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In-Land Aquaculture:

Issues and Opportunities

Workshop

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In-Land Aquaculture:

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January 24, 1997

**Alberta Research Council
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Wendell James
Workshop Coordinator

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INTRODUCTION

Aquaculture is a rapidly growing industry and the trend is likely to continue as the world's population increases and capture fisheries struggle to maintain current levels of production. Environmental issues have dogged the industry's development and have caused many to question the sustainability of some practices associated with intensive culture. In-land culture using recirculating systems is one environmentally responsible approach to intensive culture. Water is conserved, heating requirements are reduced, and discharges can be routed away from fish-bearing waters.

Water quality is critical in recirculating systems both for maximizing productivity and ensuring customer acceptance of the fish produced. Cost-effective water treatment technologies to support these systems become more challenging as the degree of recycle and density of culture increase. Two water treatment issues addressed in this Workshop are aeration and ammonia control.

To help assess the profitability of intense culture using recirculation, an economic model is presented. Some issues and opportunities related to integrating fish culture with conventional prairie agriculture are discussed. Feed often represents the largest single input cost, and some of the latest developments in feed formulation are presented with a particular emphasis on the requirements for recirculating systems.

The interactive sessions on water treatment technologies and feeds/nutrition are intended to provide an opportunity for participants to gain more knowledge related to their specific interests. The pilot facility tours will demonstrate some of the strategies for water treatment currently being investigated at the Alberta Research Council (ARC).

Through all the Workshop components, we trust that participants will be able to learn more about recirculating aquaculture and its potential application as a prairie diversification alternative. I would like to thank all the presenters, technical and administrative support staff, and participants for their roles in making this workshop a success. Since the beginning of the project on "Recirculating Systems" here at ARC, we have appreciated the support of the Alberta Fish Farmers' Association, Alberta Agriculture, Food and Rural Development, and the Prairie Farm Rehabilitation Administration (PFRA). We express a special "thank you" today to PFRA and Pro Form Feeds Inc. for co-sponsoring the Workshop.

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Workshop Coordinator

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FISH FARMING AS A PRAIRIE DIVERSIFICATION OPPORTUNITY

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Abstract

The world's capture fisheries can no longer keep up with the demand for seafood. Current trends indicate that aquaculture will need to provide 43% of global demand by 2025. The Canadian aquaculture industry is growing rapidly, particularly in salmon production. Aquaculture is an environmentally sensitive practice and Canadian policy has been written to ensure sustainable development of the industry. Recirculating aquacultural systems are considered environmentally sound and make in-land aquaculture possible. A trade-off exists between the intensity of culture and the complexity of the water treatment technology and management skills required. Diversifying prairie agriculture to include aquaculture poses some unique opportunities and challenges. Multiple sources of income reduce the overall risk of farming economics, and this principle could allow established farmers an opportunity to expand gradually into aquaculture. Ground water is generally well suited for in-land tank culture. By exercising creativity, farmers may find that aquaculture integrates well with established prairie operations.

Introduction

To those unfamiliar with the practice, the prospect of commercial fish farming on the Prairies may seem unlikely or absurd, especially if the proposed activity is to be located away from large water bodies. There are, however, global market trends, environmental concerns, and technological advances which together are making in-land aquaculture a credible prospect. Aquaculture is unlikely ever to displace a substantial fraction of conventional grain farming or animal husbandry practices, but it may provide a diversification opportunity that enterprising farmers will consider seriously. Today there are a few prairie farmers who operate full-time, commercial fish farms. Practices range from small indoor operations which produce fingerlings for stocking ponds and lakes to large grow-out facilities which supply fish to food processors. Many other farmers prefer to consider pond culture to be an interesting and relaxing hobby rather than a commercial enterprise.

With the increasing globalization of economies, marketing surveys need to consider worldwide supply and demand. Accordingly, some trend data are presented for global and Canadian production and consumption of seafood. The long-term environmental sustainability of aquaculture is considered with a few examples of problems associated with intensive culture. An overview of existing prairie aquacultural activity is provided. The unique advantages and challenges associated with intensive, recirculating aquaculture are presented followed by a discussion of prairie applications.

Aquacultural Trends

Global production and demand

The United Nations Food and Agriculture Organization (FAO) adopted a rather inclusive working definition of aquaculture by referring to it as farming (human intervention designed to increase production) of all aquatic resources, including fish, molluscs, crustaceans, and aquatic plants.⁽¹⁾ Aquaculture has increased quickly from an estimated production of 1.0 million tonnes in 1967, to 8.7 million in 1980, and 15.3 million by 1990. FAO data for the five year period from 1987 to 1992 (Figure 1) show that the world's harvest from wild fisheries has plateaued at about 85 to 100 million tonnes and that an increasing percentage of the demand for seafood is being supplied from aquacultural operations. If the pace of development can be maintained, aquaculture will be able to supply at least 40 % of the global demand for fish and shellfish over the next 15 years.⁽²⁾ Figure 2 shows the projected world demand for seafood until 2025 and the expected contributions from wild fisheries and aquaculture. Note that if population and food requirements increase as projected, approximately 43% of seafood production will need to be supplied from aquaculture by the year 2025. Increasing the wild harvest does not appear to be an option for meeting the increasing demand for seafood.

In 1992, over 80% of the world's 19.3 million tonnes of aquaculture production came from Asian countries.⁽¹⁾ North America contributed only 2.5% of the total, or 3.7% if aquatic plants are excluded. Canada's contribution to world production in 1992 was 30,852 tonnes, which represented less than 0.2% of the total. Subsistence fish farming has contributed much to the food supply of South East Asia, but has so far been less successful in relieving hunger in Africa and Latin America.⁽³⁾

Canadian aquaculture

Commercial aquaculture started in Canada in the 1950's.⁽⁴⁾ Annual production remained under 5,000 tonnes during the developmental stages which lasted until the early 1980's. As shown in Figure 3, the value of shellfish culture showed a marked increase over the seven year period from 1986 to 1993, but this was dwarfed by a twenty-fold growth in sales from salmon farms. Despite these statistics, Canada experienced a slower rate of growth in aquaculture than many other industrialized nations. Chile's salmon production, for example, grew to twice the size of Canada's in about half as much time.⁽⁵⁾ Canada's slower growth may be due in part to pride in controlling the longest combined fishing coastline in the world and the associated desire to protect the wild fishery. Another factor is the limited importance of seafood in the Canadian diet. The average annual per capita consumption is approximately 7.2 kg in Canada, compared with 20 to 25 kg in Scandinavian countries, and 37 kg in Japan.⁽¹⁾

Table 1 shows Canadian aquacultural production and value in 1993, providing a breakdown by species and regions.

Table 1: Canadian Aquaculture Production 1993 ⁽⁴⁾

	Atlantic*		Central*		Pacific*		Total	
	tonnes	\$millions	tonnes	\$millions	tonnes	\$millions	tonnes	\$millions
Finfish								
Salmon	11,096	95.8	27	0.2	21,400	149.0	32,573	245
Trout	414	2.6	4,738	23.6	115	0.6	5,267	26.8
Steelhead	403	2.8	-	-	-	-	403	2.8
Char	27	0.2	28	0.3	5	<0.1	60	0.5
Cod	5	<0.1	-	-	-	-	5	<0.1
Sub Total	11,945	101.4	4,793	24.1	21,520	149.6	38,258	275.1
Shellfish								
Manila	-	-	-	-	400	1.5	400	1.5
Clam								
Oyster	1,278	2.6	-	-	5,250	4.2	6,528	6.8
Mussel	5,141	5.7	34	<0.1	-	-	5,175	5.7
Scallop	4	<0.1	-	-	10	<0.1	14	0.1
Sub Total	6,423	8.3	34	<0.1	5,660	5.7	12,117	14.1
Total	18,368	109.7	4,827	24.2	27,180	155.3	50,375	289.2

* Pacific = British Columbia

Central = Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Territories

Atlantic = New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland

† Canadian dollars

The federal development strategy report⁽⁴⁾ includes an outlook for the industry to the year 2000, by which time the value of production, including many new species, is expected to reach \$680 million. The combined salmon and trout production is predicted to be 89,400 tonnes of which 14,900 tonnes, or one sixth, will come from Central Canada. This would represent a tripling of the 1993 salmonid production from this region. Although the report considers Central Canada to include all provinces and territories except for the Maritimes and British Columbia, at least some of the projected increase in production is likely to come from prairie aquaculture.

Prairie aquaculture

Much prairie fish farming is recreational rather than commercial. Rainbow trout is the predominant species for pond culture. Farm ponds may be stocked with fingerlings each spring to provide fishing fun later in the year and family table supply. Depending on personal preference, stocking density, size of pond, and availability of natural food, fish may be fed commercial rations or left to depend on natural aquatic life including freshwater shrimp. More intensive operations incorporate automatic feeders and aerators.

Prairie fingerling suppliers produce over 1.5 million fingerlings each year for stocking ponds and lakes.⁽⁶⁾ Most suppliers operate recirculating hatcheries and grow fingerlings to approximately 20 cm. Some commercial prairie grow-out operations use intensified pond culture, especially where abundant supplies of fresh water are available from wells, springs, or irrigation canals. Such operations tend to be seasonal, but may be combined with indoor hatcheries and processing facilities to provide year-round employment. Net pen or cage culture has been permitted on some prairie lakes. For example, Saskatchewan's new AgPro Fish Farm located on Diefenbaker Lake currently produces and processes up to 12 tonnes of rainbow trout per week.⁽⁷⁾ Although the facility operates year-round, summer is the busy season when an estimated 225 tonnes of fish are processed. Some commercial grow-out facilities are beginning to use recirculating systems and tank culture. Cultured species include rainbow trout, arctic char, Atlantic salmon, and tilapia.

Sustainability of Aquaculture

One of the most compelling arguments for recirculating aquacultural systems is their ability to function with minimal impact on the surroundings. Before developing this argument further, it is useful to look at some historical interactions between aquaculture and the environment and to note the emphasis placed on sustainability in recent policy statements.

Environmental issues

Until a few decades ago when it started becoming more intensive, aquaculture was generally considered an environmentally-sound activity. Aquatic farms had very stringent guidelines for water quality. Producers were more concerned about potential industrial contamination of their water supplies than they were about downstream effects resulting from their own activities. The quality of water resulting from many traditional aquacultural practices was often superior to that of the supply waters.⁽⁸⁾ In developing countries of the Southern Hemisphere, aquacultural operations were generally small-scale and characterized by family ownership, polyculture, integration with crop and livestock husbandry, waste recycling or beneficial use of farm wastes, diversification of food production, provision of off-season employment, and a general means of improving nutrition and incomes.⁽⁹⁾ This situation changed when entrepreneurs recognized export opportunities and, encouraged by aquacultural development agencies, developed large, modern, corporations for high-intensity aquaculture. These operations displaced many of the small-scale, traditional farmers. Many production systems were intensified without considering environmental consequences.

This scenario has been particularly evident with South Asia's marine shrimp culture where favourable economics compared to capture fisheries were demonstrated. National goals for increasing food production and meeting nutritional needs were largely set aside in favour of increasing exports and earning foreign exchange. When disease outbreaks occurred, no substantial efforts were made to address the problems, but sites were abandoned and operations moved to safer locations. Environmental activists considered this practice of shifting cultivation to be an irresponsible form of development, labeling it "rape and run." Based on some

assumptions and exaggerations, activists demanded a ban on all coastal aquaculture, generally created negative publicity for the aquaculture industry.⁽²⁾

The above example illustrates some of the problems facing the growing aquaculture industry and points out the need for rational and aquaculture-specific regulations to promote sustainable development. On both the east and west coasts of Canada, environmental questions have been raised about net pen culture, and some operations have moved in-land. If one ignores sociopolitical issues, the major environmental concerns associated with conventional aquaculture include:

- 1) Effluent water quality: suspended solids, biochemical oxygen demand (BOD), pathogens, and nutrients
- 2) Competition for water resources
- 3) Competition for land use (especially relevant for coastal culture)
- 4) Spread of fish diseases
- 5) Release of cultured fish to the wild
- 6) Energy consumption: electricity and fossil fuels
- 7) Nutritional energetics: protein transformations⁽⁹⁾

Policy statements

Sustainability has been a popular theme at recent conferences on aquaculture. The word is often used in the context of economics, but in doing so there must be an underlying assumption of environmental stewardship. An economic time frame may be inappropriate for tracking slow and subtle ecological effects.⁽⁹⁾ Unless there is a continuous supply of input resources and a suitable environment for culturing, production cannot be sustained, and economic projections become irrelevant. The FAO⁽¹⁰⁾ has defined sustainable development as follows:

Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in agriculture, forestry, and fisheries sectors) conserves land, water, plant, and animal resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable.

The initiatives outlined in Canada's Aquaculture Development Strategy report⁽⁴⁾ are designed to promote sustainable development. Here, a somewhat shorter definition of sustainable development is cited: "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs".⁽¹¹⁾ The report acknowledges that interactions between aquacultural operations and the environment are complex, but affirms that aquaculturalists and environmentalists are natural allies. Regulations and policies are promised for helping industry to develop regional environmental codes of conduct, minimize nutrient output from aquaculture sites, minimize the use of therapeutants, and generally ensure that waters used by aquacultural operations are not degraded either by these operations or by other aquatic or land-based sources of pollution. Also promised is a systematic framework for

environmental impact assessments, including risk assessment models, in accordance with the environmental assessment act.

Ensuring environmental sustainability requires industry-sensitive policies, research, improvements in technology, routine water quality monitoring, recovery and reuse of waste products, and ecologically sensitive adjustments to culturing practices.

Recirculating Aquaculture

Recirculating systems for aquaculture are ideal from the point of view of minimizing environmental impacts because they reduce or eliminate discharges into open water bodies.⁽¹²⁾ The first five of the above-listed environmental concerns can be reduced or eliminated by moving operations in-land, where practical, and using recirculating systems. These systems allow water to be conserved and can reduce heating requirements substantially.

Description and definitions

Recirculating systems are those in which water flows from a culture tank, through treatment processes, then back to the same tank.⁽¹³⁾ These are distinct from serial reuse systems where water flows from one culture tank to another without being used in the same tank twice. A generalized recirculating system is shown in Figure 4 where the primary water treatment requirements are identified. Besides insuring a continuous recirculating flow of water, the main treatment objectives are: maintaining adequate dissolved oxygen (DO), removing suspended solids, controlling ammonia and nitrite concentrations, and providing disinfection. Additional treatment steps may be required for degassing, cooling or heating, and pH control. The percentage of water recycled is defined as the percentage of total system volume that is retained on a daily (as opposed to an instantaneous) basis. A system may operate virtually as a closed loop except when a relatively large fraction of the system volume is lost during filter backwashes. This water loss must be included when calculating the recycle fraction. To maintain system volume, water losses are made up with new or “makeup” water. The flow-through rate is the volume of new water per unit time that passes through a culture tank. The density of culture depends on the ability to maintain adequate water quality. Stocking density is calculated as the mass of cultured product per volume of the culturing tank, ignoring the effects of water displaced by fish.⁽¹³⁾

Technical and economic challenges

Water quality

Effluent from aquacultural facilities tends to be of low strength compared to industrial or municipal wastewaters. For example, BOD concentrations range from 3 to 20 mg/L for aquacultural effluents⁽¹⁴⁾ compared to 110 to 400 mg/L for domestic wastewater.⁽¹⁵⁾ Because effluent flow rates from recirculating facilities are also low, meeting discharge criteria may be as simple as settling out part of the suspended solids. Increasingly, however, jurisdictions are becoming concerned about the potential spread of pathogens to wild fish, release of cultured fish

to the wild, and eutrophication of receiving waters. Both disinfection and nutrient removal may be specified in discharge permits. New strategies are being developed for recovering low level nutrients from effluent streams using plants which can produce high value fruits and vegetable crops.⁽¹⁶⁾ The options of on-site treatment and land application should be available to operators of in-land facilities.

Although effluent quality and treatment are legitimate environmental concerns, the greater challenge is to maintain adequate water quality for culturing fish in high density recirculating systems. A mass balance approach can be used for designing treatment processes.⁽¹⁷⁾ The required rates of oxygen addition and pollutant removal can be mathematically related to the feeding rates for a given set of water quality criteria. Higher stocking densities require higher feeding rates per volume of water and place a larger load on treatment components. Most water treatment processes for removing contaminants become less efficient at the low end of the concentration range, and very low concentrations can be tolerated when culturing sensitive species such as juvenile salmonids. For example, it is much easier to design a clarifier for removing 90% of suspended solids from water with an initial concentration of 50 mg/L than for removing 90% of solids from water initially containing only 5 mg/L. The same principle applies for removing nutrients such as ammonia and phosphate. Effective solids control strategies, including special processes for removing fines,⁽¹⁸⁾ become critical as the percentage of recycle increases. High density recirculating systems require processes for removing carbon dioxide, nitrate and dissolved organics. Oxygenation rather than natural aeration may be required to maintain adequate dissolved oxygen concentrations. Water sterilization using ultraviolet light or ozone is recommended for dense culture situations.

Management

Recirculating systems must be managed very carefully.⁽¹⁹⁾ Efficient water treatment processes, on-line monitoring, and back-up systems all become necessary for high density culture in systems which use a high percentage of recycled water. The associated capital and operating costs increase accordingly. Producers attempt to stock their systems at higher densities in order to offset these costs, but increasing densities again places more load on treatment systems. The challenge is always to find lower-cost treatment options which allow higher culturing densities without compromising water quality objectives.

Feed

Feed usually represents the highest single input cost. Efficient operation requires minimizing feed conversion ratios and maximizing growth rates without wasting feed. Models relating rainbow trout growth rates to feeding rates were developed recently⁽²⁰⁾ to help producers predict the most efficient feeding rates for various stages of fingerling growth and water temperatures. High protein feeds have been developed to improve conversion efficiencies and other improvements have reduced outputs of nitrogen and phosphorous. Feeds designed specifically for recirculating systems are still required.⁽²¹⁾ These would have substantially less fines, lower fat content, and result in feces that settle without breaking up.

Recirculating Systems for Prairie Aquaculture

Water supplies

Most prairie farmers do not have access to large bodies of water suitable for raising fish. Water supplies may be limited to ground water wells or dugouts. For such farmers, the only possible way to produce a commercial quantity of fish is by reusing water. The maximum stocking density recommended for extensive pond culture (with little or no supplemental feeding) is 750 fish per surface hectare.⁽²²⁾ Assuming (optimistically) an 80% seasonal survival and an average harvest weight of 0.5 kg, the maximum annual production would be 300 kg/yr. Assuming an average pond depth of 5 metres, the culturing density would be 0.006 kg/m³. By contrast, tank culturing densities over 100 kg/m³ are readily achievable for fish weighing 0.5 kg. It is technically possible to have an indoor operation on one hectare of land, operating from a modest well supply of 50 L/min, that produces over 52,000 kg/yr. However, a much larger initial investment would be required, higher operating costs, and relatively sophisticated management skills. The cost per kilogram of production could increase, depending on the cost-effectiveness of the water treatment systems used.⁽¹³⁾

The majority of prairie ground water supplies are pathogen free and have high alkalinity and hardness. Both of the latter parameters are beneficial for culturing fish, but especially the pH buffering capacity caused by alkalinity. An aeration step can be used to help remove unwanted hydrogen sulphide and iron. Well water, which tends to be cool and remain at approximately the same temperature year-round, is suitable for raising cold water species like trout, which require 12° C water for early stages and 15 or 16 ° C water for grow-out. By providing just enough heat to keep an insulated building at 15° C in the winter, no additional heating of water may be required in winter nor cooling in the summer.⁽²³⁾ The prairie climate may have additional advantages for culturing species which require even colder water.

Diversification opportunities

People who are considering starting an aquacultural operation are often warned to start gradually to minimize risk and to allow time to become familiar with all aspects of the business. At the same time they are told that only large-scale operations are economically viable.⁽²⁴⁾ These two pieces of advice are contradictory because there would never be investment capital available for a small-scale operation to expand. Perhaps a viable alternative exists for established farmers who would like to diversify operations to include aquaculture. The initial capital investment would be dramatically reduced if a land base already exists. Other opportunities for reduced capital investment would include established wells, available power, a dugout which could be used for either a grow-out pond or a waste treatment lagoon, a pick-up truck, or an existing barn which could be renovated for aquaculture.

Besides providing a diversified source of income, aquaculture could be integrated with existing farming operations. On grain farms, any nutrients produced from clarifier sludge could be beneficially applied to the land to reduce commercial fertilizer requirements. (Many aquaculture facilities have significant costs associated with sludge disposal, rather than treating it as a

valuable resource.) Farm workers who are seasonally employed could be given an opportunity to work year-round. The possibility of using canola as a feed supplement is not yet practical,⁽²⁵⁾ but creativity and research might eventually allow farm-grown commodities to supplement aquacultural feeds.

Creativity, caution, and challenge

Prairie farmers are well known for their creativity in devising unconventional devices or procedures to promote their particular style of husbandry. Perhaps nowhere is that more evident than in aquacultural facilities where a variety of low-cost alternatives are being used as clarifiers, biological filters, or aerators. The same creativity could be applied to diversification strategies, allowing farmers flexibility to blend aquaculture with their own style of farm management.

Facilities, culturing expertise, and technical prowess are not sufficient for success in aquaculture. Economic models must be examined closely before committing to intensive aquaculture and a viable marketing strategies must be in place before any capital is invested. Farmers using aquaculture only as a sideline may not have the time or desire to be involved with complex processing and marketing issues. Fortunately, some prairie processors are willing to accept live fish from producers as long as quality criteria are met.⁽²⁶⁾

The potential exists for aquaculture to be a profitable diversification activity, but farmers should expect it to require financial commitment, willingness to learn a variety of husbandry and management skills, creativity, and perseverance.

Conclusions

Global trends indicate that 43% of the world's demand for seafood will need to be supplied by aquaculture by the year 2025. The Canadian industry is growing rapidly, particularly in salmon production where sales increased twenty-fold in the period from 1986 to 1993. Prairie aquaculture historically consisted primarily of pond culture, but commercial operations now include net pen culture on lakes and in-land tank culture. Fingerling operations, grow-out facilities, and processing plants are all in business and farmed species have diversified. Environmental issues related to aquaculture are a global concern, and Canadian policy is dedicated to ensuring sustainability of the industry. Recirculating aquacultural systems are considered environmentally sound and make in-land aquaculture possible. As the extent of recirculation and the culture density increase, more sophisticated water treatment technology and management skills are required.

Diversifying prairie agriculture to include aquaculture poses some unique opportunities and challenges. Multiple sources of farm income allow gradual expansion into aquaculture, with less concern about economies of scale. In some cases existing capital items may be transferred to the aquaculture operation to decrease initial investment costs. Many groundwater supplies would be ideally suited for in-land tank culture. By exercising creativity, farmers may find that aquaculture integrates well with established prairie operations.

References

1. Boghen AD. 1995. Cold-water Aquaculture in Atlantic Canada. 2nd ed. (Boghen AD, ed), p. 3-14, The Tribune Press Ltd., Sackville, N.B., 672 p.
2. Pillay TVR. 1996. "The Challenges of Sustainable Aquaculture." In, *World Aquaculture* 27(2), p. 7-9.
3. Shepherd J. 1992. Intensive Fish Farming (Shepherd J and Bromage N, eds). p. 1-15, Oxford University Press, Don Mills, Ontario.
4. Department of Fisheries and Oceans. 1995. Federal Aquaculture Development Strategy (Fs 23-262/1995). Communications Directorate, Ottawa, Canada.
5. Armstrong R. 1995. "Quality Control and Fish Culture in Chile." In, *Bull. Aquacul. Assoc. Canada* 95-1. p. 24-31.
6. Bindle K. 1996. "Trout Farming on the Prairies." In, *Northern Aquaculture, September 1996*. p.12.
7. Polachic D. 1996. "On Diefenbaker Lake." In, *Northern Aquaculture, September 1996*. p.17.
8. Pillay TVR. 1992 "Introduction". In, *Aquaculture and the Environment*. John Wiley and Sons, Inc. New York. 189 p.
9. Hopkins JS. 1996. "Aquaculture Sustainability: Avoiding the Pitfalls of the Green Revolution." In, *World Aquaculture* 27(2). p.13-15.
10. FAO 1990. FAO "Activities Related to Environment and Sustainable Development." FAO Council Document CL98/6, Sept. 1990.
11. Brundtland GH and Khalid M. 1987. "Our Common Future." World Commission on Environment and Development. Oxford University Press. Oxford.
12. Pillay TVR. 1992. "Water and Wastewater Use". In, *Aquaculture and the Environment*, Ch. 6. John Wiley and Sons, Inc. New York. 189 p.
13. Timmons MB and Losordo TM, eds 1994. *Aquaculture Water Reuse Systems: Engineering Design and Management*. p. 1-7. Elsevier Science BV, Amsterdam. 333 p.
14. Pillay TVR. 1992. "Siting and Design of Farms". In, *Aquaculture and the Environment*, Ch. 5. John Wiley and Sons, Inc. New York. 189 p.

15. Metcalf & Eddy, Inc. 1991. Wastewater Engineering, 3rd ed. p. 109. McGraw-Hill Publishing Company, New York. 1333 p.
16. Adler PR, Takeda F, Glenn DM, Summerfelt ST. 1996. "Utilizing Byproducts to Enhance Aquaculture Sustainability." In, *World Aquaculture* 27(2). p. 24-26.
17. Losordo TM, Westers. 1994. "System Carrying Capacity and Flow Estimation." In, *Aquaculture Water Reuse Systems: Engineering Design and Management* (Timmons MB, Losordo TM, eds). p. 9-57. Elsevier Science BV, Amsterdam. 333 p.
18. James WH. 1996. "Controlling Solids Build-Up in Recirculating Systems." In, *Bull. Aquacul. Assoc. Canada* 96-3.
19. *Northern Aquaculture*, February, 1996, p. 13.
20. Arnason AN, Papst MH, Hopky GE. 1995. Feeding and Growth Rate Tables for Rainbow Trout (*Oncorhynchus Mykiss*) Derived from Fitting the Ursin-Sparre Growth Model. *Can. Tech. Rep. Fish. Aquat. Sci.* 2038: iv+33 p.
21. Morgan S. 1996. "Special Feed Needed for Recirc Systems - Rosenthal." In, *Northern Aquaculture*, June, 1996, p. 8.
22. Saskatchewan Environment and Resource Management. 1993. Aquaculture in Saskatchewan: Dugouts and Ponds. Saskatchewan Natural Resources, Regina.
23. Personal Communication. 1996. Bjornson J., Alberta Trout Growers, Tofield.
24. Wade EM, Summerfelt ST, Hankins JA. 1996. "Economies of Scale in Recycle Systems." In, *Proceedings from the Successes and Failures in Commercial Aquaculture Conference, Aquaculture Engineering Society Proceedings II*, Roanoke, Virginia, July, 1996. p.575-88.
25. Farm Forum 10:2 Pre-plant. 1996. "Can Aquaculture Help Canola Grow?" p. 2.
26. Personal Communication. 1996. Freeman R. Wheatland Management and Consulting Inc., Regina.

Figure 1: World Seafood Production From Capture Fisheries and Aquaculture⁽¹⁾

Figure 2: Projected Contributions of Aquaculture and Wild Fisheries to Global Demand for Seafood⁽¹⁾

A. Value by Species, 1986

Total: \$35,000,000

B. Value by Species, 1993

Total: \$289,000,000

Figure 3: Value of Canadian Aquaculture Species, 1986 vs. 1993⁽¹⁾

Figure 4: Generic Recirculation System

AN ECONOMIC MODEL FOR INTENSIVE RAINBOW TROUT CULTURE: FINGERLING OPERATION VS. CONTINUOUS PRODUCTION

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Abstract

This paper discusses a spreadsheet model, developed in Excel 5.0™*, that can be used to forecast the profitability of a year-round, intensive rainbow trout culturing facility. The model consists of a series of seven tables that are used to identify input and cost assumptions, prepare a *pro forma* income statement and cash flow analysis, and calculate the net present value and break even volume for the operation. Presently the model identifies significant inputs and their relative importance for determining economic viability. Results have yet to be validated using empirical data.

Two production scenarios, a fingerling operation and a continuous production system are analyzed and compared throughout the paper. The fingerling operation focuses on selling trout for stocking lakes and ponds during September, April, May and June, while the continuous production scenario assumes 1000 kg of unprocessed (live) 30 cm fish will be sold weekly. The fingerling operation is found to be unprofitable, with an NPV (Net Present Value) of -\$52,678, under the initial set of assumptions. On the other hand, the continuous production system generates an NPV of \$640,520 and has positive returns to the investor in year 4, despite higher investment and operating costs.

Introduction

A simple spreadsheet model in Excel 5.0™ is presented that can be used to evaluate the profitability of a year-round, intensive rainbow trout culturing facility. It serves as a tool for users to experiment with different equipment and cost scenarios to project long-term consequences of decisions. For example, a farmer may be looking to diversify his existing operations and have a barn that could be renovated to house a trout farm. The outcome of this scenario can be tested by the model. Also, any change in the initial input assumptions will be reflected throughout the spreadsheet to generate a new economic forecast. At this time the model identifies significant inputs and their relative importance in determining economic viability. It remains, however, to be validated by experimental data. Although the spreadsheet will perform calculations to test the economic feasibility of various scenarios, it does not examine the technical feasibility of each new assumption.

Two operating scenarios are described and analyzed below. Each enterprise was developed as realistically as possible, including appropriate water treatment technologies. It is important to

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remember that every farm is unique and the assumptions that have been made in the model may not reflect every investor's situation.

Production Systems

Fingerling Operation

The first production alternative, the fingerling operation, will be housed in a 12.2 m x 24.2 m insulated building located on the farmer's property. For the purposes of this analysis, it has been assumed that the farmer already owns the land and is looking to diversify his operations, and also that the farmer will have to construct the building. As illustrated in Figure 1, this operation will require four 3.0 m diameter tanks, four 3.7 m diameter tanks, one 1.2 m diameter tank, hatching equipment and early rearing tanks for 60,000 trout. The water treatment equipment will be housed in a separate room and there will be a small office located in the building. A makeup water supply will be maintained in a cistern located underneath the floor of the building. Water treatment for this production system will consist of low-head oxygenation, two-stage clarification for suspended solids removal, fluidized bed sand filtration for ammonia control, and ozone disinfection.

This operation will serve the fingerling market with demand patterned after that observed by Alberta Trout Growers.⁽¹⁾ Sales will occur during April, May, June and September with gross sales of approximately \$120,000 per year. It has been assumed for simplicity that the same number of fingerlings will be sold in April, May and June and that demand is equal for each size category. In September, ten centimeter fingerlings will be sold, about 40% of total sales of this size category, to stock lakes and ponds over the winter. The distribution of sales relative to each size category is summarized in Table 1. Prices were calculated based on historical record and linearized to fit the equation: Price (\$) = 0.09 x length (cm) - 0.40.

Table 1: Assumed Distribution of Fingerling Sales

	Length (cm)			
Date	10	15	20	25
April 15	8160	8160	8160	8160
May 15	8160	8160	8160	8160
June 15	8160	8160	8160	8160
September 15	9796	0	0	0
Price	0.50	0.95	1.40	1.85

Continuous Production

The second production alternative is a continuous production system that assumes sales of 1000 kg of unprocessed (live) 30 cm trout each week. Each fish will sell for \$2.30 as calculated by the above price equation. This operation will be housed in a 15.2 m x 30.5 m insulated building located on the farmer's property. Again, it is assumed that the farmer already owns the land, but will need to construct the building in order to diversify his operations. This system requires two

Figure 1: Hypothetical Fingerling Facility Layout (approximately to scale).
Tank labels indicate the maximum length of fish in each (cm).

batches of fish to be moving through the system at all times, offset in time by 3.5 weeks. As illustrated in Figure 2, tank requirements are greatly increased: two 1.2 m diameter tanks, two 2.4 m diameter tanks, two 3.0 m diameter tanks, two 3.7 m diameter tanks, two 4.9 m diameter tanks and four 5.6 m diameter tanks, two of which are needed for purging fish (holding them without feeding prior to sale). Separate hatching equipment and early rearing tanks for each train are assumed. As for the fingerling operation, there is a separate room for water treatment equipment, a cistern for makeup water, and an office. Although similar water treatment technologies are assumed, the size of equipment and associated costs have been adjusted to reflect increased fish loads.

Model

The model is patterned after the work of Patrick O'Rourke.⁽²⁾ It is a spreadsheet model in Excel 5.0™ consisting of a series of seven tables that generate an economic forecast for the operation for a given set of assumptions. For convenience, a value can be changed in either the first or second section of the spreadsheet ("investment costs" or "inputs and assumptions") and the corresponding modifications will occur throughout the rest of the model. A brief description of each section of the model and the major assumptions follow.

Section 1: Investment Costs

This first section of the spreadsheet is used to determine the investment costs, the annual depreciation and the repair and maintenance expense for each scenario. Depreciation is assumed to be straight line and is calculated as the initial investment cost divided by the estimated life of the equipment. The yearly repair and maintenance expense is estimated as 1% of the initial investment for equipment without moving parts and 5% of the initial investment for equipment with moving parts or equipment in a potentially corrosive environment.⁽²⁾ A building cost of \$117.56/m² has been assumed. Plumbing costs have been scaled in proportion to building area. Three-phase power is required for both facilities. Tables 2a and 2b show the facilities and equipment required for the fingerling and continuous production operations, respectively.

It is difficult to accurately portray the initial investment costs in this section as each facility is very site specific. For example, an investor may already own a building that can be renovated to house the operation, he may already have three-phase power running to his property, or he may own a truck that can be used for business purposes. Only the portion of the value of a truck used for business purposes would be charged to the enterprise. Any one of these reductions to investment cost would affect the profitability of the endeavor. The figures in this section are presented as examples, only.

Figure 2: Hypothetical Continuous Production Facility Layout (approximately to scale).
Tank labels indicate the maximum length of fish in each (cm).

Table 2a: Facilities and Equipment for a Fingerling Operation

Item Description	Initial** Investment (\$)	Estimated Life (years)	Annual Depreciation (SL) (\$)	Repair & Maintenance (\$)
Building - 12.2 m x 24.4 m insulated pole barn	\$35,000	20	\$1,750	\$350
Indoor drain plumbing @ \$9.07/m ²	\$2,700	15	\$180	\$27
Building plumbing @ \$18.81/m ²	\$5,600	10	\$560	\$56
Effluent system (lagoon, etc.)	\$4,200	10	\$420	\$42
Electrical (3 phase power)	\$10,000			
Pumps - 2 @ 10 hp	\$4,000	5	\$800	\$200
Reservoir tank	\$2,100	20	\$105	\$21
Biofilter & media	\$2,000	20	\$100	\$100
Clarification system	\$3,000	10	\$300	\$150
Room for ozone equipment	\$2,000	15	\$133	\$20
Feeding system (mechanical)	\$3,800	5	\$760	\$190
Harvesting equipment	\$2,800	10	\$280	\$28
Water quality monitoring & reagents	\$6,500	10	\$650	\$325
Emergency O ₂ system	\$2,000	15	\$133	\$20
Backup generator	\$6,000	15	\$400	\$60
Oxygen generator	\$10,500	5	\$2,100	\$525
Air compressor	\$5,000	5	\$1000	\$250
Ozone generator	\$15,000	10	\$1,500	\$750
Hatching equipment for 60 000 trout	\$1,500	10	\$150	\$15
Early rearing tanks for 60 000 trout	\$2,000	10	\$200	\$20
Truck	\$30,000	5	\$6,000	\$1,500
4 Tanks - 3.7 m @ \$1071 each	\$4,284	10	\$428	\$43
4 Tanks - 3.0 m @ \$900 each	\$3,600	10	\$360	\$36
1 Tank - 1.2 m diameter	\$600	10	\$60	\$6
Total	\$164,184		\$18,370	\$4,734

Table 2b: Facilities and Equipment for a Continuous Production Operation

Item Description	Initial** Investment (\$)	Estimated Life (years)	Annual Deprec. (SL) (\$)	Repair & Maintenance (\$)
Building - 15.2 m x 30.5 m insulated pole barn	\$55,688	20	\$2,784	\$557
Indoor drain plumbing \$9.07/m ²	\$4,220	15	\$281	\$42
Building plumbing \$18.81/m ²	\$8,750	10	\$875	\$88
Effluent system (lagoon, etc.)	\$4,200	10	\$420	\$42
Electrical (3 phase power)	\$10,000			
Pumps - 2 @ 10 hp	\$4,000	5	\$800	\$200
Reservoir tank	\$2,100	20	\$105	\$21
Biofilter & media	\$2,500	20	\$125	\$125
Clarification system	\$3,000	10	\$300	\$150
Room for ozone equipment	\$2,000	15	\$133	\$20
Feeding system (mechanical)	\$3,800	5	\$760	\$190
Harvesting equipment	\$2,800	10	\$280	\$28
Water quality monitoring	\$6,500	10	\$650	\$325
Emergency O ₂ system	\$2,000	15	\$133	\$20
Backup generator	\$8,000	15	\$533	\$80
Oxygen generator	\$15,000	5	\$3,000	\$750

Table 2b: Facilities and Equipment for a Continuous Production Operation (cont'd)

Item Description	Initial** Investment (\$)	Estimated Life (years)	Annual Deprec. (SL) (\$)	Repair & Maintenance (\$)
Air compressor	\$6,500	5	\$1300	\$325
Ozone generator	\$20,000	10	\$2,000	\$1,000
Hatching equipment for 60 000 trout	\$3,000	10	\$300	\$30
Early rearing tanks for 60 000 trout	\$4,000	10	\$400	\$40
Truck	\$30,000	5	\$6,000	\$1,500
2 Tanks -- 1.2 m @ \$600 each	\$1,200	10	\$120	\$12
2 Tanks -- 2.4 m @ \$735 each	\$1,470	10	\$147	\$15
2 Tanks -- 3.0 m @ \$900 each	\$1,800	10	\$180	\$18
2 Tanks -- 3.7 m @ \$1071 each	\$2,142	10	\$214	\$21
2 Tanks -- 4.9 m @ \$1665 each	\$3,330	10	\$333	\$33
4 Tanks -- 5.6 m @ \$2000 each	\$8,000	10	\$800	\$80
Total	\$216,000		\$22,975	\$5,712

**The values for the initial investments are from O'Rourke, 1996⁽²⁾ or best estimates provided by the authors.

Section 2: Inputs and Assumptions

The initial inputs and assumptions for the operation are provided here. All other sections reference this information, so changing a value here is reflected in the profitability analysis. It has been assumed that the continuous production operation is more labour intensive than the fingerling enterprise. As a result, employee wages have been increased to \$50,000 from \$30,000 to allow for one full time person and one three-quarter time person. Fuel expense has been scaled up in proportion to the amount of feed required, electricity and natural gas in proportion to building area, and pharmaceutical expenses in proportion to the number of fish produced. Also, costs for oxygen, ozone, and pumping have been scaled up for the continuous production system based on calculated feed, oxygen, ammonia removal, and recirculating flow requirements. Table 3 shows the inputs and assumptions for both the fingerling and continuous production operations.

Table 3: Inputs and Assumptions: Fingerling and Continuous Production Operations

Item	Units	Fingerling	Continuous Production	Reference
Mortality -- egg to first feeding	%/wk	2	2	
Mortality -- after first feeding	%/wk	0.5	0.5	
Average growth per day	mm/day	1	1	3
Eggs cost	\$ /1000 eggs	\$15.40	\$15.40	1
Miscellaneous expense	\$/year	\$2,000	\$2,000	
Truck insurance & licensing	\$/year	\$500	\$500	
Employee wages	\$/year	\$30,000	\$50,000	
Fees and licensing costs	\$/year	\$3,100	\$3,100	1
Electricity expense	\$/month	\$750	\$1,168	1
Estimated insurance	\$/year	\$1,500	\$1,500	1
Estimated property tax	\$/year	\$1,000	\$1,000	1
Feed	\$/25 kg	\$29	\$29	4

Table 3: Inputs and Assumptions: Fingerling and Continuous Production Operations (cont'd)

Item	Units	Fingerling	Continuous Production	Reference
Ozonation costs	\$/day	\$4	\$7.45	
Estimated phone expense	\$/month	\$250	\$250	1
Pharmaceutical expense	\$/year	\$500	\$1,040	1
Natural gas expense	\$/month	\$300	\$467	1
Diesel expense (back up generator)	\$/month	\$50	\$50	1
Travel expense (seminars, courses)	\$/year	\$2,000	\$2,000	
Advertising expense	\$/year	\$1,000	\$1,000	
Fuel expense (truck)	\$/year	\$2,000	\$6,400	
Oxygen costs	\$/day	\$8.11	\$15.00	
Pumping costs	\$/day	\$7.00	\$12.42	
Inflation average 1983-93	%	4.12%	4.12%	5
Return on TSE 100 Index 1983-93	%	8.99%	8.99%	6
Interest on long term capital	%	9.75%	9.75%	7
Beginning Working Capital	\$	\$10,000	\$10,000	
Tax Rate	%	19%	19%	8

Section 3: Production Systems

This section models the production systems. For the fingerling operation, 10 hatches were scheduled to provide the appropriate supply of a given size of fingerlings for the desired month. Fish mass, length, number, mortality, feed requirements and density were calculated on a weekly basis for each hatch. Figure 3 summarizes the calculations for the production system. The mass/length relationship was assumed to be $M = 1.105 \times 10^{-5} (L)^3$ for mass in kilograms and length in centimeters, derived from conditioning factors tabulated by Piper et al.⁽⁹⁾ Maximum allowable fish densities are assumed to follow a linear relationship to fish length according to $D = 3.33 \times L$, where D is the density in kilograms of fish per cubic metre of tank volume. Thus, for 30 cm fish, the maximum density would be 100 kg/m.³ Fish are graded according to 5 cm categories. Based on the assumed growth of 1 mm/day,⁽³⁾ average progression from one size category (and tank) to the next would take approximately 7 weeks.

For the continuous production system hatches are assumed to occur every 3.5 weeks. In addition to providing a week or two of purging time, large purging tanks allow 30 cm fish to be stored for up to 3.5 weeks until they are harvested to fulfill the hypothetical 1000 kg/week contract. Each of the two identical trains is capable of supplying 3500 kg of fish every 3.5 weeks assuming 42 weeks of active feeding. A total production time of 47 weeks is assumed, taking into account the time from hatching to first feeding (alevin stage) and the time for purging. Also, a constant feed level of 75% of maximum ration has been chosen. Maximum ration is the feed level that minimizes the time required for fish to achieve a desired weight, but does not represent the most economical feeding strategy. Arnason et al.⁽¹⁰⁾ have used Canadian data to show that roughly 90% of the maximum growth rate can be achieved at 75% of maximum ration. Their model

predicts higher growth rates than the assumed 1 mm/day. As a result, the corresponding feed conversion ratios are very conservative, ranging from 2.5 to 2.7.

Input Assumptions:

1. Production Requirements and Timing
2. Grading Criteria (e.g. 5 cm length increments)
3. Water Temperature
4. Mortality Rates: % per week, during hatching and growth stages
5. Feeding Rate (e.g. Arnason et al, ⁽¹⁰⁾ 1995: 75% of maximum ration)
6. Length: Mass Equation ($M = 1.105 \times 10^{-5} \times L^3$)
7. Maximum Culturing Density per Stage ($D = 3.33 \times L$)
8. Available Once-Through Water Flow Rate
9. Feed Cost
10. Utilities' Costs
11. Maintenance Costs

Calculations 1: Feed and Fish Mass

1. Weekly Feed Requirements
2. Weight Gain
3. Feed Conversion Ratio
4. Maximum Mass per Tank
5. Tank Volume Requirements

Calculations 2: Support Facilities

1. Oxygen Requirements
2. Ammonia Removal Rate
3. Recirculation Flow Rate
4. Clarifier and Biofilter Dimensions
5. Disinfection Requirements
6. Pump Sizes
7. Building Size

Calculations 3: Operating Costs

1. Feed
2. Eggs
3. Pharmaceuticals
4. Building Heat
5. Electricity: Pumping, Oxygen, Ozone
6. Maintenance

Figure 3: Summary of Calculations Associated with Production Facilities

Section 4: *Pro Forma* Income Statement

The annual pro forma income statement for a 10 year period is calculated in this section. A year end of June 30 is assumed for both operations. Year 0 is the time frame during which the facility is constructed. For both operations, the first hatch will have to occur around June 1 which causes operating expenses, in addition to capital investment, to be incurred in year 0.

The revenue is calculated from the fish sales as the number of fish sold multiplied by the appropriate price based on size. Expenses as estimated in Section 2 are deducted from revenue. The category "Estimated Operating Interest" only applies if a line of credit is used to supplement daily cash flows. For this study, it has been assumed that an operating loan will not be used. The "Interest Expense" line is used if the operation is partially financed by a long term loan and is calculated as the yearly interest that has been paid out on the loan. For simplicity, it has been assumed that the investor will finance the operation on his own. "Income Before Tax" is the difference between revenue and expenses. The tax paid is calculated as the "Income Before Tax" multiplied by the tax rate specified in Section 2. Finally, the "Net Income" figure is representative of the earnings for the year after expenses, interest and taxes. The partial pro forma income statement for the fingerling operation is shown in Table 4. For the continuous production scenario, the statement is appended in Table A1.

Inflation has not been factored into the analysis because a real discount rate has been used in the Net Present Value calculation in Section 7. This will be further discussed in the summary of Section 7.

Table 4: Partial *Pro Forma* Income Statement for Fingerling Operation

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Revenue						
April		\$38,352	\$38,352	\$38,352	\$38,352	\$38,352
May		\$38,352	\$38,352	\$38,352	\$38,352	\$38,352
June		\$38,352	\$38,352	\$38,352	\$38,352	\$38,352
September		\$4,898	\$4,898	\$4,898	\$4,898	\$4,898
Total Revenue		\$119,954	\$119,954	\$119,954	\$119,954	\$119,954
Expenses						
Wages	\$7,500	\$30,000	\$30,000	\$30,000	\$30,000	\$30,000
Eggs	\$173	\$1,965	\$1,965	\$1,965	\$1,965	\$1,965
Feed	\$2	\$21,955	\$21,955	\$21,955	\$21,955	\$21,955
Oxygen	\$495	\$2,960	\$2,960	\$2,960	\$2,960	\$2,960
Pumping	\$427	\$2,555	\$2,555	\$2,555	\$2,555	\$2,555
Ozonation	\$244	\$1,460	\$1,460	\$1,460	\$1,460	\$1,460
Electricity	\$1,500	\$9,000	\$9,000	\$9,000	\$9,000	\$9,000
Maint. & Repairs	\$394	\$4,734	\$4,734	\$4,734	\$4,734	\$4,734
Phone	\$250	\$3,000	\$3,000	\$3,000	\$3,000	\$3,000
Pharmaceutical	\$42	\$500	\$500	\$500	\$500	\$500
Natural Gas	\$300	\$3,600	\$3,600	\$3,600	\$3,600	\$3,600
Diesel	\$50	\$600	\$600	\$600	\$600	\$600
Miscellaneous	\$167	\$2,000	\$2,000	\$2,000	\$2,000	\$2,000
Fees & Licenses	\$258	\$3,100	\$3,100	\$3,100	\$3,100	\$3,100
Insurance	\$125	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
Depreciation	\$1,531	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370
Property Tax	\$83	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Advertising	\$83	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Travel		\$2,000	\$2,000	\$2,000	\$2,000	\$2,000
Truck Ins. & License	\$42	\$500	\$500	\$500	\$500	\$500
Fuel	\$167	\$2,000	\$2,000	\$2,000	\$2,000	\$2,000
Est. Operating Int.						
Tot. Operating Exp.	\$13,833	\$113,799	\$113,799	\$113,799	\$113,799	\$113,799
Interest Expense						
Total Expenses	\$13,833	\$113,799	\$113,799	\$113,799	\$113,799	\$113,799
Income Before Tax	(\$13,833)	\$6,155	\$6,155	\$6,155	\$6,155	\$6,155
Taxes	\$0	\$1,169	\$1,169	\$1,169	\$1,169	\$1,169
Net Income	(\$13,833)	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985

Section 5: Fixed and Variable Cost Break Down

This section illustrates the cost break down between fixed and variable costs to be used in the calculation for break even volume. A fixed cost does not vary in the short term; a variable cost does. Also, some costs will have to be paid whether the facility is operating or not, such as insurance on the building. Costs such as these would be considered fixed costs. A variable cost will no longer be incurred if the operation is shut down, such as feed expenses. Some costs will have a component of both fixed and variable costs. For example, the telephone expense will consist of a fixed set monthly fee for basic service and a variable component for long distance charges.

Section 6: *Pro Forma* Cash Flow Statement

The cash flows generated by the investment are analyzed in this section. The first part of the section consists of the cash generated by the operation. This includes “Net Income” from Section 4, pro forma income statements, and any non-cash expenses incurred throughout the year. The next two parts include “Investment Activities”, which is a negative number if equipment is bought and positive if it is sold, and “Financing Activities”, which is a positive number if debt is issued and negative if principal is repaid. Finally, cash is reconciled by taking the cash increase (decrease) from the current period and adding (subtracting) the cash from the previous period to determine a value for the cash available for the current period. The row titled “Discounted Cash Flow” is the increase in cash discounted to Year 0 dollars. The sum of this row is the NPV for the operation. The last row, Cumulative Discounted Cash Flow, is the running total of the cash flows to determine when the investment starts to generate a positive value for the investor. The cash flow statement for the fingerling operation is shown in Table 5 and for the continuous production operation it is appended as Table A2.

Table 5: *Pro Forma* Cash Flow Analysis for a Fingerling Operation

Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Operations											
Net Income	(\$13,833)	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985	\$4,985
Depreciation	\$1,531	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370	\$18,370
Cash from Op. Activities	(\$12,303)	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355
Investment Activities											
Equipment	(\$164,184)						(\$53,300)				
Financing Activities											
Issue of Debt											
Repayment of Debt											
Increase in Cash and Equivalents, beginning	(\$176,487)	\$23,355	\$23,355	\$23,355	\$23,355	\$23,355	(\$29,945)	\$23,355	\$23,355	\$23,355	\$23,355
	\$10,000	\$33,355	\$33,355	\$56,711	\$80,066	\$103,422	\$126,777	\$96,833	\$120,188	\$143,543	\$166,899
Cash and Equivalents, end.	(\$176,487)	\$33,355	\$56,711	\$80,066	\$103,422	\$126,777	\$96,833	\$120,188	\$143,543	\$166,899	\$190,254
Discounted Cash Flow											
Cumulative Discounted Cash Flow	(\$176,487)	\$21,651	\$20,072	\$18,607	\$17,250	\$15,991	(\$19,007)	\$13,743	\$12,740	\$11,811	\$10,949
	(\$176,487)	(\$154,835)	(\$134,763)	(\$116,156)	(\$98,906)	(\$82,915)	(\$101,922)	(\$88,179)	(\$75,438)	(\$63,628)	(\$52,678)

Section 7: Break Even and Net Present Value Analysis

This table shows the break even analysis and the Net Present Value (NPV) calculation. Break even is the production level required to meet all costs and obtain zero net income. For the fingerling simulation this value is not truly representative of the break even level because it does not take into account the different prices for the various sizes fish. It does, however, indicate whether the operation is producing close to the required numbers of fish for a break even scenario. In the continuous production operation, the break even production level is representative of the number of fish that must be sold to generate an NPV equal to zero.

The NPV calculation gives the “difference between an investment’s market value and its costs”.⁽¹¹⁾ It is the sum of the discounted future cash flows less the initial investment. (The initial investment considered in the NPV analysis is only the portion contributed by the investor. It does not include financing on long term loans.) The NPV is a measure of the return the investor can expect to earn on the initial investment. A positive number represents the value that the operation will generate for the investor over the specified time period. This is a signal that the investment should be undertaken. A negative number generally indicates that the investment should not be considered because the investor will not generate enough funds to cover the initial investment into the enterprise. The break even and NPV analysis for the fingerling and continuous production operations are summarized in Table 6.

The discount rate is used to bring the future cash flows into today’s dollars. For this study it is calculated as the return on the TSE 100 index (1983-93) less inflation (1983-93) plus a risk factor.⁽¹²⁾ By taking inflation out of the discount factor, inflation does not have to be considered in the pro forma income statement analysis. The risk factor is to compensate the investor for the “riskiness” of the operation. It is the return the investor expects to earn over the return he could earn elsewhere. In this model, the risk factor can be varied to reflect the investor’s personal attitude toward risk.

Table 6: Break Even and NPV Analyses for the Fingerling and Continuous Production Operations

	Fingerling Operation	Continuous Production
Total Fixed Costs	\$41,504	\$54,107
Total Variable Costs	\$72,295	\$157,146
Contribution to Overhead per Dollar of Revenue	\$0.397	\$0.606
Break Even Volume (# of fish)	104,463	89,313
Volume Sold (# of fish)	83,236	173,316
Discount Rate	7.87%	7.87%
Risk Factor	3.00%	3.00%
Net Present Value	-\$52,678	\$640,520

Results

The two measures of economic performance in this study are Net Present Value and Break Even Volume. The results for the initial assumptions for each production method are presented in Table 7 along with the results for a 10% change in each assumption. At the bottom of the table, three diversification scenarios are tested. For instance, if the farmer already had a barn that could be renovated, he could save the construction cost. A renovation cost of \$10,000 is assumed for the fingerling enterprise (scaled in proportion to building area for the continuous production enterprise) and a useful building life of 15 years. Three-phase power may already run to the property so that the initial investment would be reduced by \$10,000. The final scenario includes both of the above assumptions together. Only one variable is changed while holding everything else constant; when capital costs are altered, depreciation and repair/maintenance expense are modified accordingly. Adjusting costs incrementally shows the relative impact each variable has on the overall economic forecast. As mentioned earlier, the break even volume of fish for the fingerling operation only suggests whether the operation is close to profitable volumes. The calculation does not account for the staggered pricing based on fingerling size.

Table 7: Sensitivity Analysis for Fingerling and Continuous Production Scenarios

Fingerling Model -- 83 236 fish sold per year				Continuous Production -- 173 316 fish sold		
Variable Changed	NPV	% Change	Break Even	NPV	% Change	Break Even
Base Case	-\$52,678		104,463	\$640,520		89,317
Decrease capital inv/depr/ repair & maint by 10%	-\$32,605	38%	98,648	\$666,614	4%	84,582
Inc. selling price 10%	\$14,241	127%	91,597	\$828,983	29%	84,493
Dec. wages 10%	-\$36,277	31%	98,277	\$669,153	4.47%	87,506
Dec. feed cost 10%	-\$40,675	23%	99,862	\$680,956	6.31%	86,744
Dec. cost eggs 10%	-\$51,587	2%	104,034	\$642,440	0.30%	89,193
Dec. misc or travel 10%	-\$51,568	2%	104,026	\$641,666	0.18%	89,244
Dec. fuel 10%	-\$51,568	2%	104,026	\$644,185	0.57%	88,847
Dec. truck license 10%	-\$52,401	1%	104,337	\$640,807	0.04%	89,235
Dec. pharmaceutical 10%	-\$52,401	1%	104,337	\$641,116	0.09%	89,279
Dec. fees & licensing 10%	-\$50,958	3%	103,683	\$642,295	0.28%	88,806
Dec. electricity 10%	-\$47,608	10%	102,198	\$648,629	1.27%	86,980
Dec. insurance 10%	-\$51,846	2%	104,085	\$641,379	0.13%	89,070
Dec. tax or adv. 10%	-\$52,123	1%	104,211	\$641,093	0.09%	89,152
Dec. phone 10%	-\$51,013	3%	103,809	\$642,238	0.27%	89,207
Dec. natural gas 10%	-\$50,680	4%	103,557	\$643,750	0.50%	88,386
Dec. diesel 10%	-\$52,345	1%	104,331	\$640,864	0.05%	89,295
Dec. ozonation 10%	-\$51,856	2%	104,144	\$642,067	0.24%	89,218
Dec. oxygen 10%	-\$51,013	3%	103,819	\$643,655	0.49%	89,115
Dec. pumping 10%	-\$51,239	3%	103,906	\$643,112	0.40%	89,150
Diversification Scenarios						
Building renovation scenario	-\$27,680	47%	101,107	\$680,950	6.31%	85,779
3 phase power = \$0	-\$42,478	19%	104,463	\$650,520	1.56%	89,317
Building renovation; 3 phase power = \$0	-\$17,680	66%	101,107	\$690,950	7.82%	85,779

The model predicts, for a given set of initial assumptions, that the fingerling operation will lose money, while the continuous production scenario will be quite profitable. For the fingerling operation the NPV is -\$52,678 and the initial investment is \$164,184. This means that over the course of 10 years the farmer will recover roughly \$111,500 of his initial investment. It is interesting to note that increasing the selling price of each size of trout generates a positive NPV for the fingerling scenario and also that reducing the capital costs by 10% improved the forecast by 38%. The three diversification scenarios show promise as well. Assuming the farmer already has a building to be renovated improved the economic forecast by 47% and assuming both the building and three-phase power existed improved the outlook by 66%.

The continuous production alternative shows a very positive NPV and a break even volume that is 48% lower than the assumed level of sales. Because the NPV for this model is so high, a 10% change in any one variable has a relatively insignificant effect on the overall forecast. Increasing the selling price of the trout by 10% only improves the situation by 29% as compared to 127% for the fingerling operation. Assuming the building already exists and will be renovated results in a 6.31% improvement and assuming both a building and three-phase power are available results in a 7.82% improvement in the overall economic forecast.

Discussion

Table 7 shows that reducing the individual operating costs by 10% does affect the overall bottom line profitability. The two operating costs that have the largest impact in the fingerling operation are wages and feed which result in a 31% and 23% improvement, respectively. This is to be expected as these are the two largest costs on the income statement in Table 4. Reducing the initial investment costs by 10% also has a relatively significant affect on NPV because the depreciation expense and the repair and maintenance expense (Table 2) are simultaneously reduced. This means lower monthly operating costs are incurred so more money can be repaid to the investor each year. The other expenses in the table have little impact on NPV because their costs are small in proportion to both the initial investment costs and the total monthly costs.

A similar trend is apparent for the continuous production scenario. Reducing wages and feed cost by 10% cause the two largest improvements in profitability, 4.47% and 6.31% respectively. Changing the initial investment costs by 10% results in a 4% improvement in NPV for the reasons mentioned above. Reducing any cost under this production method has a small effect on NPV since the improvement in profitability is small relative to the NPV for the initial assumptions. It was assumed that a market existed for unprocessed (live) fish. If this were found not to be the case, a large capital cost would be incurred to incorporate processing facilities into the operation, and monthly expenses such as wages and electricity would also increase. This would drastically alter the profitability of the enterprise, but would be the topic of a completely new study.

Another change worth noting is the 10% increase in selling price. This results in a 127% improvement to the NPV associated with the fingerling operation, the only set of assumptions for which the NPV is positive. Increasing the selling price results in a 29% increase to the NPV of the continuous production operation. Although this is very pleasing to the investor, price is a

difficult variable to control. Fish can only be sold for a price the market will bear and consumers are influenced by many factors, such as the availability of the same product at a lower price, or the prices of fish that could be substituted for trout.

The cost per fish, calculated as total expenses divided by number of fish sold, is \$1.19 for the continuous production enterprise. Feed contributes \$0.41 and wages \$0.29 to this cost. This statistic cannot be accurately computed for the fingerling scenario because each size category would have a different associated cost.

This model is a useful tool to help managers to determine how production decisions will affect the profitability of the farm. It is important to reiterate that the model only examines the economic ramifications of decisions and not the technical feasibility.

Summary

In this analysis two production scenarios were studied, a fingerling model and a continuous production operation. The fingerling model focused on seasonal sales in September, April, May and June, while the continuous production operation assumed 1000 kg of 30 cm unprocessed trout would be sold weekly. Both scenarios assumed that the farmer already owned the land, but would need to construct a building to house the operation and purchase all of the necessary equipment. The same water treatment technology was considered in both systems and costs were scaled up appropriately to reflect both the higher capital investment and operating costs of the continuous production operation.

It was found that the fingerling operation had a NPV of -\$52,678, indicating that it would not be profitable under the initial assumptions. In contrast, the continuous production model was found to be very profitable with an NPV of \$640,520. A sensitivity analysis showed that the greatest improvements to the bottom line were found when the selling price was increased and when wages and feed cost were decreased. Interestingly, it was found that diversification alternatives, such as assuming an existing building could be utilized, or that three-phase power was already available, had a significantly positive impact on the economic forecast for each operation.

Conclusions

This model serves as a tool for users to experiment with different equipment and cost scenarios in order to project the long-term effects of decisions. It identifies the important inputs and assumptions in determining economic viability. These still remain to be validated through experimental data. Although the model projects the economic outcome, it does not test the technical feasibility of each assumption.

References

1. Personal communication. 1996. John Bjornson, Tofield, AB.

2. O'Rourke P. 1996. The Economics of Recirculating Aquaculture Systems. In, Proceedings from the Successes and Failures in Commercial Recirculating Aquaculture Conference, Aquacultural Engineering Society, Roanoke, Virginia. July 19-21, 1996. p. 61-78.
3. Heinen JM, Hankins JA, Weber AL, Watten BJ. 1996. A Semiclosed Recirculating-Water System for High-Density Culture of Rainbow Trout. The Progressive Fish Culturalist. 58:11-22.
4. Personal Communication. 1996. Customer Service Representative, Andrukow Farm Sales, Ryley, AB.
5. Statistics Canada. December, 1993. The Consumer Price Index. Ottawa. Cat. No. 62-001, Vol. 72, No. 12.
6. TSE Index Factbook. March 29, 1996. The Toronto Stock Exchange. Toronto, Ontario.
7. Personal Communication. 1996. Chris Ravensburg, Lending Officer, Alberta Opportunity Company.
8. Personal Communication. 1996. Vince Loewen, Chartered Accountant, Wilde, Miller, Tetreau, Vegreville, AB.
9. Piper RG, McElwain IB, Orme LE, McCraren JP, Fowler LG, Leonard JR. 1982. Fish Hatchery Management. p. 447-53. US Department of the Interior, Fish and Wildlife Service. Washington. 517 p.
10. Arnason AN, Papst MH, Hopky GE. 1995. Feeding and Growth Rate Tables for Rainbow Trout (*Oncorhynchus mykiss*) Derived from Fitting the Ursin-Sparre Growth Model. Can. Tech. Rep. Fish. Aquat. Sci. 2038:iv+33 p.
11. Ross SA, Westerfield RW, Jordan BD, Roberts GS. 1993. Fundamentals of Corporate Finance. First ed. Richard D. Irwin Inc., Boston, Massachusetts.
12. Personal Communication. 1996. George Rock, Alberta Agriculture, Food and Rural Dev. Leduc, AB.

Table A1: Partial Pro Forma Income Statement for Continuous Production Operation

		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Revenue							
	1000 kg sold per wk approx. 3333 fish						
Total Revenue		\$38,330	\$398,627	\$398,627	\$398,627	\$398,627	\$398,627
		\$38,330	\$398,627	\$398,627	\$398,627	\$398,627	\$398,627
Expenses							
	Wages	\$4,167	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000
	Eggs	\$224	\$3,362	\$3,362	\$3,362	\$3,362	\$3,362
	Feed	\$0	\$70,316	\$70,316	\$70,316	\$70,316	\$70,316
	Ozonation	\$224	\$2,719	\$2,719	\$2,719	\$2,719	\$2,719
	Oxygen	\$450	\$5,475	\$5,475	\$5,475	\$5,475	\$5,475
	Pumping	\$373	\$4,533	\$4,533	\$4,533	\$4,533	\$4,533
	Electricity	\$1,168	\$14,016	\$14,016	\$14,016	\$14,016	\$14,016
	Maint. & Repairs	\$476	\$5,712	\$5,712	\$5,712	\$5,712	\$5,712
	Phone	\$250	\$3,000	\$3,000	\$3,000	\$3,000	\$3,000
	Pharmaceutical	\$87	\$1,040	\$1,040	\$1,040	\$1,040	\$1,040
	Natural Gas	\$467	\$5,604	\$5,604	\$5,604	\$5,604	\$5,604
	Diesel	\$50	\$600	\$600	\$600	\$600	\$600
	Miscellaneous	\$167	\$2,000	\$2,000	\$2,000	\$2,000	\$2,000
	Fees & Licenses	\$258	\$3,100	\$3,100	\$3,100	\$3,100	\$3,100
	Insurance	\$125	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
	Depreciation	\$1,915	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975
	Property Tax	\$83	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
	Advertising	\$0	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
	Travel	\$0	\$2,000	\$2,000	\$2,000	\$2,000	\$2,000
	Truck Ins. & License	\$42	\$500	\$500	\$500	\$500	\$500
	Fuel	\$533	\$6,400	\$6,400	\$6,400	\$6,400	\$6,400
	Est. Operating Interest						
	Tot. Operating Exp. Interest Expense	\$11,057	\$206,853	\$206,853	\$206,853	\$206,853	\$206,853
Total Expenses		\$11,057	\$206,853	\$206,853	\$206,853	\$206,853	\$206,853
		\$11,057	\$206,853	\$206,853	\$206,853	\$206,853	\$206,853
Income Before Tax		(\$11,057)	(\$168,523)	\$191,774	\$191,744	\$191,744	\$191,774
		(\$11,057)	(\$168,523)	\$191,774	\$191,744	\$191,744	\$191,774
Taxes		\$0	\$0	\$36,437	\$36,437	\$36,437	\$36,437
		\$0	\$0	\$36,437	\$36,437	\$36,437	\$36,437
Net Income		(\$11,057)	(\$165,523)	\$155,337	\$155,337	\$155,337	\$155,337
		(\$11,057)	(\$165,523)	\$155,337	\$155,337	\$155,337	\$155,337

Table A2: Pro Forma Cash Flow Analysis for Continuous Production

Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Operations											
Net Income	(\$11,057)	(\$168,523)	\$155,337	\$155,337	\$155,337	\$155,337	\$155,337	\$155,337	\$155,337	\$155,337	\$155,337
Depreciation	\$1,915	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975	\$22,975
Cash from Op. Activities	(\$9,143)	(\$145,548)	\$178,312	\$178,312	\$178,312	\$178,312	\$178,312	\$178,312	\$178,312	\$178,312	\$178,312
Investment Activities											
Equipment	(\$216,000)						(\$59,300)				
Financing Activities											
Issue of Debt											
Repayment of Debt											
Increase in Cash Cash and Equivalents, beg.	(\$225,143)	(\$145,548)	\$178,312	\$178,312	\$178,312	\$178,312	\$119,012	\$178,312	\$178,312	\$178,312	\$178,312
Cash and Equivalents, end.	\$10,000	(\$135,548)	\$42,764	\$42,764	\$221,076	\$399,388	\$577,699	\$696,711	\$875,023	\$1,053,335	\$1,231,647
Discounted Cash Flow	(\$225,143)	(\$134,929)	\$153,242	\$142,062	\$131,698	\$122,089	\$75,542	\$104,924	\$97,269	\$90,173	\$83,594
Cum. Discounted Cash Flow	(\$225,143)	(\$360,072)	(\$206,830)	(\$64,768)	\$66,930	\$189,019	\$264,561	\$369,485	\$466,754	\$556,927	\$640,520

AERATION AND OXYGENATION REVIEW*

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Abstract

The use of aeration and oxygenation units for adding oxygen and stripping carbon dioxide in intensive aquaculture systems is discussed. Several factors that influence oxygen addition and carbon dioxide stripping are summarized. And, applications of cascade columns, multistage low-head oxygenators, and u-tubes are described.

Introduction

Increasing the concentration of oxygen in the water flowing into a fish culture tank will increase the mass of fish that can be supported in that tank (i.e., oxygen increases the tank's carrying capacity), and has been shown to be an economical means of boosting production.⁽¹⁾

Aeration and oxygenation are processes used to add oxygen to water. In the aeration process, air is brought into contact with water so oxygen transfers from the air into the water. The aeration unit also strips carbon dioxide and nitrogen if the water contains supersaturations of these gases. In the oxygenation unit process, pure oxygen gas is used (instead of air) to achieve oxygen levels in the water flow that are above standard atmospheric saturation levels.

Accumulation of high levels of carbon dioxide can become a limiting toxicity factor with high fish densities and inadequate water exchange; i.e., high fish loadings.^(2,3) Carbon dioxide toxicity is more likely to occur in intensive aquaculture systems which inject pure oxygen because oxygen injection unit processes use insufficient gas exchange to strip much carbon dioxide.⁽⁴⁾ Additionally, more carbon dioxide is usually produced in systems which inject pure oxygen because these systems have the oxygen to support higher fish loading rates. When aeration is used to supply oxygen to aquaculture systems, however, fish loading levels are lower than can be obtained with pure oxygen and enough air-water contact is generally provided to keep carbon dioxide from accumulating to toxic levels.⁽⁵⁾

* Dr. Summerfelt's review of aeration and oxygenation techniques contains major portions from previously published manuscripts. These portions of text are reprinted with permission from:

NCRAC-96, Engineering Design of a Water Reuse System⁽²³⁾ in The Walleye Culture Manual, available from NCRAC (the North Central Regional Aquaculture Centre, Michigan State University, E. Lansing, Michigan). (515) 294-5280.

and

NRAES-98, Successes and Failures in Commercial Recirculating Aquaculture, available from NRAES (the Northeast Regional Agricultural Engineering Services, Ithaca, New York). (607) 255-7654.

The aeration and oxygenation processes are reviewed below. More information on aeration and oxygenation can be obtained from several outstanding reviews.^(6,7,8,9,10,11,12)

Aeration

Air stripping and aeration are mass transfer processes that occur together when water is contacted with air to bring its concentration of dissolved gases (such as nitrogen, carbon dioxide and oxygen) into equilibrium with the partial pressures of these gases in the surrounding atmosphere. The rate of mass transfer, as defined by Ficks Law, is equal to the product of the overall mass transfer coefficient, the total interfacial contact area per unit system volume, and the concentration gradient.⁽¹³⁾ The concentration gradient is the driving force for mass transfer; i.e., the rate of oxygen transfer is greatest when the concentration of oxygen in the water is much lower than the oxygen saturation concentration.

Oxygen and carbon dioxide can be transferred to or from water with any of the non-closed aeration systems that Boyd and Watten,⁽⁶⁾ Colt and Orwicz⁽¹⁴⁾ and others have described. However, because carbon dioxide has a Henry's Law constant 200 to 300 times that of oxygen, it is more difficult to strip carbon dioxide than to add oxygen to water. Therefore, enormous quantities of air are required to achieve substantial carbon dioxide transfer rates when compared with the air-flow rates required for oxygen transfer alone. In addition, bubbles formed from diffused aeration become rapidly saturated with carbon dioxide. And, when water droplets are formed while passing through air, the shortened diffusion distance (a function of droplet diameter) enhances mass transfer out of the liquid phase. Therefore, aeration/stripping units that passes water through air are typically used to remove carbon dioxide, because in these units it is easier to provide the larger ratio of air to water volume needed for carbon dioxide exchange.⁽¹⁴⁾

The obvious way to let water fall through air is by a gravity drop, which can be: over a weir, onto a splash-board, through plastic media or stacked splash screens, down an inclined corrugated sheet (with or without holes), or down a stair-stepped surface. Because carbon dioxide stripping requires such a large volume of air per unit volume of water, it is most effective when large volumes of air can be forced through cascading water within enclosed columns (Figure 1). Increasing the air-water contact area by packing the columns with high voidage plastic media or stacked screens improves both carbon dioxide stripping and aeration. Air stripping in forced ventilation columns has been described by Onda et al.⁽¹⁵⁾ and reviewed extensively in the waste water treatment field by Kavanaugh and Trussell,⁽¹⁶⁾ Cornwell,⁽¹⁷⁾ Haarhoff and Cleasby,⁽¹⁸⁾ and Thom and Byers.⁽¹⁹⁾ Design of air-stripping columns requires selection of the following parameters: liquid loading rate; air to water volumetric loading ratio (this selection determines the air loading rate); packing depth; packing material (size and type); Grace and Piedrahita^(20,21) and Summerfelt⁽²²⁾ have reviewed and reported criteria for carbon dioxide stripper design within aquaculture systems. The general criteria are: a hydraulic fall of 1-1.5 m, a hydraulic loading of 1.0-1.4 m³/min/m², and a volumetric air:water ratio of 6:1 to 10:1. High porosity packing or splash screens are needed to avoid flooding or gas hold-up, which (along with a high hydraulic loading) increases the blower pressure requirements. Designing a stripping column to the specifications just listed allows the use of an air-handler (i.e., a high-volume but low-pressure blower) that moves large volumes against only little back pressure (2-10 cm water head), which

Figure 1. Illustration of an air-stripping tower that uses screens instead of plastic media to break-up the fall of water.

reduces the electrical requirements. If high solids loadings are expected, a stripping tower with screens or biofouling resistant media may be easier to maintain than a packed tower. Also, the air blown through the air stripper should be vented out of the building to prevent carbon dioxide from accumulating inside the building containing the recirculating aquaculture system. In a cold climate, heat can be conserved by venting the air through an air-air heat exchanger.

As an alternative or supplement to air stripping, carbon dioxide can be treated by chemical addition as described elsewhere.⁽²³⁾ Chemical addition is already required to maintain alkalinity in most recirculating aquaculture systems.

Oxygenation

Commercial oxygen is widely used to supplement oxygen levels and boost fish production in intensive aquaculture systems.

Oxygen can be produced on site using pressure swing adsorption (PSA) equipment or purchased from commercial sources as a bulk liquid or gas.^(6,8,12) Producing oxygen on site requires a source of dry air at pressures of 90 to 150 psi as well as the PSA unit, which amounts to a considerable capital investment.⁽²⁴⁾ The cost of generating oxygen using PSA units, which varies with electric rates, is about 0.5 kwh of electricity per pound of oxygen produced. The cost of

liquid oxygen varies with location. At the Freshwater Institute, the operating and capital costs (using net present value over a ten year period) of using liquid oxygen versus on site generation were compared; we found that liquid oxygen costs about three times more annually than would oxygen generated on site. However, the capital investment and risk of system failure are lower if liquid oxygen were used.⁽⁶⁾

Oxygen is not an insignificant cost, it can represent as much as 15% of feed costs if generated on site (E. Wade, Freshwater Institute, personal communication), and thus the transfer of oxygen into the fish culture water must be efficient. Gas absorption equipment is designed to take advantage of the factors governing the rate of mass transfer. Gas absorption is dependent on the area of the gas-liquid interface and the thickness and rate of surface film renewal (both dependent upon the energy transfer in the gas-liquid contactor) and also on the gradient between the saturation and existing concentrations of the gas in the water. When pure oxygen rather than air is transferred into water, the water's saturation concentration for oxygen is increased nearly 5-fold over the saturation concentration obtained when air is used. The saturation concentration can also be increased by increasing the total pressure in which the transfer occurs (e.g., via a pump or hydrostatic head). Increasing the pressure during oxygen transfer from 1 to 2 atmospheres nearly doubles the saturation concentration of oxygen in water. Increasing the absorption pressure to increase the oxygen transfer, however, may also increase the operating costs, and this must be considered when selecting an oxygenation unit. Additionally, mechanisms for stripping/venting nitrogen and argon gas released during oxygen absorption are important both to reduce the total gas pressure of the water and to increase the efficiency of oxygen transfer.

Many types of oxygen transfer equipment have been described: U-tubes, multi-staged low head oxygenation units, packed columns, spray columns, pressurized columns, oxygenation cones, oxygen aspirators, bubble diffusers, and enclosed mechanical-surface mixers. Two methods are particularly well suited to transferring oxygen to water within large recirculating systems: U-tubes and multi-staged low head oxygenation units (Figure 2). Both methods can be readily scaled-up, are easy to control, and require only a modest hydraulic head. Performance and design criteria for each are given below.

Multi-stage low head oxygenators

A multi-stage low head oxygenation unit (LHO) was patented by Watten⁽²⁵⁾ and described by Watten and Boyd⁽²⁶⁾ (Figure 2). They maximize oxygen transfer efficiency by reusing the oxygen feed gas through a series of contact chambers. Water flow is typically distributed equally to each chamber at the top of the LHO via head-controlling orifices. Water flowing through the orifices typically drops anywhere from 1 to 4 ft (0.3 to 1.2 m) into a plunge pool which seals the lower portion of each LHO chamber. The chambers typically do not contain packing, but can be packed with plastic media to improve mass transfer.⁽²⁷⁾

Figure 2. Illustrations of a multi-stage low head oxygenator (LHO™) and a u-tube.

Most evaluations of LHO units,^(27,28,29) have been in cold water (12-17°C), where the saturation of oxygen is higher than at the temperature used to raise cool or warm water fish. These studies demonstrated that LHO units provide excellent (60 to 90%) oxygen transfer efficiencies, when operated at gas to liquid ratios of less than 1 volume of oxygen feed gas for every 100 volumes of water flow ($G:L = 0.01:1$). However, the low oxygen loading rates ($G:L < 0.01:1$), which are good for maximizing oxygen transfer, limit the increase in dissolved oxygen concentrations within the flow to generally < 8 mg/L above saturation. Weber et al.⁽²⁷⁾ found that to produce dissolved oxygen concentrations of approximately 25 mg/L in 12°C water required increasing the $G:L$ to around 0.02:1. The oxygen transfer efficiency dropped to 50 to 60% at the increased $G:L$, even though plastic packing was used within the LHO chambers. Results from these studies make it clear that oxygen off-gas recycling is necessary to conserve oxygen when trying to double (or more) the saturation concentration of dissolved oxygen within the flow leaving an LHO unit. The studies also demonstrated that LHO units remove nitrogen gas when they add oxygen, which helps prevent large total gas supersaturations, even when large oxygen supersaturations are obtained.

U-tube

A U-tube maximizes oxygen transfer by using hydrostatic pressure to temporarily increase the saturation concentration of oxygen as the flow passes through the depth of the vertical, U-shaped conduit (Figure 2). U-tubes operate by continuously diffusing pure oxygen into the water entering the top of the conduit and by then entraining the oxygen bubbles in the flow passing down one side of the conduit and up through the other. Bubbles are entrained by designing the

cross-sectional area of the first conduit to create a velocity greater than the buoyant velocity of the bubbles. Watten and Beck⁽³⁰⁾ developed an equation to predict the dissolved oxygen concentration in the effluent of a U-tube for a given conduit depth, water temperature, influent dissolved oxygen saturation, and volumetric gas to liquid ratio, assuming that the diffuser is placed at the beginning of the downward conduit. Boyd and Watten⁽⁶⁾ show data indicating that U-tube systems without off-gas recycle provided oxygen transfer efficiencies of only 30-50%, but that when off-gas recycling was used, U-tubes could increase their oxygen transfer efficiencies to 55-80%. The pump pressure required for a given U-tube, generally from 1 to 6 m of water head, can be estimated by adding the head losses resulting from pipe friction, velocity, and two-phase flow. The head loss resulting from two-phase flow can be estimated with an equation provided by Watten and Beck.⁽³⁰⁾ At a constant pipe velocity, large diameter U-tubes used to oxygenate high volume flows have less total head loss than do small U-tubes that oxygenate correspondingly lower volume flows.

Because U-tubes operate at higher pressures than LHO units, it is possible to add more oxygen to a flow with a U-tube than could be achieved by using a LHO. However, U-tubes do not strip nitrogen as readily as LHO units, and a U-tube would produce higher total gas pressures per unit of oxygen transferred than an LHO unit. In addition, adding or entraining air bubbles within a u-tube will produce total gas pressures large enough to harm or kill fish.

Discussion

General guidelines for use of aeration and oxygenation units in a recirculating aquaculture system follow:

- Carbon dioxide should be air stripped after reaching its highest concentration before oxygen supersaturations are produced, and before returning to the fish culture tank (i.e., just after the biofilter and just before the oxygenation unit).
- Air stripping should occur before the oxygen transfer unit, because the aeration it produces brings the oxygen levels in the flow up to near saturation. Bringing an oxygen saturated flow to the oxygenation unit allows all of the oxygen added to go towards supersaturating the water.
- Oxygen should be added to supersaturate the flow just before the fish culture tank.
- The water should be kept from significant contact with the atmosphere after the oxygen supersaturation has been obtained.

Ideally, water is pumped only once in a system with a single serial reuse flow path. Gravity must be used to move water in all other places. Elevations suggested to integrate and create gravity flow through an example recirculating system are presented in Figure 3 .

Figure 3. Example layout of a recirculating aquaculture system.

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References

1. Collins CM, Burton GW, Schweinforth RL. 1984. *Evaluation of Liquid Oxygen to Increase Channel Catfish Production in Heated Water Raceways*. Tennessee Valley Authority, Office of Natural Resources and Economic Development, Division of Air and Water Resources, AWR-8418, Gallatin, Tennessee.
2. Colt JE, Tchobanoglous V. 1981. "Design of Aeration Systems for Aquaculture." In, *Proceedings of the Bio-engineering Symposium for Fish Culture*. American Fisheries Society, Bethesda, Maryland. (Allen LJ, Kinney EC, eds), p. 138-148.
3. Colt JE, Orwicz K, Bouck G. 1991. "Water Quality Considerations and Criteria for High-Density Fish Culture with Supplemental Oxygen." In, *Fisheries Bioengineering Symposium 10*. American Fisheries Society, Bethesda, Maryland (Colt J, White RJ, eds), p. 372-385.
4. Watten BJ, Colt JE, Boyd CE. 1991. "Modeling the Effect of Dissolved Nitrogen and Carbon Dioxide on the Performance of Pure Oxygen Absorption Systems." In, *American Fisheries Society Symposium 10: Fisheries Bioengineering Symposium*. Bethesda, Maryland. (Colt J, White RJ, eds), p. 474-481.
5. Speece RE. 1973. "Trout Metabolism Characteristics and the Rational Design of Nitrification Facilities for Water Reuse in Hatcheries." *Transactions American Fisheries Society* 102:323.
6. Boyd CE, Watten BJ. 1989. "Aeration Systems in Aquaculture." *Reviews in Aquatic Sciences* 1:425-473.
7. Colt JK., Watten BJ. 1988. "Applications of Pure Oxygen in Fish Culture." *Aquacultural Engineering* 7:397-441.
8. Speece RE. 1981. "Management of Dissolved Oxygen and Nitrogen in Fish Hatchery Waters." In, *Proceedings of the Bio-engineering Symposium for Fish Culture*. American Fisheries Society, Bethesda, Maryland (Allen LJ, Kinney EC, eds), p. 53-62.
9. Speece RE, Nirmalakhandan N, Lee Y. 1988. "Design for High Purity Oxygen Absorption and Nitrogen Stripping for Fish Culture." *Aquacultural Engineering* 7:201-210.
10. Visscher L, Dwyer WP. 1990. *Oxygen Supplementation, A New Technology in Fish Culture*. Volume 2. U.S. Department of Interior Fish and Wildlife Service, Denver, Colorado.
11. Visscher L, Godby W. 1987. *Oxygen Supplementation, A New Technology in Fish Culture*. Volume 1. U.S. Department of Interior Fish and Wildlife Service, Denver, Colorado.

12. Watten BJ. 1994. "Aeration and Oxygenation." In, *Aquaculture Water Systems: Engineering Design and Management*. Elsevier Science, New York. (Timmons MB, Losordo TM, eds), p. 173-208.
13. Treybal RE. 1980. *Mass-Transfer Operations*. 3rd Edition. McGraw-Hill Book, New York.
14. Colt JE, Orwicz K. 1991. "Aeration in Intensive Culture." In, *Aquaculture and Water Quality*. World Aquaculture Society, Louisiana State University, Baton Rouge, Louisiana (Brune DE, Tomasso JR, eds), p. 198-271.
15. Onda KH, Takeuchi H, Okumoto Y. 1968. "Mass Transfer Coefficients Between Gas and Liquid Phases in Packed Columns." *Journal Chemical Engineering of Japan* 1:56.
16. Kavanaugh MC, Trussell RR. 1980. "Design of Aeration Towers to Strip Volatile Contaminants from Drinking Water." *Journal American Water Works Association* 72:684-690.
17. Cornwell DA. 1990. "Air Stripping and Aeration." In, *Water Quality and Treatment*. 4th edition. American Water Works Associations (Pontius FW, ed), p. 229-268, McGraw-Hill Inc., New York.
18. Haarhoff J, Cleasby JL. 1990. "Evaluation of Air Stripping for the Removal of Drinking Water Contaminants." *Water SA* 16#1:13-22.
19. Thom JE, Byers WD. 1993. "Limitations and Practical Use of a Mass Transfer Model for Predicting Air Stripper Performance." *Environmental Progress* 12:61-66.
20. Grace GR, Piedrahita RH. 1993. "Carbon Dioxide Control with a Packed Column Aerator." In, *Techniques for Modern Aquaculture*. American Society of Agricultural Engineers, Saint Joseph, Michigan (Wang JK, ed), p. 496-505.
21. Grace GR, Piedrahita RH. 1994. "Carbon Dioxide Control." In, *Aquaculture Water Systems: Engineering Design and Management*. Elsevier Science, New York (Timmons MB, Losordo TM, eds), p. 209-234.
22. Summerfelt ST. 1993. "Understanding and Treating Carbon Dioxide Problems in Recirculating Aquaculture Systems." In, *Low-head Roughing Filters for Enhancing Recycle Water Treatment for Aquaculture*. Doctoral Dissertation. Iowa State University, Ames, Iowa. p. 31-62.
23. Summerfelt ST. 1996. "Engineering Design of a Water Reuse System" In, *The Walleye Culture Manual*. North Central Regional Aquaculture Center, Michigan State University, E. Lansing, Michigan (Summerfelt RC, ed), p. 277-309.

24. Wade EM, Summerfelt ST, Hankins JA. 1996. "Economies of Scale in Recycle Systems." In, *Successes and Failures in Commercial Recirculating Aquaculture* (Conference Proceedings). (Libey G, Timmons M, eds), p. 575-588, NRAES-98. Northeast Regional Agricultural Engineering Service, Ithaca, NY.
25. Watten BJ. 1989. *Multiple Stage Gas Absorber*. US Patent No. 4 880 445.
26. Watten BJ, Boyd CE. 1990. "Gas Transfer Within a Multi-Stage Packed Column Oxygen Absorber: Model Development and Application." *Aquacultural Engineering* 9:33-59.
27. Weber AW, Summerfelt ST, Hankins JA. 1995. "Evaluation of Oxygen Transfer Above Saturation Within Packed and Unpacked Low Head Oxygenators." In, *World Aquaculture Society Symposium (Proceedings)*. World Aquaculture Society, Baton Rouge, Louisiana. p. 241.
28. Dwyer WP, Peterson JE. 1993. "Evaluation of a Low Head Oxygenator at Giant Springs State Fish Hatchery, Great Falls, Montana." *Progressive Fish-Culturist* 55:121-124.
29. Wagner EJ, Bosakowski T, Miller SA. 1995. "Evaluation of the Absorption Efficiency of the Low Head Oxygenation System." *Aquacultural Engineering* 14:49-57.
30. Watten BJ., Beck LT. 1985. "Modeling Gas Transfer in a U-tube Oxygen Absorption System: Effects of Off-Gas Recycling." *Aquacultural Engineering* 4:271-297.

ALBERTA AQUACULTURE: PAST, PRESENT AND FUTURE

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Introduction

Fish farming in Alberta has had a long and varied history. Since the late 1800's when rainbow trout, speckled trout and brown trout were imported and stocked in the eastern slopes of the Rocky Mountain's, trout have been farmed for sportfishing stocking and broodstock in Alberta. Since then, the industry has expanded at an incredible rate and is now part of the "blue revolution", the fastest growing animal industry in North America. Diversification from traditional agricultural enterprises into alternate livestock is currently trendy and interest in aquaculture is high among potential investors looking for profitable, sustainable industries. Aquaculture is slightly different than other diversified livestock industries in that a solid market is already established and production knowledge about raising fish in our environment is the limiting factor.

Past and Present

Although fish farming has been going on in Alberta for some time, production statistics and general knowledge about the industry was never compiled by the governing agency. In 1988, the Department of Fish and Wildlife commissioned a study - Report On The Potential For Development of a Commercial Aquaculture Industry in Alberta by the firm.⁽¹⁾ The report outlined the regulatory framework, production profile, market in Alberta, potential growth and options for industry growth. Commercial production by the private sector was just starting in the early 1980's even though some producers had been raising trout for twenty years. The public sector hatcheries were producing millions of little trout for stocking in pothole lakes and eastern slopes streams from their hatchery system, involving their four main sites. Their fifth and newest site, Cold Lake was still under construction and started production in the mid 1980's.

The private sector marketplace has always been divided down into two distinct markets - fingerlings and table trout. In Alberta, approximately 2200 farmers purchase fingerlings every year to stock farm ponds and dugouts for recreational fishing and food production. Production of trout fingerlings in 1988 for the Alberta market was 80% Idaho and Washington, 15% B.C. and Sask. and 5% Alberta.⁽¹⁾ Table trout markets in Alberta are supplied through seven major brokers. Data collected reveals that the Alberta market for farm raised rainbow trout is between 825,000 and 875,000 pounds per year.⁽¹⁾ Production for this marketplace from Alberta sources only accounted for 50,000 pounds. The perception left by the Peat Marwick report was that there was the possibility of Alberta trout production being substituted for Idaho and Washington production, but with the American cost of production so much lower than ours, this was a remote possibility.

Over the years after the Peat Marwick report, the fish farming industry quietly grew until 1990 when the government hatcheries released Infectious Pancreatic Necrosis infected trout into 178 lakes in Alberta after three of their five facilities became infected with the disease. The Alberta Fish Farmers Association became incorporated and at that time, its primarily focus was to lobby government. The

industry was concerned about the apparent bending of the health rules for government hatcheries. In 1995, the Alberta Fish Farmers Association commissioned another study to document what the current production levels were and what they were projected to be by the year 2000. The paper - Aquaculture: A Development Plan For The Alberta Fish Farmer Association by McFarlane and Associates⁽²⁾ also identified strengths and weaknesses of the industry and assisted in the layout of an action plan.

An industry survey was done to evaluate the total production for the Alberta aquaculture industry. Commercial fish farmers were requested to provide information on total pounds of fresh fish production and numbers of individual fish sold. In 1995, total fish production was 299,900 pounds and approx. 2.5 million fish. This number was up significantly over the 1988 production numbers. Production forecasts for 1996 and 2000 showed that producers expected to continue with facility expansion with a resulting increase in production.

PRODUCTION DATA

Revenue generated from fish production follows the same increase as does the production data. Revenue generated per pound is higher for fingerling production as they are valued at a higher per pound price than table fish. Four inch fingerlings sell for \$16 per pound where as table fish sell for

\$2.25 to \$2.75 per pound. As the fingerling market becomes saturated, producers will transfer some of their production capacity over to table trout. This has the benefit of supplying a more spread out cash flow but at a lower per pound value.

The financial forecast shows significant growth will occur in aquaculture in Alberta in the next five years. As hatchery operators increase their production, capacity will be transferred to other trout species (brooks, browns, char and salmon). The possibility of a border closure for any live salmonoid in the spring of 1998 will most likely cause a short term increase in domestic trout prices. Once production increases to levels sufficient to supply the whole market, prices will probably decrease back to current levels.

FINANCIAL FORECAST

The Future

What lies ahead for the fish farmers of Alberta? To answer this question, we will have to look at the whole environment of raising fish. First, markets are expected to remain stable or increase because world demand for fish and fish products will only increase as world fisheries collapse due to overfishing, pollution or general mismanagement. Concern for our environment will result in governments implementing new regulations on water quality for discharges. Fish farming will be subject to the same regulations as other industries. As governments strive to balance budgets, traditional government hatcheries will have to produce economical fish or have the same services provided by the private sector. These are but three reasons why fish farming will continue to grow in Alberta and demand will increase for fish.

As the demand for more fish increases, traditional flow-through methods of production will pass by the wayside. These operations are very heavy users of pristine quality water, often times releasing ammonia, phosphorus and organic contaminants into the watercourse. In Alberta, water temperature control is one of the most important economic factors affecting profitability and flow-through systems lack this control method. Recirculating systems or water reuse systems address all the concerns voiced on fish farming. Water use is kept to a minimum, metabolic waste is collected and usually distributed on land as a fertilizer, escape of fish is reduced due to isolated facilities and temperature control is easily achieved.

The Alberta Fish Farmers' Association is striving to achieve its mission statement of "effectively representing Alberta's commercial fish farming industry in areas of marketing, production, education and quality control". To that end, courses like this one on inland aquaculture are of utmost importance in achieving our goals and the goals of all Alberta fish farmers, that of a profitable, vibrant and sustainable aquaculture industry.

References

1. KPMG Peat Marwick. 1988. Report on the Potential of Development of a Commercial Aquaculture Industry in the Province of Alberta. Edmonton, AB.
2. McFarlane and Associates. 1995. A Development Plan for the Alberta Fish Farmers' Association. Lethbridge, AB.

RECENT DEVELOPMENTS IN THE FORMULATION OF AQUACULTURE FEEDS

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Abstract

Aquaculture has expanded over the past fifty years due to advances in the industry. With feed costs currently representing over 50% of total production costs, many recent developments have focused on fish nutrition. Nutritional research has helped determine more precise nutrient requirements for optimum fish growth, and has emphasized the importance of ingredient quality in fish feeds. This knowledge, along with increasing economic pressures, has led to new developments in feed formulation, especially for salmon and trout feeds. Extrusion technology has enabled high energy and floating feeds to be manufactured while the past ten years have witnessed a shift in diet composition towards increased fat at the expense of both protein and carbohydrate. New "low pollution" diets are currently being developed due to growing concern for the environment, while elevating ingredient prices have forced the industry to research alternate ingredient sources. These recent developments in feed formulation have also led to new industry challenges. The high-fat content of some feeds may cause problems when fed to fish in recirculation systems. Thus, development in fish feeds is ongoing and necessary for the future growth of the aquaculture industry.

Introduction

Aquaculture has been expanding over the past fifty years at an increasing rate due to a number of developments in technology, genetics, husbandry techniques, and improved management skills. With feed costs equivalent to at least 50% of all production costs for most forms of aquaculture,⁽¹⁾ many recent advances have focussed on nutrition. Research in aquatic nutrition has helped determine more precise nutrient requirements for optimum fish growth, and has emphasized the importance of ingredient quality in fish feeds. This knowledge, coupled with increasing economic pressures, has led to many recent changes in aquatic feed formulation, especially for salmon and trout feeds.

Fish Nutrition and Feeds

Nutrients

Fish require a number of basic components in their diet. Energy, protein, lipids, carbohydrates, and vitamins and minerals are necessary for good health and growth. The concentration of each nutrient required in the diet varies with the species of fish and depends on factors such as age, stage of production, and water temperature.

Energy is not a typical nutrient. However, it is required to maintain many internal metabolic and chemical processes. Energy is released when lipids, proteins, or carbohydrates are digested, absorbed, and oxidized. Of the total, or gross, energy in the diet, only a portion of it is available to fish. Some energy is undigestible, while that which is digestible, can be lost to the environment through the gills and faeces, or lost as heat. The remaining usable energy is called metabolizable energy. In general, fish are efficient when converting feed to body tissue and require less energy than other animals. The minimum energy requirement for salmonids ranges from 14 to 17 MJ DE/kg⁻¹ dry diet⁽²⁾ but may vary depending on the level of physical activity, stress, size of the fish, and water temperature.

An adequate dietary protein content provides fish with a source of amino acids that act as "building blocks" for body tissues, and are required in the production of certain internal enzymes. There are ten essential amino acids which must be obtained from the diet or the health and growth rate of the fish will deteriorate. Protein can also provide fish with energy. However, the process required for protein catabolism is energetically more costly than when energy is obtained from lipid or carbohydrate catabolism. Most ingredients with a high protein content are also expensive and it is often economically disadvantageous to provide protein as an energy source. Thus, the digestible protein (DP) to digestible energy (DE) ratio in aquaculture feeds is very important. The optimum DP/DE ratio for salmonids has been estimated at 22-23g DP/MJ DE.⁽³⁾ In respect to the overall diet, the protein requirements of salmonids may range between 35-45% depending on the species and stage of maturity of the fish. In general, protein requirements decrease as the fish matures due to the fact that the growth rate of the fish diminishes with age.

Lipids are an excellent source of energy for fish, assist in the absorption of fat-soluble vitamins, and provide fish with essential fatty acids. The requirements for fatty acids often vary between species. However, the majority of fish species appear to require highly unsaturated fatty acids of the n-3 and n-6 series.

Carbohydrates are not required by fish, however, they can act as a suitable energy source. Unfortunately, carbohydrates are not easily digested by all fish, especially salmonids, who must obtain most of their energy from protein and fat sources.

Vitamins and minerals are required by fish in smaller quantities yet are necessary to support optimum fish growth and survival. A deficiency in just one vitamin or mineral may result in depressed growth, poor health, or increased mortality.

Feed ingredients

In the wild, fish obtain their dietary nutrients by foraging on small organisms or plants. However, intensely farmed fish must obtain their nutrients from the feed. Feed manufacturer's try to include the best possible ingredients at the lowest possible price for producers. The main ingredients used to produce fish feeds include fishmeals and fishoils, which may comprise up to 70% of the diet for salmon and trout,⁽⁴⁾ plantmeals, vitamin and mineral supplements, and small quantities of other products such as pigments and binders. The most important criteria for all fish feed ingredients is

the quality of the raw material and its digestibility, since these factors directly affect the final quality of the feed.

Fishmeals have provided the main source of protein in fish feeds for many years, especially in salmon and trout diets. Fishmeal has a high content of digestible protein, an amino acid profile similar to that of most fish, and is used more efficiently by fish as compared to other plant and animal protein sources.⁽⁵⁾ Today, a typical salmonid feed still contains large quantities of fishmeal. This high inclusion rate means that the quality and digestibility of the meal is extremely important. Since fishmeal is obtained from wild catches of different fish species, and produced by many different processing methods, the quality and digestibility of the fishmeal varies. A high quality fishmeal must be processed fresh, be cooked under low temperatures, and contain low levels of contaminants. The inclusion of antioxidants to the meal during production is essential and reduces the potential for the degradation and rancidity of the meal, both of which decrease the quality of the final feed. Other protein sources used in fish feeds may include animal by-products, such as blood and meat meal, and plant by-products such as soybean and canola meal.

Oils are added to the feed to provide fish with a source of energy. Marine oils are superior to vegetable and cereal oils since they are rich in n-3 fatty acids. Oils also help improve the physical quality of the pellet reducing the level of fines found in the feed.

Diets for some fish species are often supplemented with carotenoids. Carotenoids are chemical substances which enhance the flesh colour of fish. In the case of both salmon and trout, the final fillet colour is very important to the consumer. A bright, pink, market fillet is typically favoured and both astaxanthin and canthaxanthin produce this colour. In the wild salmon and trout obtain these pigments from feeding on small marine organisms. However, farmed salmonids will only achieve a similar fillet colour if their diets are supplemented with carotenoids. While natural sources of both astaxanthin and canthaxanthin are available to feed manufacturer's, the synthetic forms of astaxanthin and canthaxanthin are more commonly used in fish feeds due to their convenient powder form, greater stability during processing, and the production of an excellent fillet colour. Feed containing astaxanthin achieves a superior fillet colour to feed containing canthaxanthin,⁽⁶⁾ however the high price of this carotenoid often makes canthaxanthin economically more desirable to fish farmers.

Binders are substances which improve some of the physical qualities of the feed such as the durability of the pellet in water and the durability of the pellet during storage. The addition of a binder to the feed also helps to reduce the level of fines in the feed, a problem which increases feed wastage on fish farms. Some feed ingredients, such as blood meal, may contain binder-like properties already while other binders, such as wheat, agar, and collagen proteins, can be added to the feed specifically for this purpose.

Finished feeds

Top quality ingredients help produce top quality feeds. However, fish feeds should also exhibit excellent physical characteristics. Pellets should be consistent in size, shape, and colour and contain a minimum level of fines and foreign particles to provide a feed which maximizes growth, is palatable to the fish, and results in the least amount of wasted feed.

Recent Developments in Diet Formulation

Extruded feeds

Many recent developments in fish feed formulation have been possible only with the aid of technology. Prior to the 1980's, the salmon and trout farming industries used both moist, semi-moist, and steam-pelleted feeds. However, new extrusion technology has allowed extruded pellets to be manufactured.⁽⁷⁾ Extrusion is the process whereby a fish feed mixture, in a mash or mix form, is forced through a small opening at a high temperature and pressure. This allows water vapour to be trapped within the pellet. These extruded pellets float well on water and make exceptional trout feeds. The pellets are also capable of absorbing large quantities of oil and are often used to produce slow sinking salmon feeds. Extrusion technology has led to a more durable pellet with less fines and improved water stability. Because their moisture content is much lower than that of moist or semi-moist feeds, extruded feeds can also be stored for longer periods of time with less risk of spoilage.

Changes in diet composition

Over the past twenty years, a gradual change in fish feed composition has occurred, especially where salmon and trout feeds are concerned. The protein content in feeds has decreased at the expense of both fat and carbohydrate (Graph 1), and the energy content of fish feeds has increased while the DP/DE ratio has decreased (Graph 2). This is especially evident in salmon feeds where high-fat diets have become more common and may now contain 40% protein and upwards of 35% fat.⁽⁸⁾ This change is due to a number of reasons. First, high-fat diets provide producers with the economical advantage of raising faster growing fish with improved feed conversion rates.^(7,9,10) Second, fishmeal has increased in price and it now accounts for a large cost of the diet. At the same time, the market price for salmonid products has decreased. This has forced the aquaculture industry to direct more attention at reducing the protein content of feeds without affecting the growth rate of the fish. Fat is not only an energetically more efficient means of providing salmonids with energy, but it is also a more economical energy source. The third reason extends from the need to reduce excreted wastes from fish farms while the fourth reason is the fact that extrusion technology has finally made it possible to produce high-fat salmonid feeds.

In Western North America, most trout feeds contain between 13-16% fat while European trout farmers have been using feeds which contain 24-25% fat.⁽¹²⁾ High-fat diets provide a number of benefits to salmon and trout producers. They enable fish to maintain an improved growth rate with an improved feed conversion.^(7,9,10) High-energy diets have also been found to reduce water pollution caused by fish farms.^(7,10)

Feeding high-fat diets to fish does result in some disadvantages. In Europe, high-fat diets have been blamed for the softer, less pleasing fillet texture of Atlantic salmon and rainbow trout. One study found that rainbow trout fed high-fat diets contained 20% more fat in their fillets than fish fed low fat diets.⁽¹³⁾ This has also been observed in Atlantic salmon,⁽¹⁴⁾ however, consistent results have not always been observed⁽¹⁰⁾ and the variability of fat content in fish fillets is most likely due to a combination of factors.

Graph 1 - Trends in Fish Feed Formulation

NORWEIGAN DATA

Source: 1975-1990 (7)
1995 (8)

Graph 2 - Trends in Fish feed Formulation

NORWEIGAN DATA

Source: (11)

Low pollution diets

Environmental awareness, aimed at minimizing the nitrogenous (N) and phosphoric (P) waste products found in the effluent water from fish farms, has increased over the past decade. These wastes originate from uneaten feed particles and from the excretion of undigested or unutilized feed in the faeces. Both cause the eutrophication of water, and are of special concern to lakes and streams. Many European countries, such as Denmark, have started limiting the effluent levels of N and P from fish farms. This is also becoming more common in the United States.

Currently, feed manufacturer's are trying to find ways to develop less polluting fish feeds. First, the physical quality of the finished feeds continues to improve. Extruded feeds now contain less fines and foreign particles than ever before and this minimizes feed wastage. Second, a number of computer based feeding programs are now available to help improve feed conversion rates for fish farm producers. Third, many feed companies are trying to reduce the protein content of their feeds to a minimum level, since N excretion is directly related to the ingested level of protein.⁽¹⁵⁾ Fourth, high energy diets have been found to reduce N and P loading into the environment. A 35% reduction in N loading to the environment has occurred when Atlantic salmon were fed high energy diets.⁽⁷⁾ It was concluded that this reduction resulted from improved protein utilization due to the protein sparing effect caused by the dietary fat content.

Phosphorus excretion is often a more important concern for fish farmers. Since the P requirement of most salmonids ranges between 0.5-0.8% of the feed,⁽¹⁶⁾ and fishmeals often contain between 1.5-3.2% P, most P is excreted into the environment. Therefore, the fifth means of reducing fish farm wastes by feed companies is the attempt to reduce the phosphorus content of their feeds by using a fishmeal with a lower ash content (Table 1). The lower dietary P content, and the increased digestibility and bioavailability of a high quality fishmeal, reduce the total P discharge.⁽¹⁰⁾

Sixth, feed manufacturer's have also tried to lower the P and N load into the environment by reducing the fishmeal content of the feeds. Unfortunately the availability of good alternate protein sources is poor. In addition, the phosphorus found in many alternate protein sources such as plant meals, is often unavailable to the fish. Current research is now being conducted on microbial phytase enzymes, which can be added to the feed to help fish digest and utilize this form of plant phosphorus rather than excrete it.⁽¹⁷⁾

Table 1: The content, digestibility, retention, and discharge of phosphorous in three commercial rainbow trout diets.

Diet	P Content (% Dry Matter)	ADC of P (%)	Retention (% intake)	P discharge (kg/T prodn)
1	1.9	47	23	18
2	1.5	47	26	13
3	1.0	60	43	6

Source: (10)

Alternate protein sources

With the price of fishmeal increasing, and its availability decreasing, alternate protein sources are under investigation for future use in fish feeds. To date, many alternate protein sources have been used in fish feeds to some extent. Examples of these include spray dried blood meal, meat meal, poultry-by product meal, feather meal, soybean meal, canola meal, plant protein concentrates, and single-cell proteins. Unfortunately, these alternates are often poorer in quality than fishmeal. Most plant protein sources contain large quantities of carbohydrates which cannot be digested by salmonids. They may also contain antinutritional factors which adversely affect palatability and growth of fish unless the plant material is processed and these compounds are broken down or extracted. Processing plant material, is very expensive. However, as fishmeal sources continue to decrease and its price continues to increase, the future use of alternate protein sources for fish feeds seems inevitable.

High-fat diets and recirculation systems

Another concern currently faced by feed companies is the problems associated with the newly developed high-fat diets and their use in recirculation systems. Dr. Harald Rosenthal, of the University of Kiel, has suggested that the increased fat content of these feeds adversely affects the drum filters in the mechanical filtration system of recirculation system biofilters and this causes problems with the elimination of suspended solids.⁽¹⁸⁾ At a recent seminar on recirculation systems, held at the Huntsman Marine Science Centre in St. Andrews, New Brunswick, Dr. Rosenthal stated that many fish farmers would be willing to trade a portion of the improved feed efficiency gained by feeding high-fat diets to their fish, if their concerns regarding the feed, water quality, and their recirculation equipment could be resolved.⁽¹⁸⁾

Conclusion

The fish feed industry has been developing at a tremendous rate over the past few years, especially in the case of salmonid diets. This trend will continue well into the future as new problems within the aquaculture feed industry surface and new research finds the technology and knowledge to solve them.

References

1. Lall S. 1996. Research: Key to the Future Development of the Fish Feed Industry. *In*, Northern Aquaculture Feed Supplement 5. p. 5-6.
2. Cho CY, Kaushik, SJ. 1990. Nutritional Energetics in Fish: Energy and Protein Utilization in Rainbow Trout. *World Rev. of Nutr. Dietetics*. **61**: 133-172.
3. Cho CY, Woodward WD. 1989. Studies on the Protein-to-Energy Ratio in Diets for Rainbow Trout (*Salmo gairdneri*). *In*, Y. van der Honing and W H Close, eds. *Energy Metabolism of Farm Animals*. Proc. 11th Symp. Lunteren, Netherlands. Pudoc Wageningen. p. 37-40.

4. Tacon AGJ. 1993. Feed Ingredients for Crustaceans: Natural Foods and Processed Feedstuffs. FAO Fisheries Circular. p. 856-864.
5. Hardy RW, Masumoto T. 1990. Specifications for Marine By-Products for Aquaculture. *In*, S. Keller, ed. Proceedings of the International Conference on Fish By-Products. Alaska Sea Grant Program, Fairbanks, AK. p. 109-120.
6. Sabelle AO. 1996. pers. commun. Puerto Montt. Chile.
7. Johnsen F, Wandsvik A. 1991. The Impact of High Energy Diets on Pollution Control in the Fish Farming Industry. *In*, CB Cowey and CY Cho, eds. Nutritional Strategies and Aquaculture Waste. p. 51-63.
8. Wathne E. 1996. pers. commun. Dirdal, Norway.
9. Heinen JM, Hankins JA, Subramanyam M. 1995. Evaluation of Two Higher-fat Diets and Lower-fat Diet for Rainbow Trout. *J. of App. Aqua.* 5(2): 73-83.
10. Robert N, Le Gouvello R, Mauviot JC, Arroyo F, Aguirre P, Kaushik SJ. 1991. Use of Extruded Diets in Intensive Trout Culture: Effects of Protein to Energy Ratios on Growth, Nutrient Utilization and on Flesh and Water Quality. *Proc. IV Int. Symp. Fish Nutrition and Feeding, Biarritz*, 24-27. June. p. 497-500.
11. Talbot C. 1994. pers. commun. Stavanger, Norway.
12. Bergheim A, Aabel JP, Seymour EA. 1991. Past and Present Approaches to Aquaculture Waste Management in Norwegian Net Pen Culture Operations. *In*, CB Cowey and CY. Cho, eds. Nutritional Strategies and Aquaculture Waste. Fish Nutrition Research Laboratory. Department of Nutritional Sciences. University of Guelph. Guelph, Ontario. p. 117-136.
13. Faergemand J, Ronsholdt B, Alsted N, Borresen T. 1995. Fillet Texture of Rainbow Trout as Affected by Feeding Strategies, Slaughter Procedure, and Storage Post Mortem. *Wat. Sci. Tech.* 31(10): 225-231.
14. Rørå AMB, Wathne E, Thomassen MS. 1995. Quality and Growth of Atlantic Salmon (*Salmo salar*) Fed Slaughter Diets Differing in Fat Content. Manuscript for Aquaculture Nutrition. Institute of Aquaculture Research. Norway. p. 1-36.
15. Médale F, Brauge C, Vallée F, Kaushik SJ. 1995. Effects of Dietary Protein/Energy Ratio, Ration Size, Dietary Energy Source and Water Temperature on Nitrogen Excretion in Rainbow Trout. *Wat. Sci. Tech.* 31(10): 185-194.
16. Enell M. 1994. Environmental Impact of Nutrient Load from Nordic Fish Farming. *Wat. Sci. Tech.* 31(10): 61-71.

17. Cain KD, Garling DL. 1995. Pretreatment of Soybean Meal with Phytase for Salmonid Diets to Reduce Phosphorus Concentrations in Hatchery Effluents. *The Prog. Fish. Cult.* **57**: 114-119.
18. Morgan S. 1996. Special Feed Needed for Recirc Systems- Rosenthal. *In*, *Northern Aquaculture*. June. p. 8.

BIOFILTRATION FOR AMMONIA CONTROL*

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Abstract

The use of biofilters to treat ammonia and dissolved organic matter in recirculating aquaculture systems is discussed. Several factors that influence nitrification are summarized. And, applications of trickling filters, submerged filters, pressurized-bead filters, and fluidized-bed biofilters are described.

Introduction

Ammonia is a metabolic by-product of protein metabolism. Approximately 30 mg of ammonia are produced by fish per gram of feed consumed.⁽¹⁾ Ammonia is also produced by three additional reactions in recycle-systems using biological treatment: biological deamination of organic compounds (waste feed and feces), endogenous respiration, and cell lysis.⁽²⁾ At high levels, un-ionized ammonia (NH_3) is toxic to fish ($\text{LD}_{50} = 0.32 \text{ mg/L}$ for rainbow trout);⁽³⁾ and at lower concentrations (0.05 to 0.2 mg/L of unionized-ammonia) it causes a significant reduction in growth.⁽⁴⁾ For salmonid fishes, optimal conditions for growth requires an un-ionized ammonia concentration less than 0.0125 mg/L.⁽¹⁾ Therefore, ammonia must be removed from aquaculture systems before it can accumulate to toxic levels.

In once-through or single-pass aquaculture systems, ammonia is flushed away with fresh water. In reuse systems, however, insufficient ammonia is removed through simple dilution with fresh water and ammonia must be removed from the system in another manner.^(5,6) The primary method for treating ammonia in recirculating aquaculture systems is by bacterial oxidation, which has been extensively reviewed.^(7,8,9)

Biofiltration is a term coined for labeling attached growth biological treatment processes. It is a process where micro-organisms attached to a support medium biologically oxidize a portion of the ammonia nitrogen and the biodegradable organic matter in a waste stream. The oxygen required for this oxidation is called the biochemical oxygen demand, or BOD. Retention of the microbe population is obtained by their attachment to the wetted or submerged surfaces of the biofilter medium. This attachment provides the long solids retention time required for good biological oxidation. Ammonia is oxidized by autotrophic bacteria called nitrifying bacteria. Biologically degradable organic compounds are oxidized by heterotrophic micro-organisms (i.e., bacteria, protozoa, and micro-metazoa). Typically, the autotrophic and heterotrophic microbes coexist on the media surface in the biofilter.

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Nitrification

The oxidation of organic compounds and ammonia in static-bed biofilters does not take place simultaneously, as it can in a suspended growth treatment process (such as activated sludge and fluidized-sand biofilters), but successively.^(2,10) If sufficient BOD is present, organic compounds will be oxidized preferentially before ammonia is utilized as heterotrophic microbes out compete autotrophic bacteria for space on the biofilter media.^(10,11,12) After sufficient organic oxidation occurs, the heterotrophs do not have the organic substrate requirement necessary to dominate the surface space on the media and autotrophic bacteria can compete, providing nitrification.⁽²⁾ However, Schlegel⁽¹⁰⁾ states that poor nitrification is not only a result of carbon oxidizing bacteria out competing the nitrifying bacteria in the biofilter, but is also due to predation from protozoa.

Nitrification in biofilters is also reduced by oxygen deficiency, generally caused by the carbonaceous oxygen demand exerted by the heterotrophic organisms located up-filter of the autotrophic nitrifiers.^(5,11,12,13)

Bacteria convert ammonia into nitrate in a two-step process called nitrification. Two different groups of nitrifying bacteria, both believed to be obligate autotrophs (consume carbon dioxide as their primary carbon source) and obligate aerobes (require oxygen) are needed for complete nitrification.⁽¹⁴⁾ Although there are several species of nitrifying bacteria, Cutter and Crump⁽¹⁵⁾ found that *Nitrosomonas* showed considerably higher ammonia conversion rates than the others. It is generally assumed that *Nitrosomonas* converts ammonia into nitrite, NO_2^- , and that *Nitrobacter* converts the nitrite into nitrate, NO_3^- . The stoichiometry for these energy conversion reactions, ignoring cell synthesis, are:⁽¹⁶⁾

Taking nitrifier synthesis together with nitrification, the overall relationship between ammonium, bicarbonate, and oxygen consumed and cell mass, nitrate, water, and carbonic acid produced is (EPA, 1975):

As given by the stoichiometry, nitrification and nitrifier synthesis requires consumption of about 4 mg of oxygen and between 6.0-7.4 mg of alkalinity (as CaCO_3) for every mg of ammonia as nitrogen converted to nitrate.⁽¹⁶⁾ Because ammonia and nitrite are both toxic to fish at low levels, monitoring the levels of ammonia and nitrite in the culture system tanks provides a measure of the performance of the biofilter and provides a warning of conditions that may inhibit fish growth or cause a fish kill. High levels of nitrite will occur if there is an imbalance between the

bacterial populations of *Nitrosomonas* and *Nitrobacter*. Most commonly, high levels of nitrite occurs within the first month of biofilter start-up⁽⁷⁾ because the *Nitrobacter* grow slower than the *Nitrosomonas*.

Biofilters

The ammonia and organic oxidation capacity of biological filters is largely dependent upon the total surface area available for biological growth and the efficiency of the area utilization. Ideally, increasing the surface area of the media will result in a corresponding increase in ammonia removal capacity. The efficiency of nitrification per unit surface area is dependent upon the accessibility of the media surface, the mass transfer rate into the biofilm, the growth phase of the biofilm (lag, log, stationary, and death phases), and the competition with heterotrophic microbes for space and oxygen.^(17,18)

To work effectively in recycle systems, the media used in attached growth systems must have a relatively high specific surface area (i.e., surface per unit volume) and an appreciable voids ratio. The specific surface area is important as it controls the amount of bacterial growth that can be supported in a unit volume. The voids ratio is critical for adequate hydraulic performance of the system. The voids ratio characterizes how much space is provided for the water to pass through the media in close contact with the biofilm. In some cases (e.g., trickling filters and rotating biological contactors) the voids must also provide space for air ventilation so that oxygen can be transferred to the flow within the bed.

Media is classified according to its packing characteristics, i.e., random packing versus structured packing. Random packing media can be sand, crushed rock or river gravel, or some form of plastic or ceramic material shaped as small beads, or larger spheres, rings, or saddles. Structured media can be crossed stacks of redwood slats, or more commonly plastic blocks composed of corrugated plates or tubes. The media must be inert, non-compressible, and non-biologically degradable on a relative time scale.

Submerged filters

The submerged filter consists of a bed of media through which the wastewater passes in an upward (Figure 1) or downward direction. It is patterned after the anaerobic filter originally developed for methane fermentation and later used for denitrification. Bacteria growing on the submerged surfaces allow long solids retention times and the upward (or submerged downward) flow allows control of the hydraulic detention time. The media is generally large (5-10 cm rock; or 2-5 cm random or structured plastic media) so as to provide large void spaces.

Figure 1. Illustration of an upflow submerged filter with aeration and back-wash capabilities.

In addition to nitrification, the submerged filter also captures some of the biological solids.^(19,20,21) Submerged filters may have problems that result from heavy loading of organic matter when coupled with improper solids flushing and/or underdrain design. Solids accumulate in static filter beds based on both physical and biological mechanisms. Physically, suspended or settleable solids are entrapped within the filter voids due to settling, sieving, and interception. Biologically, cell mass is produced by the microbial metabolism of substrates (primarily organics and ammonia) passing through the filter, both on the surface of the media and in the voids between the media. Cell mass resulting from nitrifying bacteria is desirable. Cell mass resulting from heterotrophic organisms, though required to some extent, increases plugging problems in static media filters. And, as mentioned above, heterotrophic micro-organisms inhibit the nitrification process by predation and by out-competing nitrifying bacteria for space and oxygen. In addition, if oxygen becomes limiting, anaerobic organism such as *Beggiotoa* can grow and produce much thicker biological films, plugging the filter. Therefore, special attention must be paid to the hydraulic requirements to avoid flow conditions which allow the filter to plug^(10,20,21) or to exhaust the dissolved oxygen that is available in the water.⁽²¹⁾

The characteristics of the media in a static media filter ultimately influences the removal of suspended, settleable, and dissolved organics as well as the head loss generated and the success of flushing the filter. Media with sufficient voids for use in biofilters can be random media such as uniform crushed rock over 5 cm (2 in) diameter, or plastic media over 2.5 cm (1 in) diameter, and structured media such as plates or tubes that have large voids. Providing adequate flushing

of solids from the filter is critical.^(20,21) Solids sometimes have to be flushed from the submerged biofilter media voids daily by reversed flow flushing and bimonthly by air scour coupled with reversed flow flushing. Good solids flushing requires a properly designed underdrain, a drainable filter, a high velocity of a reversed flow of water, and a means for air scouring. Properly designed underdrains provide a support for the media and forces the water, during regular operation or during flushing, to flow uniformly through the bed.

Two innovative modifications of submerged filters have been developed to reduce two common operational problems: low available dissolved oxygen and plugging problems. The operational problems can be alleviated with supplemental oxygenation and bubble aeration. Both modifications raise the level of available oxygen, and both serve to break-up clogging to a variable extent. Vigorous aeration strips off thick growths of biofilm, thus preventing these growths from clogging the pores in the filter media.⁽²²⁾ However, aeration of the bed can have considerable impact on the flow hydraulics. According to tracer studies, the strong turbulence ensures that the substrate is evenly distributed to all parts of the filter.⁽²²⁾ Because aerated submerged filters are approximately completely mixed, and if the reaction order is greater than zero, these biofilters are more favorably operated as a multi-stage process.⁽²²⁾

Trickling filters

Trickling filters appear similar to the downflow submerged biofilters, except that the water level in the trickling filter vessel is kept below the media and the downflow keeps the media wet but not submerged (Figure 2). Because it is not submerged, air ventilates through the wet media, carrying oxygen to the bacteria and providing opportunity for carbon dioxide to strip.

Trickling filters, using biofilm grown on gravel-size stones, were the first attached growth biological contact units utilized for wastewater treatment. Trickling filters have been used extensively in wastewater treatment throughout the twentieth century. The most important reason for the popularity of the trickling filters is their ease of operation, self aerating action, and moderate capital cost. The technical innovation that impacted trickling filters the most was the development of plastic media. Plastic media is light, offers high specific surface areas ($100\text{-}300\text{ m}^2/\text{m}^3$), and void ratios of $\geq 90\%$.

As with most of the attached growth biofilters, trickling filters with high specific surface areas may be less efficient than filters of lower specific surface areas due to channeling, regional plugging, or a hydraulic load that is not sufficient to moisten all the area of the densely packed media. Inadequate control over the hydraulic detention time is an additional problem with the trickling filter.

Figure 2. Illustration of a trickling filter.

Rotating biological contactors

Rotating biological contactors (RBCs) were first used to treat wastewater in Europe in 1958.⁽²³⁾ Rotating biological contactors function by rotating honeycombed or corrugated disks or tubes on a shaft through a tank containing the wastewater. Rotation of the media through the atmosphere provides oxygen transfer to the flow and the microbial film, which helps to maintain aerobic conditions for nitrification. Rotating biological contactors have attracted attention because of their low head requirement, ability to maintain an aerobic treatment environment, and relatively low operating costs.⁽²⁴⁾ However, the capital cost of rotating biological contactors is typically much more than that of trickling filters, submerged filters, or fluidized-sand biofilters.

Typical rotating biological contactors have disks submerged to 40% of the diameter and rotational speeds of 1.5 to 2 rpms.⁽²⁵⁾ Rotating biological contactors can treat small flows, but they also scale to lengths of 8 m (25 ft) and total surface areas of approximately 8400 m² (85,000 ft²) to treat large flows.⁽²⁵⁾ Catastrophic failure of either the disks or the shaft due to heavy biomass growth were major problems in early units.⁽²⁵⁾ However, most of the problems were mechanical and recent (properly designed) rotating biological contactors have been more reliable.

Figure 3. Illustration of a rotating biological contactor.

Pressurized-bead filters

The pressurized-bead filter passes flow up-ward through floating plastic beads (Figure 4). A screen at the top of the vessel prevents the beads from washing out. Operating pressures are typically 5-15 psi.

The pressurized-bead filter has become a popular biofilter to treat small or moderate flows (≤ 1000 L/min). They are modular, compact, straight forward, and effectively remove ammonia when operated properly.⁽²⁶⁾ The pressurized-bead filter also effectively removes solids from a flow and is sometimes used only for solids removal or as a hybrid filter that combines both nitrification and solids removal. The bead filter is typically either bubble-washed or propeller washed during the backwash procedure, which ensures that trapped solids are broken free from the beads.

Nitrifying bacteria and heterotrophic micro-organisms grow on the floating plastic beads, which are cylinders about 3 mm long, and in the void spaces surrounding the beads. Because the pressurized-bead filter removes solids so effectively, large populations of heterotrophic micro-organisms can grow in the bead filter and must be periodically removed with the trapped solids in order to maintain nitrification.⁽²⁷⁾ Too frequent and vigorous back-flushing, however, has been reported to remove too much of the nitrifying bacteria, so it is important that frequency and intensity of back-flushing be controlled properly.⁽²⁷⁾ Nitrification in pressurized-bead filters is still best when a majority of the solids have already been removed from the flow.

Figure 4. Illustration of a pressurized-bead filter with propeller wash.

Fluidized bed biofilter

Fluidized-beds operate by injecting an equal distribution of water across the biofilters cross-section at the bottom of the granular bed. Water flows up through void spaces between the granules in the bed. The bed expands, becoming fluidized, when the velocity of water through the bed is sufficiently large to result in a pressure loss greater than the apparent weight (actual weight less buoyancy) per unit cross-sectional area of the bed. The relative amount of bed expansion is dependent upon the shape and diameter of the particles and the velocity and temperature of the water. Once the bed has been fluidized, the pressure drop across the bed remains constant at all bed expansions. The total head pressure required across a commercial-scale fluidized-sand biofilter is moderate (generally 4 m of water head [< 6 psi]). Summerfelt

and Cleasby⁽²⁸⁾ described the prediction of fluidization velocities, expansions, and pressure drops for different sized sands and at different water temperatures.

The design of the flow distribution mechanism is the most critical for reliable operation of fluidized-sand biofilters. Summerfelt et al.⁽²⁹⁾ describes one method for designing flow distribution mechanisms for large-scale fluidized-sand beds.

Figure 5. Illustration of a fluidized-sand biofilter.

Fluidized-bed biological filters have been shown to be both space and capital cost-efficient methods of providing nitrification in recirculating aquaculture systems.^(30,31,32) The performance of fluidized beds as nitrifying biofilters within recirculating aquaculture systems has been studied considerably.^(28,29,30,33,34,35,36,37,38,39,40) Fluidized-sand biological filters have become attractive to

commercial aquaculture producers with large recirculating systems because of their high specific surface areas (ranging 4,000-45,000 m²/m³) and low media cost (around \$40-70/m³ of graded sand) relative to other types of biofilters. Currently, there are several large-scale commercial fish producers using fluidized-sand biological filters in their recirculating systems. The integration of fluidized-sand biofilters into recirculating systems has been recently discussed.^(35,41)

Fluidized-sand biofilters in aquaculture typically use an extremely hard, whole grain crystalline silica sand, which is finely graded and has a mean effective diameter^{**} of 0.2-1.0 mm, and a uniformity coefficient^{***} between 1.3 to 1.8. Sands have a specific gravity 2.65 times that of water (1.0). Average bed expansions are often between 20 and 100%. Because sands are not perfectly uniform, larger sands move to the bottom of the fluidized beds where they expand less than the smaller sands that have migrated to the top of the bed. The average expansion of a bed at a given velocity depends upon the size gradation within the bed (i.e., uniformity coefficient), which makes it important to predict expansion of both the largest and smallest fractions of sand.⁽⁴²⁾ In particular, the largest fraction of sand must expand at the velocity selected.

Plastic pellets can also be used to make fluidized-bed biofilters. These pellets typically come from the plastic molding industry and can be obtained from suppliers of bulk plastics. The pellets are roughly spherical or cylindrical, and range in size from 1 to 3 mm. Plastic pellets can be used unmodified, although surface modified pellets are available. Plastic pellets can be purchased in different molecular formulations, or in formulations containing a heavy filler such as silica. Such pellets will have a specific gravity equal to, just greater than, or just less than 1.0. Using plastic beads having a specific gravity greater than or less than water allows for either up-flow expanded (specific gravity > 1) or down-flow expanded (specific gravity < 1) beds. Compared to fluidized-sand biofilters, fluidized plastic bead filters have lower headloss (<1 psi) and lower requirements for expansion velocity and for delivering oxygen due to their lower specific surface area.

Discussion

Each of the different biofilters has advantages and disadvantages that can affect their use in recirculating aquaculture systems. For example, trickling filters and rotating biological contactors have the advantage that they both aerate the flow during treatment, which strips some carbon dioxide and ensures that aerobic conditions are maintained for nitrification. Submerged filters (without aeration), fluidized-bed biofilters, and pressurized-bead biofilters do not provide aeration and the only available oxygen for biofilter respiration is carried in the influent flow.

^{**} The "effective size" (D_{10}) is defined as the opening size which will pass only the smallest 10%, by weight, of the granular sample. The D_{10} provides an estimate of the smallest sand in the sample and is the size used to estimate the maximum expansion at a given superficial velocity.

^{***} The "uniformity coefficient" is a quantitative measure of the variation in particle size of a given media and is defined as the ratio of D_{60} to D_{10} .

The pressurized-bead filter, when operated under the right conditions, has the advantage of filtering solids from the flow at the same time ammonia is removed.⁽²⁶⁾ Storing solids in any biofilter, however, may not be desired because solids can exert an oxygen demand and are food for heterotrophic organisms, which makes it harder for nitrifying bacteria to compete.^(13,27) Nitrifying bacteria do not compete well for surface area with the fast-growing and sometimes predatory heterotrophic microbes.^(10,11,12) Therefore, accumulations of organic-solids should be back-flushed frequently from pressurized-bead filters (and all other biofilters that can store solids). However, back-flushing pressurized-bead filters too frequently or vigorously can reduce nitrification.⁽²⁷⁾ The best biofilter management practice is to effectively remove organic solids from the flow before it reaches the biofilter.

An advantage of fluidized-bed biofilters is that they trap and store few solids. Another advantage of fluidized-bed biofilters is that the high velocities of water carries plenty of oxygen.

Use of low surface area media is a disadvantage in rotating biological contactors, trickling filters, and submerged filters because it results in larger and typically more costly biofilters. Conversely, pressurized-bead biofilters and fluidized-bed biofilters use small granular media with high surface areas, which allows the use of smaller and sometimes less costly biofilters to treat the same flow (compared to rotating biological contactors, trickling filters, and submerged filters). It is critical not to cut back media surface area on biofilters to reduce their cost and space requirements; biofilters with insufficient surface area to meet the ammonia removal demands will produce nitrite and fail often.

Trickling filters, rotating biological contactors, submerged biofilters, and fluidized-bed biofilters have been scaled to treat very large flows (e.g., > 4000 L/min). On the other hand, the pressurized-bead filter has typically not been scaled for a single unit to treat more than 1000 L/min, although a unit to treat between 1,000-2,000 L/min has been reported.⁽⁴³⁾ Because of the relatively low cost of filter sand, the fluidized-sand biofilter scales-up especially cost effectively to treat very large flows.⁽³²⁾

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Literature Cited

1. Piper RG, McElwain IB, Orme LE, McCraren JP, Fowler LG, Leonard JR. 1982. *Fish Hatchery Management*. U.S. Fish and Wildlife Service, Washington, D.C.
2. Kruner G, Rosenthal H. 1987. "Circadian Periodicity of Biological Oxidation Under Three Different Operational Conditions." *Aquacultural Engineering* 6:79.

3. Meade JW. 1985. "Allowable Ammonia for Fish Culture." *Progressive Fish-Culturist* 47:135.
4. Colt JE, Armstrong DA. 1981. "Nitrogen Toxicity to Fish, Crustaceans and Mollusks." In, *Proceedings of the Bio-engineering Symposium for Fish Culture* American Fisheries Society, Fish Culture Section, Bethesda. (Allen LJ, Kinney EC, eds), p. 39-42.
5. Liao PB, Mayo RD. 1974. "Intensified Fish Culture Combining Water Reconditioning with Pollution Abatement." *Aquaculture* 3:61.
6. Speece RE. 1973. "Trout Metabolism Characteristics and the Rational Design of Nitrification Facilities for Water Reuse in Hatcheries." *Trans. Amer. Fish. Soc.* 102(2):323.
7. Kaiser GE, Wheaton, FW. 1983. "Nitrification Filters for Aquatic Culture Systems: State of the Art." *J. World Maricult. Soc.* 14:302-324.
8. Wheaton F, Hochheimer J, Kaiser GE. 1991. "Fixed-film Nitrification Filters for Aquaculture." In, *Aquaculture and Water Quality*. World Aquaculture Society, Baton Rouge, LA. (Brune DE, Tomasso JR, eds), p. 272-303.
9. Wheaton FW, Hochheimer JN, Kaiser GE, Krones MJ, Libey GS, Easter, CC. 1994. "Nitrification Filter Principles." In, *Aquaculture Water Reuse Systems: Engineering Design and Management*. Elsevier, New York (Timmons MB, Losordo, TM, eds), p.101-126.
10. Schlegel S. 1988. "The Use of Submerged Biological Filters for Nitrification." *Water Science Technology* 20:177.
11. Harremoes P. 1982. "Criteria for Nitrification in Fixed Film Reactors." *Water Science Technology* 14:167-187.
12. Wanner O, Gujer W. 1984. "Competition in Biofilms." *Water Science Technology* 17:27-44.
13. Bovendeur J, Zwaga AB, Lobee GJ, Blom JH. 1990. "Fixed-Biofilm Reactors in Aquacultural Water Recycle Systems: Effect of Organic Matter Elimination on Nitrification Kinetics." *Wat. Res.* 24(2):207-213.
14. Sharma B and Ahlert RC 1977. "Nitrification and Nitrogen Removal." *Water Research* 11:897-925.
15. Cutter DW, Crump LM. 1983. "Some Aspects of the Physiology of Certain Nitrite Forming Bacteria." *Ann. Appl. Biol.* 20:291.
16. EPA (Environmental Protection Agency). 1975. *Process Design Manual for Nitrogen Control*. Office of Technology Transfer, Washington, D.C.

17. Alleman JE and Preston K. 1991. "Behavior and Physiology of Nitrifying Bacteria." In, *Proceedings of Regional Workshop on Commercial Fish Culture Using Water Recirculating Systems*. Illinois State University, Normal, IL.(Swann L, ed), p. 1-13.
18. Manem JA, Rittman BE. 1992. "The Effects of Fluctuations in Biodegradable Organic Matter on Nitrification Filters." *Journal AWWA* **84**(4):147-151.
19. Haug RT, McCarty PL. 1972. "Nitrification with Submerged Filters." *J. Water Pollut. Control Fed.* 44:2086.
20. Lomax KM, Wheaton FW. 1978. "Pretreatment of Fish Culture Wastewater for Nitrification." *Trans. ASAE* 197-200.
21. Summerfelt ST. 1993. *Low-Head Roughing Filters for Enhancing Recycle Water Treatment for Aquaculture*. Doctoral Dissertation. Iowa State University, Ames, Iowa.
22. Rusten B. 1984. "Wastewater Treatment with Aerated Submerged Biological Filters." *J. Water Pollut. Control Fed.*, 56: 424.
23. Calvin PC. et al. 1979. "Factors Controlling Rotating Biological Contactor Performance." *J. Water Pollut. Control Fed.* 51:601.
24. Tanaka K, Oshima A, Rittmann BE. 1987. "Performance Evaluations of Rotating Biological Contactor Process." *Water Sci. Tech.* 19:483.
25. Tchobanoglous G, Schroeder ED. 1985. *Water Quality*. Addison-Wesley Pub. Co., Reading, Massachusetts, p 168.
26. Malone RF, Chitta BS, Drennan DG. 1993. "Optimizing Nitrification in Bead Filters for Warmwater Recirculating Aquaculture Systems." In, *Techniques for Modern Aquaculture* American Society of Agricultural Engineers, St. Joseph, MI (Wang, JK, ed), p. 315-325.
27. Golz W, Rusch KA, Malone, RF. 1996. "Developing Backwash Protocols for Floating Bead Filters: A Model of Solids-loading and Biofilm Retention Effects on Nitrification." In, *Successes and Failures in Commercial Recirculating Aquaculture* (Conference Proceedings) NRAES-98. Northeast Regional Agricultural Engineering Service, Ithaca, NY.(Libey G, Timmons M, eds), p. 196-205.
28. Summerfelt ST, Cleasby JL. 1996. "A Review of Hydraulics in Fluidized-bed Biological Filters." *Trans. ASAE* 39(3), 1161-1173.
29. Summerfelt ST, Hankins JA, Durant MD, Goldman JN. 1996. "Removing Obstructions: Modified Pipe-lateral Flow Distribution Mechanism Reduces Backflow in Fluidized-sand Biofilters." *Water Env. and Tech.* 8(11):39-43.

30. Burden DG. 1988. *Development and Design of a Fluidized Bed/upflow Sand Filter Configuration for Use in Recirculating Aquaculture Systems*. Master's Thesis, Louisiana State University, Baton Rouge, LA.
31. Losordo TM, Westerman PW. 1991. "An Analysis of Biological, Economic and Engineering Factors Affecting the Cost of Fish Production in Recirculating Aquaculture Systems." In, *Workshop on the Design of High-Density Recirculating Aquaculture Systems*, Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, Louisiana, p. 1-10.
32. Wade EM, Summerfelt ST, Hankins JA. 1996. "Economies of Scale in Recycle Systems." In, *Successes and Failures in Commercial Recirculating Aquaculture* (Conference Proceedings). NRAES-98. Northeast Regional Agricultural Engineering Service, Ithaca, NY.(Libey G, Timmons M, eds), p. 575-588.
33. Bullock G, Hankins J, Heinen J, Starlipper C, Teska J. 1993. *Quantitative and Qualitative Bacteriological Studies on a Fluidized Sand Biofilter Used in a Semi-Closed Trout Culture System*. Biological Report 17, U.S. Fish and Wildlife Service, Washington, D.C.
34. Cooley PE. 1979. *Nitrification of Fish-Hatchery Reuse Water Utilizing Low-Density Polyethylene Beads as a Fixed Film Media Type*. Master's Thesis, Idaho State University.
35. Heinen JM, Hankins JA, Weber AL, Watten BJ. 1996. "A Semi-closed Recirculating Water System for High Density Culture of Rainbow Trout." *Progressive Fish Culturist* 58:11-22.
36. Owsley DE, Jeris JS, Owens R. 1988. "Ammonia Removal Allows Effluent Reuse at Fish-Hatchery Using Fluidized Bed Reactors." In, *Proceedings of the 43rd Purdue Industrial Waste Conference*. Lewis Publishers, Chelsea, MI, p. 449-457.
37. Paller MH, Lewis WM. 1988. "Use of Ozone and Fluidized -bed Biofilters for Increased Ammonia Removal and Fish Loading Rates. *The Progressive Fish-Culturist* 50:141-147.
38. Thomasson MP. 1991. *Nitrification in Fluidized Bed Sand Filters for Use in Recirculating Aquaculture Systems*. Master's Thesis, Louisiana State University, Baton Rouge, Louisiana.
39. Weaver DE. 1991. "Performance of Fine Sand Fluidized Bed." In, *Workshop on the Design of High-Density Recirculating Aquaculture Systems*. Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, Louisiana, p. 18-23.
40. Wimberly DM. 1990. *Development and Evaluation of a Low-density Media Biofiltration Unit for Use in Recirculating Finfish Culture Systems*. Master's Thesis. Louisiana State University, Baton Rouge, LA.

41. Summerfelt ST. 1996. "Engineering Design of a Water Reuse System." In, *The Walleye Culture Manual*, North Central Regional Aquaculture Center, Michigan State University, E. Lansing, Michigan.
42. Cleasby JL, Fan KS. 1981. "Predicting Fluidization and Expansion of Filter Media." *Journal of the Environmental Engineering Division, American Society of Civil Engineers* 107:455-471.
43. Delos Reyes AA, Malone RF. 1996. "Design and Evaluation of a Commercial-scale, Paddle-washed Floating Bead Filter." In, *Successes and Failures in Commercial Recirculating Aquaculture* (Conference Proceedings) NRAES-98. Northeast Regional Agricultural Engineering Service, Ithaca, NY. (Libey G, Timmons M, eds), p. 183-195.

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