DEVELOPMENTS IN FISH CULTURE

Feasibility of removing nitrogen gas from the Ennis National Fish Hatchery water supply and increasing oxygen saturation by injecting oxygen.

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October 1998

REMOVAL OF NITROGEN GAS FROM ENNIS NFH WATER SUPPLY

All water for the Ennis NFH is supplied from Blaine Spring which surfaces about 3 mile north of the hatchery. The water flows about 600 feet before it is collected into pipelines to the hatchery. Buildings and a hypalon cover have been placed over both arms of the spring. This water at the ground source is low in oxygen (6.3 ppm, 71% saturation) and supersaturated (130%) with nitrogen gas. The water must be treated to make it suitable for fish production. Historically the untreated water, after flowing through about 1000 feet of pipe and entering tanks and raceways at the hatchery, contained about 7.5 ppm oxygen (85% saturation) and 110% to 115% nitrogen gas. Total gas averaged about 108% saturation.

Under the above conditions, the fish were severely stressed with gas bubble disease as evidenced by the presence of gas bubbles in blood vessels, under the skin, in the gills and behind the eyeballs. Mortality of sac fry and swim up fry was excessive. Prior to installation of packed columns, post spawning mortality was as much as 50% among females and 50% to 100% of males. Stress from the gas bubble disease may have weakened the fish so that they were overcome by infection with bacteria and fungus.

Packed columns were installed in the rearing tanks in the hatchery building during 1984. The columns were 8" in diameter and 5' high and were filled with 42' of 1" Glitch rings. The columns increased the oxygen content in the water by about 1.0 ppm to an average of 8.3 ppm (94% saturation). Total gas was reduced to 102% or less and nitrogen gas was reduced to 104% or less. Since the columns were installed fry survival has increased and popeye has been eliminated, but gas bubbles are still present in the fish. These bubbles may still be reducing fish health and quality.

Packed columns were installed to aerate the water to all outside raceways during 1987 and 1988. These columns were 24" diameter X 5' high and were filled with 3" diameter Koch rings. Oxygen was increased to 8.3 ppm (94% saturation) total gas was reduced to 102% and nitrogen gas was reduced to 104% or less. Post spawning mortality of fish was greatly reduced and post spawning fungus was almost eliminated. However gas bubbles can still be found in some adult fish reared in water containing these low saturation levels. Westers (1983, unpublished) concluded that chronic losses of salmonid fingerlings in several Michigan hatcheries were caused by low level gas supersaturation.

Packed columns are effective in increasing the oxygen content of water to near 100% saturation and reducing nitrogen gas to near 100% saturation. In most fish cultural situations this is all that is economically feasible to do. Oxygen injection into sealed columns is required to produce supersaturated oxygen conditions, which is necessary to reduce nitrogen gas saturation below 100%. In most cases the cost of installation, operation and maintenance of such a treatment system will outweigh any potential fish health benefits. Harmful effects and health of fish reared in water containing nitrogen gas at 104% saturation or less has not been definitely determined.

Doulos and Kindschi (1990) found that fish growth, fin quality and feed conversions were not improved when Snake River cutthroat trout, Oncorhynchus clarki Richardson, and Eagle Lake rainbow trout, Oncorhynchus mykiss Richardson, were reared at oxygen saturation levels of 172% and 150%. During the cutthroat study oxygen saturation averaged 172% and total gas pressure ranged from 102% - 117% and 94% of the fish had gas bubble disease. Total gas pressure should be maintained below 110% to avoid gas bubble disease. Edsall and Smith (1988) also found no improvement in growth rate or feed conversion when Kamloops rainbow trout, Oncorhynchus mykiss, and Snake River cutthroat trout, Oncorhynchus clarki, were reared for 125 days in water containing oxygen at 180% versus 94% saturation and 183%, 127% or 97% respectively. Edsall and Smith (1990) found no improvement in growth rate or feed conversion when Arlee rainbow trout, oncorhynchus mykiss, were fed to satiation with demand feeders for 100 days in water containing 187% oxygen saturation versus 95% oxygen saturation.

Supersaturated oxygen conditions provide no improvement in fish growth, feed efficiency or fish quality. The only proven benefits of oxygen supersaturation is to increase the carrying capacity of rearing facilities. Westers, etal. (1988), stated that in Michigan hatcheries a 1.0 mg/L increase of oxygen in the water could easily represent a 20 to 25 percent increase in production capacity when oxygen content was already greater than 90% saturation. Colt and Watten (1988), stated that the use of pure oxygen could increase production capacity of existing facilities by 1.7 to 3.0 times; and that initial capital costs associated with the use of pure oxygen are in the range of $0.20 to $1.00/lb of annual production. Their estimated annual operating cost of a pure oxygen system was $0.05 to $0.20/lb of production. Nirmalakhandan, et al. (1988) estimated capital costs for conventional hatchery construction at $100 to $150 per kg of fish production capacity. He concluded that increasing production capacity with oxygen injection would be more economical than constructing new facilities but more research needed to be done to determine the effect of increased fish densities on fish quality.

When fish loading rates in rearing facilities are increased by oxygen injection, the build up of un-ionized ammonia (NH_3) and carbon dioxide (CO_2) become the limiting factors. The maximum allowable level of NH_3 ammonia for salmonids is 0.025 mg/l and the upper limit for CO_2 is 20 mg/l (Piper, etal., 1992). Salmonids produce 1.375 mg/l CO_2 for every mg/l O_2 consumed (Watten, etal., 1988). So the available oxygen (above 5.0 ppm) must not exceed 14.5 mg/l (20 mg/l CO_2 / 1.375 = 14.5) to maintain CO_2 below 20 mg/l. The lowest oxygen level trout can tolerate is 5.0 ppm (Piper, etal, 1982). Based on these figures, 11.2 mg/l of oxygen could be added to the water at the Ennis NFH (8.3 mg/l + 11.2 mg/l = 19.5 mg/l) to provide 14.5mg/l available oxygen. This would increase production capacity 120 to 150% above current conditions. Current production capacity of the Ennis NFH is 40 million eyed eggs per year, but only 20 million are requested. Egg requests are not expected to exceed current production capacity in the forseeable future.

Packed columns are used in all rearing units at the Ennis hatchery and have increased the oxygen content of the water to 95% saturation and reduced total gas to

102% and nitrogen gas to <104% saturation. At these low levels gas bubbles can still be found in the capillaries of the fish. Blockage of blood flow by these gas bubbles may be causing tissue damage, fin splitting and occasional mortality.

Recent tests at the Ennis hatchery demonstrated that nitrogen gas can be reduced to < 100% saturation and total gas to about 100% saturation by using oxygen injection into sealed columns (Table 1). This was accomplished by using completely sealed columns and by using conventional columns with the top sealed. A test will now be conducted to determine whether gas bubbles can be eliminated from the fish by rearing in water containing less than 100% nitrogen gas saturation.

In recent tests at the Ennis hatchery, nitrogen gas was reduced to 98% saturation and total gas to 101.7% by injecting 1.0 L/min of oxygen into a conventional column sealed at the top only with a plastic bag (Table 1). A test to determine whether gas bubbles can be eliminated from fish by rearing in water with < 100% nitrogen gas will require 2 tanks (replicates) with 1.0 L/min of oxygen injected into each. Total oxygen use would be 2,880 liters per day. The test will continue for 150 days or until the fish are 6 inches long. This will require 432,000 liters (15,254 cu ft.) of oxygen. This amount would require the use of liquid oxygen. A 4500 cu. ft. tank of liquid oxygen can be obtained from General Distributing Company in Bozeman, MT (406-586-5927) for $98.00 plus $1.00/day tank rental. One 4500 cu ft tank would supply two raceways with 1.0 L/min each for 30 days. Five tanks of oxygen would be required to complete the test. Total cost of oxygen would be $640.00 (5 X $98 = $490 + $150 rent = $640).

Table 1. N_2 gas removal with 8" diameter column 5' high with 4½' of 1"rings sealed, open and top sealed. April 1-11, 1997.

COLUMN	GPM FLOW	L/MIN O_2 INJECT	°C TEMP	PPM O_2	BP	ΔP	%SAT TOTAL GAS	%SAT N_2 GAS
SEALED	96	0	12.2	7.0	**621**	46	107.4	115.1
SEALED	96	6	12.2	12.1	621	39	106.1	98.0
SEALED	25	1	12.2	8.9	621	16	102.6	102.9
SEALED	25	2	12.2	12.4	621	23	103.7	93.7
SEALED	25	0	12.2	6.7	621	9	101.5	108.1
SEALED	55	0	12.2	7.0	621	4	100.8	106.2
SEALED	55	3	12.2	12.1	621	15	102.0	93.0
OPEN	20	3	12.2	10.5	624	12	102.0	97.4
OPEN	42	0	12.2	8.3	624	12	101.9	104.0
OPEN	42	3	12.2	8.8	624	12	101.9	102.5
OPEN	96	3	12.2	8.7	624	12	102.0	102.8
OPEN	96	0	12.2	8.2	621	13	102.1	104.4
TOP SEALED	20	3	12.2	12.4	624	15	102.2	92.3
TOP SEALED	42	3	12.2	8.9	624	6	101.0	101.0
TOP SEALED	96	3	12.2	8.6	624	13	102.0	103.3
TOP SEALED	96	6	12.2	9.1	624	14	102.3	102.0
TOP SEALED	20	0	12.2	8.3	617.5	11	101.6	103.55
TOP SEALED	20	1.5	12.2	10.6	617.5	12	101.8	96.75
TOP SEALED	20	1.0	12.2	9.7	617.5	10	101.7	98.16
TOP SEALED	20	1.0 AIR	12.2	9.7	617.5	7	101.3	104.54
TOP SEALED	20	10.0 AIR	12.2	8.1	617.5	12	101.8	104.37
TOP SEALED	20	30.0 AIR	12.2	8.2	617.5	9	101.4	103.53
SPRING @ SOURCE			12.2	6.3	617.5	114	118.8	130.51
SPRING @ RACE-WAY INTAKE			12.2	6.5	617.5	98	116.3	127.18
SPRING @ HATCHERY INTAKE			12.2	6.6	617.5	91	114.9	125.41

The optimum water flow rate for maximum oxygen absorption efficiency is 1.0L/min/cm^2 of cross sectional column area (Dwyer, Kindschi & Smith, 1988, pg. 13). For an 8" diameter column = 85 gpm (8" dia = 324 cm^2, 324L = 85 gal).

Tests at Ennis showed that injecting 1.0 LPM 0_2 per 20 gpm water flow into 8" diameter sealed columns reduced N_2 gas to 98% saturation and raised 0_2 1.4 ppm to 111% saturation. A 1.4 ppm increase in O_2 could allow a 50% increase in carrying capacity of rearing facilities.

If this can be extrapolated to higher flows, it will require 750 (26.5 cu. ft.) LPM O_2 to treat 15,000 gpm water flow. Rounding this to 30 cu. ft./min system capacity = 1800 cu. ft/hr or 43,200 cu. ft./day. Liquid O_2 purchased in 4500 cu. ft. bottles costs $.032/cu. ft. Cost of oxygen would be $1382.40/day (43,200 cu. ft. X $.032/cu. ft. = $1,382.40) or $504,576/yr.

When 25.5 L/min O_2 was injected into 2300 gpm of 48 degrees Fahrenheit reuse of water at Jackson NFH, Wyoming, O_2 was increased 2.47 ppm, N_2 gas 99.7% to 101.3% total. Total O_2 injected at Jackson NFH was 11.30 L/min per 1000 gpm water flow.

Extrapolating this to 15,000 gpm water flow at Ennis would require 169.5 L/min (6 cu. ft.) O_2. This would be the very minimum required to get N_2 below 100%. This would require 8.640 cu. ft. O_2 per day @ $.032/cu. ft. = $276.48/day X 365 = $100,915.00/year cost for oxygen alone. Cost of oxygen/1000 gpm water flow = $6,728.00/year.

Colt and Watten (1988) stated that liquid O_2 costs from $.01 to $.03/ft^3 but was more reliable than oxygen generators and installation and operating cost was much less.

Assuming an annual O^2 cost of $6728.00/1000 gpm water flow treated (Jackson rate) it would cost $504,570.00 per year to treat 15,000 gpm of Ennis (tables).

Table 2: Annual O_2 cost/1000 gpm water flow treated at Jackson NFH and at Ennis NFH.

	Jackson Rate	Ennis Rate
GPM WATER FLOW	ANNUAL O_2 COST	ANNUAL O_2 COST
1000	$6728.00	$33,638.00
2000	$13456.00	$67,267.00
3000	$20184.00	$100,914.00
4000	$26912.00	$134,552.00
5000	$33640.00	$168,190.00
6000	$40368.00	$201,828.00
7000	$47096.00	$235,466.00
8000	$53824.00	$269,104.00
9000	$60552.00	$302,742.00
10000	$67280.00	$336.380.00
12000	$90736.00	$403,656.00
15000	$100920.00	$504,570.00

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