, using similar submerged aspirating aeration systems. The submersible aspirating aerators operate up to about 14 to 40 ft water depth. Water depths beyond 15 ft may require compression fan at the air inlet tube for better oxygen transfer (Table 1).

Other Aerators. The University of Minnesota developed and tested an oxygenation system in 1994. In this system, pure oxygen was pressurized in polyurethane bags under water. Under pressure, molecular oxygen migrated through the membrane and dissolved in water. However, mixing was an issue and biological growth on bags caused too much clogging.

Table 1. **Performance Chart of Submersible Aspirating Aerators**[a]

Hp	ACFM of air supplied[b]		
3	30	-	22
7.5	80	-	40
10	115	-	90
25	215	-	150
30	250	-	160
40	320	-	270
50	370	-	320

[a]From Framco Users Manual 1974.
[b]Based on impeller submergence.

Pure oxygen dispersion through Saturn diffused-air aeration devices were also introduced recently. But the cost effectiveness and capital investment are not known. Oxygen transfer efficiency should be very good, but published test data and cost effectiveness are not available yet.

5. Conclusion

Testing oxygen transfer efficiency of aeration equipment is as an art rather than a science. There are several variables and conditions have to be considered. They can individually or in combination will adversely affect the end result and give misleading results. It is very easy to manipulate one or several of these conditions and come up with inflated results. In this regard, caution that the test conditions should duplicate the actual operating condition, is recommend. When the manufacture includes a disclaimer that "… these results are done under controlled conditions and the actual transfer rate may be different", the customer should ask for the conditions under which the tests were conducted. If not satisfied, they should ask the suppliers to provide them with test results under the designed field conditions. If the test reports come with some correction factors that are not familiar, it is affirmative that a clarification of the correction factor and the values used should be provided by the manufacturer. It may be crucial that the test procedure, data collection, and values are evaluated by the people who are familiar with the test data collection and computation of the data. There are several companies manufacturing various aeration and mixing equipment. Some provide two to five year warranties. The warranties are good, but if the manufacturing companies' are fixing the units every month as their routine maintenance on their own expense, be aware, once the warranty period is over, who will be servicing them?

Multiple units are better than using a single larger powered unit. Most of the time the installation lists provided by the manufacturers are useless. What the installation lists provides is only the list of the customers who have been under their service contract and get the free maintenances. In most cases these installations are maintained free by the company for promotional show case installation and referral purposes only.

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