2nd Workshop on Recirculating Aquaculture Systems Aalborg, Denmark, 10-11 October 2013

Program and Abstracts

DTU Aqua Report No. 267-2013

Edited by Anne-Johanne Tang Dalsgaard

DTU Aqua
National Institute of Aquatic Resources

2nd Workshop on Recirculating Aquaculture Systems Aalborg, Denmark, 10-11 October 2013

Program and Abstracts

DTU Aqua Report No. 267-13

Edited by Anne Johanne Dalsgaard

The workshop is organised by DTU Aqua and NordicRAS

Supported by:
Nordic Council of Ministers
North Denmark Region

Main sponsors:
BioMar A/S
Grundfos DK A/S

Other sponsors:
AKVA Group
Billund Aquaculture

The granted support is hereby acknowledged.

DTU Aqua
National Institute of Aquatic Resources

Preface

Welcome to the 2nd Workshop on Recirculating Aquaculture systems held by the Nordic Network on Recirculating Aquaculture Systems and organized by DTU Aqua. The workshop aims at bringing together researchers and industrial partners with an interest in RAS, creating an opportunity for exchanging practical experiences and scientific knowledge on the newest developments in RAS.

The workshop in 2013 is held in parallel with DanFish International 2013 hosting DanAqua: an aquaculture exhibition focusing particularly on recirculating aquaculture technology.

The 1st workshop was held in Helsinki, Finland in 2011 with 126 participants from thirteen European countries. There were 37 speakers who, like the audience in general, represented all kinds of experiences and approaches to the subject. Practitioners (farmers and RAS entrepreneurs), feed companies and researchers made oral contributions, creating an interesting mix of industry and research experiences. This year, presumably reflecting the increasing interest in recirculation technology, there are even more speakers and participants from even more countries. We have this time decided to bring in knowledge from related research areas, hoping that this will inspire new perspectives and reflections for the future development of RAS, and we hope you will perceive this with open minds.

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). The network was founded in 2011 with support from the Nordic Council of Ministers. The steering committee consists of country representatives from Denmark, Norway, Sweden, Finland and Iceland:

- Asbjørn Bergheim, IRIS, Norway
- Helgi Thorarensen, Holar University College, Iceland
- Jouni Vielma, Finnish Game and Fisheries Research Institute, Finland
- Per Bovbjerg Pedersen, DTU Aqua, Denmark
- Torsten Wik, Chalmers, Sweden

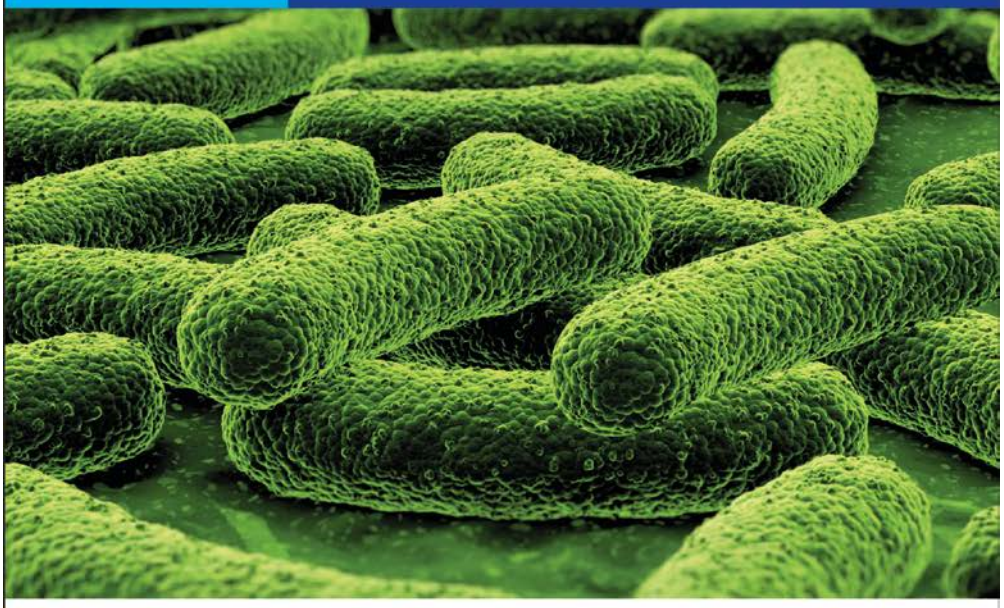
It is our hope and plan that this workshop will be a recurrent event every other year. We are therefore very pleased that the interest in the workshop this year again has been overwhelmingly positive. We wish you some interesting and pleasant days in Aalborg.

On behalf of NordicRAS
Anne Johanne Dalsgaard, DTU Aqua

Table of contents

ORBIT

ORBIT 929 FEED FOR FISH AND FOR THE BACTERIA IN THE BIOFILTER



ORBIT 929

Higher yield in recirculation aquaculture systems

ORBIT is a feed for RAS systems that allows achieving up to 25 % additional production capacity on the same biofilter, compared to other high performance feed types.

Fish farming in modern RAS systems asks for taking care of two living organisms - the fish and the bacteria living in the biofilter.

With ORBIT now also the bacteria can perform at their optimum, resulting in a maximum yield of your RAS system.

Add to that, a cleaner and healthier production water and reduced emissions to the environment.

BioMar

www.biomar.dk

Program for the 2nd workshop on Recirculating Aquaculture Systems

Thursday 10 October 2013		Abstract no.
08^{00} - 09^{00}	**Registration**	-
Opening session, 09^{00} – 10^{05} Chair: A.J. Dalsgaard, Technical University of Denmark		-
09^{00} – 09^{10}	**Opening and welcome** A. Bjarklev, President, Technical University of Denmark	-
09^{10} - 09^{15}	**Welcome address from the industry** J. Bregnballe, President, AquaCircle, Denmark	-
09^{15} - 09^{40}	**Keynote: Current views on water quality control in RAS** J. Verreth, Wageningen University and Research Centre	1
09^{40} - 10^{05}	**Keynote: Changing demands to feed and raw materials for feed for RAS** N. Alsted, Executive Vice President, BioMar	2
10^{05} – 10^{45}	**Coffee break**	-
Session 1a: Water quality and feed, 10^{45} - 12^{15} Chair: P.B. Pedersen, Technical University of Denmark		-
10^{45} – 11^{00}	**Nitrogen waste load from juvenile rainbow trout (*Oncorhynchus mykiss*)** A.J. Dalsgaard et al.	3
11^{00} – 11^{15}	**Effects of diet composition and ultrasound treatment on particle size distribution and carbon bioavailability in feces of rainbow trout** A. Meriac et al.	4
11^{15} – 11^{30}	**Feed for RAS** K. Ekmann	5
11^{30} – 11^{45}	**Plant protein substitution of fish meal: Effects on rheology** A. Brinker	6
11^{45} – 12^{00}	**Dietary effects on fecal waste fraction in Atlantic salmon (*Salmo salar*)** A. Kamstra et al.	7
12^{00} – 12^{15}	**Factors affecting faecal stability in salmonids: a meta-analysis** M. Schumann	8
12^{15} – 13^{45}	**Lunch**	-
Session 1b: Water quality and biofiltration, 13^{45} - 15^{45} Chair: A. Brinker, Fisheries Research Station of Baden Württemberg		-

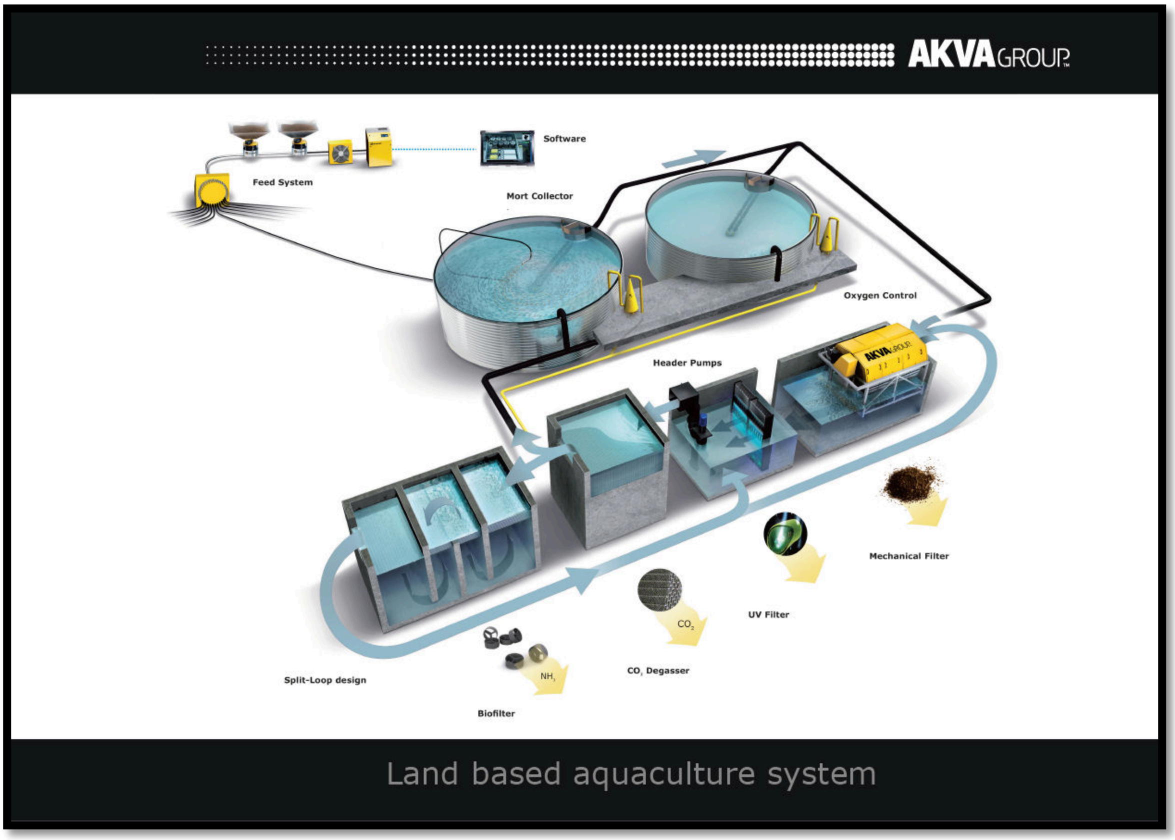
Thursday 10 October 2013		Abstract no.
13^{45} – 14^{15}	**Keynote: New molecular tools reveal microbial composition and function in N-removing water treatment systems** P. Halkjær Nielsen, Aalborg University	9
14^{15} – 14^{30}	**Biofilter-specific responses to intense water treatment in RAS** L. Pedersen et al.	10
14^{30} – 14^{45}	**Micro screens and micro-particles in replicated recirculating aquaculture systems** P. Fernandes et al.	11
14^{45} – 15^{00}	**Effects of salinity and exercise on Atlantic salmon postsmolts reared in land-based recirculating aquaculture systems (RAS)** B.F. Terjesen et al.	12
15^{00} – 15^{15}	**Actual water quality and fish performance in industrial RAS: Results from production of Atlantic salmon in Norway** F. Mathiesen	13
15^{15} – 15^{30}	**Effects of alkalinity on (1) carbon dioxide stripping during cascade aeration and (2) ammonia removal and nitrite accumulation within moving bed biofilters** S. Summerfelt et al.	14
15^{30} – 15^{45}	**The effect of carbon dioxide accumulation on the growth of juvenile turbot (*Scophthalmus maximus*) cultured in a Recirculating Aquaculture System (RAS)** K.T. Stiller et al.	15
15^{45} - 16^{15}	**Coffee break**	-
Session 2: Microbiology and harmful substances, 16^{15} – 17^{45} & 18^{15} - 19^{15} Chair: S. Summerfelt, The Conservation Fund Freshwater Institute		-
16^{15} - 16^{45}	**Keynote: Probiotics as disease control in aquaculture** L. Gram, Technical University of Denmark	16
16^{45} - 17^{00}	**Evidence for the role of sludge digestion in removal of the off-flavor compounds, geosmin and 2-methylisoborneol, from recirculating aquaculture systems** L. Guttman and J. van Rijn	17
17^{00} - 17^{15}	**Depuration systems and techniques to mitigate off-flavor from Atlantic salmon cultured in a commercial scale recirculating aquaculture system** J. Davidson et al.	18
17^{15} - 17^{30}	**Prevention of off-flavours in fish by ultrasonic water treatment** H. NamKoong et al.	19
17^{30} - 17^{45}	**The chronic effects of nitrate, ortho-phosphate and trace metals (Fe, Zn, Cu, Co, Mn) on production performance and health of juvenile turbot (*Psetta maxima*)** C. van Bussel et al.	20

Thursday 10 October 2013		Abstract no.
17^{45} – 18^{15}	**Sandwich break**	-
18^{15} - 18^{30}	**HABs (Harmful algal blooms) in RAS** P. Andersen	21
18^{30} - 18^{45}	**Ozonation in marine RAS: Effects of residual oxidants on fish health and biofilter performance** J. P. Schroeder et al.	22
18^{45} – 19^{00}	**Studies on hormone accumulation and early maturation of Atlantic salmon *Salmo salar* in freshwater recirculation aquaculture systems** C. Good et al.	23
19^{00} – 19^{15}	**Danish Salmon: A brief overview** M. Russel	24

20^{15} - 24^{00}	**Workshop dinner at Restaurant Fusion** Strandvejen 4, st. tv, DK-9000 Aalborg Tel.: +45 35 12 33 31 Website: http://en.restaurantfusion.dk/gourmetrestaurant_aalborg E-mail: info@restaurantfusion.dk

Friday 11 October 2013		Abstract no.
Session 3: End-of-pipe treatment, 08^{30} - 10^{30} Chair: J. van Rijn, The Hebrew University of Jerusalem		-
08^{30} - 09^{00}	**Keynote: A new physico-chemical approach for efficient and cost effective fresh-water RAS operation** O. Lahav, Technion	25
09^{00} – 09^{15}	**Nitrogen removal from recirculation water and waste sludge in a marine RAS via partial denitrification and anammox** P. Chingombe et al.	26
09^{15} – 09^{30}	**Reducing waste discharge from RAS: Yield of volatile fatty acids from anaerobic sludge digestion by batch or fed-batch methodology, and biomethane potential of the sludge** K. Suhr et al.	27
09^{30} – 09^{45}	**Examples of sludge thickening methods from the industry** B. Hald Olsen	28
09^{45} – 10^{00}	**Design of the "self-cleaning inherent gas denitrification-reactor" and its application in a RAS for pike perch (*Sander lucioperca*) production** A. Müller-Belecke and U. Spranger	29
10^{00} – 10^{15}	**Water consumption and waste load in flow-through and recirculating systems for Atlantic smolt production** A. Bergheim et al.	30
10^{15} - 10^{30}	**Containerized RAS solution for flexible and easy installation in aquaculture production systems** J. Bregnballe	31
10^{30} – 10^{55}	**Coffee break**	-
Session 4: Pecha Kucha, 10^{55} - 11^{55} Chair: L.F. Pedersen, Technical University of Denmark		-
10^{55} - 11^{05}	**Biofilter nitrification performance in replicated RAS at different salinities** T. Cavrois and L.-F. Pedersen	32
11^{05} - 11^{15}	**Quantification of respiration and excretion rates in European Lobster (*H. gammarus*)** A. Drengstig et al.	33
11^{15} - 11^{25}	**Dynamic model for a fish tank in recirculating aquaculture systems** P. Prat and B.G. Plósz	34
11^{25} - 11^{35}	**Recirculating aquaculture system for high density production of the calanoid copepod *Acartia tonsa* (Dana)** M.V.T. Thuy et al.	35

Friday 11 October 2013		Abstract no.
11^{35} - 11^{45}	**Recent advances within intensive recirculated aquaculture system cultivation of the calanoid copepod *Acartia tonsa* (Dana)** P.M. Jepsen et al.	36
11^{45} - 11^{55}	**Aquaponics based on geothermal energy** R. Thorarinsdottir	37
11^{55} – 12^{55}	**Lunch**	-
Session 5: System design and operation, 12^{55} - 15^{00} Chair: H. Thorarensen, Holar University College		-
12^{55} - 13^{25}	**Keynote: Aquaculture unit processes and production systems: performance measures, analysis, and evaluation** J. Colt, Northwest Fisheries Science Center	38
13^{25} - 13^{40}	**Processes to improve energy efficiency during low-lift pumping and aeration of recirculating water in circular tank systems** S. Summerfelt et al.	39
13^{40} - 13^{55}	**Pumps for recirculation** M. Z. Jensen	40
13^{55} - 14^{10}	**New web-based program and online water quality monitoring system for RAS farms** T. Kiuru	41
14^{10} - 14^{25}	**Rearing density in combination with water temperature affect Atlantic salmon smolt welfare and performance during intensive production in recirculating aquaculture system (RAS)** J. Kolarevic et al.	42
14^{25} - 14^{40}	**Nutrient digestibility and growth in rainbow trout (*Oncorhynchus mykiss*) are impaired by short term exposure to moderate excess total gas pressure from nitrogen supersaturation** P.V. Skov et al.	43
14^{40} - 14^{55}	**Future development of RAS in commercial farming** O. Garay	44
14^{55} - 15^{00}	**Goodbye and see you next time** NordicRAS	-



Billund Aquaculture

Billund Aquaculture is the market leader in Recirculated Aquaculture Systems (RAS) with more than 27 years of experience.

We cover the range from turn-key fish farming systems from hatcheries to Grow-Out land-based farms to high quality fish farming equipment and components.

Our technologies is well proven and documented by our own farms and by supplying more than 114 re-circulated fish farming systems in 25 countries.




Billund Aquaculture

Billund Aquaculture • Klovermarken 27 • DK-7190 Billund • Denmark
Phone +45 75 33 87 20 • mail: office@billund-aqua.dk • www.billund-aqua.dk

Abstracts of oral presentations

Presented at the
2nd Workshop on Recirculating Aquaculture Systems
(NordicRAS.net)

10-11 October 2013
Aalborg, Denmark

No 1
Current views on water quality control in RAS

Johan Verreth
Aquaculture and Fisheries Group, Wageningen University, P.O.Box 338, 6700 AH Wageningen, The Netherlands

Corresponding author: johan.verreth@wur.nl

Abstract
Recirculation systems are increasingly being used in different sectors of aquaculture and as a consequence, the requirements for water quality control differ as well. Marine fish need a different environment than freshwater fish, carnivorous fish differs from omnivorous or detrivorous fish, juveniles from alevins. Current RAS are mostly designed to control oxygen, CO_2, pH, TAN and other nitrogen levels in the rearing water and have as a secondary goal to reduce nutrient discharge into the environment. However, there is a growing awareness of the changes in water quality due to minor constituents such as minerals, metals and other compounds. The global competition for feed ingredient resources has consequences for future feed compositions and will affect also the water quality in RAS. The current paper will address different aspects of this topic.

No 2
Opening keynote: Changing demands to feed and raw materials for feed for RAS

Niels Alsted
BioMar Group, Værkmestergade 25, 6th floor, DK-8000 Aarhus C, Denmark

Corresponding author: na@biomar.com

Abstract
Development of feed recipes for RAS based on a sustainable use of raw materials is essential for the future of farming in RAS. But raw materials for aquaculture are subject to a high degree of price fluctuations based on factors not defined by the sector. In the recent years these fluctuations have become extreme and for some raw materials, huge fluctuations are expected to continue and in some cases they will be combined with outright scarcity on some key feed ingredients. The special criteria for raw material used for RAS recipes and the need for stability in the production environment in RAS require extra attention and give specific challenges for fish feed suppliers. This limits flexibility at a time where flexibility is needed more than ever to compensate for the price fluctuations and availability issues. This calls for intensive R&D to handle the special demand for RAS diets.

No 3
Nitrogen waste load from juvenile rainbow trout (*Oncorhynchus mykiss*)

Anne Johanne Dalsgaard[1]*, Bodil Katrine Larsen[1], and Per Bovbjerg Pedersen[1]
[1)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author: jtd@aqua.dtu.dk

Abstract
Predictions of the expected load of nutrients deriving from the production of fish, including diurnal variation, nutrient quantity (concentration) and form (solid, suspended, dissolved), are essential for water quality and variations therein, and for designing and dimensioning different cleaning devises in recirculating aquaculture systems (RAS).
A series of laboratory feeding studies were carried out with juvenile rainbow trout (*Oncorhynchus mykiss*) fed a fishmeal based diet to characterize the output of solid and dissolved nitrogen (TN, NH_4-N and urea) over time, and the implications of fish size (50-250 g) and feed ration.
Results showed that protein (nitrogen) digestibility decreased with fish size and ration, meaning that the solid output of nitrogen increased with fish size and ration. Similarly, the dissolved output of total nitrogen, ammonia and urea (mg/kg fish) measured for up to 48 h after a meal and deriving from fish fed similar ration (1.6%), increased with fish size, indicating that the fish became less efficient in converting nitrogen into growth. For fish of equal size (~120 g) fed increasing, but yet restricted amounts of feed, there appeared to be an upper limit to NH_4-N excretion, suggesting an increasingly better utilization with increasing, but still restrictive, feeding. NH_4-N and urea deriving from fish of approximately 70 and 120 g constituted approximately 73-82% and 11-13%, respectively of excreted TN (filtered samples). Urea ($(NH_2)_2CO$) is typically not accounted for when measuring and reporting biofilter performance, however, urea may as shown contribute an important fraction of dissolved N. Urea does not accumulate in RAS but is most likely broken down to NH_4-N by microbes using urease and concomitantly converted to NO_3-N in the biofilter, meaning that biofilters in many cases will be more efficient (i.e. have higher surface specific activity) than actually reported.

No 4
Effects of diet composition and ultrasound treatment on particle size distribution and carbon bioavailability in feces of rainbow trout

Andre Meriac[1,2]*, Ep H. Eding[1], Andries Kamstra[2], and Johan A. J. Verreth[1]
[1)] Aquaculture & Fisheries Group, Wageningen University, De Elst 1, 6708 WD Wageningen, The Netherlands, [2)] IMARES Yerseke, Korringaweg 5, 4401 NT Yerseke, The Netherlands

*Corresponding author: andre.meriac@wur.nl

Abstract
Advances in feed formulation and ingredient selection allow for high or even total substitution of fish meal with plant ingredients at equal growth performance. However, the increased inclusion of fibers originating from plant ingredients will affect the amount and composition of the produced fecal waste. Fibers like hemicellulose, cellulose and lignin are considered as indigestible, mechanically resilient and slowly degradable in biotechnological processes. This consequently affects solid waste recovery with microscreens and subsequent waste treatment in RAS. The goal of our research was to investigate differences in particle size distribution in fecal waste produced on a high and low fiber diet. Furthermore, we investigated whether ultrasound conditioning can be used to (1) decrease particle size and (2) increase the amount of readily degradable carbon for a possible downstream treatment process like denitrification.
Fecal waste was collected from rainbow trout (*Oncorynchus mykiss*), which were fed either a high fiber (HNSP) or low fiber (LNSP) diet. The fecal waste from each tank was sonicated with high-intensity, low-frequency ultrasound at five different energy levels (20 kHz, 0.6 W/ml for 0, 0.25, 1, 4, and 16 min). The particle size distribution of the treated samples was subsequently measured by sequential wet sieving (1000, 500, 200, 100, 63, 36 µm mesh size). Furthermore, we measured total chemical oxygen demand (tCOD) and dissolved COD (sCOD) in the sonicated sample, and total suspended solids in the collected filtrate. Carbon bioavailability in sonicated fecal waste samples was determined in a separate experiment, using an oxygen uptake test with aerobic sludge from a denitrification reactor.
Results showed that almost 50% of the fecal waste produced with the HNSP could be recovered with a microscreen of 36 µm. In contrast, ~95% of the solid waste produced with the LNSP diet was smaller than 36 µm. A higher dietary fiber content resulted in a higher percentage of mechanically resistant particles which could be recovered by microscreens. Ultrasound treatment had only a limited effect on particle size distribution. Ultrasound treatment resulted in an additional conversion of ~10% of solid COD into sCOD for both diets. The specific energy necessary for this conversion is equivalent to 1-5 kW/h/kg DM. The low absolute increase in carbon biodegradability combined with a high investment of energy suggests that ultrasound treatment does not seem to be a feasible option to increase carbon bioavailability in fecal waste for further treatment.

No 5
Feed for recirculation aquaculture systems (RAS)

Kim S. Ekmann
BioMar A/S, Mylius Erichsensvej 35, DK-7330 Brande, Denmark

Corresponding author: kse@biomar.dk

Abstract
Where the primary focus when optimizing diets for traditional farming is fish performance, feeds for RAS should be optimized for maximum performance of both fish and mechanical/biofilters to ensure optimal physical and chemical water parameters.
The present study is an amalgamation of results from several previous trials, each of which have contributed to optimize one or more of the following parameters:

- Optimization of dietary digestible protein-to-energy ratio to reduce excessive protein catabolism
- Dietary amino acid optimization to reduce excessive protein/amino acid catabolism and improve retention of digested protein
- Using highly digestible raw materials to reduce faecal discharge of dry matter, phosphorus and nitrogenous compounds
- Using raw materials that have a neutral or beneficial effect on faecal matter firmness, improving passive/mechanical removal of faecal waste
- Improving the digestibility of dietary phosphorus from vegetable raw materials sources by the means of phytase

The present study was carried out on juvenile rainbow trout (*Onchorynchus mykiss*) and comprised one feeding trial determining feed conversion ratio (FCR), specific growth rate (SGR) and feed intake (FI) followed by a digestibility trial determining protein, lipid and NFE digestibility. The digestibility trial was followed by a two day closed-circuit trial allowing estimation of gill- and urine excreted N and P over time, which in turn made it possible to make nitrogen and phosphorus budgets. Throughout trials one traditional commercial trout diet was tested against two proposed versions of recirculation diets. Fish fed the two experimental diets showed consistently lower FCR values (0.68 to 0.69) compared to the commercial diet (0.73). Obtained SGRs and FI were very similar in fish fed all diets (ranging between 1.9-2.2%/d and 1.3-1.5%/d, respectively). Protein and phosphorus digestibilities of the two experimental diets (92.4-93.4% and 74.7-75.1%, respectively) were significantly higher than observed in the commercial diet (89.6% and 62.6%, respectively), while no significant differences were seen in lipid digestibility of the diets (85.6-88.0%). Collectively, these dietary measures allowed a reduction of nitrogen excreted *via* faeces and gills/urine of 40.7-45.4% and 16.4-20.9% per kg produced fish, respectively, and a reduction of phosphorus excreted *via* faeces between 47.5-50.9% when using the proposed recirculation diets. Phosphorus excreted *via* urine was not significantly different between dietary treatments.

No 6
Plant protein substitution of fish meal: Effects on rheology

Alexander Brinker
Fisheries Research Station, Argenweg 50/1, 88085 Langenargen, Germany

Corresponding author: Alexander.Brinker@lazbw.bwl.de

Abstract
One of the main challenges in the sustainable production of carnivorous fish species is to yield more fish than are consumed during stock rearing. A promising avenue of research is the substitution of the fish meal component of feeds with plant protein. However, there are inherent risks in the deployment of such feeds, and serious consideration should be given not only to nutritional content, but also to the mechanical quality of resulting faecal wastes.
The present investigation, incorporating three extensive trials with replicate treatments, examined the rheological properties of fish wastes resulting from salmonid diets in which fish meal substitution ranged from zero to 100%. All resulting faeces were shown to be thixotropic in nature, independent of diet. However dietary composition did influence the resulting consistency of faecal structure and the characteristic stresses at which faecal wastes change from viscoelastic solids into viscoelastic liquids. Substituting 100% of fish meal with plant proteins leads to faeces that disintegrate rapidly into very fine solids, which threaten the viability of aquacultural operations. This extreme destabilization could not be mitigated by the addition of guar gum (0.3% HV 109), a rapidly hydrating non-starch polysaccharide, previously proven to be highly effective in stabilizing faecal waste under other circumstances. A likely explanation involving dissolution effects of an unknown emulsifier is discussed.
It is further shown that understanding the relationship between active food components and the mechanical properties of chyme and faeces is a key factor in tackling some problematic properties of aquacultural wastes. Mechanical improvements in faecal structure increase the removability of waste particles, thereby contributing to optimization of water quality.

No 7
Dietary effects on fecal waste fraction in Atlantic salmon (*Salmo salar*)

Andries Kamstra[1]*, Ep H. Eding[2], and Rob van de Ven[1,2]
[1)] IMARES Yerseke, Korringaweg 5, 4401 NT Yerseke, The Netherlands; [2)] Aquaculture & Fisheries Group, Wageningen University, De Elst 1, 6708 WD Wageningen, The Netherlands

*Corresponding author: andries.kamstra@wur.nl

Abstract
Fecal waste not removed by the solids removal process affects system water quality and biofilter performance in RAS. Fecal waste in RAS is mainly removed by screening. Therefore, fecal particle size distribution (PSD) is an important parameter to determine treatment efficiency. In literature, lab-scale determination of fecal particle size fractionation has been described by agitation of fecal material and subsequent fractionation. However, most of this work is dealing with the suspended solids fraction while results in terms of chemical oxygen demand (COD) fractionation (solid and dissolved) are lacking while COD is one of the main parameters in system design. Fecal particle size distribution and composition can be affected by diet formulation. Therefore, the objective of this research was: test the effect of diet formulation on waste fractionation taking all fractions and relevant parameters into consideration.
Three diets were formulated and tested: a commercial control (1), the control with a mix of binders added (2), and an alternative formula containing more vegetable ingredients and the same combination of binders (3). The diets were tested in duplicate in 6 identical RAS over a period of 4 weeks. At the end of the experimental period fecal waste was collected by dissection. Part of this material was used for determination of rheological parameters. The remaining part was used in a screenability trial. Viscosity and elasticity of feces was determined with a Rheometer MCR 301 (Anton Paar). For determination of screenability fecal waste was agitated with air for 5 minutes in 1 l of demineralised water. TS, N and COD were determined on 3 fractions: > 280; 1.2-280; and <1.2 micron. The intermediate fraction was also analysed for PSD with a DIPA2000.
Diet composition had a significant effect on fecal rheology. Average viscosity (Pa·s) was 97, 146 and 279 for diets 1, 2 and 3 while elasticity (Pa) ranged from 438, 568 till 1358 respectively. The fractionation of COD showed a significant relationship between viscosity and the fraction of COD>280 µm ($y = 0.62x + 128.8$; $R^2 = 0.68$). Roughly 50% of dry matter (DM) and COD in all diets was found in the fraction <1.2 µm. The fraction of the DM with a particle size smaller than 40 µm amounted to 75, 64 and 71% for diet 1, 2 and 3 respectively. Hardly any material in the size range of 60 to 280 µm could be detected. Diet 3 produced fecal material with a large fraction of very small particles probably originating from the vegetable components in the diet. Treatment efficiency of the drum filters (100 µm screen, water exchange 500L/kg feed) for COD based on a mass balance was 77, 84 and 80% for diet 1, 2 and 3 respectively.

This work has been funded under the EU seventh Framework Programme by the Feed & Treat project (FP7-SME-286143). The views expressed in this work are the sole responsibility of the authors and do not necessary reflect the views of the European Commission.

No 8
Factors affecting faecal stability in salmonids: a meta-analysis

Mark Schumann
Fisheries Research Station, Argenweg 50/1, 88085 Langenargen, Germany

Corresponding author: Mark.Schumann@lazbw.bwl.de

Abstract
Suspended solids present a major issue in the management of recirculating aquaculture systems (RAS), with the potential to impact on whole system efficiency. Faecal waste is the main source of suspended solids and the physico-chemical properties of faeces are decisive in determining the efficiency of mechanical treatments and the resulting quality of treated water. Thus there is an urgent need to learn more about factors influencing faecal stability. Prominent among these factors is diet composition, especially given pressure on the aquaculture industry to substitute fishmeal in aquafeeds.
A meta-analysis was carried out on data from nine independent feeding trials in order to examine the effects of feed composition and other potential factors on the stability of rainbow trout faeces. The dataset included information pertaining to more than 50 diets, which varied in terms of quality and quantity of macronutrients and functional additives, and their influences on rheological stability of feces, stock and growth and feed efficiency. The stability of faeces resulting from all diets was measured on technically identical rheometers (Paar Physica - UDS 200). The measuring system applied was a MP 313 (plate: Ø 50 mm, 0°) with a gap width of 1 mm. Multivariate statistical techniques were used to analyse the data.
The results demonstrate the influence of dietary and faecal composition, feed digestibilty and fish size on the stability of faecal wastes. It is further shown that the effects of some factors on faecal stability can be partly offset by the use of plant-polysaccharide binders such as guar gum.

No 9
New molecular tools reveal microbial composition and function in N-removing water treatment systems

Per Halkjær Nielsen
Center for Microbial Communities, Department of Biotechnology, Chemistry and Environmental Engineering, Aalborg University, Aalborg, Denmark
Corresponding author: phn@bio.aau.dk

Abstract
A well-functioning plant treating wastewater from recirculating aquaculture or any other origin relies on a good understanding of the microbial communities. Treatment efficiency, water quality and operational costs depend very much on the microbes in the system and how the plants are operated. In the past 5 years an exciting development in novel cultivation-independent approaches has taken place to study these communities, particularly related to DNA/RNA sequencing technologies. This opens new possibilities for studying the microbial communities, including identification, quantification, functions and interactions of the microorganisms.
The identification of all species within a microbial community can now be reliably investigated by a novel method called 16S amplicon sequencing (16S sequencing). We have applied 16S sequencing in several systems related to wastewater treatment and among these the project "Microbial Database for Danish Wastewater Treatment Plants" (or MiDas-DK). The project was initiated in 2006 to improve our knowledge about the microorganisms in wastewater treatment plants with biological N and P removal. The project is a collaboration between Aalborg University, Dansk Spildevandsteknisk Forening, consultants and many wastewater treatment plants (approx. 50). We determined the identity of different functional groups carrying out nitrification, denitrification, and other processes. Interestingly, the survey showed that 60-80% of the biomass consisted of a stable core of 30-40 abundant species present in all plants throughout the entire study, although with significant variations in abundances. Similar investigations have still not been conducted in aquaculture recirculation units, but we expect a similar trend.
An important outcome has been new knowledge about the "normal" microbial composition of Danish wastewater treatment plants, the stability of the populations through time and many factors that affect and control their presence. Thus, this understanding can in some cases be used to carry out "design" or manipulations in order to remove unwanted species or stimulate others for general trouble-shooting and optimization of plants.
The function of the microbial communities can be revealed by other new methods such as metagenomics and metatranscriptomics. Metagenomics, or environmental genomics, provides comprehensive information about the entire microbial community of a certain ecosystem, e.g. a wastewater treatment plant by sequencing all DNA after extraction. Analyses of metagenomes can give extensive information about the functional potential of the microbes by studying their genes and can be regarded as the blueprint needed to study expressed genes and proteins (transcriptomics and proteomics), thereby providing information about the active functions of the microbes in the system and eventually the performance of the engineered system. Only few studies have been carried out in wastewater systems so far, as they require large expertise, but the results are very promising, although many pitfalls exist. Integration of all these methods is known as "Systems Microbiology" and is anticipated to revolutionize the studies of microbial communities in the coming years.

No 10
Biofilter-specific responses to intense water treatment in RAS

Lars-Flemming Pedersen[1]*, Remko Oosterveld[2], and Per Bovbjerg Pedersen[1]
[1)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark; [2)] Wageningen University, Aquaculture and Fisheries, the Netherlands

*Corresponding author: lfp@aqua.dtu.dk

Abstract
A number of factors have been identified to affect the nitrification process in biofilters and the resulting water quality in RAS. In this study we compared the nitrification performance (removal capacity and robustness) of two types of biofilters – fixed bed (FB) and moving bed (MB) filters (n=4) and measured the resulting water quality. The biofilters (equal in size, filling rate, surface specific area and hydraulic load) were connected to the same RAS operated under constant conditions for more than three months. After evaluation of steady state nitrification performance, a deliberate chemical disturbance was introduced to the RAS in terms of intense water treatment with hydrogen peroxide (nominal conc. of 50 mg/l) without bypassing any of the four filters.
Steady state levels were 0.15 ± 0.07mg TAN/l and 0.23 mg/l NO_2-N ± 0.04). After H_2O_2 exposure, TAN levels increased, reaching 1.05 mg TAN/l and returned to steady state levels within 10 hours. For nitrite, more than a ten-fold increase in concentration (2.82 mg NO_2-N /l) was observed, lasting for three days before gradually returning to pre-exposure levels reached seven days after H_2O_2 exposure. No fish mortality occurred during the experiment, and fish behavior and appetite was not affected neither during nor after H_2O_2 exposure.
FB had a higher initial TAN and nitrite removal rate (0.21 g TAN/m^2/d and 0.23 g NO_2-N/m^2/d, respectively) compared to MB (0.16 g TAN/ m^2/d and 0.13 g NO_2-N/m^2/d). During H_2O_2 application, nitrification rates in FB were reduced by approx. 40 % and in MB by 50 %. After H_2O_2 exposure, nitrification in FB was found to recover faster than in MB. FB degraded approximately 20% more H_2O_2 than MB at the same loading, suggesting a significant contribution from activated sludge presumably present among the fixed biofilter elements. FB generally had a higher TAN removal rate compared to MB, and also had a net nitrite removal as opposed to MB.

No 11
Micro screens and micro-particles in replicated recirculating aquaculture systems

Paulo Fernandes[1]*, Lars-Flemming Pedersen[1], and Per Bovbjerg Pedersen[1]
[1)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author: pafe@aqua.dtu.dk

Abstract
Solids accumulation is a primary area of focus in recirculating aquaculture systems (RAS). Large solids are quickly removed from RAS by installing mechanical filters, which can, however, lead to high background concentration of micro-particles within the system. Although in such quantities, there is a severe lack of information on micro-particles, specifically towards potential system impairments they may induce.
This study investigated the effects of 4 different mesh sizes (no mesh, 100, 60 and 20µm), in groups of replicated RAS, on dissolved and solid substances, nitrification kinetics and rainbow trout (*Onchorhynchus mykiss*) growth. The filters were backwashed three times a day, and operational conditions were kept at constant level for six weeks, at a daily feeding level of 250g per system, and resulting feed loadings of 3.1kg feed$\cdot m^{-3}$ of make-up water. At the end of the six-week period, an intensive backwashing campaign and biofilter nitrification trials were also conducted.
Microscreens were observed to remove particles and affect other parameters compared to initial conditions. Increased β-value, lower particulate surface area and solid organic substances, were all observed at the end of the trial in the filtered systems. Furthermore, they all reached a steady-state regarding particulate compounds accumulation, and the time to reach system equilibrium was reduced with decreasing mesh size. Most particulate parameters accumulated in the control group, and system equilibrium had not been reached by the end of the experiment. Data from an intensive backwashing campaign, performed after the experimental period, further support the steady-state hypothesis in filtered systems.
0'-order nitrification rates (k_{0a}) were equivalent for all systems (0.15±0.022) and comparable to literature k_{0a} levels, typically between 0.1-0.2g$\cdot m^{-2}\cdot d^{-1}$ in RAS. Unfortunately, no information could be acquired on 1st-order kinetics, as the sampling ended too early and contained insufficient resolution. More information on 1st-order kinetics could have provided adequate evidence of the intrinsic interaction between organic micro-particles and biofilters in RAS.
Microscreens induced a significant effect in removing particulate compounds, but only when compared to systems without a dedicated filter. Moreover, a 20µm mesh did not significantly improve water quality, as demonstrated by equivalent water chemistry and particulate compounds, compared to the 100µm treatment. The resulting leveling of filtered systems is hypothesized to be related to a high particle removal/production rate and constant operations and conditions, related to stable feed loading.

No 12
Effects of salinity and exercise on Atlantic salmon postsmolts reared in land-based recirculating aquaculture systems (RAS)

Bendik F. Terjesen[1]*, Trine Ytrestøyl[1], Jelena Kolarevic[1], Sara Calabrese[2,3], Bjørn Olav Rosseland[4], Hans-Christian Teien[4], Åse Åtland[5], Tom Ole Nilsen[2], Sigurd Stefansson[2], Sigurd O. Handeland[6], and Harald Takle[7]

[1)] Nofima AS, NO-6600 Sunndalsøra, Norway; [2)] Dept. of Biology, University of Bergen, Bergen, Norway; [3)]Marine Harvest Norway, Bergen, Norway; [4)]Norwegian University of Life Sciences, Ås, Norway; [5)]NIVA, Bergen, Norway; [6)]UNI Research, Bergen, Norway; [7)] Nofima AS, NO-1430 Ås, Norway

*Corresponding author: bendik.terjesen@nofima.no

Abstract

A central question in land-based RAS for Atlantic salmon postsmolts is which rearing salinity to use. Removal of CO_2 and TAN has been reported to be less efficient in seawater SW-RAS vs. freshwater FW-RAS. However, little is known about effects of salinity on postsmolt performance, physiology, maturation and welfare in RAS. Another factor is that design of culture tanks will influence hydraulics; however, optimal water velocities for postsmolts in RAS are not known. Earlier studies on exercise during the parr FW-stage have shown beneficial effects on growth and disease resistance. In Norway, land-based production has recently been permitted to 1kg-sized postsmolts, based on hypotheses of reduced cage-phase mortality and sealice pressures on wild salmon. This trial is part of a larger postsmolt program on closed-containment systems on land and in sea, funded by The Research Council of Norway, and a consortium led by Marine Harvest, Smøla Klekkeri og Settefisk, and Grieg Seafood.

Atlantic salmon smolts (n=600 per tank, 68±1 g/ind.) were stocked in two 3.2m^3 tanks per treatment (6 treatments in total), using three RAS in Nofima Centre for Recirculation in Aquaculture. All RAS had a comparable relative feed loading, a daily system volume exchange of 28%, and a temperature of 12.2±0.8˚C. The fish were subjected to either 12, 22 or 32 ppt salinity, and within each salinity, tanks were set-up either with ~1 body lengths (BL) per second water velocity (two tanks) or <0.3 BL/s (two tanks). Water quality and removal efficiencies were evaluated. At average ~250g, 450g, and 850g, fish were weighed, welfare indicators scored, and tissues sampled for organ indices, blood physiology, and gene expression.

CO_2 removal efficiency was higher in 12 ppt RAS, compared to 32 ppt. Body weight (BW), SGR, and TGC were significantly affected by salinity and exercise. At 250g, both exercise and lower salinity increased heart index. Calculated for the trial duration, the 12 ppt and 1 BL/s treatment showed the highest growth rate (SGR, TGC) and BW, being significantly higher than at 32 ppt. The 32 ppt treatments showed higher mortality (28.9%) compared to 22 ppt (2.6%), and 12 ppt (1.0%). None of the treatments led to any apparent maturation, based on male gonadosomatic index, being on average 0.05% of BW. Analyses on welfare, physiological indicators and gene expression are underway. As a preliminary conclusion, the results suggest that RAS for Atlantic salmon should include use of reduced salinity and water velocities promoting exercise of the postsmolts.

No 13
Actual water quality and fish performance in industrial RAS: Results from production of Atlantic salmon in Norway

Frode Mathiesen
Grieg Seafood ASA, C. Sundtsgt. 17/19, P.O. Box 234 Sentrum, 5804 Bergen, Norway

Corresponding author: frode.mathisen@griegseafood.com

Abstract
With the aim of saving water, improve the general fish health and increase the productivity, Grieg Seafood has built out RAS for almost all their smolt production. The first site was opened in 2008 and in 2014 the company will have 7 500 tons feeding capacity in RAS.
The experience with RAS is positive. It takes 2-3 months to mature the bioreactors and achieve full nitrification capacity, but then the systems are very stable. Typical nitrogen levels at full feeding are: 0.6 mg/l TAN and 0.16 mg/l NO_2-N. In lack of denitrification, NO_3 is controlled by running minimum 300 l makeup/kg feed. This gives up to 40 mg/l NO_3-N. The energy loss in the system is then minimal and the temperature stays 4-6°C above the temperature on the intake water.

No 14

Effects of alkalinity on (1) carbon dioxide stripping during cascade aeration and (2) ammonia removal and nitrite accumulation within moving bed biofilters

Steven T. Summerfelt[1]*, Anne Zühlke[2], Jelena Kolarevic[3], Britt Kristin Megård Reiten[3], Roger Selset[3], Xavier Gutierrez[3,4], and Bendik Fyhn Terjesen[3]

[1)] Conservation Fund Freshwater Institute, Shepherdstown, WV, USA; [2)] University of Rostock, Rostock, Germany; [3)] Nofima, Sunndalsøra, Norway; [4)] NIVA Chile, Puerto Varas, Chile

*Corresponding author: s.summerfelt@freshwaterinstitute.org

Abstract

Super-intensive water recirculating systems (WRAS) that use low flushing rates and include pure oxygen supplementation to support high stocking densities are increasingly more common in salmonid production; these conditions can rapidly deplete alkalinity, creating low pH conditions, and push the system's capacity to maintain safe levels of NH_3, NO_2, and CO_2. Nitrification consumes approximately 0.16 kg $NaHCO_3$ per 1 kg feed consumed by the fish. Inadequate alkalinity has been reported to reduce nitrification and 40 mg/L (as $CaCO_3$) is the minimum required for nitrification reported in wastewater literature.

A study was conducted at Nofima (Sunndalsøra) in two replicate water recirculating systems – used to produce Atlantic salmon smolt – to evaluate the effects of alkalinity on carbon dioxide (CO_2) stripping during cascade aeration, plus total ammonia nitrogen (TAN) and nitrite nitrogen (NO_2-N) removal within moving bed biological filters. Alkalinity treatments of 10, 70, and 200 mg/L were maintained using a pH controller and chemical dosing pumps supplying sodium bicarbonate ($NaHCO_3$). Each treatment was replicated three times in each WRAS. Both WRAS were operated at each treatment level for 2 weeks; water quality sampling was conducted during each second week. A constant feeding of 24 kg/day/WRAS was provided every 1-2 h, and continuous lighting, which minimized diurnal fluctuations in water quality. WRAS hydraulic retention time and water temperature were 4.3 d and 12.5±0.5˚C, respectively.

No differences were distinguished in TAN removal efficiency, which ranged from 41-50% removal each treatment, or in NO_2-N accumulation, which averaged 0.41 to 0.58 mg/L but was quite variable. Continuous alkalinity addition appears to have met the biological needs of nitrification, even at alkalinity levels as low as 10 mg/L. No differences in CO_2 stripping efficiency were distinguished, mean efficiencies ranged from 54-57% across the 2 m tall forced-ventilated aeration columns. However, system pH was significantly lower at an alkalinity of 10 mg/L. When switching treatments, the pH drop was faster from 10 and 70 mg/L, compared to 200 mg/l alkalinity, which is of importance in case of alkalinity dosing malfunction.

No 15

The effect of carbon dioxide accumulation on the growth of juvenile turbot (*Scophthalmus maximus*) cultured in a Recirculating Aquaculture System (RAS)

Kevin Torben Stiller[1,2]*, Klaus Heinrich Vanselow[1], Damian Moran[3], Stefan Meyer[2], and Carsten Schulz[2]

[1)] Forschungs- und Technologiezentrum Westküste der Universität Kiel, Hafentörn 1, 25761 Büsum, Germany; [2)] Gesellschaft für Marine Aquakultur, Hafentörn 3, 25761 Büsum, Germany; [3)] Department of Biology, Lund University, Sölvegatan 35, 223 62 Lund, Sweden

*Corresponding author: stiller@ftz-west.uni-kiel.de, stiller@gma-buesum.de

Abstract

The accumulation of carbon dioxide (CO_2) in intensive RAS systems is a welfare and production concern, however, we have little understanding of the long term effects of CO_2 on fish growth, in particular for marine species. Long term exposure to elevated CO_2 tends to decrease growth, but the physiological basis for reduced weight gain is unclear. We used a novel RAS respirometry system to measure the growth, feed conversion and metabolism of juvenile turbot over two months. The use of long-term automated respirometry coupled with a dietary study allowed us to separate the effects of CO_2 on growth, feed intake, feed conversion efficiency and oxygen consumption.

The RAS respirometry system consisted of 10 tanks (250 L volume each) as described in Stiller et al. 2013 (Aquacult. Eng. 55: 23-31). Three CO_2 concentrations were tested. We used CO_2 levels of 5, 26, 42 mg L^{-1} (~3000, 15000, 25000 μatm; pH 7.37, 6.44, 6.66), with three replicate tanks per treatment and one reference tank without fish. An automated water chemistry analysis unit measured O_2, pH, temperature, total ammonia nitrogen and dissolved CO_2. 14 Turbot (55 g, density 3.1 kg m^{-3}) per tank were maintained at a salinity of 20‰, carbonate alkalinity of 110 mg L^{-1} and 18°C for two months. A commercial diet was administered once per day until satiation, and uneaten food was collected from a solids collector. Daily water exchange was around 10% of total RAS volume.

While the CO_2 levels tested were within a chronic tolerance range, the results showed that turbot exhibit a clear dose-response effect for most of the measured variables. Compared to the low CO_2 treatment, the elevated CO_2 levels caused a sizable decrease in weight gain (25% and 55% reduction). The feed conversion ratio was significantly worse at the high CO_2 level compared to the lower concentrations. Feed intake, fish condition and specific growth rate were strongly and negatively dose-dependent with respect to CO_2 exposure.

Our minimum effect concentration (26 mg L^{-1}) is lower than reported for spotted wolfish and seabass (> 30 mg L^{-1}) but higher than for salmon and Atlantic cod (both below 16 mg L^{-1}). The difference in weight gain between treatments was most likely due to reduced feed intake. Long term hypercapnia trials and the determination of minimum concentration effect thresholds will help RAS designers size CO_2 degassing systems to ensure adequate welfare and production conditions.

No 16
Probiotics as disease control in aquaculture

Lone Gram[1]* and Paul D'Alvise[1]
[1)] Bacterial Ecophysiology and Biotechnology Group, Department of Systems Biology, Søltofts Plads bldg 221, DK-2800 Kgs. Lyngby, Denmark

*Corresponding author: gram@bio.dtu.dk

Abstract
Bacterial infections are a problem in aquaculture and the use of antibiotics should be limited to reduce the risk of development of antibiotic resistant bacteria. The use of live bacteria (probiotics) that can control bacterial pathogens is a concept currently being developed in many areas (human, poultry, pigs, plants). In aquaculture, several challenge-trial studies have demonstrated that several bacteria (*Pseudomonas, Vibrio, Roseobacter*) can reduce mortality from pathogenic bacteria and hence aid in the reduction of antibiotic usage.
Also in marine larviculture, bacterial diseases are a key problem that limits reliability and cost-efficiency of juvenile production, and constrains introduction of new species and breeding programs. The main source of pathogenic bacteria is live feed cultures, since opportunistic pathogenic bacteria thrive well in the rapidly increasing nutrient concentrations.
The probiotic bacterium *Phaeobacter gallaeciensis* antagonizes many species of fish-pathogenic bacteria and was capable of reducing the concentrations of pathogenic *Vibrio* spp. in gnotobiotic experimental cultures representing the larviculture food chain (microalgae, rotifers, *Artemia*). Also, *P. gallaeciensis* dramatically reduced mortality of *Vibrio*-infected cod larvae and even in non-challenged larvae.
Phaeobacter gallaeciensis, which occurs naturally in coastal waters and is part of the normal microbiota of fish and mollusk larvae cultures, could be applied preventively in cultures of marine fish larvae and live feed to reduce the incidence of bacterial infections.

No 17
Evidence for the role of sludge digestion in removal of the off-flavor compounds, geosmin and 2-methylisoborneol, from recirculating aquaculture systems

Lior Guttman[1] and Jaap van Rijn[1]*

[1)] Department of Animal Sciences, The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot 76100, Israel

*Corresponding author: jaap.vanrijn@mail.huji.ac.il

Abstract

Occurrence of the off-flavor compounds geosmin and 2-methylisoborneol (MIB) is common in the aquaculture industry. Both compounds, produced by cyanobacteria, fungi and bacteria (mainly actinobacteria), impart an earthy-musty flavor to water even when present at very low (nanograms per liter) concentrations. Due to their hydrophobic nature, geosmin and MIB are readily and strongly absorbed by the lipid-rich fish tissue while their release from the tissue is slow. Conventional methods for disinfection such as ozonation and chlorination have little effect on geosmin and MIB concentrations in the water. Currently, purging of fish with clean water for several days prior to marketing is most often used to secure off-flavor free fish.

In the current study, two geosmin and MIB producing bacterial strains were isolated from an aerobic and organic-rich nitrification filter and a drum filter in a recirculating aquaculture system (RAS) for tilapia culture. Bacterial isolates were found to be closely related to *Streptomyces roseoflavus* and *Streptomyces thermocarboxidus.* Both isolates were able to grow under aerobic as well as oxygen limited conditions with highest geosmin and MIB production rates under the former conditions. A decrease in geosmin and MIB levels was found in the digestion basin of the RAS. It was found that geosmin and MIB were strongly absorbed by the sludge in this basin. From parallel runs with non-sterilized sludge it was concluded that, in addition to physical/chemical removal processes, geosmin and MIB were also biologically degraded within the sludge. Continuous enrichments of crude sludge with geosmin and MIB resulted in the isolation of three bacterial strains capable of growth with geosmin or MIB as the sole carbon and energy sources. The bacterial strains were found to be closely related to *Variovorax paradoxus, Rhodococcus sp.* and *Comamonas sp.* All isolates showed highest geosmin and MIB removal rates when these compounds were present as sole carbon and energy source in the growth medium. Addition of more readily available carbon sources resulted in higher growth rates of the isolates and slower geosmin and MIB removal rates. While *Variovorax paradoxus*-like isolate revealed similar growth rates under aerobic and non-aerated conditions, the two other bacterial strains grew fastest under aerobic conditions. By means of fluorescent *in situ* hybridization (FISH), the prevalence of bacteria belonging to the Rhodococcus and Comamonas genera was evident in sludge derived from the digestion basin.

No 18

Depuration systems and techniques to mitigate off-flavor from Atlantic salmon cultured in a commercial scale recirculating aquaculture system

John Davidson[1]*, Kevin Schrader[2], Bruce Swift [3], Eric Ruan[4], Jennifer Aalhus[4], Manuel Juarez[4], and Steven Summerfelt[4]

[1)] The Conservation Fund's Freshwater Institute, Shepherdstown, West Virginia, USA; [2)] United States Department of Agriculture, Agriculture Research Service, University of Mississippi, USA; [3)] TRI-GEN Fish Improvement Ltd., Ponoka, Alberta, Canada; [4)] Lacombe Research Centre, Agriculture and Agri-Food Canada, Lacombe, Alberta, Canada

*Corresponding author: j.davidson@freshwaterinstitute.org

Abstract

Fish cultured within recirculating aquaculture systems (RAS) can bioaccumulate earthy or musty off-flavors due to off-flavor compounds, geomsin and MIB, that are produced by bacteria that thrive in system biofilms. As a general practice, trout and salmon cultured within RAS are transferred to separate clean-water depuration systems to purge these unpalatable flavors. Three research studies were conducted to evaluate technologies and standard operating practices (SOPs) to optimize purging kinetics of Atlantic salmon transferred to replicated depuration systems.

Atlantic salmon cultured within a partial reuse system to 1-2 kg (Study 1) and a commercial scale 150 m^3 RAS to 3-5 kg (Studies 2 and 3) were stocked within 12 identical partial reuse systems (0.5 m^3) for three 2 x 2 factorial depuration trials evaluating: 1) hydrogen peroxide (H_2O_2) disinfection and granular activated carbon (GAC) filtration of the makeup flow; 2) the same treatments as Study 1 but with larger salmon; and 3) H_2O_2 disinfection of the depuration system and presence/absence of aeration media. Prior to each study, the depuration systems were used for rainbow trout culture to establish biofilm-coated surfaces and a realistic worst-case-scenario for purging. Fish were kept off feed during the depuration period. Six salmon were harvested from the original culture systems on Day 0 and filleted for baseline assessment of off-flavor concentrations. Thereafter, fillet and water samples were taken at daily intervals from the depuration systems up to Day 10 to evaluate off-flavor kinetics.

During Study 1, off-flavor concentrations increased for all treatments, emphasizing the need to begin with clean, biofilm-free depuration systems. Study 2 indicated that pre-treatment of systems with H_2O_2 combined with GAC filtration of the makeup water resulted in the greatest reduction of off-flavor levels in the culture water and salmon fillets. However, H_2O_2 disinfection alone appeared to be just as effective. Study 3 demonstrated that depuration systems that are disinfected with H_2O_2 and absent of aeration media were the most effective at purging off-flavor concentrations from salmon compared to control systems that were not disinfected and contained aeration media.

These studies demonstrated that the depuration process for Atlantic salmon can be optimized with only 6 to 10 days of purging when using SOPs that provide clean and relatively biofilm-free systems. Aeration media should not be used within depuration systems because of the challenges posed for effective cleaning, disinfection, and inactivation of off-flavor producing bacteria. In addition, disinfection of depuration systems using hydrogen peroxide appears to enhance off-flavor removal.

No 19
Prevention of off-flavours in fish by ultrasonic water treatment

Hansup NamKoong[1]*, Jan P. Schroeder[2], G. Petrick[3], and Carsten Schulz[1,2]
[1)] Institute of Animal Breeding and Husbandry, Christian-Albrechts-Universität, Kiel, Germany; [2)] Gesellschaft für Marine Aquakultur (GMA) mbH, Hafentörn 3, 25761 Büsum, Germany; [3)] AIMES GmbH, Kösterberg 10, 24238 Selent, Germany

*Corresponding author: hnamkoong@gma-buesum.de

Abstract
The most common off-flavour compounds in aquaculture are 2-Methylisoborneol (2-MIB) and Geosmin (GSM), which are secondary metabolites released by different microorganisms, such as cyanobacteria or actinomycetes, that exist in most aquaculture plants. Due to a high bioaccumulation factor in the lipid-rich tissue even very low concentrations of 2-MIB and GSM in the water cause an undesired earthy-musty smell and taste of fish meat. The occurrence of off-flavours in fish leads to a loss of quality and reduces the marketability of the product. However, purging off-flavours by moving the fish to clean, odor-free water for a certain time prior to harvest is still the only reliable but highly cost- and time-intensive way to counteract off-flavours in aquaculture. Until now, alternative strategies and processes for efficient off-flavour prevention are still lacking.
Hence, the aim of this study was to investigate the potential of ultrasonic water treatment to decrease the concentration of relevant off-flavour compounds in recirculating aquaculture water.
Therefore, both freshwater and saltwater were spiked with 2-MIB and GSM standards and treated with a lab-scale ultrasound transducer at a frequency of 850 kHz in pulsed mode. Additionally, samples from commercial recirculating aquaculture systems containing natural 2-MIB and GSM were also treated. The off-flavour compounds were extracted with a liquid-liquid-extraction, concentrated and analyzed using a GC-MS. Furthermore, the effect of salinity on the removability of 2-MIB and GSM via ultrasonic treatment was investigated.
Results demonstrate that ultrasonic water treatment significantly reduces the tested off-flavour compounds in all tested sample types, whereat the reduction of GSM was slightly higher compared to that of 2-MIB. The addition of salt to freshwater samples improved the reduction of both off-flavour compounds by ultrasonic treatment significantly. Thus, ultrasonic water treatment might provide a new opportunity to remove off-flavour compounds effectively in recirculating aquaculture systems. Moreover, the addition of salt to freshwater systems cultivating euryhaline fish species seems to be a feasible method to enhance the removal efficiency of ultrasonic water treatment with respect to the off-flavour compounds Geosmin and 2-MIB.

No 20

The chronic effects of nitrate, ortho-phosphate and trace metals (Fe, Zn, Cu, Co, Mn) on production performance and health of juvenile turbot (*Psetta maxima*)

Chris G.J. van Bussel[1,2]*, Jan P. Schroeder[2], and Carsten Schulz[1,2]

[1)] Institute of Animal Breeding and Husbandry, Christian-Albrechts-Universität, Kiel, Germany; [2)] Gesellschaft für Marine Aquakultur mbH (GMA), Büsum, Germany

*Corresponding author: chris.vanbussel@gma-buesum.de

Abstract

In recirculating aquaculture systems (RAS) there is a trend to reduce water exchange levels. Consequently several substances accumulate in the system water. The most important inorganic compounds that accumulate are nitrate, ortho-phosphate and the trace elements iron (Fe), zinc (Zn), copper (Cu), manganese (Mn) and cobalt (Co). However, until now the effects of elevated levels of these substances in the culture water on marine fish species are unknown. Therefore, the effects of these inorganics on growth, feed utilization and several health parameters of a marine fish species, the turbot (*Psetta maxima*) were studied.

In 12 independent RAS nitrate levels were increased by addition of a $NaNO_3$ and KCl solution. In a dose-response study the effects of four different nitrate levels (4, 125, 250 and 500 mg/l NO_3-N) on the performance of juvenile turbot were evaluated. Growth was negatively linear affected with nitrate concentration. Effects on fish health were only observed at ≥ 250 mg/l NO_3-N. Blood parameters were not affected, suggesting that turbot are capable of keeping homeostasis up to 500 mg/l NO_3-N.

In a second dose-response study the effects of four different ortho-phosphate levels (4, 25, 50, 75 mg/l ortho-P) were studied by addition of a $Na_2HPO_4 \cdot 2\ H_2O$ and KCl solution. It was found that ortho-P levels did not negatively affect health and growth of turbot up to 75 mg/l ortho-P. Fish reared at 25 mg/l ortho-P showed a tendency for higher feed intake and growth compared to the control groups, suggesting that turbot are capable of taking up and utilize waterborne phosphorus.

In a third study, in 5 independent RAS the accumulation of metals at 5 different water exchange rates (between 1000 and 10 l/kg feed) were simulated by adding metals in the sulphate form. The accumulation of metals (Fe, Zn, Cu, Co, Mn) did not negatively affect turbot growth up to water exchange rates as low as 10 l/kg feed applied. However Zn, Co and Mn bioaccumulated in turbot whole body, resulting in decreased dry matter content.

The negative linear relation between nitrate concentration and turbot growth is the main factor limiting intensification of marine RAS. Ortho-phosphate is harmless to turbot and does not affect growth. Waterborne trace metals bioaccumulate in turbot resulting in a decreased dry matter content, but health and growth are unaffected. Using denitrification, intensification of turbot RAS up to water exchange levels of 10 l/kg feed should be possible.

No 21
HAB's in RAS

Per Andersen
Orbicon A/S, Jens Juuls Vej 16, 8260 Viby J. Denmark

Corresponding author: pean@orbicon.dk

Abstract
HABS = Harmful Algal Blooms do occur in RAS systems and cause fish kills and/or have negative impact on fish production and cause economical loss. No HAB monitoring routines are developed and implemented in RAS at present and much have yet to be learned about which HAB species cause problems in RAS and how to control/mitigate the HAB development and optimize production. Examples of HAB's in RAS caused by mixotrophic dinoflagellates will be presented. Furthermore the Danish Strategic Research Project HAB-fish (2012-2016) http://www.habfish.dk/ with the following aims will be introduced:

- Development of molecular tools for the rapid and exact identification and enumeration of ichthyotoxic algae in Danish waters
- Discovery of new algal ichthyotoxins and to develop methods for their identification and quantification
- A much better understanding of how fish and fish fry react towards ichthyotoxins from fish-killing algae
- Improved understanding of how fish and fish fry may possibly acclimate to the ichthyotoxins/ichthyotoxic algae and the possible use of this knowledge in the aquaculture to avoid fish kills in the future

A "HAB's in RAS monitoring approach" will be suggested and discussed as a necessary starting point for the future development of a cost effective RAS management in relation to HABS.

No 22
Ozonation in marine RAS: Effects of residual oxidants on fish health and biofilter performance

Jan P. Schroeder[1]*, Simon Klatt[1], Stefan Reiser[2], Sven Wuertz[3], Reinhold Hanel[2], and Carsten Schulz[1,4]

[1)] Gesellschaft für Marine Aquakultur (GMA) mbH, Hafentörn 3, 25761 Büsum, Germany; [2)] Thünen-Institute of Fisheries Ecology, Hamburg, Germany; [3)] Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; [4)] Institute of Animal Breeding and Husbandry, Christian-Albrechts-Universität, Kiel, Germany

*Corresponding author: schroeder@gma-buesum.de

Abstract

In marine recirculating aquaculture systems (RAS) ozone is often applied for the improvement of process water quality as well as for disinfection of make-up water. Especially for disinfection purposes ozone residuals are required, potentially leading to a fast formation of secondary oxidants in seawater, as residual ozone reacts rapidly with halogen ions to form halogenated oxidants, summed up as ozone-produced oxidants (OPO). OPO are much more stable than ozone itself and may accumulate in the system, leading to potential deleterious impacts on the cultured organisms as well as on nitrifying bacteria in the biofilter. Knowledge of species-specific sensitivities towards these OPO and respective safety-values are hence important requirements for a safe ozone application.

Therefore, the sensitivity of different aquaculture species such as turbot (*Psetta maxima*) and Pacific white shrimp (*Litopenaeus vannamei*), as well as nitrifying biofilter-bacteria towards OPO was investigated in a series of acute and chronic exposure experiments.

Whereas a chronic exposure of juvenile turbot and Pacific white shrimp to OPO concentrations as low as 0.1 and 0.15 mg/l chlorine equivalent caused an impairment of health and welfare, as reflected in histological alterations of the gills or oxidative stress, no significant adverse effects could have been found at a concentration of 0.06 mg/l even at chronic exposure, revealing an OPO concentration of ≤ 0.06 mg/l to be an adequate safety level for the tested marine aquaculture species.

Compared to fish and shrimp the nitrifying bacteria used for biofiltration were proven to be much more tolerant towards OPO. Laboratory experiments revealed that the immobilization on biocarriers increases the tolerance of the tested nitrifying bacteria dramatically, suggesting the biofilm to be highly protective against OPO. Chronic exposure experiments could not reveal any harmful impact on biofilter performance for OPO concentrations up to 0.15 mg/l chlorine equivalent, even at continuous exposure. In contrast, nitrifying activity was enhanced at all tested OPO concentrations compared to the control without ozonation. By oxidizing organic substances, ozone might contribute to the repression of heterotrophic bacteria resulting in a competitive advantage for autotrophic nitrifying bacteria in the biofilter.

According to the presented results, rather fish health and welfare seem to be the limiting factors for ozone dosage than biofilter performance.

No 23
Studies on hormone accumulation and early maturation of Atlantic salmon *Salmo salar* in freshwater recirculation aquaculture systems

Christopher Good[1]*, John Davidson[1], Ryan L. Early[2], Elizabeth Lee[2], Gregory Weber[3], and Steven Summerfelt[1]

[1)] The Conservation Fund's Freshwater Institute, 1098 Turner Road, Shepherdstown, WV 25443 USA; [2)] Department of Biological Sciences, University of Alabama, 300 Hackberry Lane, Tuscaloosa, AL 35401 USA; [3)] United States Department of Agriculture – Agriculture Research Service's National Center for Cool and Cold Water Aquaculture, 11876 Leetown Road, Leetown, WV 25430 USA

*Corresponding author: c.good@freshwaterinstitute.org

Abstract

Recent research trials growing Atlantic salmon *Salmo salar* to market size in a land-based, closed-containment, water recirculation aquaculture facility have indicated that early male sexual maturation can be problematic in this environment. In one growout trial at The Freshwater Institute, almost 75% of males had matured by 2 kg in size, and were culled to prevent subsequent unwanted health, behavioral, and economic consequences while the remaining salmon were grown to 4-6 kg. As early maturation could represent an important obstacle for producers interested in raising salmon in freshwater closed-containment systems, subsequent studies have focused on investigating this phenomenon in order to achieve a better understanding and to develop strategies to prevent or eliminate early maturation. *Study 1*: We raised Atlantic salmon to market size in six replicated recirculation aquaculture systems (RAS) operated at either high or low water exchange rates; at study's end, using enzyme immunoassays we quantified levels of circulating hormones (cortisol, testosterone, 11-ketotestosterone (11-KT), progesterone, and estradiol) in RAS water, to determine the impact of exchange rate, as well as biofiltration, on the levels of soluble hormones to which the fish were being exposed. Triplicate water samples were collected at three separate sites in each RAS: pre-biofilter, post-biofilter, and at the makeup water influent. At the time of abstract submission, preliminary results indicate that among the hormones examined, only testosterone was associated with significantly higher concentrations in low exchange RAS relative to high exchange RAS. Biofiltration was associated with a significant reduction in concentration of 11-KT, in both high and low exchange RAS. Circulating concentrations of testosterone, 11-KT, and estradiol were significantly higher than influent makeup water; the majority of quantified cortisol and progesterone concentrations were not significantly different between RAS and makeup water. *Study 2*: We exposed juvenile Atlantic salmon to two photoperiod regimes (either 24h continuous lighting, or 18h light : 6h dark) to determine if either treatment regime was associated with higher levels of early male sexual maturation. At approximately 350 g in size, 30 males (identified post-mortem) from each treatment group were sampled for plasma 11-KT quantification; the remaining salmon were marked to identify experimental cohort and then comingled in a single large growout system under continuous lighting. Subsequent plasma samples will be collected as the salmon grow to market size. At the time of abstract submission, laboratory results are still forthcoming, but will be available and discussed in detail during the conference presentation.

No 24
Danish Salmon: A brief overview

Mark Russel
Danish Salmon A/S, Søren Nordbys Vej 15, 9850 Hirtshals, Denmark

Corresponding author: mru@markrussellaqua.com

Abstract
Danish Salmon is a new recirculation facilty based in Hirtshals with the aim to produce 2.000 tons of Atlantic salmon per year. A brief summary of the project background, planning, construction and current status will be presented.

No 25
A new physico-chemical approach for efficient and cost effective fresh-water RAS operation

Ori Lahav
Faculty of Civil and Environmental Engineering Technion - Israel Institute of Technology Haifa 32000, Israel

Corresponding author: agori@techunix.technion.ac.il

Abstract
The talk will focus on a new physico-chemical process for ammonia and (potentially) phosphorus removal from fresh-water recirculated aquaculture systems (RAS). To clarify the incentive for the development of the new process, conventional RAS N and P removal processes will be reviewed, and their advantages/disadvantages discussed in light of the new approach.
The described method relies on continuous separation of NH4+ from RAS water using ion-exchange resin columns, which, upon exhaustion, are regenerated by simultaneous chemical desorption and indirect electrochemical ammonia oxidation directly to N2(g). The concept requires maintaining the pond water at pH<7 to allow for high NH4+ and at the same time non-limiting NH3 concentration. Approach advantages include (1) independence of temperature, potential bacterial predators and chemical toxins effects; (2) no startup period is required and the system can be switched on and off at will; and (3) the fish are grown in water with much lower bacterial concentration, making potential for both disease and off-flavor, lower. Process limitations include the fact that the concept can be performed only in fresh water and not in zero-discharge systems (due to the ion exchange step), and that atmospheric air has to be used for oxygen supply (due to the low pH maintained in the pond water which necessitates efficient CO2 stripping).
Following the initial description the talk will focus on results obtained in 51 d operation of a 500 liter pilot-scale RAS for initial proving of the new concept. The described system was stocked by 105 tilapia fish (initial weight 35.8 g), which were maintained at high TAN concentrations (10 to 23 mgN L-1) and fish density of up to 20 kg m-3. NH3(aq) concentrations in the fish tank were maintained lower than the assumed toxicity threshold (0.1 mgN L-1) by operating the pond water at low pH (6.5-6.7). The low pH resulted in efficient CO2 air stripping, and low resultant CO2(aq) concentrations (<7 mg L-1). Due to efficient solids removal, no nitrification was observed in the fish tank and measured nitrite and nitrate concentrations were very low. The system was operated successfully, first at 10% and then at 5% daily makeup water exchange rate. The fish grew at a rate identical to their established growth potential and showed no signs of stress or disease. The normalized operational costs, calculated based on data derived from the pilot operation, amounted to 28.7 $cent per kg fish feed. The results showed the process to be highly feasible from both the operational and economic standpoints.

No 26
Nitrogen removal from recirculation water and waste sludge in a marine RAS via partial denitrification and anammox

Purazen Chingombe[1], Yvonne Schneider[2], Taavo Tenno[3,4]*, Sheila Kvindesland[5], and Bernhard Wett[6]

[1)] Centre for Sustainable Aquatic Research, Department of Biosciences, College of Science, Swansea University, Singleton Park, Swansea, SA2 8PP, UK; [2)] Institute for Sanitary Engineering and Waste Management (ISAH), Leibniz Universitaet Hannover, Welfengarten 1, 30167 Hannover, Germany; [3)] aqua consult Ingenieur GmbH, Mengendamm 16, D-30177 Hannover, Germany; [4)] Institute of Chemistry, University of Tartu, 14a Ravila St., 50411 Tartu, Estonia; [5)] Teknologisk Institutt, Forusbeen 10, 4033 Stavanger, Norway; [6)] ARAconsult Unterbergerstrasse 1, Innsbruck, 6020, Austria

*Corresponding author: Taavo@aquaconsult.ee

Abstract

The *DeammRecirc* project aimed to develop a deammonification treatment removing nitrogen from recirculated water in the aquaculture industry following the recent success of using anaerobic ammonium oxidation (anammox) to remove nitrogen in other waste water treatments. As anammox bacteria convert ammonium with nitrite to dinitrogen gas, the project developed a process configuration allowing nitrogen removal from water and sludge in RAS farms.

To adapt DEMON® sludge from a reject water treatment plant slowly to typical conditions in RAS farms, lab-scale SBRs were seeded, and after stable anammox conversion performance was reached with initial conditions (25 °C, reject water with $NaNO_2$,) the boundary conditions were changed to investigate the influence of low temperatures (25 - 15 ^{o}C), high salt concentrations (freshwater to saltwater) and coupling anammox to partial denitrification to degrade NO_3^-.

Water and sludge samples from AAL (sea bass farm) were analysed for nitrogeneous and organic compounds. Sludge samples were screened for anammox bacteria by Fluorescence In Situ Hybridization (FISH) and for acidification and denitrification rates. Mass balances for N and C were used for the development of the DeammRecirc treatment concept and model (BioWin software) with the treatment of RAS sludge and water by acidification, partial denitrification and anammox.

The DeammRecirc prototype was implemented in a pilot-scale RAS (European sea bass) including initial enrichment of anammox bacteria from sludge (controlled by ^{15}N enrichment experiments and PCR) and optimization of acidification/partial denitrification.

Stepwise adaptation of anammox bacteria to low temperature (15 °C) allowed minimization of the decline in conversion activity. In contrast, increasing salinity above 10‰ lead to irreversible loss of anammox activity. Therefore, for marine RAS systems, anammox bacteria had to be grown from plant-specific inoculum. After 4 months of enrichment with (nitrogen dosing and restriction of organics), the presence of anammox bacteria (closely related to Candidatus *Scalinua wagnerii*) was proven. After 10 months of pilot plant operation, the nitrogen loads were 2.2 g/day NH_4^+-N and 1.1 g/day NO_2^--N. COD released by acidification was used for partial denitrification of up to 90% of the initial NO_3^- concentration to NO_2^-. However, less ammonia than expected was released.

The project demonstrated that enrichment of marine anammox from fish waste sludge is possible and devised a transferable enrichment strategy. Partial denitrification and acidification studies of sludge have enabled better control of nitrite production but sufficient ammonium supply requires more investigation to increase the nitrogen removal efficiency.

This study was part of the DeammRecirc project funded by EU FP7 programme "Research for the benefit of SMEs".

No 27

Reducing waste discharge from RAS: Yield of volatile fatty acids from anaerobic sludge digestion by batch or fed-batch methodology, and biomethane potential of the sludge

Karin I. Suhr[1]*, Carlos O. Letelier[1], and Ivar Lund[1]

[1)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author: ksu@aqua.dtu.dk

Abstract

The solid waste from recirculating aquaculture systems (RAS) being rich in nutrients and organic matter poses a hazard to the local ecosystem, if not properly treated. However, the bioavailable carbon in the sludge also represents a substrate for biological nutrient removal (N, P), or sustainable combustive energy when stored as methane.

In this study, the yield of volatile fatty acids (VFA) from anaerobic digestion (AD) of solid waste from a rainbow trout RAS system was measured by batch and fed-batch methodology. The batch (B) AD continued for 20 days (in triplicate), and fed-batch (FB) AD reactors were maintained at 1.25, 5, and 10 days hydraulic retention time (in duplicate). The biomethane potential (BMP) of the sludge was estimated by the assay proposed by Angelidaki et al. 2009.

The VFA production was fastest at 1-1.25 days retention time (B: 79.9 ± 15.0 mg VFA /g TVS_0 /d_1 and FB: 66.6 ± 6.8 mg VFA /g TVS_0 /$d_{1.25}$ vs. B: 31.7 ± 3.4 mg VFA /g TVS_0 /d_5 and FB: 26.4 ± 3.1 mg VFA /g TVS_0 /d_5), and no clear effect of the method applied was evident on the VFA yield measured up to day 10 (B: 162.1 ± 12.5 mg VFA /g TVS_0) or 10 days HRT (FB: 166.9 ± 26.4 mg VFA /g TVS_0). In the B AD, two of the triplicates showed further increase in VFA-yield beyond day 10 and reached a maximum VFA of 216.6 ± 4.8 mg / g TVS_0, whereas the deviating batch expressed a VFA consumption. The degradation of the organic matter during AD released soluble N and P. Initially in the undigested sludge, only 6 - 9 % of the N and P were present as total ammonia N (TAN) and ortho-P, but after 10 days AD, TAN made up 24 % and 17 % of total Kjeldahl-N, and ortho-P 53 % and 44 % of total P, in B and FB, respectively.

The biomethane potential of the sludge showed an average value of 318 ± 29 STP ml CH_4 /g TVS_0. This yield corresponded to 0.91 g methane-COD /g TVS, and was about 4 times higher than the maximum VFA yield from the AD (216.6 mg VFA /g TVS ≈ 0.23 g VFA-COD / g TVS). This suggests that after retrieval of VFAs for use in biological nutrient removal processes, biomethane generation should ultimately follow to fully exploit the available organic carbon.

No 28
Examples of Sludge thickening methods from the industry

Bjarne Hald Olsen
Billund Aquakulturservice A/S, Kløvermarken 27, 7190 Billund, Denmark

Corresponding author: bjarne@billund-aqua.dk

Abstract
The RAS technology is known as environmentally friendly and efficient for intensive fish farming in fish tanks. Still there is a challenge in order to reduce the discharge volume of sludge being produced by the mechanical and biological filters inside the RAS. Examples of different methods for thickening the sludge will be given.

No 29
Design of the “Self cleaning Inherent gas Denitrification-reactor” and its application in a RAS for pike perch (*Sander lucioperca*) production

Andreas Müller-Belecke[1]* and Ulrich Spranger[2]
[1)] Institute of Inland Fisheries Potsdam-Sacrow, Im Königswald 2, 14469 Potsdam, Germany; [2)] Kunststoff-Spranger GmbH, Reißiger Gewerbering 9, 08525 Plauen, Germany

*Corresponding author: andreas.mueller-belecke@ifb-potsdam.de

Abstract
First denitrification reactors have proven their functionality in commercial recirculation aquaculture systems (RAS). Nevertheless, clogging occurs due to the low hydraulic loads necessary to accomplish anoxic conditions for a successful denitrification process in RAS, which hampers the adjustment of stable working conditions within fixed bed denitrification reactors. Reactors working on the basis of activated sludge demand careful hydraulic control and/or complex configurations for sludge retention.
To develop a low-maintenance denitrification reactor, an enclosed moving bed filter, driven by recirculation of the inherent, oxygen poor gas was designed. A Self cleaning Inherent Denitrification reactor (SID-reactor) of 0.65 m³, which offered a moving bed volume of 0.39 m³ was connected with a RAS of semi-industrial scale for pike perch (*Sander lucioperca*) production. This species indicates suboptimal environmental conditions (as e.g. NO_3-N concentrations above approx. 68 $mg \cdot l^{-1}$) by prompt reduction of the feed intake. In different experimental series, the SID-reactor was operated with denatured ethanol, methanol, acetic acid or glycerin as carbon sources and changing operational modes.
Clogging was prevented safely by a 40 second inherent gas recirculation twice an hour, which provided continuous, maintenance free operation with marginal energy demand. With inlet (RAS) and outlet NO_3-N concentrations in the range of 49 $mg \cdot l^{-1}$ and 12 $mg \cdot l^{-1}$, mean denitrification rates of 199 g to 235 g NO_3-N per m³ moving bed volume and day were determined for all tested carbon sources. Nevertheless, no negative effects on the feed intake of the reared pike perch were detected only when using methanol. Changing the mode of operation to continuous circulation of the filter bed at inlet NO_3-N concentrations of 26 $mg \cdot l^{-1}$, the denitrification performance reached 451 g NO_3-N per m³ moving bed volume and day. The SID-reactor allowed for the reduction of freshwater exchange in the pike perch RAS from 600 l to 70 l (-88%) and the sodium bicarbonate buffer from 182 g to 31 g (-83%) per kg of administered food. The easy and reliable operation of the SID-reactor could help to establish controlled denitrification as a routine purification step in RAS.

The study was supported by the Deutsche Bundesstiftung Umwelt (DBU), Germany.

No 30

Water consumption, effluent treatment and waste load in flow-through and recirculating systems for salmonid production in Canada – Iceland – Norway

Asbjørn Bergheim[1]*, Helgi Thorarensen[2], Andre Dumas[3], Arvid Jøsang[4], O. Alvestad[4], and Frode Mathisen[4]

[1)] IRIS – International Research Institute of Stavanger, Norway; [2)] Holár University College, Iceland; [3)] Coastal Zones Research Institute, Canada; [4)] Grieg Seafood ASA, Norway

*Corresponding author: Asbjorn.Bergheim@iris.no

Abstract

Based on the NORA-funded project "Tomorrow's aquaculture systems" and current monitoring at Grieg Seafood's hatcheries, water flow and effluent loads from land-based farms producing salmon smolt and charr have been surveyed. Both flow-through systems (FTS) with – without end-of-pipe treatment and recirculating systems (RAS) are included.
Water consumption is reduced to 1 – 3% in RAS compared with in FTS. With regard to effluent load, the removal attempts in RAS facilities significantly reduce the load. Efficiently run FTS farms attaining high feed utilization with end-of-pipe solid removal also indicate low effluent load close to the levels in RAS farms. A high degree of variation between farms was however demonstrated.

Table: Water use, consumption of electric energy and waste discharge from RAS and FTS farms for production of salmonids (ranges in brackets: Norway – Canada, monthly max-min throughout the year; Iceland, farm based max – min)

Parameter, per kg produced fish	Norwegian RAS[a]	Canadian RAS[a]	Norwegian FTS[a,b]	Icelandic FTS[c]
Water use, m^3	0.8	0.3	22.0 (20 – 25)	95.0 (38 – 330)
Energy consumed, KWh	4.1	20.0	-	4.3 (0.0 - 9.7)
Waste load, g:				
Suspended solids	16.6 (3.9 - 60)	52.2	20.9	806 (41 - 1612)
BOD_5	8.5 (2.7 - 26)	-	13.8	14.1 (5.4 – 36)
Total phosphorus	2.3 (1.2 - 6.2)	-	2.3	-
Total nitrogen	19.7 (9.4 - 80)	-	24.0	72.3 (26 - 115)

[a)] Norwegian - Canadian RAS & FTS: Grieg Seafood's smolt farms.
[b)] FTS with end-of-pipe treatment.
[c)] Icelandic FTS farms: 9 farms producing juveniles, smolt and post-smolt Atlantic salmon and Arctic charr.

No 31
Containerized RAS solution for flexible and easy installation in aquaculture production systems

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

Corresponding author: jbregnballe@akvagroup.com

Abstract
A containerized solution for Recirculation Aquaculture Systems (RAS) has been developed to make on-site installations easier and smoother with a minimum of set-up time. The system consists of mechanical filtration, biofilter, micro particle filter, pumps, alarms and motor control centre, all fitted inside a 40 feet container with a degassing unit on top. Total maximum capacity is 225 kg feed per day with a water flow to the fish tanks of 400 m3 per hour. The system can be integrated with existing equipment on site or it can be fitted with additional external equipment such as oxygenation, UV, end of pipe discharge treatment etc. Due to the mobility of the system it serves as a fully flexible alternative to permanent RAS installations. It suits perfectly for newcomers in RAS technology, and can be used in the start-up phase of larger production systems or when extra water treatment is urgently needed on existing farms.

No 32
Biofilter nitrification performance in replicated RAS at different salinities

Thomas Cavrois[1] and Lars-Flemming Pedersen[2]*

[1)] Institut National des Sciences et Techniques de la Mer, CNAM, Cherbourg, France; [2)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author: lft@aqua.dtu.dk

Abstract

Few studies have addressed the potential effect of salinity on ammonia and nitrite removal in aquaculture biofilters. In this study we tested the validity of a common rule of thumb stating that nitrification performance in saltwater is reduced by one third compared to freshwater systems.

Twelve identical long-term operating 1.7 m3 pilot scale RAS with submerged fixed biofilter were used for the study. After well-defined nitrification equilibrium in freshwater (manually cleaned RAS followed by constant operating conditions until steady state), all twelve RAS were emptied and designated one of each four salinity concentrations (0 – 11 – 22 and 32 ppt.) by refilling with new make-up water. Rainbow trout were reintroduced at 18 kg m^3/system (fresh water acclimated trout transferred to 0 and 11 ppt; 32 ppt acclimated rainbow trout transferred to 22 and 32 ppt) and exposed to a constant feed loading regimen at 320 l make-up water pr. kg feed. Daily measurement of TAN, nitrite and nitrate were made in the start-up phase, showing transient ammonia accumulation (all below 1.2 mg TAN/l) in RAS operated at 22 and 32 ppt. Nitrite levels in freshwater and 11 ppt salinity were equal and did not increase (< 0.40 mg N/l), whereas baseline nitrite transiently peaked at 2.0 mg N/L in 22 ppt. and recovered to levels below 0.4 mg N/l within three days. In contrast, nitrite concentration accumulated during a prolonged period in all three RAS at 32 ppt. and reached levels up to 16 mg N/l before low nitrite levels were regained. Fish performed equally well in freshwater and at intermittent salinities, whereas ceased appetite and mortality were pronounced in two out of three high salinity RAS. The study included assessment of nitrification performance in terms of full system TAN spiking and separate batch spike experiments testing colonized biofilter elements from the salinity four groups of RAS.

No 33
Quantification of respiration and excretion rates in European lobster (*H. gammarus*)

Asbjørn Drengstig[1]*, Asbjørn Bergheim[2], Stig Westerlund[2], and Ann-Lisbeth Agnalt[3]

[1)] Norwegian Lobster Farm AS, Stavanger, Norway; [2)] IRIS - International Research Institute of Stavanger, Stavanger, Norway; [3)] Institute of Marine Research, Bergen, Norway

*Corresponding author: ad@hobas.no

Abstract

Land-based farming requires knowledge on key parameters as feed utilisation/feed conversion ratio (FCR), oxygen consumption, excretory values on carbon dioxide (CO_2) and total ammonia (TAN). Currently, knowledge is lacking on among others respiration and excretion rates of European lobster. This is urgently needed for dimensioning criteria for water treatment units in Recirculating Aquaculture Systems (RAS). According to Wickins and Lee (2002), the desirable levels of water quality for clawed lobsters are temperature of 18 to 22˚C, salinity of 28 to 35 ‰, above 6.4 mg O_2 /L, pH of 7.8 to 8.2 and less than 14 µg N/L as un-ionized ammonia.

Norwegian Lobster Farm conducted a few preliminary studies aiming to determine respiration and excretion rates. The studies indicated strongly fluctuating oxygen consumption in lobster of different size at 19˚C. The large variability in oxygen consumption at various sizes also demonstrated rapid adaptability to new conditions. Stress influenced respiration rates to increase to approximately twice the standard rates. Ammonia analyses indicated, as expected, a higher specific excretion rate in terms of mg TAN/kg x min in juveniles compared with sub adults. However, replicate sampling of the same size groups demonstrated considerable fluctuation from one test situation to another. Increased excretion rate in the larger animals was positively correlated with increased oxygen consumption.

Norwegian Lobster Farm is currently undertaking a major study jointly with IRIS and Institute of Marine Research in order to determine the range of optimal and critical/threshold levels of key water quality parameters for European lobsters.

No 34
Dynamic model for a fish tank in recirculating aquaculture systems

Pau Prat[1]* and Benedek Gy Plósz[1]
[1)] Department of Environmental Engineering (DTU Environment), Technical University of Denmark, Miljøvej Building 113, DK-2800 Kongens Lyngby, Denmark

*Corresponding author: papb@env.dtu.dk

Abstract
Danish legislation (Danish Ministry of Environment, 2012) has recently established emission-based limits for aquaculture systems based on total nitrogen (TN), total phosphorus (TP) and organic matter. Hence, future recirculating aquaculture systems (RAS) growth is being challenged by more sustainable and environmentally responsible production.
RAS have been studied in terms of design and operation. Experiments have been performed to optimize feeding composition, fish growth and treatment components to increase the capability of these systems to culture fish. RAS can also be studied through modeling experiments. Treatment components have been studied and modeled in their engineering fields and they can be coupled to a model for a fish culture tank (Wik et al., 2009, Pedersen et al., 2012). Adequate fish tank model should be as simple as possible, but sufficiently complex to describe the features shown by measured data.
The activated sludge model (ASM) family are widely accepted to model wastewater treatment plants based on biological treatment. The general formalism applied in these models is the Gujer matrix with processes stoichiometry and kinetics, and the description of organic substances in wastewater engineering based on COD units (Henze et al., 2000). RAS model based on ASM takes advantage of the models already developed in the wastewater engineering fields (e.g. biofilms).
This study presents a modeling approach for the processes occurring in the fish tank, which are: feed loss in the water column, fish feed uptake, fish growth, fish evacuation and fish respiration. These processes have been implemented in the simulation platform WEST® (MikebyDHI). A new model category has been developed based on the common language for concepts, nomenclature and matrix notation of ASM1 (Henze et al., 2000).
The full paper will present a detail description of the processes modeled and the values used for the model parameters and processes rates, which were obtained from McKenzi et al., (2007) for the rearing of rainbow trout. Modeling results are compared with the data included in Dalsgaard and Pedersen (2011) and Pedersen et al., (2012). The modeling results show that RAS can be modeled including dynamics in the fish tank and treatment units. The model presented can be adapted to other aquaculture system.
The model gives researchers and practitioners the opportunity to identify best management and operational strategies to improve RAS. The model can be used to select treatment units that help to increase fish production at low environmental costs.

No 35
Recirculating aquaculture system for high density production of the calanoid copepod *Acartia tonsa* (Dana)

Minh Vu Thi Thuy[1]*, Gunvor Øie[2], and Helge Reinertsen[1]

[1)] Department of Biology, Centre of Fisheries and Aquaculture, Norwegian University of Science and Technology, (NTNU), Trondheim, Norway; [2)] SINTEF Fisheries and Aquaculture AS, SINTEF Sealab, Trondheim, Norway

*Corresponding author: minhvu@ruc.dk

Abstract

The calanoid copepod *Acartia tonsa* (Dana) is one of the most promising copepod species for marine larviculture. This species has a wide tolerance to temperature and salinity, small size, can produce resting eggs. All their nauplii, copepodites and adults can be use as excellent feeds for marine fish larvae. Yet, the biomass and egg production of *A. tonsa* has been limited mainly due to the challanges to culture them at high density.

The development of recirculating aquaculture system (RAS) in recent decades has opened a new culturing system that is expected to provide more stable environmental conditions to favor the production of *A. tonsa* at high density. The current study was initiated to preliminarily apply a recircultating aquaculture system (RAS) for *A. tonsa* production. A flow through aquaculture system (FTAS) was also run in parallel to evaluate the capacity of RAS compared to the FTAS.

Both RAS and FTAS (3 replicates per system) were set up in the same room to ensure the equal condition. The initial densities of copepods were 20000 nauplii L^{-1} for investigation of growth and development in the early phase and 5000 ind L^{-1} in the copepodite and adult stages for testing reproduction capacity. *A. tonsa* fed the unicellular algae *Rhodomonas baltica* were registered for four weeks in triplicate 50 L tanks in each system. Water quality parameters were recorded daily for temperature, oxygen, pH, salinity, particles and every five days for nitrogenous waste and bacteria through the experimental period in both systems.

Unexpectedly, the hatching ratio of eggs was lower in RAS compared to FTAS that may be explained by a higher concentration of nitrite, nitrate and bacteria including *Vibrio* spp., haemolytic bacteria and fast growing bacteria. *A. tonsa* cultured in both RAS and FTAS had the similar survival, growth, and reproduction, yet the nauplii developed into copepodites faster in RAS (110h) compared to FTAS (158h). This can be an indication for the potential for culturing or maintaining *A. tonsa* nauplii and early copepodite stages at higher densities before feeding larvae of marine species. The RAS also needs a further optimisation of water quality by a denitrifying filter component to stabilize for copepod cultivation and an implementation of disease control treatment is also required.

No 36

Recent advances within intensive Recirculated Aquaculture System cultivation of the calanoid copepod *Acartia tonsa* (Dana)

Per M. Jepsen[1]*, Jacob K. Højgaard[1], Guillaume Drillet[2], Mohamed-Sofiane Mahjoub[2], Moloud Rais[2], Aliona Novac[3], Johannes Schjelde[1], Claus Andersen[1], and Benni W. Hansen[1]

[1)] Department of Environmental Social and Spatial Change, Roskilde University, Universitetsvej 1, 4000 Roskilde, Denmark; [2)] DHI Singapore, DHI Water & Environment (S) Pte. Ltd., 1 CleanTech Loop, CleanTech One #03-05, 637141 Singapore; [3)] Faculty of Biology, "Alexandru Ioan Cuza" University of Iasi, Romania

*Corresponding author: pmjepsen@ruc.dk

Abstract

Danish aquaculture has within recent years focused upon rearing of new marine fish species. A major challenge for rearing of marine fish species is relevant diets for their fish larvae. Copepods and their larvae stage "nauplii" are well documented as the ideal live feed for a variety of marine aquaculture species. Copepodites and nauplii are superior as live feed compared to rotifers and *Artemia* both in terms of nutritional value, behaviour and prey size.

In 1980s the copepod *Acartia tonsa* (Dana) was isolated in the Danish strait of Øresund and has been studied and kept in cultures ever since. An interesting trait with the species is that the eggs can be provoked into a resting stage, where the egg can be stored for one year, similar to Artemia cysts. This is the most promising storage technique for distribution of copepod eggs to aquaculture facilities worldwide. The eggs can be hatched and the nauplii can be feed to marine fish larvae.

A restriction is that copepod cultures for producing eggs are after 30 years of research still not stable and in large enough scale for bulk production of eggs. Recently a unique copepod Recirculated Aquaculture System (RAS) at Roskilde University (Denmark) was constructed as a part of the IMPAQ project "IMProvement of AQuaculture high quality fish fry production". We present recent advance within RAS culture for copepods, and lesson learned from rearing the specie. Further we present physical and biological culture restrictions in terms of water quality (NH_3), chemical and physical copepod densities, and its effects on copepod egg production (fecundity).

We found that NH_3 affect nauplii cultures negatively at levels above 30 µg NH_3 L^{-1}, and adult cultures at levels above 477 µg NH_3 L^{-1}. In terms of chemical and physical densities egg production was limited at densities above 2000 adults L^{-1}.

No 37
Aquaponics based on geothermal energy

Ragnheidur Inga Thorarinsdottir
SVINNA-Engineering Ltd. - Fannafold 61 - 112 Reykjavík, Iceland; University of Iceland, Sæmundargötu 2, 101 Reykjavík, Iceland

Corresponding author: svinna@svinna.is; rith@hi.is

Abstract
Aquaponics is a subtraction of the words aquaculture and hydroponics. The wastewater from the fish is used as resources in the horticultural production where plants take up the nutrients and hence cleanse the water before being returned to the fish. Thus, aquaponics is a resource efficient closed loop food production system, mimicking the nature itself. Rakocy and his coworkers at the University of Virgin Islands have done extensive research on aquaponics (Rakocy, 2009; 2002; 1999a,b; Rakocy et al., 2009; 2006; 2004; 2001) and in recent years the interest for aquaponics has been increasing. A European funded project is in the start-up phase with collaborating partners from Iceland, Denmark and Spain. In Iceland the overall objective is to implement commercial viable aquaponics with a stable year round production using geothermal heat and supplemental lighting in the winter period.
Aquaponics methodology is mainly based on three technologies, grow beds, nutrient film (NFT) and floating raft systems (Bernstein, 2011). The grow beds are media-based systems while the plant roots grow directly into the water in the NFT (in thin layer of water) and raft systems (floating plates in large water tanks). These latter systems work well but needs filtering to avoid fish waste to accumulate on the plant roots. In the media-based system the grow bed becomes the filtration system for all the waste products. Moreover, a media-based grow bed has almost no limits to the types of plants you can grow. NFT and raft systems have lower levels of nutrients because of the solids removal and there is not sufficient strength to bear up large plants. However, these systems are convenient for smaller plants as salad, greens and herbs. Bernstein (2011) suggests that hybrid aquaponics systems including both media-based and either raft or NFT systems will be the optimum solution. As today these types of hybrid systems are in the early days of development and the literature offers scarce resources on optimum solutions.
The main research questions put forward focus on optimising the economic benefit from aquaponics compared with conventional agriculture and horticulture methods. This includes comparison of different fish species and plant species, respectively. Furthermore, cold (salmonids) and warm water (tilapia) species available in Iceland (Dalsgaard et al., 2013) will be evaluated for aquaponics systems. The holistic approach also comprises the system design, alternative feed in form of duckweed and insects, illumination assessment and the use of geothermal energy and other renewable energy sources. The design of the system and the first steps forward will be presented.

No 38
Aquaculture unit processes and production systems: performance measures, analysis, and evaluation

John Colt
Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA

Corresponding author: John.Colt@noaa.gov

Abstract
The performance of unit processes and production systems can be measured in a wide variety of units. Selection of performance units is especially critical when different species or production systems are compared. For unit processes such as biological filters or aerators, performance should be measured in terms of mass of compound added (or removed) divided by the total energy used. Ideally, energy use should be based on direct measurement of power consumption and measured duty cycle. The number of published articles with this type of energy consumption information is small because of the lack equipment, safety concerns, and operational constraints. Commonly, energy consumption is based on name-plate power information and an assumed duty cycle. For some systems, it may be possible to adjust individual component energy use based on total system energy usage. The mass transfer characteristics of unit processes are best documented for laboratory and pilot-scale units. The performance of commercial units may be significantly less than for smaller systems and not replicated. The lack of measured energy consumption and mass transfer data significantly impacts our ability to compare different process options.
The performance of production systems has typically included food conversion ratio (FCR), specific growth rate (SGR), and total weight gain. Other efficiency ratios can be based on whole animal outputs (total weight gain, dry weight gain, protein gain, and gross energy), carcass outputs (dressed weight gain, edible weight gain, dry weight of edible weight gain, and edible protein energy), and inputs (wet weight of feed, dry weight of feed, energy content, and protein content). There is little agreement on which of these efficiency ratios are most important or their computation.
Life Cycle Assessment (LCA) offers an international standard method to evaluate the global impact of a product or a process on the environment. For production systems, the uncertainties in on-site energy consumption values discussed above may have a significant impact on the accuracy of impact assessment. In addition, the potential impact of methane and nitrous oxide production in pond, flow-through, and reuse system may be significant. Evaluation of these impacts will require direct measurement of gas production rates and characterization factors.

No 39
Processes to improve energy efficiency during low-lift pumping and aeration of recirculating water in circular tank systems

Steven T. Summerfelt[1]*, Timothy Pfeiffer, Lauren Jescovitch, Ethan Metzgar, and Dane Schiro

[1]Conservation Fund Freshwater Institute, 1098 Turner Road, Shepherdstown, West Virginia 25443, USA

*Corresponding author: s.summerfelt@freshwaterinstitute.org

Abstract

Dissolved oxygen and carbon dioxide control are typically the first two water quality parameters to limit fish production in water recirculating systems. Conventional gas transfer technologies for aquaculture systems require a considerable capital investment and contribute to increased electricity demand. In addition, diffused aeration in a circular culture tank can interfere with the hydrodynamics of water rotation and the speed and efficiency of solids fractionation to the tank's bottom-center drain. To improve the energy efficiency of pumping and aerating water in circular tank-based recirculating systems while maintaining culture tank hydrodynamics, three processes were developed and evaluated that provide high water flow and low lift method of gas exchange immediately adjacent to the circular culture tank. One process incorporates a sidewall box airlift pump that is built into the wall of the circular culture tank; a second process incorporates a propeller aerator mounted at the top of the riser chamber in this same sidewall box; the third process incorporates a forced-ventilated cascade column and low-head axial flow pump into the same sidewall box.

All three sidewall box aeration technologies created a simple partial water reuse system and were evaluated when attached to a 1.2 m tall fiberglass wall panel of a 3.7 m diameter circular tank. Results, including pumping rate, oxygen and carbon dioxide transfer efficiency, and energy requirements, will be reported and contrasted for each of the sidewall box aeration processes. The potential for increased energy efficiency in water recirculation systems through improved low-lift pumping and gas transfer processes will be discussed.

No 40
Pumps for recirculation

Mikael Zacho Jensen
Grundfos DK A/S, Martin Bachs Vej 3, DK-8850 Bjerringbro, Denmark

Corresponding author: mzjensen@grundfos.com

Abstract
The presentation will focus on three points with respect to pumps for RAS:

- Examples of energy focus points, when you design a recirculation system, seen from a pump perspective.
- What happens to the energy consumption, when pumps are run by a frequency converter.
- A short introduction of test setup in 2 applications, mechanical cleaning and oxygen cones.

No 41
New web-based program and online water quality monitoring system for RAS farms

Tapio Kiuru[1]*, Anna-Maria Eriksson-Kallio[2], and Henna Lampinen[3]
Arvotec, Ruukintie 45, FI-79620 Huutokoski, Finland; [2)] Finnish Food Safety Authority Evira, Finland; [3)] VTT Technical Research Centre of Finland, Finland

*Corresponding author: tapio@arvotec.fi

Abstract
Water quality related fish health problems are quite different in traditional aquaculture and in recirculation aquaculture systems. Whereas impacts of individual water quality parameters on fish health in traditional aquaculture are rather well known, considerably less is known about combined fish health effects of different water quality parameters, and fish's ability to adapt to water conditions existing in recirculation aquaculture systems. Part of the challenge in finding causality between water parameters and possible disease and/or change in welfare indicators has been a lack of on-line water quality monitoring systems. Finnish Food Safety Authority Evira, Arvo-Tec Ltd. and VTT Technical Research Centre of Finland have started a two year research project called “On-line water parameter monitoring and fish health in production scale RAS”, which aims to lead to a better understanding of causal relationships in water quality and fish health in production scale RAS. The project has two parts: 1) finding suitable sensors for on-line water parameter monitoring (most importantly ammonia, nitrite, nitrate, carbon dioxide and suspended solids), and 2) finding causality between water parameters and possible disease and/or change in welfare indicators in rainbow trout. The first part of the project has shown a potential in the use of new sensor technology and has led to new innovation combining on-line water quality monitoring system and feeding control system. In the second part of the project two production cycles (10g-800g) of rainbow trout are followed in a commercial RAS-farm, and water quality parameters and fish health indicators (fin-index, histopathology, bacteriology, parasitology) will be compared.

No 42

Rearing density in combination with water temperature affect Atlantic salmon smolt welfare and performance during intensive production in recirculating aquaculture system (RAS)

Jelena Kolarevic[1]*, Grete Baeverfjord[1], Harald Takle[2], and Bendik Fyhn Terjesen[1]

[1)] Nofima, NO-6600 Sunndalsøra, Norway; [2)] Nofima, NO-1432 Ås, Norway

*Corresponding author: jelena.kolarevic@nofima.no

Abstract

Recirculating aquaculture systems (RAS) are becoming an important part of the Atlantic salmon production worldwide. The possibility for increased production on a given amount of water, more stable environment for the fish and increased biosecurity are some of the advantages that are appealing both to the industry and the general public. However, the investment costs and economical profitability dictate the desire to further intensify the production in RAS. In this trial we aimed to establish the limiting density for Atlantic salmon parr during fresh water stage in RAS.

Atlantic salmon parr with an initial weight of 80 g were stocked in two RAS in the Nofima Centre for Recirculation in Aquaculture (NCRA). The RAS were operated at different temperatures: 12-13°C and 14-15°C, with an average difference between systems of 2.3°C for the duration of the trial. Water from each RAS was provided to six octagonal 3.2m^3 tanks. Three tanks per RAS had a starting fish density of 30 kg/m^3, and three other tanks were stocked to 60 kg/m^3. During the twelve weeks of the trial, regular sampling of fish and water and monitoring of fish welfare indicators were done.

The results indicate that fish density is a critical factor for fish welfare in RAS. No signs of adverse effects were observed up to 100 kg/m^3. However, at a fish density of 120 kg/m^3 in the high density tanks, the fish in the high temperature-high density tanks developed a panic behaviour followed shortly after by a high mortality occurrence. At all sampling points measured water quality parameters remained within recommended units. Examination of the external welfare indicators at termination demonstrated that fish in low density tanks at both temperatures (approaching 70-80 kg/m^3) remained in good condition, whereas the high density tanks at both temperatures showed signs of reduced welfare. There was no differentiated growth response related to temperature, or fish density, up to a fish size of 150 g (about 100 kg/m^3 in the high density tanks) after which the growth in the high density tanks showed signs of stagnation, and there was a differentiated response between temperature groups. It is of importance to explore this topic further, as consequences for design, dimensions and operation of RAS smolt production are great.

No 43

Nutrient digestibility and growth in rainbow trout (*Oncorhynchus mykiss*) are impaired by short term exposure to moderate excess total gas pressure from nitrogen supersaturation

Peter Vilhelm Skov[1]*, Lars-Flemming Pedersen[1], and Per Bovbjerg Pedersen[1]

[1)] Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author: pvsk@aqua.dtu.dk

Abstract

Excess levels of dissolved nitrogen gas (N2) may occur in recirculating aquaculture systems, as a result of aeration efforts, localized occurrences of denitrification, or from insufficient degassing of makeup water. If levels of dissolved N2 are sufficiently high, or if oxygen (O2) is also maintained at or above saturation, this leads to a supersaturation in total gas pressure (TGP). Depending on severity, total gas pressures above saturation may lead to gas bubble trauma, evident by visual inspection of the fish.

Physiological effects of subclinical levels of TGP are not well known and have not been investigated for rainbow trout. Using a modified Guelph system which allowed for manipulation of dissolved gas levels, the present study examined the effects of N2 supersaturation, with or without simultaneous excess TGP, on digestibility of macronutrients, growth, feed conversion, and cost of growth.

Supersaturation with N2 (DP 22mmHg) without total gas supersaturation (DTGP -6 mmHg) did not have any significant effects on feed intake, feed conversion or growth. Short term (16 days) exposure to N2 supersaturation (DP 36mmHg) in combination with a DTGP of 23 mmHg did not affect feed intake, nor did it cause GBT or any apparent changes in behaviour. Excess TGP did, however, significantly reduce apparent lipid digestibility, feed conversion, and the thermal growth coefficient, compared to control treatments in which N2 and O2 were maintained below saturation levels. In addition to a significant decrease in available metabolizable energy (energy intake corrected for faecal loss), this group also had significantly higher cost of growth.

These results suggest that even moderate TGP supersaturation negatively affect aquaculture production by a dual effect on energy uptake and energy expenditure, possibly caused by a general stress response to dissolved gases. Continuing the experiment over 25 days eliminated any significant differences on production variables, suggesting that rainbow trout exposed to moderate excess levels of TGP for longer periods were able to adapt to some degree.

No 44
Future development of RAS in commercial farming

Oscar Garay
Salmones Magallanes S.A., Gabriela Mistral 657, Puerto Natales, Reg. XII, Chile

Corresponding author: ogaray@salmonesmagallanes.cl

Abstract
The growing demand for marine products at a worldwide level has transformed the aquaculture industry into a success story. This is especially true with respect to farmed salmon. There are, however significant risks associated in a medium in which the producer has limited control. It is in this spirit that the aquiculture industry has turned its attention to develop systems allowing for greater environmental controls such as those required for improved water quality. Such handling, which assures uniform quantitative and qualitative results, competitiveness, and viability, is directly linked to technological advances.
Since of first step of RAS in Denmark thirty years ago until now there have been great advances in recirculation systems. The numbers of RAS hatcheries have increased dramatically over the last decade around the world and are being used in the production of various aquatic organisms and with increasingly industrialized systems. The presentation show a look at the progress of RAS systems and what we can expect in the medium and long term future.

Colophon

2nd Workshop on Recirculating Aquaculture Systems
Aalborg, Denmark, 10-11 October 2013
Program and Abstracts

Edited by Anne Johanne Dalsgaard

October 2013
DTU Aqua, National Institute of Aquatic Resources

Cover photo: Peter Vilhelm Skov

DTU Aqua report No. 267-13
ISBN 978-87-7481-167-1 (print)
ISBN 978-87-7481-175-6 (web)
ISSN 1395-8216

Reference: Dalsgaard, A.J. (ed.), 2013. 2nd Workshop on Recirculating Aquaculture Systems. Aalborg, Denmark, 10-11 October 2013. Program and Abstracts. DTU Aqua Report No. 267-13. National Institute of Aquatic Resources, Technical University of Denmark, 61 pp.

DTU Aqua
National Institute of Aquatic Resources
Technical University of Denmark

North Sea Science Park
9850 Hirtshals
Denmark
Tel: + 45 35 88 33 00
Mail: aqua@aqua.dtu.dk

www.aqua.dtu.dk