UTILIZATION OF LEAKY PIPES AS AERATION SYSTEM FOR AQUACULTURE

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ABSTRACT

This paper aims to study the possibility of using the leaky pipes as a diffused-air aeration in the aquacultural systems. Air pressure in the pipe, standard oxygen transfer rate (SOTR), and standard aeration efficiency (SAE) were determined to evaluate the performance of these pipes under different air flow rates (14.1-106.0 m^3/h) and water hydrostatic pressures (0.5-2.0 m H_2O) for five and ten pipes on the line. The results indicated that the air pressure increased with increasing of both hydrostatic pressure and airflow rate. The effect of the hydrostatic pressure on the air pressure was higher than that of the air flow rate. The standard oxygen transfer rate (SOTR) increased with increasing the hydrostatic pressure in the aeration tank. Using ten leaky pipes on the air pipe caused an increase in the standard oxygen transfer rate (SOTR) compared to the use of five pipes treatment. The standard aeration efficiency (SAE) decreased with increasing the air flow rate. It could be concluded also that, the effect of air flow rate on the SAE is greater than that of the hydrostatic pressure. The results revealed also that the SAE increased with increasing the number of leaky pipes.

Key Words: Aquaculture - Leaky Pipes – Aeration – Diffuser.

1. INTRODUCTION

Subsurface aerators mix water and air together in aeration tank and transfer oxygen from the air bubbles into the water (Ali, 1999). The standard sources of air in aquaculture are blowers, air pumps, or compressors. The primary differences between them are the pressure requirements and the volume of discharge (Timmons et al., 2002). Diffused-air aeration systems use air compressors or blowers to supply air and diffusers, porous pipe to release air bubbles into the water. In diffused-air systems, air is introduced at the bottom of a pond or tank or at given point in the water column, and oxygen is transferred as the bubbles ascend through the water column. The amount of oxygen transferred depends on the

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number, size and relative velocity of the ascending bubbles; the dissolved oxygen deficit; and the hydrostatic pressure at which the bubbles are released. Air bubble size varies from extremely fine to coarse, depending on the diffusion device used. Some common diffusers are porous diffusers (air stone), porous diffuser pipe, nonporous diffusers, perforated pipe, airlift pumps, and U-tube systems (Lawson, 1995).

Most diffused-air systems release large volumes of air at low pressure. The minimum operating pressure increases with increasing hydrostatic pressure above the diffuser, since enough pressure must be provided to force air from the diffuser against the total pressure (atmospheric plus hydrostatic) at the discharge point (Boyd, 1990).

Diffuser aerator injects air or oxygen into a body of water in the form of bubbles, and oxygen transferred from the bubbles to the water by diffusion across the liquid film. Since bubbles rise in a water column, there is a relative motion between water and bubbles. This causes water circulation and renewing of the surface area in contact with the bubble, which increases oxygen transfer (Wheaton, 1993).

The standard aeration efficiency (SAE) is an expression of the amount of oxygen transferred by the aerator per unit of energy consumption under standard conditions (0 mg/L, 20 °C, and clean water) (Lawson, 1995). Colt and Orwicz 1991, reported that the standard aeration efficiency (SAE) values were 2.5 kgO_2/kWh for aeration cone; from 2.0-2.1 kgO_2/kWh for air-lift pump, and 1.2-2.0, 1.0-1.6 and 0.6-1.2 kgO_2/kWh for fine, medium and coarse air diffuser. The average value ranged from 0.6-3.9 kgO_2/kWh for air diffuser which obtained by Boyd, 1990. Due to differences in site conditions, operational modes, and specific aerator units, it is impossible to suggest a single rigid design procedure (Colt and Orwicz, 1991). Therefore, this work was conducted to study the performance of leaky pipes (which were used in subsurface irrigation system) as aerator for aquacultural system.

The particular objectives were to study the effect of airflow rate and hydrostatic pressure on the air pressure inside the pipes, the standard oxygen transfer rate (SOTR) and the standard aeration efficiency (SAE).

2. EXPERIMENTAL PROCEDURE

The present study aimed to use the leaky pipes as an air diffuser in the aquacultural systems. The study was carried out at a private farm, near Cairo, Egypt. The effect of air discharge rate, hydrostatic pressure in the aeration tank and the number of leaky pipes on the lateral pipe on the standard oxygen transfer rate in the aeration tank was studied. To achieve that, 6-air flow rates (14.1, 28.3, 42.4, 63.6, 84.8, and 106.0 m^3/h) were used. The hydrostatic pressures in the aeration tank were 0.5, 1.0, 1.5, and

2.0m H_2O. The numbers of leaky pipes were five and ten pipes. The air pressure was measured at different airflow rates and hydrostatic pressures. The standard oxygen transfer rate (SOTR) and standard aeration efficiency (SAE) in the aeration tank at different treatments were determined.

2.1. System description:

This system consists of a pressure air blower, PVC pipes (50mm in diameter), leaky pipes (13mm in diameter), and PVC couples (elbow and T-shape). These pipes were immersed in an aeration tank.

The pressure air blower (3 Phase) works on Maximum Duty 2.0m H_2O at free air. A 5m PVC pipe (50mm in diameter) was fitted on the blower, as shown in Figure (1), and connected to other 2.5m PVC pipe with elbow. This pipe was ended by a T-shape PVC couple, which was branched into two directions (one meter each). The leaky pipes (five meters long) were mounted on this pipe at distances of 20cm. Aeration tank was built of concrete and its dimensions were 2×5×2m for width, length and depth, respectively. Airflow was regulated using 2” ball valve.

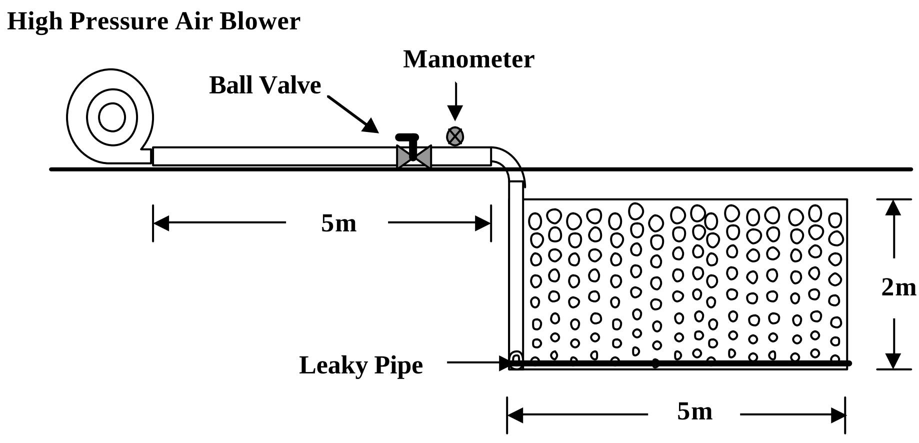

Figure (1): Layout of the experimental

2.2. Measurements:

Airflow rate was measured and controlled by measuring the air velocity in the pipe. It was measured using a “hot wire anemometer” (Service: Testo, GmbH &Co., Germany). The air pressure was measured with a manometer, which was inserted in the air stream through a small opening on the PVC pipe. The current and voltage were measured with an Ampere and Voltmeter, respectively. The dissolved oxygen concentration and temperature in aeration tank were measured by a dissolved oxygen meter (Cole-Parmer Instrument Co., Model #53012-Series).

2.3. The standard aeration efficiency (SAE) determination:

To determine the standard aeration efficiency (SAE) in the aeration tank, the current dissolved oxygen concentration was measured, and the water in the tank was deoxygenated with 0.1-mg/L cobalt chloride ($CoCl_2 \cdot 6H_2O$) and 10.0-12.0 mg/L sodium sulfite (Na_2SO_3) for each mg/L of dissolved oxygen (Boyd, 1986). The cobalt chloride and sodium sulfite were dissolved in a pail of water from the tank and splashed over the water surface in the tank. The dissolved oxygen meter probe was immersed in the middle of the water tank. The dissolved oxygen concentrations (DO) were measured at one-minute intervals until the dissolved oxygen reached 85% of saturation.

The dissolved oxygen deficits (OD) were obtained by subtracting dissolved oxygen concentrations in the tank from dissolved oxygen concentrations at saturation (Ce), which estimated, using the following equation (Soderberg, 1995):

$$Ce = 125.9 / (32 + 1.8\,T)^{0.625} \qquad (1)$$

where:

Ce = the equilibrium concentration of oxygen, mg/L at atmospheric pressure;

T = the water temperature, °C.

The oxygen transfer coefficient was computed by using the points representing 10% and 70% oxygen saturation (Boyd and Watten, 1989) and using the following equation:

$$(K_La)_T = [LN\,(OD_1) - LN\,(OD_2)] / [(t_2 - t_1)/60] \qquad (2)$$

where:

$(K_La)_T$ = overall oxygen transfer coefficient at temperature of test water, h^{-1};

OD_1 = oxygen deficit at point 1, mg/L;

OD_2 = oxygen deficit at point 2, mg/L;

t_1 = time at point 1, min;

t_2 = time at point 2, min.

Water temperature influences oxygen transfer. The oxygen transfer coefficient was adjusted at 20 °C using the following equation:

$$(K_La)_{20} = (K_La)_T \div \theta^{T-20} \qquad (3)$$

where:

$(K_la)_{20}$ = oxygen transfer coefficient at 20 °C, h^{-1};

θ = it ranges from 1.016-1.047, 1.024 is recommended. (Lawson, 1995);

The overall oxygen coefficient was used to estimate the standard oxygen transfer rate in the aeration tank. The oxygen transfer rate was calculated at standard conditions (0 mg/L-dissolved oxygen, 20 °C, and clear water) using the following equation:

$$SOTR = (K_l a)_{20} \times DOC_{20} \times V \times 10^{-3} \qquad (4)$$

where:

SOTR = standard oxygen transfer rate, kgO_2/h.

DOC_{20} = dissolved oxygen at saturation for 20^oC and standard pressure, mg/L.

V = volume of water in tank, m^3.

The power required for the blower was computed by the following equation (Boyd and Ahmad, 1987):

$$Power\ (P) = 1.73 \times I \times E \times PF / 1000 \qquad (5)$$

where:

P = power (kW).

I = current (amperes).

E = voltage (volts).

PF = power factor.

The standard aeration efficiency (SAE) was determined as follows:

$$SAE = SOTR / P \qquad (6)$$

where:

SAE = standard aeration efficiency, kgO_2/kWh.

3- RESULTS AND DISCUSSION

Figure (2) shows the effect of air flow rate (14.1-106.0 m^3/h) and hydrostatic pressure (0.5-2.0m H_2O) in the aeration tank on the air pressures inside the pipe for five and ten leaky pipes. The results indicated that the air pressure increased with increasing of both hydrostatic pressure and airflow rate (Boyd and Moore, 1993). Air pressure ranged from 9-21, 13-29, 16-34, and 22-42 kPa for five leaky pipes, whereas, it ranged from 8-23, 11-26, 17-32, and 24-35 kPa for ten leaky pipes.

It was noticed that the effect of the hydrostatic pressure on the air pressure was higher than that of the air flow rate, where, air pressure increased 1.5-2.5 times as the air flow rate increased from 14.1 to 106.0 m^3/h (7 times), while, it increased 2-3 times as the hydrostatic pressure increased from 0.5 to 2.0m H_2O (4 times).

Regarding the effect of number of leaky pipes, the results revealed that using five or ten leaky pipes gave no big differences in the air pressure inside the pipe at various air flow rates and hydrostatic pressures.

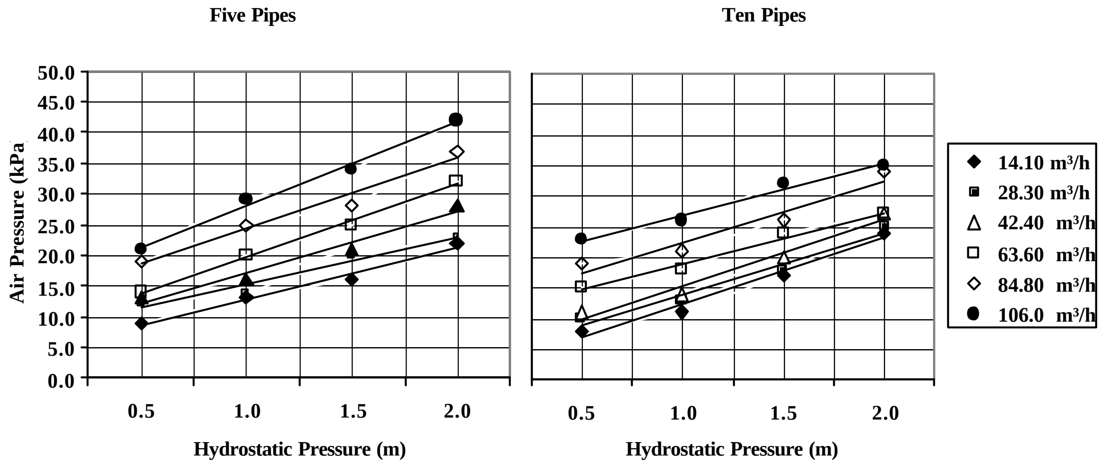

Figure (2): Air pressure (kPa) for five and ten leaky pipes at different hydrostatic pressures (m H_2O) and airflow rates (m^3/h).

Multiple regression was carried out for the air pressure data as influenced by both air flow rate and hydrostatic pressure in the aeration tank for five and ten pipes. The following equations were the best fit for the data:

Five Pipes: AP = - 1.03 + 0.179 AF + 10.5 HP (R^2=0.966)

Ten Pipes: AP = - 0.07 + 0.153 AF + 9.73 HP (R^2=0.966)

where:

AP = air pressure (kPa);

AF = airflow rates (m^3/h);

HP = hydrostatic pressure (m H_2O).

Figure (3) shows the standard oxygen transfer rate (kgO_2/h) for five and ten leaky pipes at different hydrostatic pressures (m H_2O) and airflow rates (m^3/h). The results clarity that the standard oxygen transfer rate (SOTR) increased with increasing the hydrostatic pressure in the aeration tank, where it ranged from 0.53-1.48 and 0.54-1.90 kgO_2/h when the hydrostatic pressure ranged from 0.5 to 2.0m H_2O at 14.1 m^3/h air flow rate for the five and ten leaky pipes, respectively. Meanwhile SOTR ranged from 0.10-0.31 and 0.13-0.54 kgO_2/h at 106.0 m^3/h air flow rate. This may be due to the higher hydrostatic pressure, the longer time for the bubbles inside the tank which caused increasing the oxygen transfer rate (Boyd and Moore, 1993).

It could be also concluded that the standard oxygen transfer rate (SOTR) decreased with increasing the air flow rate in the aeration tank, where it decreased from 0.53-0.10 and 0.54-0.13 kgO_2/h when the air flow rate increased from 14.1-106.0 m^3/h at 0.5m H_2O hydrostatic pressure for the five and ten leaky pipes, respectively, while it decreased from 1.48-0.31 and 1.90-0.45 kgO_2/h at 2.0m H_2O hydrostatic pressure. This may be owed to that increasing the flow rate resulted in large size bubbles which escape faster to the surface and this decreases the oxygen transfer rate compared to the lower flow rate which results in small bubbles that have higher contact surface areas with the water which in turn increases the SOTR (Boyd and Moore, 1993). The effect of number of leaky pipes on the standard oxygen transfer rate (SOTR) is also shown in table and figure, where, using ten pipes caused an increase in the standard oxygen transfer rate (SOTR) compared to the use of five pipes treatment. It is worthy to be mentioned that, the standard oxygen transfer rate reached 1.48 kgO_2/h for the five pipes compared to 1.90 kgO_2/h for the ten-pipes at the lower flow rate (14.1 m^3/h) and higher hydrostatic pressure (2.0m H_2O) while it was 1.48 kgO_2/h for the five pipes compared to 1.90 kgO_2/h for the ten pipes at the lower flow rate (14.1 m^3/h) at the same hydrostatic pressure. This may be attributed to that with the same air flow rate, the ten pipes have the chance to distribute the air with small bubbles and slow velocity, which causes increasing of the contact time with the water, and consequently, increasing the SOTR (Boyd and Moore, 1993).

Multiple regression was carried out for the SOTR data as influenced by both air flow rate and hydrostatic pressure in the aeration tank for five and ten pipes. The following equations were the best fit for the data:

Five Pipes: SOTR = 0.69 - 0.01 AF + 0.396 HP (R^2=0.90)

Ten Pipes: SOTR = 0.75 - 0.01 AF + 0.540 HP (R^2=0.89)

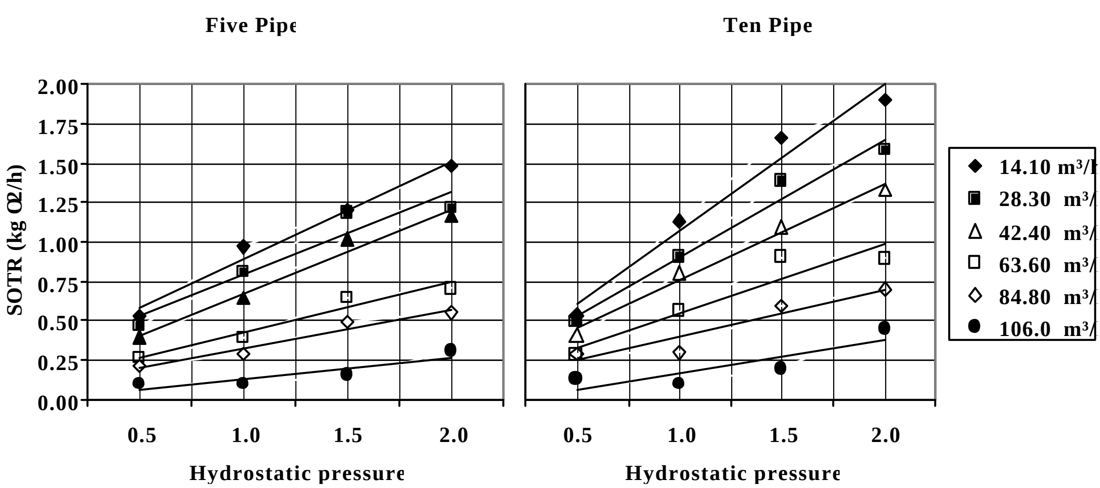

Figure (3): Standard oxygen transfer rate (SOTR) for five and ten leaky pipes at different hydrostatic pressures (m H_2O) and airflow rates.

Figure (4) shows the standard aeration efficiency (kgO_2/kWh) for five and ten leaky pipes at different hydrostatic pressure (m) and airflow rates (m^3/h). The results clarity that the standard aeration efficiency (SAE) decreased with increasing the air flow rate, where it decreased from 3.53-0.09 and 3.60-0.11 kgO_2/kWh when the air flow rate increased from 14.1-106.0 m^3/h at 0.5m H_2O hydrostatic pressure for the five and ten leaky pipes, respectively, while it decreased from 2.69-0.20 and 3.45-0.29 kgO_2/kWh at 2.0m H_2O hydrostatic pressure. This may be due to increasing the flow rate required more power and according to Boyd and Moore, 1993, the SAE is inversely proportional to the power. It could be seen that the effect of air flow rate on the SAE is greater than that of the hydrostatic pressure, where it decreased 35 times as the flow rate changed from 14.1-10.6 m^3/h at 0.5m H_2O hydrostatic pressure, and at the higher hydrostatic pressure (2.0m H_2O), the SAE increased about 20 times. On the other hand, increasing the hydrostatic pressure from 0.5-2.0m H_2O caused slight increase in the SAE at the various flow rates. This is acceptable and normal due to the increase of the power required due to the increase of the flow rate is higher than that required due to the increase of the hydrostatic pressure.

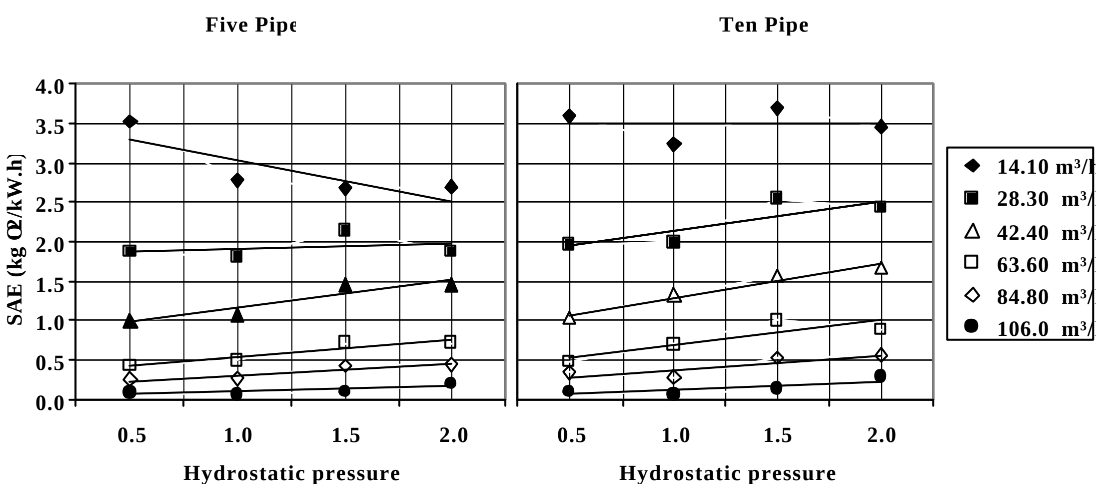

Figure (4): Standard aeration efficiency (SAE) for five and ten leaky pipes at different hydrostatic pressures (m H_2O) and airflow

The results revealed also that the SAE increased with increasing the number of leaky pipes. This may be due to the effect of using ten pipes in increasing the SOTR and the SAE is directly proportional to the SOTR.

Multiple regression was carried out for the SAE data as influenced by both air flow rate and hydrostatic pressure in the aeration tank for five and ten pipes. The following equations were the best fit for the data:

Five Pipes: $SAE = 2.75 – 0.030\ AF + 0.050\ HP$ (R^2=0.84)

Ten Pipes: $SAE = 3.02 – 0.034\ AF + 0.238\ HP$ (R^2=0.85)

4- CONCLUSIONS

From the results of this study, the following conclusions could be made:

1- The air pressure increased with increasing of both hydrostatic pressure and airflow rate.

2- The effect of the hydrostatic pressure on the air pressure was higher than that of the air flow rate. Where, air pressure increased 1.5-2.5 times as the air flow rate increased from 14.1 to 106.0 m^3/h (7 times), while, it increased 2-3 times as the hydrostatic pressure increased from 0.5 to 2.0m H_2O (4 times).

3- The standard oxygen transfer rate (SOTR) increased with increasing the hydrostatic pressure in the aeration tank. Where it ranged from 0.53-1.48 and 0.54-1.90 kgO_2/h when the hydrostatic pressure ranged from 0.5 to 2.0m H_2O at 14.1 m^3/h air flow rate for the five and ten leaky pipes, respectively. Meanwhile SOTR ranged from 0.10-0.31 and 0.13-0.54 kgO_2/h at 106.0 m^3/h air flow rate.

4- Using ten leaky pipes on the air pipe caused an increase in the standard oxygen transfer rate (SOTR) compared to the use of five pipes treatment. Where it reached 1.48 kgO_2/h for the five pipes compared to 1.90 kgO_2/h for the ten-pipes at the lower flow rate (14.1 m^3/h) and higher hydrostatic pressure (2.0m H_2O). While it was 1.48 kgO_2/h for the five pipes compared to 1.90 kgO_2/h for the ten pipes at the lower flow rate (14.1 m^3/h) at the same hydrostatic pressure.

5- The standard aeration efficiency (SAE) decreased with increasing the airflow rate. Where it decreased from 3.53-0.09 and 3.60-0.11 kgO_2/kWh when the air flow rate increased from 14.1-106.0 m^3/h at 0.5m H_2O hydrostatic pressure for the five and ten leaky pipes, respectively, while it decreased from 2.69-0.20 and 3.45-0.29 kgO_2/kWh at 2.0m H_2O hydrostatic pressure.

6- It could be concluded also that, the effect of air flow rate on the SAE is greater than that of the hydrostatic pressure. Where it decreased 35 times as the flow rate changed from 14.1-10.6 m^3/h at 0.5m H_2O hydrostatic pressure, and at the higher hydrostatic pressure (2.0m H_2O), the SAE increased about 20 times. The results revealed also that the SAE increased with increasing the number of leaky pipes.

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