Workshop on Recirculating Aquaculture Systems Helsinki, October 5-6, 2011

Book of Abstracts

DTU Aqua Report No 237-2011

By Anne Johanne Tang Dalsgaard (ed.)

DTU Aqua
National Institute of Aquatic Resources

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The Nordic Network on Recirculating Aquaculture Systems and the workshop are supported by the Nordic Council of Ministers

Preface

Dear all

Welcome to the 1st workshop on Recirculating Aquaculture Systems (RAS) organized by the Nordic Network on Recirculating Aquaculture Systems (www.NordicRAS.net). The network was initiated by DTU Aqua, and was formally founded at a steering committee meeting in April 2011, Hirtshals, Denmark with country representatives from Denmark, Norway, Sweden, Finland and Iceland. The steering committee consists of:

- Per Bovbjerg Pedersen, Head of Section, DTU Aqua, Denmark
- Jouni Vielma, Senior Research Scientist, Finnish Game and Fisheries Research Institute, Finland
- Helgi Thorarensen, Professor, Holar University College, Iceland
- Asbjørn Bergheim, Senior Research Scientist, International Research Institute of Stavanger AS (IRIS), Norway
- Torsten Wik, Associated Professor, Chalmers University of Technology, Sweden

The Nordic Network on Recirculating Aquaculture Systems and the workshop in Helsinki are supported by the Nordic Council of Ministers. Finland holds the Presidency of the Nordic Council of Ministers in 2011, and sustainable aquaculture is a focus area in the Finnish Presidency Programme. The theme of this workshop on Recirculating Aquaculture Systems is in consistence with this focus, as RAS technology is considered an important element in the future of aquaculture, facilitating the rearing of fish with minimum environmental impact.

While aquaculture is developing quite fast in the rest of the word, the aquaculture industry is more stagnant in the Nordic countries. The aim of the Nordic Network on Recirculating Aquaculture Systems is to help speed up the development by identifying people in the different countries working with RAS, and facilitate the cooperation between not-yet connected educational and industrial partners. Consistent with this, the aim of the workshop is to bring researchers and industrial partners with an interest in RAS together, creating a unique opportunity for exchanging practical experiences and scientific knowledge on the newest developments in RAS.

The Nordic Network on Recirculating Aquaculture Systems is a lasting network, and everybody with an interest in RAS is most welcome to join (please refer to our website: NordicRAS.net). Furthermore, it is our hope and plan that this workshop will be a recurrent event, taking place every other year. We are therefore very pleased that the interest in the workshop has been overwhelmingly positive, promising well for the future of this initiative. Let’s aim for some fruitful and joyful days in Helsinki.

Anne Johanne Dalsgaard
Organiser of the Nordic Network on Recirculating Aquaculture Systems

Acknowledgements

The Nordic Network on Recirculating Aquaculture Systems would like to acknowledge Research Director Riitta Rahkonen and Taija Pöntinen from the Finnish Game and Fisheries Research Institute for pleasent cooperation regarding planning of the Aquaculture Forum event in Helsinki. Furthermore, we appreaciate the help provided by DTU Aqua Communication officer Karin Stubgaard and Secretary Grete Solveig Byg concerning the network webpage and practicalities associated with organising the workshop. We thank members of the Aquaculture Conference planning group for making the workshop become a part of the Aquaculture Forum event in Helsinki: Ministerial Adviser Orian Bondestam, Finland; Eero Aro, Finnish Game and Fisheries Research Institute; Helge Paulsen, Nordic Council of Ministers, Denmark; Johan Åberg, Finnish Fish Farmers Association; Niclas Purfürst, Jordbruksverket, Sweden; Tore Riise, Ministry of Fisheries and Coastal Affairs, Norway. Finally, we thank the Aquacultural Engineering Society (AES.org) for co-sponsoring the registration fee for 20 students attending the workshop.

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Abstracts of oral presentations

Presented at the

1st RAS workshop organised by the Nordic Network on

Recirculating Aquaculture Systems

(NordicRAS.net)

October 5-6, 2011

Helsinki, Finland

No 1

Recirculation systems in Europe: state of the art and prospects

Jean Paul Blancheton[1]*, Luigi Michaud and Emmanuelle Roque d'Orbcastel
[1]Institut Français de Recherche pour l'Exploitation de la MER (IFREMER), Station de Palavas, Chemin de Maguelone, 34250 Palavas les Flots, France

*E-mail: jean.paul.blancheton@ifremer.fr

Abstract
Recirculating Aquaculture systems (RAS) still produce a small fraction of European aquaculture, fresh water species and marine species.
Nowadays, EU and national governments tend to stimulate the development of RAS, as it is considered as the most environment friendly system. An overview of the state and perspectives of development of recirculation systems in Europe will be presented.
Within the concept of sustainability, a global approach of production systems is now possible, using life cycle assessment (LCA). It takes into account a set of potential environmental impacts of the system, from its building to its destruction. The comparison of the global environmental impact of trout production in flow through and low head RAS using LCA shows that feed is the main factor affecting the environmental balance, at all scales. This emphasizes the importance of providing the best possible environment to the fish, for a good welfare status and optimal feed conversion.
One of the key conditions for an optimal environment in RAS is mastering the bacterial population which, in intensive systems, consume approximately as much oxygen as the fish. The impact of the bacterial activity on the fish (possible pathogenic pressure, compounds they uptake and release), are still under investigation. A state of the art of the main findings and questions related to RAS bacterial population will be presented.
The main differences between the environmental balances of RAS and flow through systems are relative to water use, eutrophication potential and energy use. Water dependence and eutrophication potential are lower in RAS, but they consume more energy than flow through systems.
Recommendations and directives from institutional, national and regional bodies suggest the implementation of strict waste reduction measures. Therefore, appropriate waste treatment systems are further to be developed. Several national and international projects demonstrated that the treatment and reuse of waste water from recirculation systems allows to completely close the water loop at small scale.
The goal of zero environmental impact aquaculture is obviously not realistic and will never be reached, but reduced energy consumption, improved feeding and bacterial flora management and waste valorization, will contribute to close of the gap.

No 2

How Billund Aquaculture has designed 1000 ton/y salmonid RAS system in DK

Bjarne Hald Olsen
Billund Aquakultur Service ApS, Kløvermarken 27, 7190 Billund, Denmark

E-mail: bjarne@billund-aqua.dk

Abstract
Even all economic evaluations on the minimum commercial size of a full grow is around 3000 tons a year as a standalone company, it was possible to create a commercial 1000 ton/y farm in Hvide Sande in DK due to existing infrastructure on site and use of investor's infrastructure. The design was optimized in relation to test conducted in Chile in RAS.
A whole new concept was designed to achieve the lowest energy consumption compared to any other RAS done by Billund Aquaculture. Main focus has been to have smallest possible handling of the fish and lowest possible investment. One of the most important aspects of the design is bio-security in all parts of the design process due to the fact that systems like these are much depended on that no pathogens get's in the system.
Due to the fact that the farm is built in an environmentally regulated country there is a need for economical solutions for efficient effluent treatments solutions on well proven technologies, because there is no space for failures. The Langsand Laks AS farm in Hvide Sande will be ready in end 2012 and deliver it first fish by August 2013.

No 3

Topic: How to design 500-1000 ton salmonid RAS technology

Jacob Bregnballe
AKVA group Denmark A/S, Navervej 10, 7000 Fredericia, Denmark

E-mail: jbregnballe@akvagroup.com

Abstract
The RAS design phase is dealt with at project management level starting with client identification and project definition followed by the system design including quality assurance and technical sign off.
Biological and technical design measures are discussed in more detail to explain the various approaches and designs for larger salmonid productions (500-1000 ton) such as portion sized rainbow trout, salmon smolt and land based grow-out systems for large salmon and trout.

No 4

Topic: How to design 500-1000 tons salmonid RAS system: Cost-effective RAS production of trout and salmon

Jens Ole Olesen
Inter Aqua Advance A/S, Muslingevej 36 B, 8250 Egå, Denmark

E-mail: joo@interaqua.dk

Abstract

Conventional open flow production of trout and salmon is under increasing criticism and opposition from authorities and green groups, and netcage farmers are facing increasing challenges from adverse climatic and biological conditions and cultural and social impacts. New technologies and strategies are required for future productions in a world of increasingly demanding consumers.

State of the art RAS technology incorporating dynamic MBBR water treatment offers possibilities for introduction of sustainable productions. A standard plant for trout production of 500-1000 tons/year using raceway technology is presented with cost break down and energy profile.

RAS production of market size salmon of 5-6 kg is a challenge with respect to achieving profitable production due to the high upfront investment and long production time. A new modular based concept for salmon farming allowing optimal production planning for 2,300 tons/year provides cost-effective production conditions, competitive with cage farming. The production scenario, investment budget and cost breakdown is presented.

No 5

Topic: How to design 500-1000 tons salmonid RAS system

Idar Schei
AquaOptima AS, Brattørkaia 17B, 7010 Trondheim, Norway

E-mail: idar.schei@aquaoptima.com

Abstract
The presentation will focus on:

- Design based on AquaOptima's development during 18 years as RAS supplier
- General design criteria and basic elements in water treatment system
- Lay-out of different departments and complete farm
- Pictures from a commercial salmon farm made to produce 1000 tons of Atlantic salmon

No 6

Topic: How to design a 500-1000 ton salmonid RAS system

Eivind Lygren[1]*, Andreas Brunstad[1] and Marius Hægh[1]
[1]Krüger Kaldnes, Kreftingsgate 37, 3045 Drammen, Norway

*E-mail: Eivind.lygren@krugerkaldnes.no

Abstract
Kruger Kaldnes is owned by Veolia Water, a world leading company within water treatment technology. Kruger Kaldnes has for almost 20 years supplied the aquaculture business with the recognized and very flexible Kaldnes TM Moving Bed (MBBR) technology. Our sister company Hydrotech, has at the same time developed a very efficient method for particle removal, the so-called Hydrotech filters. These two technologies form a corner stone in the Kruger Kaldnes RAS concept. The RAS concept has been well accepted in i.e. commercial smolt production plants and turbot and seabass fattening farms. Lately we have received a number of requests for land based RAS systems for salmonids. Kruger Kaldnes therefore has designed a modular system with the following characteristics:

- Close integration of the water treatment system with the fish farming basins, avoiding use of pipes
- Low energy consumption (1,5-1,9 kWh/kg of fish) (preliminary calculation excluding any external heating and cooling if needed)
- Compact plants with a small footprint area (2,2-2,4 m^2/ton yearly production with 5 m deep fish tanks) (production unit including water treatment based on mechanical filters, Kruger Kaldnes MBBR, oxygenation based on a combination of pure oxygen and aeration, ozonation and foaming, and CO_2 and N_2 removal, and sludge treatment by anaerobic digestion, excluding fish processing, feed silos, oxygen storage tanks, administration building and parking area etc)
- Modular units based on 500 ton/yr or 1000 ton/yr units that can be expanded limitless in all directions.
- Simple and safe operation
- Low investment cost (a detailed overview to be presented in the workshop)
- Low operation cost (a detailed overview to be presented in the workshop)
- Low production cost (a detailed overview to be presented in the workshop)

No 7

Topic: Designing feed for RAS

Louise Buttle[1]*, Thomas Gitlesen[1], Peter Rugroden[1], Jan Vidar Jakobsen[1] and Kari Ruohonen[1]
[1]EWOS Innovation, Dirdal N-4335, Norway

*E-mail: louise.buttle@ewos.com

Abstract
EWOS is a global feed company operating in 5 countries (Canada, Chile, Norway Scotland and Vietnam). The main feed business is salmon aquaculture. Increasingly there is a demand from customers for a recirculation aquaculture system (RAS) feed. A pre-requisite of RAS feeds in freshwater is the physical quality of the feed, the fish digestibility and the physical integrity of the faeces. This presentation will give a brief outline of the development of a RAS feed and the parameters considered.

Fifteen feeds were manufactured at the EWOS Innovation pilot plant in Dirdal, Norway. Each of these feeds, including a control, was a standard formulation containing fish meal for freshwater feeds and had a feed ingredient (described as "binder" A to M) added at a low inclusion level (<1%). Physical and chemical analysis on these feeds included water stability and moisture content. Several binders were selected for further testing in fish trials.

Atlantic salmon (40g) were stocked into tanks, supplied with freshwater. Duplicate tanks of fish were fed one of the proposed RAS diets (Binder A to E) for a period of 20 days. A control where no RAS binder was added to the feed was included. At the end of the trial, fish were killed, weighed and faeces were dissected out (n=10 per tank). Photos of the dissected out faeces were taken. In addition, the faeces were assessed by an apparatus using diffraction of a lazer beam to measure the size of the faeces particles. No clear differences were observed in visual observation of the faeces, however, it was possible to see differences between the different feed-binders in the particle size distribution and in the breakdown of the faeces when subjected to mechanical agitation.

Fish trials were designed to further assess the properties of two binders, and different dietary levels were formulated and tested in Atlantic salmon held in freshwater tanks. Analysis focused on the use of the lazer assessment and also apparent digestibility coefficients were analysed. No effect on digestibility was observed.

A couple of key ingredients that improve the suitability of feeds for RAS systems were identified in Atlantic salmon fish trials and feed assessment. Further testing in commercial size RAS systems is planned.

No 8

Topic: Designing feed for RAS - a key to maximum output

Peter B. Jessen
BioMar A/S, Mylius Erichsensvej 35, 7330 Brande, Denmark

E-mail: pbj@biomar.dk

Abstract
This presentation is about the considerations and experiences of a fish feed producer when developing and launching a fish feed for a modern and intensive recirculating aquaculture system.
Historically the development of feed has been focussed on maximizing growth, health and quality of the fish plus eventually minimizing the environmental impact of the production according to legislation. All at lowest possible feed cost. The principles for feed for RAS are exactly the same except for the environmental issue. In a RAS system this is no longer just an issue between the farmer and the local authorities, but a highly important economical parameter. The investments in a RAS system are significant and consequently the system will often be the factor limiting the capacity of the farm. The efficiency is of outmost importance to the output and thus to the financial result.
Development of a feed for RAS is a fourfold job involves following issues:

- Determination of the optimal balance between digestible protein and digestible energy in the feed in order to minimize the use of protein as source of energy causing the formation of ammonia
- An amino acid profile tailored to the needs of the fish – again to minimize the loss of nitrogen compounds
- Selection of highly digestible raw materials minimizing the general loss of nutrients
- Assuring coherent and easily removable faeces with a minimum of dissolved nutrients

Trials at BioMar R&D facilities as well as in commercial farms have shown it is possible to increase production in a RAS by up to 25 % compared to a standard high performance feed.
The feed was launched in 2010 and together with the feed has BioMar offered the farmers a comprehensive support in order to optimize the conditions and the management of the RAS-systems to maximize the production and thus the economic output of the farm. This has given both parties valuable experiences.

No 9

Topic: Designing feed for RAS

Jón Árnason
Matís ohf, Icelandic Food and Biotech R&D, Vínlandsleið 12, 113 Reykjavík, Iceland

E-mail: jon.arnason@matis.is:

Abstract
The principle of diet design for any animal is to cover the needs for nutrients for the production in question.
In recirculation aquaculture systems (RAS), firstly the needs of the fish have to be covered, but in addition the needs of the bio filter have to be taken care of to ensure their efficiency in removing undesirable components from the system.
In terms of nutritional quality of feed it is important to tailor the composition of available nutrients in the diet to maximum growth of the fish in the RAS. This has to do both with the balance between nutrients as well as the overall availability of all nutrients in order to minimize the total loud of nutrients that enter the bio-filter in the system.
The relationship between fish growth and nutrient needs in diets will be discussed as well as the effect on nutrient loud on biofilters.

No 10

Topic: Designing feed for RAS - effect of feed type on filter biology in RAS

Hanno Slawski[1]*, Jørgen Kiærskou[1] and Michael V.W. Kofoed[2]
[1]Aller Aqua A/S, Allervej 130, DK-6070 Christiansfeld, Denmark
[2]Danish Technological Institute, Chemistry and Biotechnology, KongsvangAllé 29, DK-8000 Århus C, Denmark

*E-mail: hs@aller-aqua.dk

Abstract
With the introduction of recirculating aquaculture systems (RAS), more than 90% of the process water from fish farms is reused. The expansion of fish farms is no longer limited by water use, but more on their discharge of nitrogen to the recipient. The purpose of the on-going investigationis to enhance the quality of the water along with the well-being of the fish, and at the same time decrease the environmental impact through optimization and development of feed for recirculating aquaculture systems. Through laboratory tests measures for the maximum potential of the current microbiology of the filter of two model 3 farms were obtained and correlated with the actual nitrogen load to the filters. It was found that the microbiology of the filters could sufficiently handle applied feed amounts. In on-going experiments, the utilization of the filter is further optimized by several approaches. First, the assimilative fraction of the feed nitrogen is increased. Although the filters can handle the nitrogen load, only half of the nitrogen content in the feed is assimilated into fish biomass even under favourable conditions. Development of feeds in which the amino acid composition of the feed is optimized to that of the fish could enhance nitrogen assimilation into animal tissue and decrease the amount of excreted nitrogen. Secondly, the solid fraction of the excreted nitrogen is increased. Feeds which increase the fraction of solids would promote the removal of excreted nitrogen through the sumps and not through the filter. As a result a lower filter capacity would be required. Thirdly, the stability of excreted matter is improved. Problematic clogging of the biofilters by organic debris decreases nitrification rates by reducing the oxygen transfer to the nitrifying biofilms. The result is a need for frequent backwash or manual labour to maintain optimal filter function. Large faecal particulates can be removed via the sumps, but the aeration employed in the fish tanks often disrupts these large particulates. More compact faecal pellets would diminish this disruption and decrease the need for cleaning and maintenance of the biofilters.

No 11

Effects of feed and system operation on waste output

Steinar Skybakmoen
OppdrettsTeknologi/Fishfarming Technology, Nordslettveien 177, N-7038 Trondheim, Norway

E-mail: steinar@oppdrettsteknologi.no

Abstract
There are several estimates and some measurements of discharges from fish farms. However, there seems to be a limited scope of such measurements from RAS facilities. In connection with the documentation of a new RAS facility at Salmar, measurements that can be used to calculate discharges have been made. Combined with theoretical calculations, this gives insight into what is practical treatment efficiency of the purification processes in a RAS for several water quality parameters. Several measurements are being planned and there will be done constructive and operational changes that will affect water quality for the fish and discharge quantities for the environment in a positive direction.

No 13

Arctic charr and tilapia – first step to the green circle

Ragnheidur Inga Thorarinsdottir
Islensk Matorka Ltd, Sudurlandsbraut 6, 108 Reykjavik, Iceland

E-mail: ragnheidur@matorka.is

Abstract
Iceland has abundant resources of hydro power, geothermal heat, cold fresh water and seawater. The total aquaculture production in Iceland is though only approximately 5,000 tons per year and could be increased substantially. The increased production volume would be based on utilizing the geothermal resources, waste water from power plants and energy intensive industries, the clean ground water, the huge amount of organic waste materials, large farming land together with knowledge and experience in the energy and food sector. This would create many new job opportunities and strengthen the export of fresh fish products and related businesses.

Islensk Matorka Ltd in Iceland cultures Arctic charr and tilapia at commercial scale in two landbased stations in South Iceland. The production is based on renewable energy and water resources utilizing low-temperature geothermal heat and pure water from boreholes in the area. The company started export of Arctic charr in May 2011. The marketing of tilapia for export and to Icelandic consumers started in August 2011. The company can supply the market with fresh tilapia and Arctic charr all year round and the market acceptance supports the plans of Islensk Matorka for future expansion.

The advantage of producing two species in the same station has proofed to be valuable as the production cost is decreased and moreover, the sales and marketing benefits. The company would like to take the next steps including other rapid growing warm water species that could be raised in the same water system as tilapia.

The landbased stations in South Iceland have been based on flow-through, but will now be developed into highly productive and sustainable recirculation systems. The new system will include hydroponics, that is growing plants in water tanks in green houses utilizing the effluents from the aquaculture rich in nutrients needed for the plants. After the water filtration by the plants the water can be recirculated to the aqauculture. Combining aquaculture with hydroponics in a symbiotic environment like this is known as *aquaponics*. This new system will provide a solution for increased production capacity for landbased stations with minimal environmental impact and become one of the future green growth business solutions.

Aquaponic science is still considered to be at an early stage, and the first units are mainly small based on a few tons annual fish production. The landbased stations of Islensk Matorka Ltd. in Iceland with access to renewable energy and geothermal heat provide excellent opportunities for the business development into large commercial units. If the plans proof to be successful this could become one of the breakthrough for European aquaculture in the future.

No 14

Closed cycle production of European lobster in land-based Recirculating Aquaculture System (RAS)

Asbjørn Drengstig[1]*and Asbjørn Bergheim[2]
[1]Norwegian Lobster Farm AS, Stavanger, Norway.
[2]IRIS - International Research Institute of Stavanger, Stavanger, Norway

*E-mail: ad@hobas.no

Abstract
In the past, farming of European lobster in land-based systems has turned out to be difficult. The ideal system for rearing lobsters individually should be relatively inexpensive to construct and operate, simple to maintain, based on automatic feeding and self-cleaning of tanks and cages, ensure stable and favourable water quality, utilize space in three dimensions, enable high lobster densities, conserve water at high temperatures, ensure high survival and permit easy access to the livestock for inspection and feeding. Several attempts have been made to mass-produce these cannibalistic crustaceans under controlled environments. However, none of the attempts proved to be successful in incorporating all of these features into a single design. Thus, the development of land-based lobster farming has been severely hampered by lack of suitable technology and production methods. The major constraints have been the need for individual rearing cages to avoid cannibalism, need of heated water, lack of high quality dry food, high labour costs, inadequate technological solutions and high investment costs. At present, there is a lack of basic information on respiration and excretion rates of European lobster and thus insufficient dimensioning criteria for water treatment units in recycle systems. Norwegian Lobster Farm initiated such investigations together with IRIS in 2010, a still on-going project.

Today, Norwegian Lobster Farm operates the world's first and, so far, the only land-based RAS farm producing plate sized lobsters with an annual capacity of 2 metric tons (MT). The company also operates its own brood-stock and a small scale hatchery with an annual capacity of 60,000 IV stage juveniles. Norwegian Lobster Farm has patented a single cage technology in 23 countries enabling commercial RAS based lobster farming. The company employs a moving bed biofilter where the recirculation system is designed to fit the water management for the patented technology. The farm is fully automated with self-cleaning of tank and cages, automated feeding, image processing of every single lobster every day and remote desktop solution for surveillance 24 hours a day.

In 2008, Norwegian Lobster Farm launched a genetic mapping programme in cooperation with the Institute of Marine Research in Bergen. The overall aim is to develop a genetic databank to select best performing brood-stock by monitoring growth, survival and feed conversion ratio (FCR) in the surviving offspring. Screening of the juveniles is currently under evaluation. The company has started to manipulate the temperature of the brood-stock to obtain hatching throughout the year. Moreover, the brood stock consists of males and females and successful mating was observed in 2010.

Norwegian Lobster Farm is currently expanding the production to 20 MT annually, with the aim at producing 100 MT annually in 2013.

No 15

Experiences and challenges farming pike-perch

Julia Lynne Overton
AquaPri Innovation, Lergårdvej 2, 6040 Egtved, Denmark

E-mail: julia.overton@aquapri.dk

Abstract
Aquapri A/S has been producing pike-perch (*Stizostedion lucioperca*) for the last 6 years. Production is focused around juveniles (10g) and fish for consumption (800-1200g). Pike-perch is a thermophilic fish, requiring temperatures over 20-23ºC in order to achieve optimal growth. Therefore recirculated water technology is the only feasible way to maintain constant warm water temperatures. Under these conditions it is possible to produce juvenile fish within 3-4 months, and fish for consumption within 13-15 months from newly hatched larvae. Current production for 2011 is aimed at 1 million juvenile fish, most of which are sold to other aquaculture companies for on-growing, and around 250 tonnes fish for consumption.
There have been many challenges experienced both with producing pike-perch and the use of recirculated technology. Development of a functional larval rearing and weaning process, along with reduction of losses due to deformities, cannibalism and stress during handling, has improved survival and growth.
All year round production of eggs and larvae has been vital for the ongoing development process and for up scaling production. RAS systems are used in order to provide the necessary environmental conditions (temperature and photoperiod) in order to achieve four separate spawning seasons a year.

No 16

A floating bag system for small scale aquaculture

Ola Öberg
KTH, Mark- och vattenteknik, 100 44 Stockholm, Sweden

E-mail: olaoberg@kth.se

Abstract
A floating bag system is a potentially interesting compromise between a traditional net cage system and an outdoor, land-based closed system. It can be operated with lower environmental impact than the cage system and can be built with lower investment cost than a land based facility.
The advantage compared to net cage farming, besides that they may be operated as either semi-closed or entirely closed systems depending on requirements and investment possibilities, is that the bag system can be placed in a more sheltered water in the archipelago. Sheltered water gives protection to wind and waves, but also closer distance to land which shorten the time spent on reaching the farm. Another advantage is the slightly higher temperature in shallow water, giving the fish a head start in the spring. The disadvantages to net cage farming are the external energy dependence to run the system, but also the dependence on more equipment that can fail.
The advantage to a land based system is mainly land use. The system can be placed nearly in any watershed. The equipment used is the same and the liner used in the bags is similar to the liner in a pond system. The disadvantage to a pond system is the higher risk for weather related damage of the equipment.
The presentation will elaborate on some experiences of running a floating bag system.

No 17

Smolt production

Thue Holm
Langsand Laks AS, Langsand 34, 6960 Hvide Sande, Denmark

E-mail: th@langsandlaks.dk

Abstract
In smolt production of Salmo Salar in RAS and flow through there some issues in better smolt survival in sea than archived today by many RAS farms but the RAS systems gives much more flexibility to solve these challenges if managed and designed correct.
Better survival in sea when transferring from RAS systems is not only solved by producing bigger smolt. A successful smolt transfer is depended on the general condition of the fish and how it is prepared to go in the open sea cage environment.
Good condition of the smolt is achieved in RAS by:

- Having a well exercised fish thought out the whole production cycle
- Low CO_2
- No over saturated oxygen water in the fish tank
- Good water parameters
- Efficient grading and vaccination systems which are as gentle to the fish as possible.

To prepare the fish for the transfer it is important:

- That the fish is acclimatized in relation to temperature, salinity and light
- Proper size smolt is used
- Successful smoltification

These are issues that RAS smolt farmers are faced with in their production in relation delivering good quality of smolt to sea cages. In Langsand Laks AS faces less problems in transfer of the smolt to the Sea water RAS due to the controlled environment in the system.

No 18

Model Trout Farms

Christina R. Kongested
Kongeåens dambrug ApS, Kongeåvej 87, 6650 Brørup, Denmark

E-mail: mail@kongeaaensdambrug.dk

Abstract
Kongeåens Dambrug Aps comprises three separate trout farms producing 3,000 mt market size rainbow trout (*Oncorhynchus mykiss*) per year in Model Trout Farms - Recirculating Aquaculture Systems (RAS). Kongeåens Dambrug was founded in 1974 as a traditional, earthen pond, flow-through system, taking in water via damming of the local stream, and leading the effluent back into the stream after minor cleaning by sedimentation. In 2004, the trout farm Kongeåen Dambrug was rebuilt into one of the first Model Trout Farms RAS in Denmark. Raceways in these types of farms are built in concrete, and the farms apply the cost and environmental efficient RAS technology to treat the water, including: airlifts, sludge cones / traps, drum filters / microscreens, biofilters, and constructed wetlands. The intake of freshwater (make-up water) is reduced by a factor 10-15 in comparison to traditional farms, and very importantly, the water comes from drain or bore wells (i.e., ground water) rather than from natural watercourses, thereby removing the potential impact on the local fauna. The water is recirculated at least 95% (internal recirculation flow/(internal recirculation flow + water intake)).

Rebuilding Kongeåen trout farm has reduced the discharge of nitrogen by more than 50%, and phosphorus and organic matter by more than 90%, while the production of trout has doubled. Furthermore, the risk of disease outbreaks has been reduced, reducing the need for medicine. BKD/PKD can occur, but generally the major problem now is associated with bad/swollen gills. Based on the positive results and experience achieved on Kongeåen trout farm, the farms Nielsby and Fole, owned by Kongeåens Dambrug Aps, have also rebuild into Model Trout Farms.

No 20

AquaCircle

Jesper Heldbo
AquaCircle Secretariat, Pligtgårdsvej 22, 2660 Brøndby Strand, Denmark

E-mail: jesper@aquacircle.org

Abstract
AquaCircle is a Danish association established in 2006 by different companies, fish farmers, institutions, and private actors with an interest in reciculating aquaculture systems (RAS).
It is an information centre aiming at contributing to further development of recirculating aquaculture technology/systems. Acquired information and innovations are applied to improve the Danish aquaculture industry, ensuring that it is an industry that continuously develops, sells and exports RAS components / equipment, complete RAS, and associated services.
AquaCircle distributes relevant information on recirculating aquaculture technology to decision-makers, administrators, financial institutions and other communities.
To ensure a continuous recruitment of qualified research scientist and other employees to the aquaculture industry, AquaCircle also supports relevant education on all levels.

No 21

AES – Aquacultural Engineering Society

Asbjørn Bergheim, President 2011
IRIS - International Research Institute of Stavanger, Stavanger, Norway

E-mail: asbjorn.bergheim@iris.no

Abstract
AES was established in the USA in 1993, but is presently an international organisation. The Society also welcomes non-engineers, such as biologists, food scientists, veterinarians, nutritionists, geneticists, and those representing other related disciplines as new members. At present, the total membership constitutes c. 300. The cost of joining AES is minimal, only $30 a year; including a web-based subscription to Aquacultural Engineering (AE) the annual cost is $60. Membership for students is free.
The top reasons to join AES are the following:

- Build your knowledge by receiving AE (6-8 issues annually) and AES Newsletter
- Build a professional network by attending AES sponsored workshops and conferences. Such events are announces in AES Newsletter
- Build your profession, credibility and expertise

Other obvious advantages for AES members are funding of students to attend conferences, e.g. has the Society's Board of Directors approved to sponsor half of the registration fee for 20 students at this workshop here in Helsinki, and not least the AES awards for outstanding papers and rewards for outstanding member contributions.
AES is closely connected to the newly established Nordic Network on Recirculating Aquaculture Systems organizing this workshop.
To become a member of AES is easily done, just enter the web site: www.aesweb.org

No 22

Waste characterisation in RAS

Alexander Brinker
Fishery Research Station Baden-Württemberg, Argenweg 50/1, 88085 Langenargen Germany

E-mail: Alexander.Brinker@lazbw.bwl.de

Abstract
The effective functioning of recirculating aquaculture systems (RAS) requires adequate waste control. In RAS especially, dilution is no solution, and wastes must be removed continuously. Waste management hardware is costly in terms of initial outlay and running costs, and operating requires solid technical know-how.

This contribution will focus on food-derived waste, which in aquacultural operations appear in two important forms, soluble wastes and solids. These two fractions cause different problems for fish stock and the aquaculture system and present different challenges for effective treatability/removal. Dissolved wastes are associated with problems of toxicity, mainly caused by the nitrogen fractions (ammonia, nitrite, nitrate) and in strictly closed systems, there may also be accumulations of heavy metals and the like. Taste-affecting substances such as geosmin may also be of concern. The removal of dissolved nutrient wastes from the water is generally tackled using biofiltration with nitrification and, depending on water exchange, denitrification. In consequence, biofiltration is a key feature of successful RAS farming. Solid wastes derive almost entirely from fish faeces. The fine material may be toxic or cause mechanical damage, for example to fish gills, but the main challenge is the need to prevent solid wastes and associated organic load entering the biofiltration system. This removal is typically performed by mechanical means, mostly microscreening. The efficacy of screening depends on proportion of total wastes in the solid domain and on the size distribution of suspended particles. Particle size depends in turn on the shear forces experienced during transportation to the filter, on the intrinsic stability of the faecal cast and on the duration of exposure to shear forces and microbial degradation. Furthermore, solid bound wastes are subject to leaching, the extent of which is influenced by particle size and exposure time.

This presentation will examine methods for characterizing suspended solids with respect to size distribution, stability and density and, to a lesser degree, their response to harmful shear sources. Data will be presented to illustrate the potential for recent salmonid feed formulations to influence the physicochemical properties of suspended solids, and in this regard the generally negative importance of feed components of vegetable origin for salmonids. A new approach to aquacultural waste management will be described, using feed-induced manipulation of faecal stability and density.

No 23

Reflections about physical feed quality

Turid Synnøve Aas
Nofima, NO-6600 Sunndalsøra, Norway

E-mail: synnove.aas@nofima.no

Abstract
High quality feed and high feed intake is required for optimal growth in fish. The quality of feed is determined by both nutritional and physical properties.

Transportation, storage in large units and conveying of feed may cause pellet breakage and dust formation. Small particles affect water quality, and minimising the formation of these is particularly important in recirculation systems. Furthermore, small particles may stick in the pipes of the feeding system, it is waste of valuable feed resources and represents economic loss for the fish farmer. Thus, high physical feed quality is demanded in today's intensive aquaculture. However, our research so far has shown that physical feed quality affects the biological response in the fish (Baeverfjord et al., 2006;Aas et al., 2011b), and the feed intake seems to be highly dependent on physical feed quality.

A large variety of feed ingredients is used in fish feed, and since these have different properties in feed production, the physical properties of commercial feeds vary. Different feeds produce different amounts of small particles upon handling, and some produce mainly dust whereas others tend to break and produce larger particles (Aas et al., 2011a). To minimise the amount of dust fed into the fish cages, dust forming feeds must be avoided. The feeding system must be optimised, since bends and roughness inside the pipes cause pellet attrition. Furthermore, low air speed and high feeding rate in the feeding system has been shown to give smallest amounts of small particles when using large pellets in a pneumatic feeding system for open sea cages (Aas et al., 2011a).

Whereas pellet attrition is relatively easy to discover and a fish farmer is likely to return a batch of poor feed, losses due to suboptimal feed intake and growth are difficult to discover and quantify, but may be of large value for the farmer. Thus, several factors must be taken into account when searching for the optimal pellet quality, and the feed that is preferred by the fish may not be the quality that is most convenient for handling and transport.

Aas, T.S., Oehme, M., He, G., Sørensen, M., Lygren, I., and Åsgård, T. 2011a. Analysis of pellet degradation of extruded high energy fish feeds with different physical qualities in a pneumatic feeding system. Aquacultural Engineering 44, 25-34.

Aas, T.S., Terjesen, B.F., Sigholt, T., Hillestad, M., Holm, J., Refstie, S., Baeverfjord, G., Rørvik, K.-A., Sørensen, M., Oehme, M., and Åsgård, T. 2011b. Nutritional responses in rainbow trout (*Oncorhynchus mykiss*) fed diets with different physical qualities at stable or variable environmental conditions. doi: 10.1111/j.1365-2095.2011.00868.x.

Baeverfjord, G., Refstie, S., Krogedal, P., and Åsgard, T. 2006. Low feed pellet water stability and fluctuating water salinity cause separation and accumulation of dietary oil in the stomach of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 261, 1335-1345.

No 24

Feed as the key to sustainable aquaculture

Anders K. Kiessling
Department of Wild Life, Fisheries and Environment, Swedish University of Agricultural Sciences (SLU), 901 83 Umeå, Sweden

E-mail: anders.kiessling@slu.se

Abstract
In open systems feed is both the single largest cost to the farmer and the major factor affecting the environmental impact of fish farming, including production and transport of the feed as well as effluence from the farm during production. The main difference from terrestrial intensive animal production is that fish is farmed in water where recapture of dissolved nutrients are very difficult. RAS technology has the ability of equalising the problem between terrestrial and aquatic production. The two major issues terrestrial animal production, beyond local environment effects and high input of non-renewable energy, is the use of human grade food resources and secondly the loss of nutrients out of the food production system. Present RAS systems share both these problems with terrestrial animal production as well as the issue of non-renewable energy resources but it is reducing the problem of local impact. In order to make RAS production truly sustainable all these issues, including profitability and animal ethics, must be addressed. This presentation focuses the issue of feed resources competing with human food resources and the loss of nutrients out of the food production system as well as some of the problems specific for aquatic systems these issues impose.

No 25

Feed and organic matter

Anne Johanne Dalsgaard
Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark

E-mail: jtd@aqua.dtu.dk

Abstract
Organic waste from fish production is conventionally measured as BOD_5 (biological oxygen demand measured during 5 days) and COD (chemical oxygen demand (includes BOD_5)). Organic waste is of particular concern for several reasons. The easily degradable part (BOD_5) may have an immediate, negative impact on the receiving water body by reducing dissolved oxygen concentrations and increasing sedimentation. Within aquaculture systems, a high organic load may affect fish health and performance directly (e.g., gill disease) as well as indirectly (proliferation of pathogenic bacteria and parasites, reduction of dissolved oxygen concentrations, etc.). In recirculating aquaculture systems (RAS), a high organic load caused by limited water exchange may affect biofilter performance by favouring heterotrophic bacteria at the expense of autotrophic, nitrifying bacteria.
Organic waste in RAS primarily originates from undigested feed, but also metabolic losses, mucus, dead tissue, feed waste and intake water may contribute. The nutrient composition of the feed affects the quantity and composition of the organic (undigested) waste, and including for example plant protein ingredients may affect the distribution between particulate and unsedimented (suspended and dissolved) organic waste.
Quantifying aquaculture waste, including organic matter, nitrogen (N) and phosphorus (P), into different waste fractions (particulate and unsedimented) is essential for optimising the design of different treatment setups with specific cleaning objectives. A series of studies were carried out to measure the solid and unsedimented waste from juvenile rainbow trout (*Oncorhynchus mykiss*) fed three commonly applied commercial diets (Dalsgaard and Pedersen, 2011). Furthermore, it was hypothesized that particulate COD can be calculated from undigested nutrients. There were only minor differences between the diets. Generally, 48% of ingested N was recovered in the water and 7% in the solids. For phosphorus, 1% was recovered in the water and 43% in the solids. More COD was recovered as solids than as unsedimented waste, while it was opposite for BOD_5. A BOD_5/COD ratio of 0.5 was derived, indicating that unsedimented organic waste is characterized by easily degradable organic matter. In comparison, a solid BOD_5/COD ratio of 0.2 indicated that this waste fraction contains high amounts of hard-to-degrade organic matter. The study confirmed that solid COD can be quite accurately calculated from the composition of undigested nutrients.

Dalsgaard, J., Pedersen, P.B. 2011. Solid and suspended/dissolved waste (N, P, O) from rainbow trout (*Oncorhynchus mykiss*). Aquaculture 313, 92-99.

No 26

Composition of excreta from salmonid farming in resirculated aquaculture systems

Trond Storebakken[1]*, Yuexing Zhang and Margareth Øverland
[1]Aquaculture Protein Centre CoE, Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences, N-1432 Ås, Norway

*E-mail: trond.storebakken@umb.no

Abstract

Materials released from fish farming into the water are mainly solids from uneaten feed and faeces, and water solubles from metabolism and leakage from feed and faeces. Physical feed quality and feeding systems must be in a manner that ensures minimum loss of dust. This is more feasible in resirculated aquaculture systems (RAS) than in open sea-cage systems with pneumatic transport of feed in tubes over long distances. Thus, undigested material and metabolites account for most of the excreta. It is feasible to carefully monitor feed intake so that near-satiation feeding can be achieved, with virtually no feed loss. It is realistic to produce rainbow trout growing from 0.1 to 0.3 kg with a feed conversion ratio (FCR) of 0.72 kg feed (kg gain)$^{-1}$ if fish meal is the main source of protein, and 0.76 kg feed (kg gain)$^{-1}$ in a diet composed with 95% of protein from essential amino acid supplemented, dephytinized soy protein concentrate (SPC). Less concentrated plant feed ingredients will result in higher FCR.

Depending on the selection and processing of ingredients and feed, faecal nitrogen losses can range from 4.7 to 6.1 kg nitrogen (N) t^{-1} produced. Faecal phosphorus (P) loss may be as high as 5.7 kg t^{-1} in a fish meal (FM) diet, 3.8 kg t^{-1} in a diet with 95% soy protein concentrate (SPC), and as low as 2.5 kg t^{-1} in the same diet with phytase-treated SPC. Most of the organic faecal material originates from indigestible non-starch polysaccharides (NSP) and undigested starch. The starch excretion is highly increased when the limited capacity for digestion is overridden. Nutrient leakage from faeces must be minimized by rapid filtration in RAS.

Metabolic losses mainly depend on diet formulation, water temperature, fish size, and feeding rate. The N-metabolites are ammonia from deamination and urea from catabolism of nucleic acids. If rainbow trout are fed fish-meal (FM) based diets, metabolic loss of N may be in the range of 17 kg t^{-1}, while completely replacing the FM by 95% dephytinized and essential amino acid supplemented soy protein concentrate (SPC) and 5% of a combination of Antarctic krill meal and dehydrated water solubles from krill, was 23 kg t^{-1}. Similar values for values for P were 0.17 kg t^{-1} for the FM diet, 0.28 kg t^{-1} for a diet with untreated SPC, and 0.08 kg t^{-1} in the SPC is incubated with phytase.

Mineral elements like Ca, P, Mg and Zn may be accumulated in RAS, and fish are able to take these up from the water.

No 27

Water quality in Recirculating Aquaculture Systems (RAS)

Ep Eding[1]*, Catarina Martins[1,2], Edward Schram[3], Andries Kamstra[3] and Johan Verreth[1]
[1]Aquaculture and Fisheries group (AFI), Wageningen University, the Netherlands
[2]Centro de Ciências do Mar, Universidade do Algarve, Portugal
[3]IMARES, Wageningen University and Research Center, the Netherlands

*E-mail: Ep.Eding@wur.nl

Abstract
In conventional RAS, treatment units are designed and installed to control water quality in the culture tanks by counteracting the accumulation of fish metabolites and the consumption of oxygen by fish. Additional water treatment units such as e.g. UV and ozonation are installed for further improvement of water quality. In some farms denitrification is installed in the recirculation loop for Nitrate-N concentration control.
Conventional Recirculating Aquaculture Systems (RAS) use in general small amounts of water per kg feed (100-1000L/kg feed) when compared to flow through systems (> 50.000L/kg feed). In innovative RAS applying denitrification water use in RAS can be further reduced to 30L/kg feed depending on the cultured fish species (Martins et al., 2009). Reasons to reduce fresh water use in RAS in the Netherlands are:

(1) prevention of costs for fees on groundwater. Fees are approximately 0.23€/m^3 groundwater when installing a groundwater extraction installation with a capacity larger than $10m^3/h$;
(2) reducing the cost for heating supply water;
(3) restrictions on the effluent volume discharged to the local sewer;
(4) fees for waste discharge, pollution units which are mainly based on the amount of COD and Kjeldahl-N discharge.

The further reduction in water use per kg feed in RAS results in accumulation of compounds not treated sufficiently by conventional water treatment units. This development raises the concern that in RAS used for ongrowing fish accumulation of substances may impair:

(1) fish growth performance;
(2) welfare and
(3) flesh quality.

Impaired growth performance is reported for some species cultured in RAS as compared with flow-through systems, e.g. sea bass *Dicentrarchus labrax* and *Oreochromus niloticus.* Although the mechanism behind growth retardation in RAS is currently unknown several hypothesis have been reported such as the accumulation of growth inhibiting factors (GIF): (1) fish metabolites (e.g. steroids), (2) system-produced compounds (e.g. quantity and composition of bacteria, bacteria metabolites related with the age of the biofilter) and (3) feed-related substances (e.g. heavy metals) (Martins et al., 2009). This presentation will focus on water quality parameters which might affect fish performance in RAS when closing the recirculation system further.

Martins, C.I.M., Eding E.H., Verdegem M.C.J., Heinsbroek, L.T.N, Schneider, O, Blancheton J.P., Roque d'Orbcastel E. and Verreth, J.A.J. 2010. Review: New developments in Recirculating Aquaculture Systems in Europe: A perspective on environmental sustainability. Aquacultural Engineering 43, 83-93.

No 28

Influence of some typical RAS water quality parameters on fish physiology and system management

Bendik Fyhn Terjesen
Nofima , Feed and Nutrition, NO-6600, Sunndalsøra, Norway

E-mail: bendik.terjesen@nofima.no

Abstract
Recirculating aquaculture systems (RAS) for production of Atlantic salmon smolts are becoming common in several parts of the world. In this talk focus will be placed on the physiology and metabolism of two nitrogenous compounds, ammonia and nitrite, which are critical factors in dimensioning and management of RAS for Atlantic salmon. In two recent experiments we found that the Atlantic salmon parr is able to activate several of the classic ammonia detoxification mechanisms, and early adverse effects were not detectable after long-term chronic exposure, and no significant effects on smoltification were found. Furthermore, preliminary results from a study on nitrite exposure indicated that as expected, chloride influences nitrite toxicity, but despite high Cl: NO_2-N ratios, nitrite still accumulated in plasma of the Atlantic salmon parr, and growth rate was reduced during the early phases of exposure. The results will be discussed in relation to RAS design, dimensioning and management.

No 29

Water quality criteria for salmonids in intensive fish farming

Sveinung Fivelstad
Bergen University College, P.O. Box 7030, Nygårdsgaten 112, 5020 Bergen, Norway

E-mail: sfi@hib.no

Abstract
Oxygen is generally the first limiting factor for the water flow requirement in a land based aquaculture system, while carbon dioxide or pH is the second limiting factor.
Carbon dioxide has both direct physiological effects on the fish, as well as indirect effects by changing the pH and thereby the chemistry of metals in the water. The most widely used safe level for carbon dioxide was earlier 20 mg/L free carbon dioxide.
For carbon dioxide the safe criterion used for the Norwegian smolt production is 15 mg/L. This criterion is based on experiments performed mainly on Atlantic salmon smolts between 4 and 10 °C. However, a recent experiment on Atlantic salmon parr showed that carbon dioxide is more toxic at 5 °C compared to 15 °C. Carbon dioxide toxicity is dependent on the fish species, life stage, temperature, pH and metal form and concentration in the water.
Rainbow trout may have a higher safe level than Atlantic salmon in freshwater. Generally, effects on growth are found above 20-30 mg/L. The present presentation will focus on pH, Al and carbon dioxide and effects on physiology, growth and survival. Physiological effects as increased ventilation frequency, increased partial pressure of carbon dioxide, increased bicarbonate concentration and reduced plasma chloride will be shown (and related to growth).

No 30

Water quality and growth of fish in RAS systems

Helgi Thorarensen
Department of Aquaculture and Fish Biology, Holar University College, Iceland

E-mail: helgi@holar.is

Abstract
Water recirculation aquaculture systems offer both opportunities and challenges for growing fish. The closed systems offer a level of control of temperature and water quality and allow conditions to be maintained near optimum for the growth of the fish. However, it is not possible to control entirely the water quality in closed systems and, therefore, the growth of fish especially in intensive systems may be compromised compared with fish reared in flow-through systems.
Water quality in aquaculture is primarily determined by the levels of O_2, CO_2 and NH_3 and has a significant effect on the growth rate of aquaculture fish. The growth rate of many species increases progressively with oxygen saturation up to 100%. The concentration of CO_2 and NH_3 can also limit the growth of fish although critical levels vary among species. The critical levels of water quality variables in aquaculture are normally determined under conditions where only the variable in question is varied. However, this method may not give comprehensive answers to the question of where the critical limits should be set. In closed systems, all water quality variables change at the same time. Under these conditions, complex interactions among water quality variables may limit the growth rate of fish at levels where each of these variables would not be limiting by itself. There are only few studies that have compared the growth of fish in water recirculation systems and simple flow through systems. Most of these studies have in fact suggested that fish in recirculation systems do not grow as well as fish reared in flow-through systems. Before aquaculture companies move towards further intensification of fish farms with reduced water exchange rates further information is required on the growth performance of fish in water recirculation systems compared with fish reared in flow-through systems.

No 31

Influence of feed ingredients on water quality parameters in RAS

Per Bovbjerg Pedersen[1]*, Lars-Flemming Pedersen[1], Karin Suhr[1], Anne Johanne Dalsgaard[1] and Erik Arvin[2]
[1]Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark
[2]Technical University of Denmark, DTU Environment, Department of Environmental Engineering, Bygningstorvet, Building 115, 2800 Kgs. Lyngby, Denmark

*E-mail: pbp@aqua.dtu.dk

Abstract
Although feed by far is providing the major input to RAS, relatively little is published about the correlation between feed composition and the resulting water quality in such systems.
In a set-up with 6 identical RAS, each consisting of a fish tank (0.5 m^3), a swirl separator, a submerged biofilter (0.67 m^3/100 m^2) and a trickling filter (0.17 m^3/33 m^2), two different feed types were tested in a triplicate set-up.
The two feed types used were identical recipes (44% protein, 30% fat) except for the inclusion of 0.2 % guar gum (Grindsted Guar, Danisco) in one of the types. The inclusion level of plant-based protein in the diets was relatively high (68% of protein).
Growth performance (SGR, FCR) was not different between the feed types.
Fish in each system - and thereby the system itself - were fed 500 g feed/day. After 8 weeks on the same commercial feed type, test feed was administered to the systems for 49 consecutive days. Each week, 24h-water samples (1 sample/hour) were collected from each system. The sludge collected in the swirl separator that day was also collected. Water and sludge were subsequently analysed for nitrogen, phosphorous and organic matter content.
Inclusion of guar gum had impact on water quality in the systems as well as on matter removed by the swirl separators. In the RAS water, phosphorous (P_{tot} and P_{diss}) concentrations were reduced by guar gum. Organic matter content (COD_{diss}) in the water was also reduced.
Corresponding to this, more dry matter, more COD and more phosphorous were removed by the swirl separators.
As might be expected from the high protein digestibility (determined in a separate study), no effects were generally observed on nitrogen compounds.

No 32

Modeling of TAN in recirculating aquaculture systems by AQUASIM

Erik Arvin[1]* and Lars-Flemming Pedersen[2]
[1]Technical University of Denmark, DTU Environment, Department of Environmental Engineering, Bygningstorvet, Building 115, 2800 Kgs. Lyngby, Denmark
[2]Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark

*E-mail: erar@env.dtu.dk

Abstract
Modeling of total ammonium nitrogen (TAN) in recirculating aquaculture systems (RAS) contribute to identifying and quantifying the most important processes and their relative contribution to removal of TAN. AQUASIM is a flexible modular simulation system for water quality in natural and technical systems developed by EAWAG (Reichert, 1994). AQUASIM allows simulating complex biological, chemical and physical processes in standardized hydraulic systems.
We used AQUASIM to model the steady state TAN concentrations in 12 experimental recirculating aquaculture systems (RAS) operated by DTU AQUA in Hirtshals, Denmark (Pedersen et al., 2009). Water from the fish rearing tank is treated in a sedimentation tank and subsequently by biological treatment in a submerged biofilter and in a trickling filter. Generally, the performance of the biological treatment was very well and average TAN concentrations in the RAS were in the range 0.1-0.4 mg TAN/L depending on the cumulative feed load. The average nitrite concentrations were a little higher than the average TAN concentrations, in the range 0.2-0.6 mg N/L.
Our TAN model simulated TAN removal by the following processes: 1 & 2: Nitrification in the biofilm in the submerged biofilter and in the trickling filter, 3. nitrification by suspended nitrifyers (flocs) in all compartments of the RAS, and 4. TAN assimilation associated to biomass growth.
The simulation model was able to describe the measured TAN concentration very well after least square optimization of the nitrification rate constants in the biofilm and in the suspended biomass. Thus, it was demonstrated that AQUASIM is a very useful simulation tool that can be applied to improving process understanding as well as to contributing to fish production optimization.

Pedersen, L.-F., Pedersen, P.B., Nielsen, J.L., and Nielsen, P.H. 2009. Peracetic acid degradation and effects on nitrification in recirculating aquaculture systems. Aquaculture 296, 246-254.

Reichert, P., 1994. Aquasim - a tool for simulation and data-analysis of aquatic systems. Water Science and Technology 30, 21-30.

No 33

Modelling and simulation of RAS

Torsten Wik
Department of Signals and Systems, Chalmers University of Technology, SE 412 96 Göteborg, Sweden

E-mail: tw@chalmers.se

Abstract
From a system point of view, recirculating aquaculture systems (RAS) are in general more complex than flow-through systems. Not only because they may include quite extensive water treatment but also because of the feedback interactions between the water treatment system, the feed, the fish and the control systems attached. As a consequence, their behavior can be difficult to predict, analyze and also to control. In particular for RAS in land based fish tanks, where the water exchange should be as small as possible, there is a strong feedback and high demands on the water treatment, e.g. the maintenance of an efficient nitrification, denitrification and organic removal.
Modeling and simulation can be an important tool to deal with this increased complexity, and move the development of RAS further towards an ecologically sustainable fish production. Many different models have been developed to describe fish growth, energy needs, gastric evacuation, feed conversion etcetera. However, when RAS are modeled these models are in general connected to simplified and stationary models of the wastewater treatment (WWT). Within the research area of biological wastewater treatment on the other hand, advanced models of different treatment stages have been developed, though without aquaculture in mind. In general, the dynamics is then considered because in most applications the conditions the bacteria are exposed to vary intrinsically depending on, for example, changes in weather conditions, time of the day and day in the week.
RAS are also intrinsically varying, and never in a true steady state, simply because the fish is growing and, hence, the load on the treatment is also increasing. In the work presented here we suggest a framework for integrating the two modeling cultures (Aquaculture and WWT). This means that the waste from fish and feed has to be described in terms of the components needed for the wastewater treatment models. It also means that some additional processes and components needed for aquaculture have to be added to the standard WWT models. Some practical experiences from the development of a RAS simulator are addressed and as an illustration a RAS for Eurasian Perch is modeled and simulated.

No 35

Waste management in Recirculating Aquaculture Systems

Jaap van Rijn
The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot, Israel

E-mail: vanrijn@agri.huji.ac.il

Abstract
Waste management in aquaculture depends to a large extent on the type of culture method used. Whereas, in some systems, such as conventional earthen-bottom ponds, waste products do not accumulate due to the fact that fish density does not exceed the natural carrying capacity of the system, in other culture systems, such as open raceways, highly diluted waste is produced, which often cannot be treated. In RAS, due to a reduction in water use, concentrated solid and dissolved wastes are produced. Such concentrated wastes can be treated and thus allow for a considerable reduction in waste discharge as compared to more open culture systems. Waste reduction methods in RAS are either based on end-of-pipe treatment of the concentrated effluent waste, are an integrated part of the water recirculation loop of such systems, or are a combination of both. In addition, other management practices in RAS such as using high quality feeds, applying controlled feeding regimes to minimize accumulation of unused feed and using sophisticated methods for water quality monitoring and control, all result in more efficient fish growth, hence, waste reduction. End-of-pipe treatment of solid and dissolved aquaculture wastes from freshwater RAS is similar to that of treatment methods used in other animal husbandry practices. Among these methods are: direct land application of aquaculture waste, treatment of waste by regional/municipal wastewater treatment plants or by on-site systems such as aerobic and anaerobic lagoons, constructed wetlands and composting facilities. In marine RAS, effluent treatment is more restricted than in freshwater systems and here natural and constructed wetlands are sometimes used. In addition, some marine RAS systems are operated as part of a polyculture system in which fish culture effluent is used for production of valuable byproducts such as seaweed and bivalves. Waste management within RAS is often limited to conversion of ammonia to nitrate by nitrification and CO_2 removal by degassing. Thus, except for part of the carbon, all other elements excreted by the fish accumulate in these systems and require removal by water exchange and solids capture. Additional waste treatment procedures within the reuse water flow of commercial RAS systems are used to a limited extent. An example of a RAS operated with additional waste treatment steps is a system in which sludge is retained in order to induce many of the natural processes occurring in the sediment of conventional fish ponds. In this system, sludge is concentrated by means of settling or mechanical filtration and kept in treatment basins that are part of the reuse water flow of the RAS. Like in anaerobic, organic-rich sediments, gasification of nitrogen and carbon as well as bacterial-mediated phosphorus mineralization reduce the waste production in these RAS to such an extent that water and waste discharge are very low or not required.

No 36

Towards environmentally sustainable aquaculture: Exploiting fermentation products from anaerobic sludge digestion for fueling nitrate removal in RAS

K.I. Suhr[1]* and P. Bovbjerg Pedersen[1]
[1]Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark

*E-mail: ksu@aqua.dtu.dk

Abstract
Aquaculture is the world’s fastest growing food production sector (FAO, 2007). The continuous growth in many countries, however, relies heavily on the ability to reduce the emission of nutrients and chemicals from the fish farms. A way to manage and treat the nutrient aquaculture wastes is by production in recirculating aquaculture systems (RAS). In Denmark, more than 50 % of total fresh-water rainbow trout production is made in semi-intensive RAS, called ModelTroutFarms (MTF). MTF efficiently removes organic matter (93%), phosphorous (76%), and nitrogen (50%) (Svendsen et al., 2008). This makes nitrogen the limiting process parameter for further environmentally viable increase in production. Nitrogen removal is a two step transformation process, with (1) ammonia-N oxidation to nitrate-N in the RAS’ biofilter, and subsequently (2) nitrate-N reduction to N_2 in the constructed wetlands. The latter being the final cleaning component of the MTF set-up. No specific denitrification filter has so far been implemented in Danish MTFs. An *in-situ* study was conducted at a commercial MTF (1000 ton/year) for evaluating the potential of using the fermentation products from anaerobic digestion in the sludge storage basins, to fuel denitrification in specific denitrification filters. In experimental filters (5.5 m^3) nitrate-containing outlet water was mixed with drainage water from the sludge storage basins according to a factorial design varying C/N ratio from 4 to 12 (COD_s /NO_3-N) and hydraulic retention time (HRT) from 50 to 180 min. The highest removal rate recorded, 125 g NO_3-N/$m^3_{reactor}$/d, was found in treatments at the design center point, and multivariate response surface analysis modeled a maximum N-removal at C/N ratio of 8.8 and HRT of 114 min. The effect of C/N ratio depended on the HRT: At low HRT, variation in C/N ratio had no effect on N-removal. On the contrary, at high HRT, the highest N-removal was measured at high C/N ratio but significant ammonia-N was simultaneously produced, most probably by dissimilatory nitrate reduction to ammonia (DNRA). Running the filters at high HRT and low C/N ratio rendered a relatively lower nitrate-N removal rate but significantly higher ammonia-N reduction, which could indicate anaerobic ammonia oxidation (anammox) activity. A controlled laboratory anaerobic MTF sludge digestion experiment showed that app. 40% additional nitrate-N reduction could theoretically be achieved if implementing the use of fermented sludge as carbon source for denitrification. Besides the N-reduction, the directly linked sludge (/organic matter) reduction is a beneficial side effect of such an operational set-up.

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No 38

Application and analytical verification of peracetic acid use in different types of freshwater aquaculture systems

Lars-Flemming Pedersen
Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark

E-mail: lfp@aqua.dtu.dk

Abstract
Peracetic acid (PAA) is a highly reactive peroxygen compound with wide-ranging antimicrobial effects. PAA has recently gained substantial attention, due to additional beneficial attributes such as easily degradability and harmless disinfection byproducts. However, PAA is only sporadically used by the aquaculture industry as it is difficult to apply in correct dosages. This study describes the degradation kinetics of PAA when used as an aquaculture disinfectant. Effects of temperature, organic matter content and initial PAA dosage on the chemical fate of PAA is reported. Furthermore, investigations of water sanitation with PAA application were used to analytically verify actual PAA concentration under real conditions at different kinds of aquaculture systems. A characteristic instant disinfection demand was found to be significantly positively related to water COD content, and PAA half-lives were found to be in the order of a few minutes. The study revealed that PAA degrades so rapidly that insufficient disinfection is a likely outcome. The observations have applications for optimizing water treatment strategies with PAA. The investigations also indicated that the rapid degradation and hence swift presence of PAA in RAS made raceway disinfection possible without bypassing the biofilters. Future perspectives, benefits and drawbacks on the use of PAA in RAS are discussed.

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Probiotics

Rannveig Bjornsdottir
Matís ohf / University of Akureyri, Icelandic Food and Biotech R&D, Borgum við Norðurslóð, 600 Akureyri, Iceland

E-mail: rannveig.bjornsdottir@matis.is

Abstract
High mortality rates and deformities are considered major bottlenecks in intensive culturing of many fish species, with bacterial numbers and the establishment of an unfavourable bacterial community among the possible underlying causes identified. High fish densities entail increased organic nutrient availability that has been found to support the multiplication of opportunistic bacterial groups. Trends towards increased intensification of aquaculture production systems therefore call for solutions aimed at microbial manipulation and control of the microbial community of such systems.
Beneficial effects have been verified without successful colonization of the probionts in the gastrointestinal lumen of fish and repeated applications of the probionts to the systems therefore necessary. Hence, the bio-filters of RAS represent an interesting location for the establishment, growth and maintenance of probiotic organisms applied to the systems.
The presentation will give a literature overview of the current status in use of probiotics in recirculating aquaculture systems.

Animal welfare and stress in salmon smolts (*Salmo salar* L.) produced in land-based Recirculating Aquaculture System (RAS)

Martin H. Iversen[1]* and Robert A. Eliassen[1]
[1]University of Nordland, Faculty of Bioscience and Aquaculture, Bodø, Norway

*E-mail: martin.haugmo.iversen@uin.no

Abstract
The purpose of the study was to compare daily stress levels measured as plasma cortisol in commercial salmon smolt production based on Recirculation Aquaculture System (RAS). One also wished to follow routine handling during a production cycle in the RAS system to pinpoint possible bottlenecks which could have a negative impact on stress levels, and thus compromise the animal welfare.

The experiment was done at the smolt production plant of Fútaklettur (Faroe Islands) autumn 2007. Background plasma cortisol levels was measured every 14 days in two production tanks (350 m^3) after standard procedure, and earlier studies by the authors have shown that a increase in plasma cortisol above resting levels could give a early warning of compromised production prior to increased mortality and disease outbreak. During a normal salmon smolt production cycle the fish has experienced several handling episodes as grading, vaccination and transfer to sea, and in this experiment one wished to study the stress response (as plasma cortisol and mortality) during vaccination and transfer to sea.

The results show that the daily stress levels measured as background plasma cortisol at the smolt production plant of Fútaklettur (Faroe Islands) is in average low, and compared to Norwegian smolt plants (flow through) some of the lowest ever recorded. However due to the limit availability of freshwater in the plant a vaccination cycle of a 350 m^3 tank was completed in 4 to 5 day. During this time the both mortality and stress levels accumulated, and the animal welfare was compromised. Similar results was shown during transport and transfer to sea. The compromised animal welfare was due to prolonged handling time and the breaking point for salmon smolt regarding to stress levels and mortality seemed to arise during the third day of handling. These bottlenecks during handling in the RAS system could easily be avoided with good management. Handling of fish in larger units with handling duration over two days should be avoided or stretched over longer time with ample time of recovery during this phase, thus avoiding consequences of accumulated stress.

No 40

Off-flavour in farmed fish

Edward Schram[1]*, William Swinkels[2], Miriam van Eekert[3], Els Schuman[3], Christiaan Kwadijk[1], Jan van de Heul[1], Tinka Murk[1,4], Johan Schrama[5] and Johan Verreth[5]
[1]IMARES, Wageningen UR, The Netherlands
[2]Nijvis BV, Nijmegen, The Netherlands
[3]LeAF, Wageningen, The Netherlands
[4]Department of Toxicology, Toxicology Section, Wageningen University, The Netherlands
[5]Aquaculture and Fisheries group, Wageningen University, The Netherlands

*E-mail: Edward.schram@wur.nl

Abstract
Off-flavour is an important product quality issue as well as a significant economic problem for RAS and pond aquaculture because in many cases off-flavoured fish is rejected by consumers. Most common are earthy-musty off-flavours caused by the bioaccumulation geosmin and 2-methyl-iso-borneol (MIB) in fish tissues, which are produced by a wide range of microbiota as secondary metabolite.
Attempts to control microbial geosmin and MIB production in ponds have been largely unsuccessful, probably because the biological functions of geosmin and MIB and the conditions inducing their production are not clear. In an on-going survey we aim to link off flavour incidence to operating conditions, design and management of commercial RAS. Preliminary results suggest that nitrifying trickling filters are the main geosmin and MIB source in RAS. By lab scale comparison of trickling and moving bed biofilters we are currently investigating biofilm management as a way to reduce geosmin and MIB production.
Waterborne geosmin and MIB are rapidly taken up by the fish via their gills and accumulated in body fat until a dynamic equilibrium between the water and lipid fractions in the system is reached. Presently aquaculture producers utilize the reversibility of this process to depurate off flavours from fish by placing them in water free of geosmin and MIB. We predict that a physiological approach towards depuration will give better results and reduce its duration. We are therefore currently studying the physiology and kinetics of adsorption, distribution, metabolism and excretion of GSM and MIB in several fish species. Preliminary results show that, in contrast to previous reports, fish metabolize geosmin.

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Parasites in RAS

Niels Henrik Henriksen
Dansk Akvakultur, Vejlsøvej 51, Byg. J, 8600 Silkeborg, Denmark

E-mail: niels@danskakvakultur.dk

Abstract
Intensive recirculation aquaculture system (RAS) gives an extraordinary good opportunity to avoid and control parasite infection in fish farming. But most RAS also gives some parasites an extraordinary good opportunity to grow and multiply if or when the parasites get into the systems. Whether you are going to have success or not depends on many different factors such as fish flow, water supply, general bio security, water treatment, system design, fish species and parasite species in your geographically region. From a veterinarian point of view an indoor completely “closed” RAS is an easy way to totally avoid any parasites problems, but these systems are often very expensive to build and run. In Denmark we have during the last ten years seen many different forms of RAS system. From extensively outdoor systems still using water from streams/rivers to intensive indoor systems using borehole water. And the parasite problems are very different from system to system. The Danish model-farms for rainbow trout is a good example of how introduction of RAS gives new problems but also gives the fish farmer better opportunities to avoid unacceptable economically losses from parasite infections.
From an environmental protection point of view, RAS are most often a big advantage, reducing the effluent of parasite medicines and biocide to the receiving water systems. This is due to either a minimal use of the substances and/or a better opportunity to reduce or eliminate the substances within the farm before disposal.

No 42

Marine Model Trout Farms: developments in marine RAS

Per Bovbjerg Pedersen
Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, 9850 Hirtshals, Denmark.

E-mail: pbp@aqua.dtu.dk

Abstract
Economical and environmentally sustainable production of large salmonids in sea water has in Denmark been called for during some years. Based on the experience gained from the Danish Model Trout Farms in freshwater, a rather similar concept has been developed for farming of larger fish in sea water. This development and demonstration unit in commercial scale will during the next four years hopefully provide scientific and practical basis and support for further development in coming generations of Marine Model Trout Farms for large salmonids.
The unit consist in the recirculation loop of one large fish tank, ø25 m, depth 4.5 m, i.e. tank volume some 2,000 m^3; a drum filter (HydroTech); 9 separate pumps (Grundfos NB 150-200/224), 2 for each of 3 submerged biofilter-sections and 3 pumps bypassing the submerged biofilters, leading directly to the large trickling filter where the water from the submerged biofilters also enter. Each submerged biofilter contains 22.6 m^3 filter elements (RK BioElements 750 m^2/m^3; RK plast) and the trickling filters contains 90 m^3 (BioBlock 200, Exponet). From the trickling filter water is led directly back to the fish tank.
According to fish stock, feeding level and water temperature the pumps can be individually turned on/off primarily in relation to oxygen need and consumption in the fish tank. In a 1 year batch production some 20 t of fish will be introduced in April and some 80 t are supposed to be harvested in December.
End-of-pipe treatment is a two-step process. First, nitrogen is removed in a full-scale experimental set-up where sludge from the drum filter is hydrolysed and the VFAs generated used as energy-source for the denitrification process in separate tanks/filters. Final polishing follows in a constructed wetland.
For the first 2 years of operation production will be focussed on rainbow trout production, mimicking the typical Danish net cage farming cycle, where the cages are stocked with fish of 750 – 1,000 g in April/May and all harvested before Christmas weighing some 4 kg/pcs. During these two years important production parameters such as growth-rate, feed conversion and pigmentation will be compared to net-cage results and a full-cost comparison will be performed. After 2 years Atlantic salmon will be farmed in all-year operation.
The project is supported by the Danish GUDP joint cooperation between research and industry, and the participants are: The North Sea Center (facilities); AquaPri (fish producer); Biomar (feed producer); Billund Aquaculture (system supplier); RK Plast (producer of biofilter elements) and DTU Aqua. Facts, Experience gained, facts and figures will be presented.

Colophon

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DTU Aqua
National Institute of Aquatic Resources
Technical University of Denmark

Jægersborg Allé 1
DK-2900 Charlottenlund
Tel: + 45 35 88 33 00
Fax: + 45 35 88 33 33

www.aqua.dtu.dk