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Preliminary trials on effectiveness of MTR(Mass Transfer Reactor) system in aerating fish stocks

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An advanced mobile technology is described for saturating water with oxygen. The MTR(Mass Transfer Reactor) is 2~10 times more effective in dissolving oxygen in water compared to most other systems used in aquaculture, because it can generate extremely small(0.005~0.05mm) bubbles. New fish farming facilities could make use of this technology to build deeper ponds for raising multiple species with optimized conditions for DO(dissolved oxygen), food, light, etc. The proposed technology offers higher DO levels with minimal operating costs. It is easy to use and maintain, with a high reproducibility. Accordingly, the MTR can be industrially applied in the treatment of fish waste and reduction of water consumption during fish farming.

Key words : Mass Transfer Reactor, dissolving oxygen, fish oxygen utilization, oxygen supplementation

1. Introduction

To sustain life oxygen, water and food are the basic requirements for most living creatures. The oxygen consumption of fish is effected by several external and internal environmental parameters. The external parameters include oxygen availability in water, water quality, and physical variables(Carrick, 1981), whereas, the most important internal ones are related to the condition of the fish, their age, sex, and activity (Garside, 1959). All these variables are species-specific and vary in relation to other conditions e.g. quality of food. Certain fish species can only survive a very short time with hypoxia(generally salomonid species), yet others can endure longer durations of anoxia(generally cyprinids and tilapias), sometimes up to two hours(Palacios and Ross, 1986). Like water quality and food, oxygen must be available in sufficient quantity or fish will suffer, get sick, and even die. Given a suficiently sustained oxygen density fish and yields can be multiplied(Banks, 1987; Clay, 1979; Hamor et al., 1966). With adequate water quality and oxygen supply the ammonia toxicity is reduced or eliminated; (Thurston et al., 1981), as a result fish will be healthier, and less susceptible and more resistant to disease. They will require less food, and grow faster. An adequate oxygen supply diminishes the toxicity of metabolites(Downing and Merkens, 1955). Conversely, however, oxygen can be toxic if oversupplied(Barthelemy et al., 1981; Wiebe and McGavock, 1932).

Oxygen should be present in a desired ratio with other gases soluble in the water otherwize fish become sick and die from supersaturation(gas bubble disease -Edsall and Smith, 1991; Nebeker et al., 1976). In natural conditions, oxygen is added at the water surface, a process accelerated by wave and wind action, However, there is seldom enough mixing of the water levels, and thermal stratification results. The lower layers become oxygen-deficient, CO_2 increases, and the pH drops. Eventually, the lower layers become anaerobic and totally non-productive. To alleviate these situations, many fish farmers use a variety of different devices to add oxygen artificially (Colt et al., 1988; Lippink and Valentine, 1988; Visscher and Godby, 1987). Paddlewheels, u-tubes(Watten and Beck, 1985), packed columns(Bouck et al., 1984), pressurized packed columns(Lippins and Valentine, 1988), spray columns(Boersen and Chesney, 1987), and high pressure injection(Shutte, 1986) are the most common methods used in aquaculture. Fountains, which have the lowest capital cost, spray the water into the air, thereby increasing the surface area and adding oxygen to the falling water, however, their function is limited. Most of the various systems have limitations either due to area and depth, localization and insufficient mixing for all but small ponds, or the use of large bubbles which rise quickly through the water preventing efficient gas exchange and require excessive energy.

Oxygen is only slightly soluble in water, therefore, a lot of oxygen is typically wasted through surface bubbling. However, a higher air pressure cannot be used because compressed nitrogen causes GBD(gas bubble disease). Accordingly, the development of an optimized system is desirable(Edsall and Smith 1991). The proposed MTR(Mass Transfer Reactor) can monitor and control DO(Dissolved Oxygen) economically in order to consistently maintain the best balance relative to the season, day, and even minute. The MTR is a flow-through device with no moving parts that allows gases to be dissolved into liquids at ambient temperatures and low pressures. It is compact and very portable. This simple system offers significant benefits, which will be discussed later in this article.

Preliminary trials on the feasabiltiy of the MTR system to deliver DO and its subsequent utilization by fish were carried out at the Sam Livingston Fish Hatchery.

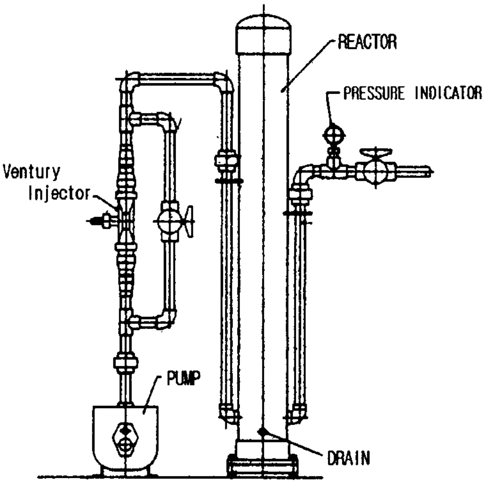

Fig. 1. Schematic diagram of experimental apparatus.

2. Materials and Methods

2.1 Oxygen Transfer Efficiency Tests

The oxygen transfer efficiency tests were carried out according to procedures described in the revised ASCE standard method(1992), and considering the additional requirements of the Ontario Ministry of the Environment(MOE)(Boyle, 1986). The experimental settings are illustrated in Fig. 1.

In outline, good quality tap water was deoxygenated to a DO level lower than 0.5mg/l using Na_2SO_3 with $CoCl_2$ as a catalyst. The system was run for at least 5 minutes to reach a steady state with the desired water and air flow conditions. Then, the dissolved oxygen profile was recorded every 15 seconds using YSI dissolved oxygen meters(YSI 5707B). (Note; The influent DO for the test was at zero, hence, the transfer efficiency was optimized, and could be used for design purposes).

Reference was made to third-party literature (Diffused Aeration Products - Parkson Corporation) for three other methods in order to facilitate general comparisons. Using the technologies discussed, air was introduced into the water through a venturi, or pumped in through various nozzles or perforated pipe. The other dispersal techniques, included fine-bubble diffusion stones and ceramics which produced small bubbles, or the spraying of water into the air using fountains or paddlewheels. The previously published oxygen transfer efficiencies were then compared with the results produced with the MTR. To determine the level and rate of oxygen saturation, a series of monitored tests were undertaken(Mao et al., 1994). The following charts show typical mass transfer rates under similar conditions(Table 1 and Fig. 2).

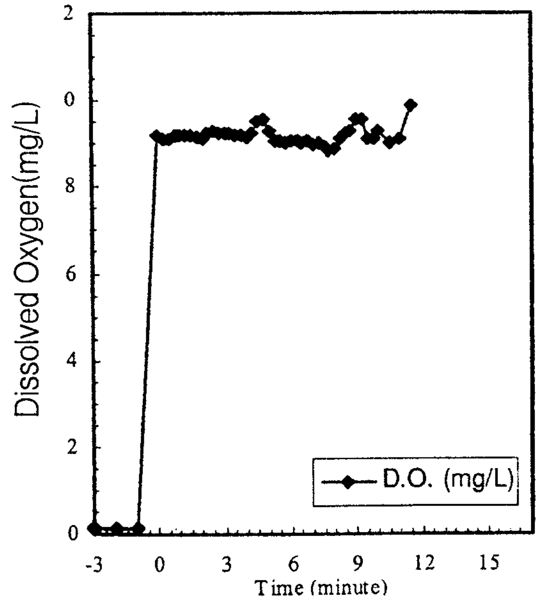

Fig. 2. DO profile on aeration time by MTR

2.2 Fish Oxygen Utilization Tests

To measure the DO consumption by a fish in

Table 1. Comparison of oxygen transfer efficiencies

Method/Technology	Tank Temp (℃)	Holding Tank Size	Initial DO (ppm)	Final DO (ppm)	SOTE* (%)	Typical Bubble Size	Power Used (KWH)	Flow Rate (Water)	Kg O_2 per KWH	Total Time (MIN)
Low speed Surface	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.2-2.4	
High-speed floating	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.2-2.4	
Coarse Bubble	13	140 gal	0	10	6.0	10 mm	0.5	N/A	.6-1.2	102
Medium Bubble	13	140 gal	0	10	10.0	3-4 mm	0.5	N/A	1.0-1.6	61
Fine Bubble	13	140 gal	0	10	12.5	2-3mm	0.5	N/A	1.2-2.0	49
Aeration Panel	13	140 gal	0	10	23.5	.05-1.2 mm	0.5	N/A	2.4	26
MTR	13	140 gal	0	10	61.0	.005-0.05mm	0.5	10 gpm	6.0	10

* SOTE : Standard Oxygen Transfer Efficiency

Table 2. Experimental measurements taken at Sam Livingston Fish Hatchery

Unit Test Conditions

Total No. of fish in pond	6,388	Total O_2 used per hr.(g)	224	Initial O_2 Concentration	8ppm
Weight in Kg	1,133	O_2 use in mg/kg/hour	198	Volume of water	109m^3
Average fish weight in grams	177	O_2 use in mg/fish/hour	35	O_2 depletion without adding supplemental O_2	2.06ppm/hr
Calculated size of fish in cm	25	Pond Temperature	13		

Test Measurements

Time (sec)	DO (mg/L)	Total O_2 content in the pond in mg	Total O_2 decline per 5minutes in mg	O_2 absorbed per five minutes: O_2 consumed by fish minus total O_2 decline in mg	O_2 absorbed per hours : O_2 consumed by fish minus total O_2 decline in mg	Total O_2 supplied by reactor per hours in mg (Calc.from weight of O_2)	Total O_2 utilized by the fish in percent	O_2 consumption of fish mg/Kg/hour	O_2 remaining in the pond per Kg of fish in mg/Kg	O_2 supplied by reactor in the pond per Kg of fish in mg/Kg
0	6.85	746.650	10.900	7,267	87.204	92,000	94.79%	231		
5	6.80	741.200	10.900	7,267	87.204	92,000	94.79%	173	83	81
10	6.70	730,300	10,900	7,267	87.204	92,000	94.79%	173	77	81
15	6.60	719,400	10,900	7,267	87.204	92,000	94.79%	173	77	81
20	6.50	708,500	10,900	7,267	87,204	92,000	94.79%	231	77	81
25	6.40	697,600	10,900	7.267	87,204	92,000	94.79%	173	77	81
30	6.30	686,700	10,900	7.267	87.204	92,000	94.79%	231	77	81
average	6.55	713,950	10,900	7.267	87.204	92,000	94.79%	198	78	81

Results

O_2 injection at 0.94 l/min		Total Kg fish supported by injection of O_2 at 1.125l/min	465
		No of R B Trout supported by injection of 1.125 l/min.@13.3C	2,624
		% of pond load supported	41
O_2 Cyl. weight at start in g.	23,308		
O_2 Cyl. weight at end in g.	23,262	O_2 use from flow meter(liters)	34
Total O_2 injection in mg.	46,000	Percent accuracy of flow meter	83.4 %
Total standard liters of O_2 injected	28		
mg per hour injected	92,000	1. MTR reactor Dissolved Oxygen with 95% efficiency.	
Total gr. O_2 reduction+injection	212	2. The oxygen provide was almost totally used by the fish.	
		3. The 10 gpm test reactor sustained 465Kg of fish.	
O_2 depletion per hour in ppm	1.10	4. Reactors up to 2000g/min are available : there is reason to rxpect proportionally similar results with larger reactors.	

water oxygenated by an AQUATEX reactor. a Burrows pond of 109,000 liters with 8,388 rainbow trout(*Oncorhynchus mykiss*) weighing an average of 177g were selected. Measurements of the DO level and temperature were conducted with a calibrated YSI 5707B dissolved oxygen meter.

Initially, all the fresh water supplies to the pond were closed. The water was kept moving by two pumps with capacities of 135 and 225 l/min. The diminishing oxygen levels were measured every five minutes until the amount of decrease became about the same at each interval - an oxygen content of around 5mg/l. That measurement

Table 3. Comparison of the performance of the test results of MTR with those reported in literature(Colt, 1981, 1987, 1988)

Parameter	K_{La} (Hour^{-1})	SOTE** (%)	SAE (kg O_2/kWH)
MTR	81.2	60.9	6.5
Aeration Panel*	-	44	5.2
Coarse Bubble	<15	<18	<3.1
Mechanical	<10	<10	<2

*represents the best fine bubble aeration technology, according to the manufacturer
** SOTE : Standard Oxygen Transfer Efficiency

established a value for the oxygen consumption of the particular stock at a given temperature and water flow. One to two hours later, the regular water supply was reestablished and the level of oxygen recovered. In the second part of the test all the conditions were the same as in the first test, except that oxygen was continuously added with an MTR generator.

The experiment was set up in such a way that the results could be easily repeatable. The relevant measurements were taken(fish weight, temperature, etc.), calculations were made(average weight, size of fish, etc.), and the DO level was monitored over 30 minutes. First, the DO level dropped, indicating the amount used by the fish. Thereafter, the MTR began to recycle the water, and oxygen from an oxygen generator was introduced through a venturi and then passed through the reactor where it was totally dissolved(Fig. 1). Another 30 minutes of DO measurements were taken, and the experiment was concluded. The tests were repeated three times, and produced the same results(Table 2).

3. Results

Calculations were made to determine the basic oxygen consumption rate of the fish, and the amount of oxygen required to sustain a kilogram of fish was thus established. Thereafter, a simple set of calculations could deduce the amount of oxygen added via the reactor, the amount of oxygen that was dissolved, and how much was

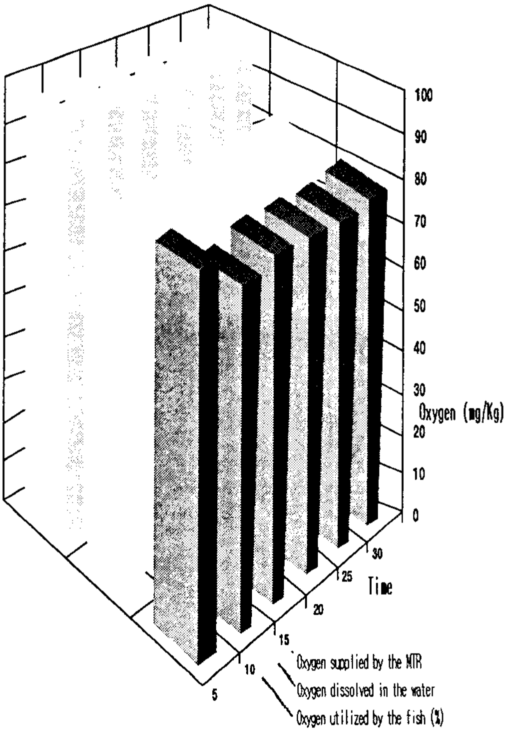

Fig. 3. Graphical representation of the results of the fish tank aeration tests

used by the fish. The efficiencies of these processes were then calculated and are reported in Table 3 and Fig. 3.

4. Discussion

In a series of monitored tests the MTR supplied higher DO levels with a minimal operating cost(i.e. 6.5kgO_2/kWH). In this type of test, no other aeration device was able to reach that kind of efficiency. Previous studies(Colt, 1981, 1987, 1988) reported that a variety pond aeration devices produced between 0.16-2.4kgO_2/kWH. The only device with a performance comparable to the MTR system is U-tube aeration. It exhibited a lower DO production capability(0.95kgO_2/kWH), and if 20 to 30cm of head was available, its efficiency was as high as 9.58kgO_2/kWH. However, it is a substantially larger system with a slower response time to demand changes, plus it requires space for a permanent construction site that requires higher capital and installation costs. (Boersen and Chesney, 1981; Colt and Tchobanoglous, 1981; Mitchell and Kirby Jr., 1974).

The MTR requires little space. It is mobile and can be used for fish transport. It is also very reliable because it has no moving parts, and it is virtually maintenance free. Where constant oxygen levels are crucial, the risks of a power loss can be prevented with the use of Uninterruptable Power Supplies(UPS) or backup generators.

The results of the tests also indicated that for an optimal oxygen supply the MTR output should be set to match the oxygen demand of the fish(Table 2, Fig. 4.). If that condition was fulfilled then the efficiency of oxygen utilization was nearly 95 percent. It was also observed that the oxygen demand of undisturbed fish remained constant until it was no longer less than the difference between the arterial and venous oxygen content of the fish blood. This was 4.57mg/l for rainbow trout, 4.28mg/l for carp(Cyprinus carpio), 1.8mg/l for flounder(Platichthys stellatus), and 5.57mg/l for eel(Anguilla anguilla), (Evans, 1993). This idea is supported by the observations of Spoor(1990), who reported that fingerling brook trout (Salvelinus fontinalis) prefer 5mg/l or higher oxygen concentrations, which can be explained by the interaction within the variables of gas exchange, such as blood-to-water oxygen partial pressure(Evans, 1993; Hamor, 1967a, 1975b; Hamor & Garside, 1975, 1977, 1979). The gas exchange rate of the blood was calculated using

$$Ge = Qb \times Lb(Pb1/Pb2)$$

where Qb = volume flow of blood, Lb = solubility of gas in blood, Pb1 = gas tension of blood going in, Pb2 = gas tension of blood going out(Dickens and Neil, 1964). In several tests some salmonids and centrarchids were unable to swim at mean oxygen concentrations less than 2.84mg/l(Katz et al., 1959). The oxygen consumption of feeding rainbow trout has been reported as 1.6 times higher than that for fasting trout(Cho et al., 1982), therefore, oxygen supplementation should satisfy that period and then be diminished between those periods. Accordingly, a system with a fast response, like the MTR

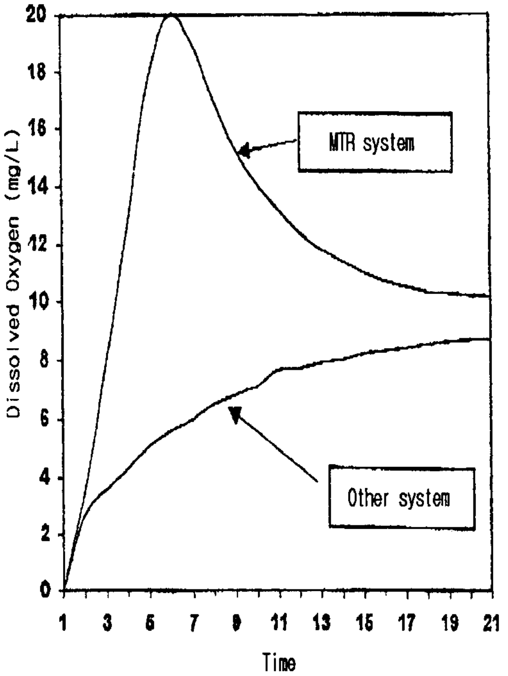

Fig. 4. Conceptual schematic representation of the difference in approach that MTR takes relative to other technologies. The level of supersaturation can be precisely controlled to minimize the risk of gas bubble disease.

system, is attractive as it can follow the necessary oxygen level changes required by fish production, and the resulting profit from the operation will potentially increase significantly. The 94.8 percent oxygen transfer efficiency of the MTR system is at least ten percent higher(if not much higher) than other advanced systems(Schutte, 1986; Kindschi et al., 1989).

5. Conclusions

1) The MTR(Mass Transfer Reactor) reactor is 2～10 times more effective in dissolving oxygen in water than most other systems used in aquaculture, because it can generate extremely small(0.005～0.05mm) bubbles.
2) New fish farming facilities could make use of the technology to build deeper ponds for raising multiple species with optimized conditions for DO, food, light, etc.
3) The MTR can produce higher DO levels with minimal operating costs.
4) The system is easy to use and maintain, with a high reproducibility. It has very useful applications in treating fish waste and reducing water consumption during the raising of fish.

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