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DOES THE WATER REUSE AFFECT THE FISH GROWTH, WELFARE QUALITY?

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Abstract

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The fish production in aquaculture is growing from year to year. However capacities of current aquaculture facilities are limited. So the need of intensification of old facilities and building new intensive facilities is obvious. The high intensity of fish culture generates some questions. Could water reuse affect fish growth, welfare, health or quality of final product? A lot of research was performed for this issue but just a few works compared water reuse systems (RAS) versus flow thru systems (FTS). A problem with CO_2 oversaturation was solved by shallow diffusers. Fin erosion seems to be a problem of high stocking density and system hygienic but it is not related directly to water reuse. A few papers were written about biochemical blood stress markers but it was mostly aimed to acute crowding or changes were found at extreme stocking densities over 124 $kg.m^3$ for rainbow trout and 70 $kg.m^3$ for sea bass. The fish are able to accustom to increased noise produced by RAS equipment very fast so it don't affect fish negatively. There wasn't found any prove of main water reuse to fish influence in the available literature. All results indicates that if the ecological parameters are kept in natural range for the fish reared in RAS, there is no negative effect of water reuse on fish.

recirculation, fin erosion, carbon dioxide, stocking density, RAS

With the increasing Earth population, there is gradual increase in demand on protein as human nutrient resource. Fish is one of high quality protein sources. In comparison to e.g. pork stock, fish culture has much less impact on the environment. Fish natural sources have been running short, lately. Several major fish species can never be restored naturally. In general, fish necessary for human nutrition come from natural aquatic environment – ocean or fresh water (lakes, rivers). Current rearing systems focus on the creation of "natural" pond conditions or intensive fish culture in flow-through systems (FTS). Warm-water fish production in Europe is mostly concentrated on cyprinids and situated in ponds. Warm water fish rearing capacities in the Eastern Europe are still sufficient. European consumers' orientation turns increasingly to coldwater fish like salmonids. Salmonids are reared in FTS or recirculation aquaculture systems (RAS), which allow considerably higher production intensity per cubic meter and lower need of water per kg of fish produced. In FTS, water flows through just once. FTS depend highly on water source quality, quantity and stability. Both the water quantity necessary for fish production and the amount of pollutants out leaving with water are very high. This does not satisfy requirements of new trends in the environmental protection and especially water quality preservation. Therefore, old systems are modified and new systems for water cleaning and conditioning are used. New facilities range from simple sedimentation areas and diffusers to highly sophisticated biological nutrient removal by means of plants and/or bacteria. Other modifications make use of partial water recycling and the latest technologies are allowing production intensifying or water consumption reduction, or both. On the other hand, these modifications result in slight waste concentration increase in the outlet water, as well. The most sophisticated and up-to-date solution of this problem is represented by a new RAS enabling "complete" water reuse (zero discharge systems). In most cases, these modern technologies are being developed in

Denmark, Israel, Netherlands or France, which, as developed countries, act in compliance with strict environmental standards and, in addition, some of them lack suitable water sources. New RAS allows concentrated unsuspended solids' removal from the system. Unsuspended solid removal means recipient's direct pollution decrease of up to 38% (d'Orbcastel *et al.*, 2009b). Modern RAS are equipped with biofilters, which transform ammonia and nitrites toxic for fish into almost harmless nitrates by means of biologic nitrification as described in Jokumsen and Svedsen (2010). Nitrates' toxicity is less than 40,000–130,000 (Tilak *et al.*, 2002; Tilak *et al.*, 2007) times lower in comparison to unionized ammonia, depending on fish size (Adelman *et al.*, 2009; Camargo *et al.*, 2005; McGurk *et al.*, 2006). The toxicity of nitrates usually declines with increasing fish body weight (Adelman *et al.*, 2009; Camargo *et al.*, 2005; McGurk *et al.*, 2006); however, in case of Siberian sturgeon (*Acipenser baeri*) where Hamlin (2006) reversed trend of nitrate toxicity, related to fish weight, has been found. The outlet water rich with nutrients is cleaned in biological ponds or lagoons and channels (Gennaro *et al*, 2006; Jokumsen and Svedsen 2010) and denitrification biofilters are added to fully recirculating aquaculture facilities (FRAF) (Arbiv and van Rijn, 1995; Jokumsen and Svedsen, 2010; Schneider *et al.*, 2011; Schnel *et al.*, 2002; van Rijn *et al.*, 2006; van Rijn and Rivera, 1990). This can make the need for water per the amount of fish produced lower tenfold, while increasing system carrying capacity by almost one third (d'Orbcastel *et al.*, 2009a, c). The insufficient and uncertain production and catches of highly valuable fish like pikeperch (*Sander lucioperca*), Eurasian perch (*Perca fluviatilis*), European catfish (*Silurus glanis*) and eel (*Anquilla anquilla*) hinders their intensive RAS rearing, too. Fish and shellfish production was tripled from 1990 to 2005 (FAO, 2005) and the aquaculture production increased to 55.1 millions of tons by 2009 (FAO, 2010).

As mentioned above, RAS allow considerably high production intensity at quite low need for makeup water. RAS reduce the pollutants' release from the system to recipient rapidly. Waste caught can be used as a fertilizer on fields, gardens or directly at ponds. High production intensity gives rise to some questions. For instance: "What if the water reuse affects fish welfare and the condition of the whole organism and quality of produced fish?"

The review is aimed mostly to salmonids and percids as representatives of highly sensitive fish.

Review of current knowledge

There is a number of criteria for evaluation the influence of used technology on fish. Production characteristics like fish growth, feed conversion ratio (FCR), mortality, specific growth ratio (SGR) and biochemical stress markers are used. Morfological deformities and nutrition value can be used too, but these are mostly secondary effects of a problem in system. Criteria monitored are usually affected by the synergic influence of the environment and nutrition. A group of parameters, which will exactly reflect this influence in practice should be selected. This group of parameters will serve as a base for evaluation of the need for rearing system modification. The aim of this review is to collect parameters used for the system evaluation and the production intensity concerning fish organism.

The first problem arose at the beginning of the intensification with the use of oxygenation (liquid oxygen addition). It consisted in too high water saturation by carbon dioxide. The excessive CO_2 concentration caused decrease of SGR, FCR and worsened the health, causing nefrocalcification in particular. This was observed at salmonids kept in CO_2 concentrations higher than 16 mg. l^{-1} at different exposition times by Blancheton *et al.* (2007a, b), d'Orbcastel *et al.* (2009b, c), Fikri *et al.* (2000), Fivelstad *et al.* (2003), Good *et al.* (2009; 2010), and Smart *et al.* (1979). This problem can be solved by use of shallow diffusers (80 cm below the water level). Shallow diffusers degas CO_2 from the water very efficiently. CO_2 degassing works on the principle of different gasses solubility in water and air to liquid ration. CO_2 supersaturation problem is not recent to new systems.

Another gas-related problem is nitrogen (N_2) supersaturation. It accompanies the use of deep airlifts performing water circulation and the use of spring-/groundwater or water cooling, which decreases gas solubility in water. N_2 supersaturation is much more dangerous for young fish and the impact on fish depends highly on actual species and O_2 saturation influence. N_2 supersaturation can cause gas bubble disease (GBD). The disease may occur in a chronic form at approximately 103% and in acute form at more than 110/115% total gas pressure (TGP). (Bohl, 1997; Saeed and Al-Thobaiti, 1997; Wagner *et al.*, 1995).

Higher noise level produced by strong blowers can affect the fish in modern RAS. Blowers are the source of substantial air volume used as water circulation engine by the airlift and by diffusers in rearing raceways in the whole system in modern RAS. Davison *et al.* (2009) performed a five-month test on rainbow trout (*Oncorhynchus mykiss*), aimed at the noise issue. They found that the group of fish from the same source, which was exposed to higher noise level, had worse SGR and FCR in the first month of the test. At the end of the test, there were no significant differences between groups exposed to higher and lower noise level. Specific sound can even have a positive influence on fish growth and welfare. Papoutsoglou *et al.* (2007 and 2008) performed two experiments with common carp (*Cyprinus carpio*) and sea bream (*Spharus aurata*), respectively. When Mozart's music was applied to fish underwater, improved SGR, more homogenous groups and reduced stress neurotransmitters were found.

One of the most frequently watched parameter in intensive aquaculture is the stocking density. Many authors made their research regarding this issue. They found different indicators of the influence of stocking density to the fish. D'Orbcastel *et al.* (2009a) performed a 77-day test with rainbow trout. They found more fish with caudal fin erosion in RAS than in FTS. The results were not able to prove the influence RAS on fish, because the water-flow velocity in RAS was three times higher than in FTS. Higher number of fish with caudal fin erosion might have been caused by more often fish mutual contact caused by their higher motion activity. D'Orbcastel *et al.* (2009c) compared the growth and survival of rainbow trout in RAS and FTS in another test. They did not find any significant differences. Good *et al.* (2009) compared the growth and health of rainbow trout (*Oncorhynchus mykiss*) in RAS at stocking densities from 25 to 80 kg. m^{-3}. No significant differences were found. Sirakov and Ivancheva, (2008) compared the growth of rainbow trout and brown trout (*Salmo trutta m. fario*) in RAS at stocking densities from 0.84 to 3.57 kg. m^{-3} and 0.77 to 2.21 kg. m^{-3}, respectively. They found decreasing SGR and FCR with increasing stocking densities. Fish were kept in closed system with cyclic daily water changing and insufficient biofiltration. The worse results at brown trout might have been caused by its higher sensitivity to manipulations and rapid changes. Brown trout was more affected than rainbow trout. Rasmussen *et al.* (2007) studied SGR, FCR and caudal fin erosion at rainbow trout in RAS. They used different stocking densities (from 41 to 124 kg. m^{-3}), sizes of fish and feeding frequencies. They found decreasing SGR and FCR and more fish with eroded caudal fin with increasing stocking density at the end of the test. The influence of feeding frequency wasn't significant. Garcia-Ulloa *et al.* (2005) reared a fingerling of red tilapia (*Oreochromis mossambicus*) in RAS at stocking densities from 3 to 8 individuals per litre. They did not found any significant differences in SGR, FCR and survival rate among tested groups. Rafatnezhad *et al.* (2008) investigated the effect of stocking density influence on growth, survival, fin erosion and stress markers in blood (plasma cortisol, glucoses, amount of hemoglobin, etc.) of juvenile beluga (*Huso huso*). In the beginning, they used the same fish (93 g per individual), which weighed from 211 to 362 g per individual at the end of 8-week test. They used the stocking densities from 0.5 to 3.0 kg. m^{-3} at the end of the test. There were no significant differences in stress markers, at all. They found decreasing individual growth with increasing stocking densities. Statistically (>0.05) higher percent of fish with caudal fin erosion was found in the group with 3 kg. m^{-3}. This can be explained by more often contact of fish, which can not stop swimming. Other fins were not eroded. Sammouth *et al.* (2008) studied the impact of stocking densities from 10 to 100 kg. m^{-3} on sea bass (*Dicentrarchus labrax*) in RAS and its response to nodavirus infection. Fish performance, stress indicators (plasma cortisol, proteonemia plus other blood parameters – Na^+, K^+, glucose, pH, total CO_2) and water quality were monitored. At the end of the 63-day period, resistance to infection was also studied by a nodavirus challenge. With regards to the different density treatments, there was no significant difference between the daily feed intake (DFI) and the specific growth rate (SGR) up to a density of 70 kg. m^{-3}. Between the treatments concerning feed conversion ratio (FCR) and the mortality rate, no significant difference was found. No density effect was observed in case of the fish stress level (plasma cortisol) or on sensitivity to the nodavirus challenge. Under these experimental rearing conditions, the density above 70 kg. m^{-3} had an impact on growth performance (DFI and SGR) indicators and also some blood parameters (CO_2) at the highest density tested (100 kg. m^{-3}). They found decreasing FCR at stocking densities above 70 kg. m^{-3}. FCR was for 14 % worse at the stocking density of 100 kg. m^{-3}. Di Marco *et al.* (2008) investigated stress markers (plasma cortisol, non-esterified fatty acids – NEFA, glucose, crude protein, triacylglicerols and cholesterol) in blood of sea bass. Fish of middle weight of 139.8 g were kept in RAS at stocking densities of 15, 30 and 45 kg. m^{-3} for 6 weeks. After six weeks, they found a statistically higher NEFA in the group with the highest stocking density. Immediately after the test, the stocking density increased rapidly to 100 kg. m^{-3} for 15 minutes. After the stocking density increase, stress markers were measured. The group reared at the highest stocking density had statistically higher levels of NEFA and plasma cortisol and lower glucose levels in blood. All watched parameters returned to normal values in two days at all groups. Authors recommend two days delay between any extreme interventions. Saoud *et al.* (2007) watched the stocking density impact on marbled spinefoot (*Siganus rivulatus*) reared in RAS. They did not find any impact on fish at stocking densities from 1.2 to 4.8 kg. m^{-3}. Stocking densities used for the test were much lower than those used for salmonids or other freshwater fish.

Another question is, whether the water reuse can affect taste, consistence and nutrition value of the final product. The quality of final fish product is affected by the composition of environmental conditions, feed and feeding technique. Frank *et al.* (2009) compared the sensory parameters of barramundi (*Lates calcarifer*) from their natural environment and from three types of intensive aquaculture – the above-surface plastic tanks (RAS), in-ground lined pond (FTS) and earth ponds (FTS). They compared these four varieties by a sensory test made by human and by gas chromatography and simultaneous mass spectrometry, where they were aimed at aromatic substances important for the taste and smell. They found that fish from intensive cultures have more intensive typical smell and taste (more aromatic substances) than fish from nature. Additional "muddy", "earthy", and "musty" flavour notes perceived in case of lined and earth pond reared samples were related to the presence of 2-methyl isoborneol and geosmin in these samples.

It was caused by natural character of ponds. Mareš *et al*. (2010) compared the sensory descriptors and nutrition quality of rainbow trout from different farms all over the Czech Republic, which use the same feed. They found that the rearing system (RAS vs. FTS) and the water flowing in have a statistically proved impact on taste and nutrition quality of the final product. From the basic data of this research, we know that fish from RAS had statistically highest content of proteins and fat (>0.05) in flesh. The sensory evaluation showed worse juiciness, aroma and taste intensity, but much more pleasant smell and taste for RAS than FTS, respectively. Water-flow speed impact on the structure and quality of meat has not been proved, yet.

Along with the water reuse, the question of disease control emerges. We can say that brand new RAS is disease-free. Due to often use of ground water and usual UV treatment of the incoming water, infecting of the system can happen only, when user does not take enough care to biosecurity. After infecting the system, RAS have more problems than FTSAnd their impact is usually much worse. If we simplify the situation in RAS depending on the amount of conditioning water, we can compare the situation in RAS and FTS mathematically. If we compare common rearing raceway Danish RAS with two fifths of its volume allocated to biofilter of the total volume of 1000 m³ to FTS of 600 m³ volume and we do not take filter sediments and sedimentation areas into consideration, we can make calculations easily. If the water reuse rate is 95 % and water in FTS changes three times a day. Accumulation of pathogens in RAS is sixty times higher than in FTS. Possible concentration of pathogens is sixty times higher and the possibility of fish infection is sixty times higher, as well. Another thing is the water mixture in RAS, so if some pathogen gets to one raceway in the system it will immediately spread all over the system and can infect the rest of the fish. In FTS with parallel raceways, this problem is not relevant. The other thing is if some of pathogens aren't destroyed in biofilter. When we use any medicaments to cure any disease in RAS, we have to count with biofiltering units and their reaction to it. Bacteria in the filter are quite sensitive to most antibiotics. In FTS, they just flow away with discharged water and are adulterated in recipient at undetectable concentrations, usually.

CONCLUSIONS

Results achieved by different authors are not uniform. Results concerning fin erosion at RAS and FTS are not usually supported statistically, so we can not make conclusions regarding decreased or increased welfare or even impact of RAS vs. FTS respectively. The fin erosion seems to be the result of the function of high stocking density and system sanitary parameters, which can be explained only after a research focused directly on this problem. Other possible direct unfavourable impacts of RAS use on fish were not proved and further research on this is recommended. We can conclude that if all ecological parameters relevant for the fish-rearing in RAS are fulfilled, RAS do not have any negative impact on fish health, welfare and to nutrition values of the end product from the intensive RAS. The quality of final product can be affected by the technology used, but until there are no fixed standards of the quality of all products, we can not compare anything efficiently.

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