A Guide to Recirculation Aquaculture

An introduction to the new environmentally friendly and highly productive closed fish farming systems

Author: Jacob Bregnballe

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Preface

Stringent environmental restrictions to minimise pollution from hatcheries and aquaculture plants in northern European countries have sparked the rapid technological development of recirculation systems. However, recirculation also secures a higher and more stable aquaculture production with less diseases and better ways to control the hatchery parameters that influence growth. This development is welcome and fully in line with the FAO Code of Conduct for Responsible Fisheries. The present guideline on recirculation aquaculture supplements the environmentally sustainable aquaculture work of the FAO Subregional Office for Central and Eastern Europe.

The water recirculation technique also implies that hatcheries no longer necessarily need to be placed in pristine areas near rivers. Now they can be built almost anywhere with a much smaller source of clean germ-free water. It has therefore been a pleasure for FAO to support the production of this guide which we hope can inspire and help aquaculture farmers to adopt recirculation systems in the future.

Thomas Moth-Poulsen
Senior Fisheries and Aquaculture Officer
FAO

Food and Agriculture Organization of the United Nations

Already one of the world's fastest growing agri-food sectors, aquaculture has the potential for further growth in providing the world's population with high quality and healthy fish products. With global capture production of around 90 million tonnes, aquaculture production has maintained a constant annual growth reaching a global production of about 70 million tonnes in 2013.

Increased focus on sustainability, consumer demands, food safety and cost effectiveness in aquaculture production calls for the continuous development of new production technologies. In general, aquaculture production affects the environment, but state-of-the-art recirculation methods reduce this effect considerably compared to traditional ways of farming fish. Recirculation systems thereby offer two immediate advantages: cost effectiveness and reduced environmental impact. This guide focuses on the techniques for the conversion from traditional farming methods to recirculated aquaculture and advises the farmer on the pitfalls to be avoided along the way.

The guide is based on the experience of one of the foremost experts in this area, Jacob Bregnballe from the AKVA group. It is hoped that the guide will be a useful tool for fish farmers who are considering converting to recirculation systems.

Aina Afanasjeva
Director
Eurofish

Eurofish
INTERNATIONAL ORGANISATION

Introduction to the author Jacob Bregnballe and the AKVA group

Jacob Bregnballe from the AKVA group has been working with recirculation aquaculture for more than 30 years. He has been running his own fish farm in Denmark for 25 years, and has been involved in many technological innovations for improving recirculation systems for a wide range of different aquaculture species. He has also worked as an international aquaculture consultant, and holds a master's degree from Copenhagen University. Today he is the Business Director of Land Based Aquaculture in AKVA group, the largest aquaculture technology company in the world covering all aspects of aquaculture production both on shore and at sea. The company has more than 30 years of experience in the design and manufacture of steel cages, plastic cages, work boats, feed systems, feed barges, sensor systems and fish farming software, and provides solutions and support for any requirement in the field of recirculation aquaculture.

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Chapter 1: Introduction to recirculation aquaculture

Recirculation aquaculture is essentially a technology for farming fish or other aquatic organisms by reusing the water in the production. The technology is based on the use of mechanical and biological filters, and the method can in principle be used for any species grown in aquaculture such as fish, shrimps, clams, etc. Recirculation technology is however primarily used in fish farming, and this guide is aimed at people working in this field of aquaculture.

Recirculation is growing rapidly in many areas of the fish farming sector, and systems are deployed in production units that vary from huge plants generating many tonnes of fish per year for consumption to small sophisticated systems used for restocking or to save endangered species.

Recirculation can be carried out at different intensities depending on how much water is recirculated or re-used. Some farms are super intensive farming systems installed inside a closed insulated building using as little as 300 litres of new water, and sometimes even less, per kilo of fish produced per year. Other systems are traditional outdoor farms that have been rebuilt into recirculated systems using around 3 m^3 new water per kilo of fish produced per year. A traditional flow-through system for trout will typically use around 30 m^3 per kilo of fish produced per year. As an example, on a fish farm producing 500 tonnes of fish per year, the use of new water in the examples given will be 17 m^3/hour(h), 171 m^3/h and 1 712 m^3/h respectively, which is a huge difference.

Figure 1.1 An indoor recirculation system.

Another way of calculating the degree of recirculation is using the formula:

(Internal recirculation flow/(internal recirculation flow + new water intake)) x 100

The formula has been used in figure 1.2 for calculating the degree of recirculation at different system intensities and also compared to other ways of measuring the rate of recirculation.

Type of system	Consumption of new water per kg fish produced per year	Consumption of new water per cubic meter per hour	Consumption of new water per day of total system water volume	Degree of recirculation at system vol. recycled one time per hour
Flow-through	30 m^3	1 712 m^3/h	1 028 %	0 %
RAS low level	3 m^3	171 m^3/h	103 %	95.9 %
RAS intensive	1 m^3	57 m^3/h	34 %	98.6 %
RAS super intensive	0.3 m^3	17 m^3/h	6 %	99.6 %

Figure 1.2 Comparison of degree of recirculation at different intensities compared also to other ways of measuring the rate of recirculation. The calculations are based on a theoretical example of a 500 tonnes/year system with a total water volume of 4 000 m^3, where 3 000 m^3 is fish tank volume.

Seen from an environmental point of view, the limited amount of water used in recirculation is of course beneficial as water has become a limited resource in many regions. Also, the limited use of water makes it much easier and cheaper to remove the nutrients excreted from the fish as the volume of discharged water is much lower than that discharged from a traditional fish farm. Recirculation aquaculture can therefore be considered a most environmentally friendly way of producing fish at a commercially viable level. The nutrients from the farmed fish can be used as fertilizer on agricultural farming land or as a basis for biogas production.

The term “zero-discharge” is sometimes used in connection to fish farming, and although it is possible to avoid all discharge from the farm of all sludge and water, the waste water treatment of the very last concentrations is most often a

Figure 1.3 An outdoor recirculation farm.

costly affair to clean off completely. Thus an application for discharging nutrients and water should always be part of the planning permission application.

Most interesting though, is the fact that the limited use of water gives a huge benefit to the production inside the fish farm. Traditional fish farming is totally dependent on external conditions such as the water temperature of the river, cleanliness of the water, oxygen levels, or weed and leaves drifting downstream and blocking the inlet screens, etc. In a recirculated system these external factors are eliminated either completely or partly, depending on the degree of recirculation and the construction of the plant.

Recirculation enables the fish farmer to completely control all the parameters in the production, and the skills of the farmer to operate the recirculation system itself becomes just as important as his ability to take care of the fish.

Controlling parameters such as water temperature, oxygen levels, or daylight for that matter, gives stable and optimal conditions for the fish, which again gives less stress and better growth. These stable conditions result in a steady and foreseeable growth pattern that enables the farmer to precisely predict when the fish will have reached a certain stage or size. The major advantage of this feature is that a precise production plan can be drawn up and that the exact time the fish will be ready for sale can be predicted. This favours the overall management of the farm and strengthens the ability to market the fish in a competitive way.

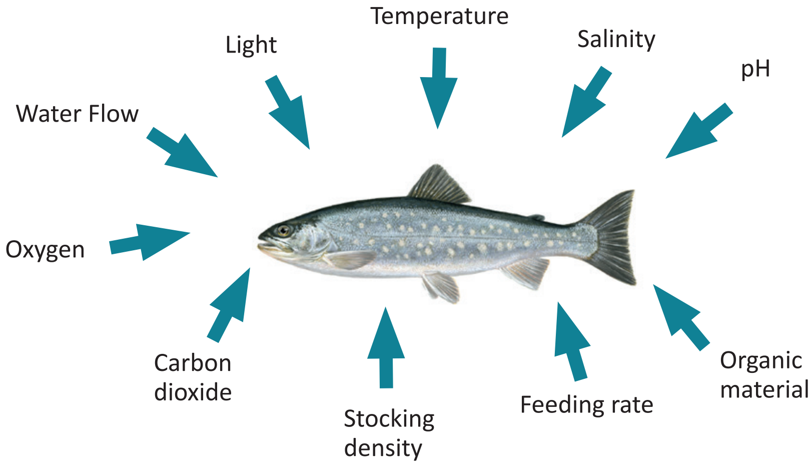


Figure 1.4 Some of the parameters affecting the growth and well-being of a fish.

There are many more advantages of using recirculation technology in fish farming, and this guide will deal with these aspects in the following chapters. However, one major aspect to be mentioned right away is that of diseases. The impact of pathogens is lowered considerably in a recirculation system as invasive diseases from the outside environment are minimised by the limited use of water. Water for traditional fish farming is taken from a river, a lake or the sea, which naturally increases the risk of dragging in diseases. Due to the limited use of water in recirculation the water is mainly taken from a borehole, drainage system or spring where the risk of diseases is minimal. In fact, many recirculation systems do not have any problems with diseases whatsoever, and the use of medicine is therefore reduced significantly for the benefit of the production and the environment. To reach this level farming practice it is of course extremely important that the fish farmer is very careful about the eggs or fry that he brings on to his farm. Many diseases are carried into systems by taking in infested eggs or fish for stocking. The best way to avoid diseases entering this way, is not to bring in fish from outside, but only bring in eggs as these can be disinfected completely from diseases.

Aquaculture requires knowledge, good husbandry, persistence and sometimes nerves of steel. Shifting from traditional fish farming into recirculation does make many things easier, however at the same time it requires new and greater skills. To be successful in this quite advanced type of aquaculture calls for training and education for which purpose this guide has been written.

Chapter 2: The recirculation system, step by step

In a recirculation system it is necessary to treat the water continuously to remove the waste products excreted by the fish, and to add oxygen to keep the fish alive and well. A recirculation system is in fact quite simple. From the outlet of the fish tanks the water flows to a mechanical filter and further on to a biological filter before it is aerated and stripped of carbon dioxide and returned to the fish tanks. This is the basic principle of recirculation.

Several other facilities can be added, such as oxygenation with pure oxygen, ultraviolet light or ozone disinfection, automatic pH regulation, heat exchanging, denitrification, etc. depending on the exact requirements.

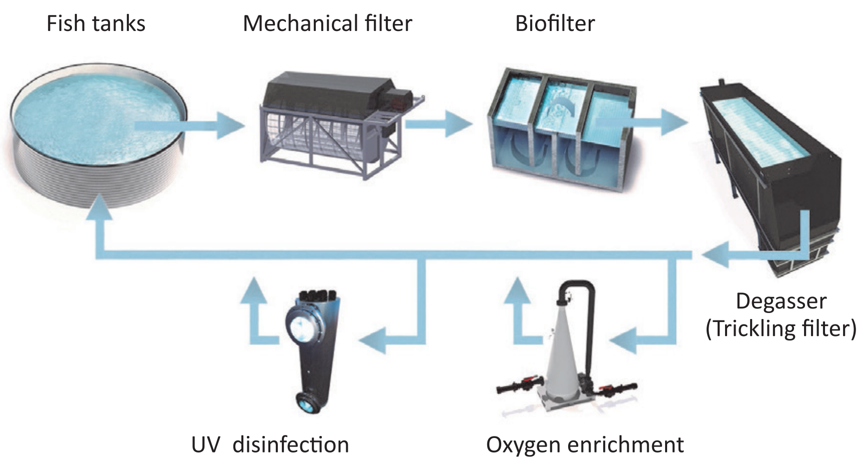


Figure 2.1 Principle drawing of a recirculation system. The basic water treatment system consists of mechanical filtration, biological treatment and aeration/stripping. Further installations, such as oxygen enrichment or UV disinfection, can be added depending on the requirements.

Fish in a fish farm require feeding several times a day. The feed is eaten and digested by the fish and is used in the fish metabolism supplying energy and nourishment for growth and other physiological processes. Oxygen (O_2) enters through the gills, and is needed to produce energy and to break down protein, whereby carbon dioxide (CO_2) and ammonia (NH_3) are produced as waste products. Undigested feed is excreted into the water as faeces, termed suspended

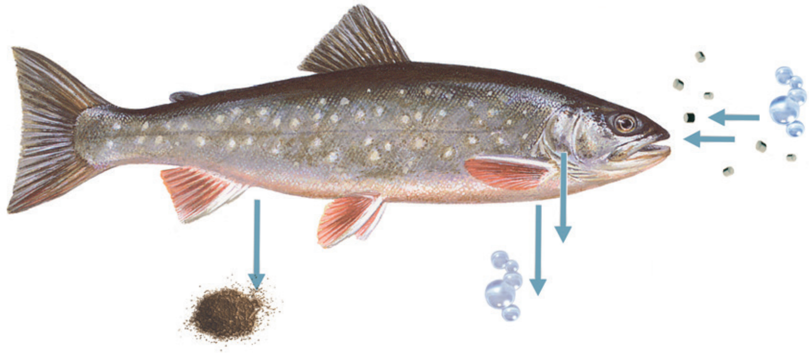


Figure 2.2 Eating feed and using oxygen results in fish growth and excretion of waste products, such as carbon dioxide, ammonia and faeces.

solids (SS) and organic matter. Carbon dioxide and ammonia are excreted from the gills into the water. Thus fish consume oxygen and feed, and as a result the water in the system is polluted with faeces, carbon dioxide and ammonia.

Only dry feed can be recommended for use in a recirculation system. The use of trash fish in any form must be avoided as it will pollute the system heavily and infection with diseases is very likely. The use of dry feed is safe and also has the advantage of being designed to meet the exact biological needs of the fish. Dry feed is delivered in different pellet sizes suitable for any fish stage, and the ingredients in dry fish feed can be combined to develop special feeds for fry, brood stock, grow-out, etc.

In a recirculation system, a high utilization rate of the feed is beneficial as this will minimise the amount of excretion products thus lowering the impact on the water treatment system. In a professionally managed system, all the feed added will be eaten keeping the amount of uneaten feed to a minimum. The feed conversion rate (FCR), describing how many kilos of feed you use for every kilo of fish you produce, is improved, and the farmer gets a higher production yield and a lower impact on the filter system. Uneaten feed is a waste of money and results in an unnecessary load on the filter system. It should be noted that feeds especially suitable for use in recirculation systems are available. The composition of such feeds aims at maximising the uptake of protein in the fish thus minimising the excretion of ammonia into the water.

Pellet size	Fish size, gram	Protein	Fat
3 mm	40 – 125	43%	27 %
4.5 mm	100 – 500	42 %	28 %
6.5 mm	400 – 1200	41 %	29 %

Composition, %	3.0 mm	4.5 mm	6.5 mm
Fishmeal	22	21	20
Fish oil	9	10	10
Rape seed oil	15	15	16
Haemoglobin meal	11	11	11
Peas	5	5	5
Soya	10	11	11
Wheat	12	11	11
Wheat gluten	5	5	5
Other protein concentrates	10	10	10
Vitamins, minerals, etc.	1	1	1

Figure 2.3 Ingredients and content of a trout feed suitable for use in a recirculation system. Source: BioMar.

Components in a recirculation system

Fish tanks

Tank properties	Circular tank	D-ended raceway	Raceway type
Self-cleaning effect	5	4	3
Low residence time of particles	5	4	3
Oxygen control and regulation	5	5	4
Space utilization	2	4	5

Figure 2.4 Different tank designs give different properties and advantages. Rating 1-5, where 5 is the best.

The environment in the fish rearing tank must meet the needs of the fish, both in respect of water quality and tank design. Choosing the right tank design, such as size and shape, water depth, self-cleaning ability, etc. can have a considerable impact on the performance of the species reared.

If the fish is bottom dwelling, the need for tank surface area is most important, and the depth of water and the speed of the water current can be lowered (turbot, sole or other flatfish), whereas pelagic living species such as salmonids will benefit from larger water volumes and show improved performance at higher speeds of water.

In a circular tank, or in a square tank with cut corners, the water moves in a circular pattern making the whole water column of the tank move around the centre. The organic particles have a relatively short residence time of a few minutes, depending on tank size, due to this hydraulic pattern that gives a self-cleaning effect. A vertical inlet with horizontal adjustment is an efficient way of controlling the current in such tanks.

In a raceway the hydraulics have no positive effect on the removal of the particles. On the other hand, if a fish tank is stocked efficiently with fish, the self-cleaning effect of the tank design will depend more on the fish activity than

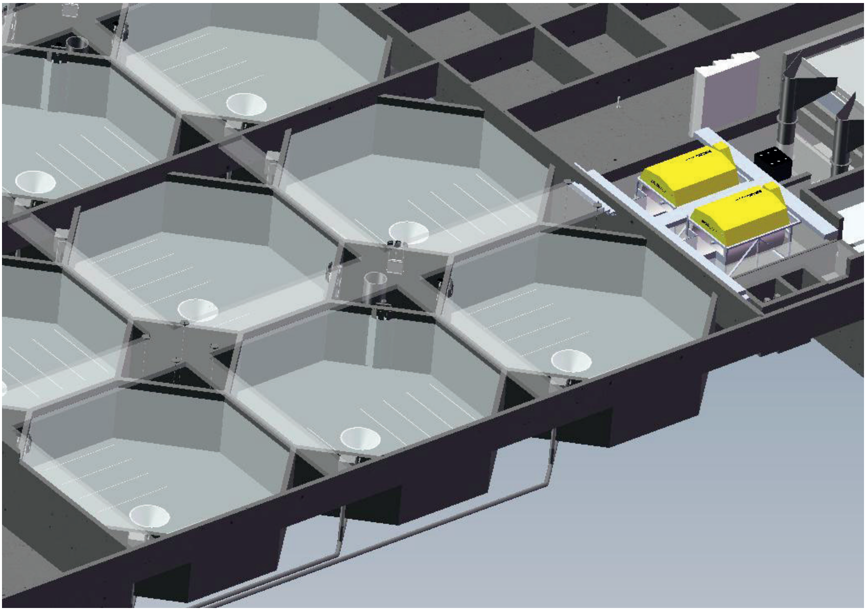


Figure 2.5 An example of octagonal tank design in a recirculation system saving space yet achieving the good hydraulic effects of the circular tank. Source: AKVA group.

on the tank design. The inclination of the tank bottom has little or no influence on the self-cleaning effect, but it will make complete draining easier when the tank is emptied.

Circular tanks take up more space compared to raceways, which adds to the cost of constructing a building. By cutting off the corners of a square tank an octagonal tank design appears, which will give better space utilization than circular tanks, and at the same time the positive hydraulic effects of the circular tank are achieved (see figure 2.5). It is important to note that construction of large tanks will always favour the circular tank as this is the strongest design and the cheapest way of making a tank.

A hybrid tank type between the circular tank and the raceway called a “D-ended raceway” also combines the self-cleaning effect of the circular tank with the efficient space utilization of the raceway. However, in practice this type of tank is seldom used, presumably because the installation of the tank requires extra work and new routines in management.

Sufficient oxygen levels for fish welfare are important in fish farming and are usually kept high by increasing the oxygen level in the inlet water to the tank.

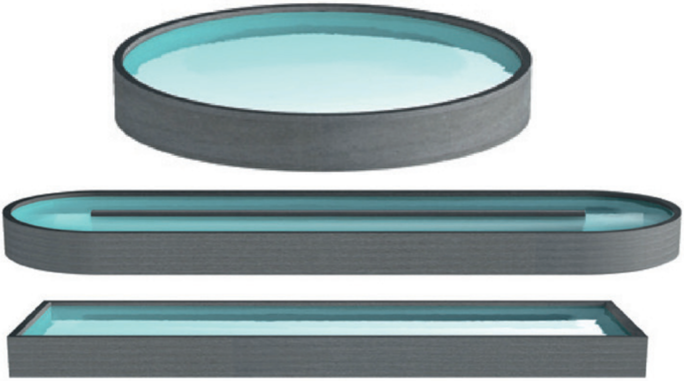


Figure 2.6 Circular tank, D-ended raceway, and raceway type.

Direct injection of pure oxygen in the tank by the use of diffusers can also be used, but the efficiency is lower and more costly.

Control and regulation of oxygen levels in circular tanks or similar is relatively easy because the water column is constantly mixed making the oxygen content almost the same anywhere in the tank. This means that it is quite easy to keep the desired oxygen level in the tank. An oxygen probe placed near the tank outlet will give a good indication of the oxygen available. The time it takes for the probe to register the effect of oxygen being added to a circular tank will be relatively short. The probe must not be placed close to where pure oxygen is injected or where oxygen rich water is fed.

In a raceway, however, the oxygen content will always be higher at the inlet and lower at the outlet, which also gives a different environment depending on where each fish is swimming. The oxygen probe for measuring the oxygen content of the water should always be placed in the area with the lowest oxygen content, which is near the outlet. This downstream oxygen gradient will make the regulation of oxygen more difficult as the time lag from adjusting the oxygen up or down at the inlet to the time this is measured at the outlet can be up to an hour. This situation may cause the oxygen to go up and down all the time instead of fluctuating around the selected level. Installation of modern oxygen control systems using algorithms and time constants will however prevent these unwanted fluctuations.

Tank outlets must be constructed for optimal removal of waste particles, and fitted with screens with suitable mesh sizes. Also, it must be easy to collect dead fish during the daily work routines.

Tanks are often fitted with sensors for water level, oxygen content and temperature for having complete control of the farm. It should also be considered to install diffusers for supplying oxygen directly into each tank in case of an emergency situation.

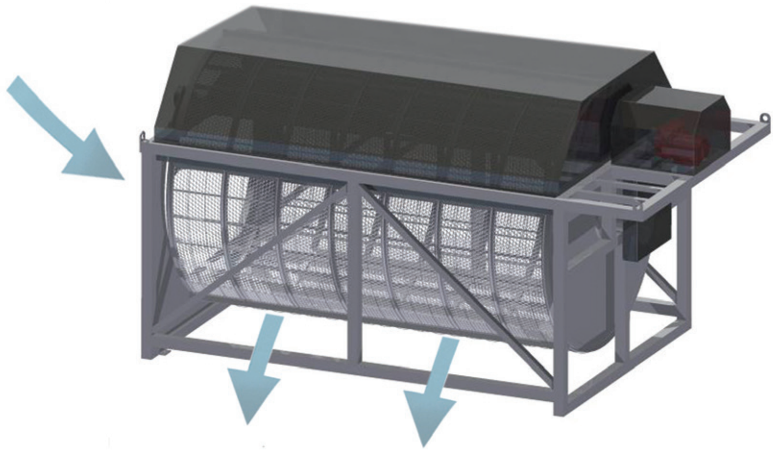


Figure 2.7 Drumfilter. Source: CM Aqua.

Mechanical filtration

Mechanical filtration of the outlet water from the fish tanks has proven to be the only practical solution for removal of the organic waste products. Today almost all recirculated fish farms filter the outlet water from the tanks in a so called microscreen fitted with a filter cloth of typically 40 to 100 microns. The drumfilter is by far the most commonly used type of microscreen, and the design ensures the gentle removal of particles.

Function of the drumfilter:

1. Water to be filtered enters the drum.

2. The water is filtered through the drum's filter elements. The difference in water level inside/outside the drum is the driving force for the filtration.

3. Solids are trapped on the filter elements and lifted to the backwash area by the rotation of the drum.

4. Water from rinse nozzles is sprayed from the outside of the filter elements. The rejected organic material is washed out of the filter elements into the sludge tray.

5. The sludge flows together with water by gravity out of the filter escaping the fish farm for external waste water treatment (see chapter 6).

Microscreen filtration has the following advantages:

- Reduction of the organic load of the biofilter.
- Making the water clearer as organic particles are removed from the water.
- Improving conditions for nitrification as the biofilter does not clog.
- Stabilising effect on the biofiltration processes.

Biological treatment

Not all the organic matter is removed in the mechanical filter, the finest particles will pass through together with dissolved compounds such as phosphate and nitrogen. Phosphate is an inert substance, with no toxic effect, but nitrogen in the form of free ammonia (NH_3) is toxic, and needs to be transformed in the biofilter to harmless nitrate. The breakdown of organic matter and ammonia is a biological process carried out by bacteria in the biofilter. Heterotrophic bacteria oxidise the organic matter by consuming oxygen and producing carbon dioxide, ammonia and sludge. Nitrifying bacteria convert ammonia into nitrite and finally to nitrate.

The efficiency of biofiltration depends primarily on:

- The water temperature in the system.
- The pH level in the system.

To reach an acceptable nitrification rate, water temperatures should be kept within 10 to 35 °C (optimum around 30 °C) and pH levels between 7 and 8. The water temperature will most often depend on the species reared, and is as such not adjusted to reach the most optimal nitrification rate, but to give optimal levels for fish growth. Regulation of pH in relation to biofilter efficiency is however important as lower pH level reduces the efficiency of the biofilter. The pH should therefore be kept above 7 in order to reach a high rate of bacterial nitrifying. On the other hand, increasing pH will result in an increasing amount of free ammonia (NH_3), which will enhance the toxic effect. The aim is therefore to find the balance between these two opposite aims of adjusting the pH. A recommended adjustment point is between pH 7.0 and pH 7.5.

Two major factors affect the pH in the water recirculation system:

- The production of CO_2 from the fish and from the biological activity of the biofilter.

- The acid produced from the nitrification process.

Result of nitrification:

$$NH_4 \text{ (ammonium)} + 1.5\ O_2 \rightarrow NO_2 \text{ (nitrite)} + H_2O + 2H^+ + 2e$$
$$NO_2 \text{ (nitrite)} + 0.5\ O_2 \rightarrow NO_3 \text{ (nitrate)} + e$$

$$NH_4 + 2\ O_2 \leftrightarrow NO_3 + H_2O + 2H^+$$

CO_2 is removed by aeration of the water, whereby degassing takes place. This process can be accomplished in several ways as described later in this chapter.

The nitrifying process produces acid (H^+) and the pH level falls. In order to stabilize the pH, a base must be added. For this purpose lime or sodium hydroxide (NaOH) or another base needs to be added to the water.

Fish excretes a mixture of ammonia and ammonium (Total Ammonia Nitrate (TAN) = ammonium (NH_4^+) + ammonia (NH_3)) where ammonia constitutes the main part of the excretion. The amount of ammonia in the water depends however on

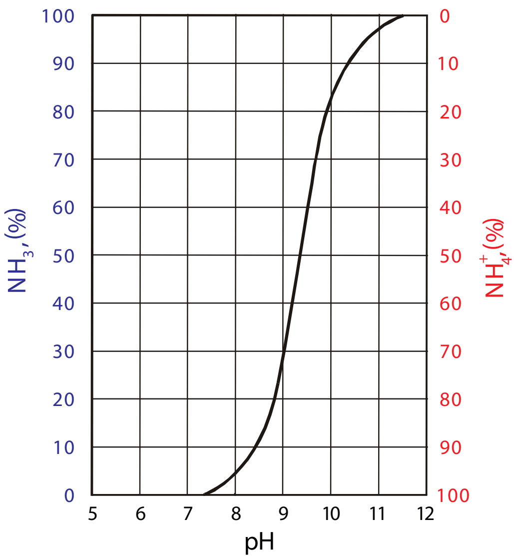


Figure 2.8 The equilibrium between ammonia (NH_3) and ammonium (NH_4^+) at 20 °C. The toxic ammonia is absent at pH below 7, but rises fast as pH is increased.

the pH level as can be seen in figure 2.8, which shows the equilibrium between ammonia (NH_3) and ammonium (NH_4^+).

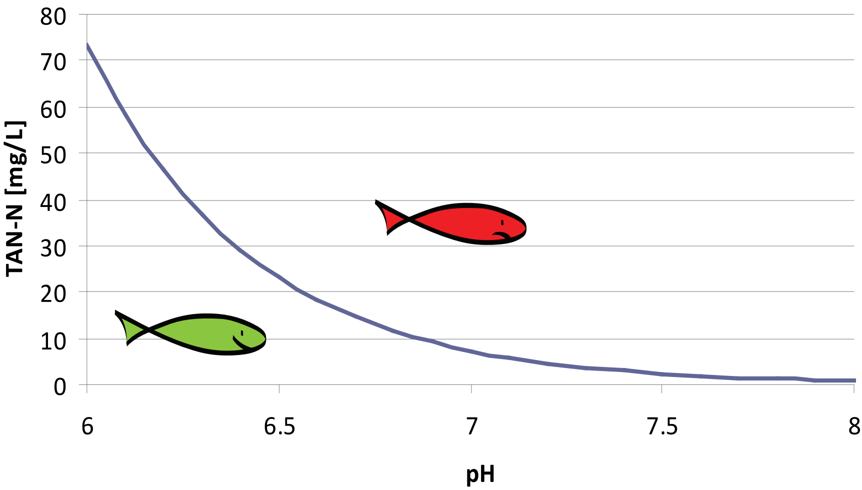


Figure 2.9 The relation between measured pH and the amount of TAN available for breakdown in the biofilter, based upon a toxic ammonia concentration of 0.02 mg/L.

In general, ammonia is toxic to fish at levels above 0.02 mg/L. Figure 2.9 shows the maximum concentration of TAN to be allowed at different pH levels if a level below 0.02 mg/L of ammonia is to be ensured. The lower pH levels minimises the risk of exceeding this toxic ammonia limit of 0.02 mg/L, but the fish farmer is recommended to reach a level of minimum pH 7 in order to reach a higher biofilter efficiency as explained earlier. Unfortunately, the total concentration of TAN to be allowed is thereby significantly reduced as can be seen in figure 2.9. Thus there are two opposite working vectors of the pH that the fish farmer has to take into consideration when tuning his biofilter.

Nitrite (NO_2^-) is formed at the intermediate step in the nitrification process, and is toxic to fish at levels above 2.0 mg/L. If fish in a recirculation system are gasping for air, although the oxygen concentration is fine, a high nitrite concentration may be the cause. At high concentrations, nitrite is transported over the gills into the fish blood, where it obstructs the oxygen uptake. By adding salt to the water, reaching as little as 0.3 ‰, the uptake of nitrite is inhibited.

Nitrate (NO_3^-) is the end-product of the nitrification process, and although it is considered harmless, high levels (above 100 mg/L) seem to have a negative impact on growth and feed conversion. If the exchange of new water in the system is kept very low, nitrate will accumulate, and unacceptable levels will be reached. One way to avoid the accumulation is to increase the exchange of new water, whereby the high concentration is diluted to a lower and trouble-free level.

On the other hand, the whole idea of recirculation is saving water, and in some instances water saving is a major goal. Under such circumstances, nitrate concentrations can be reduced by de-nitrification. Under normal conditions, a water consumption of more than 300 litres per kg feed used is sufficient to dilute the nitrate concentration. Using less water than 300 litres per kg feed makes the use of denitrification worth considering.

The most predominant denitrifying bacteria is called *Pseudomonas*. This is an anaerobic (no oxygen) process reducing nitrate to atmospheric nitrogen. In fact, this process removes nitrogen from the water into the atmosphere, whereby the load of nitrogen into the surrounding environment is reduced. The process requires an organic source (carbon), for example wood alcohol (methanol) that can be added to a denitrification chamber. In practical terms 2.5 kg of methanol is needed for each kg nitrate (NO_3-N) denitrified.

Most often the denitrification chamber is fitted with biofilter media designed with a residence time of 2-4 hours. The flow must be controlled to keep outlet oxygen concentration at app. 1 mg/L. If oxygen is completely depleted extensive production of hydrogen sulphide (H_2S) will take place, which is extremely toxic to fish and also bad smelling (rotten egg). Resulting production of sludge is quite high, and the unit has to be back-washed, typically once a week.

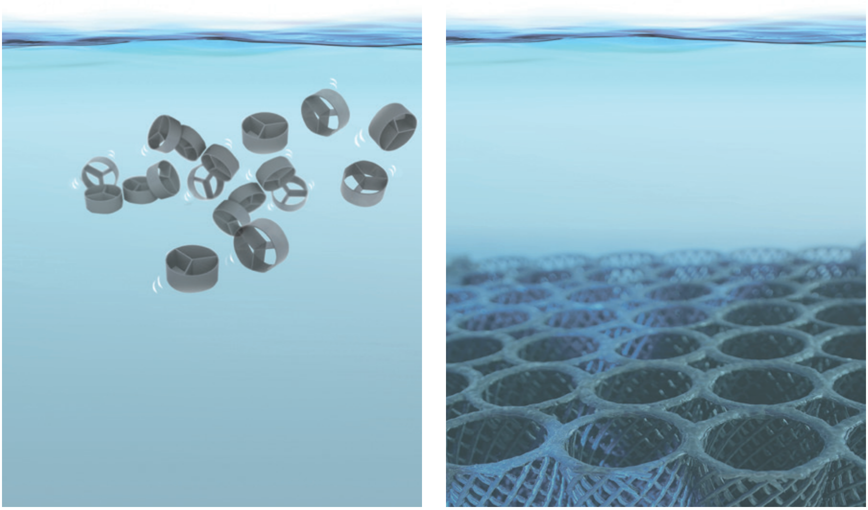
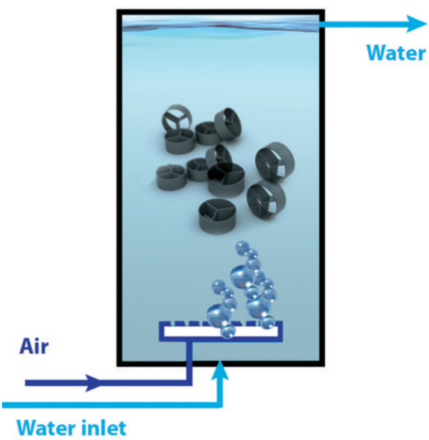


Figure 2.10 Moving bed media on left and fixed bed media on right.

Biofilters are typically constructed using plastic media giving a high surface area per m^3 of biofilter. The bacteria will grow as a thin film on the media thereby occupying an extremely large surface area. The aim of a well-designed biofilter is to reach as high a surface area as possible per m^3 without packing the biofilter so tight that it will get clogged with organic matter under operation. It is therefore important to have a high percentage of free space for the water to pass through and to have a good overall flow through the biofilter together with a sufficient back-wash procedure. Such back-wash procedures must be carried out at sufficient intervals once a week or month depending on the load on the filter. Compressed air is used to create turbulence in the filter whereby organic matter is ripped off. The biofilter is shunted while the washing procedure takes place, and the dirty water in the filter is drained off and discharged before the biofilter is connected to the system again.

Biofilters used in recirculation systems can be designed as fixed bed filters or moving bed filters. All biofilters used in recirculation today work as submerged units under water. In the fixed bed filter, the plastic media is fixed and not moving. The water runs through the media as a laminar flow to make contact with the bacterial film. In the moving bed filter, the plastic media is moving around in the water inside the biofilter by a current created by pumping in air. Because of the constant movement of the media, moving bed filters can be packed harder than fixed bed filters thus reaching a higher turnover rate per m^3 of biofilter. There is however no significant difference in the turnover rate calculated per m^2 (filter surface area) as the efficiency of the bacterial film in either of the two



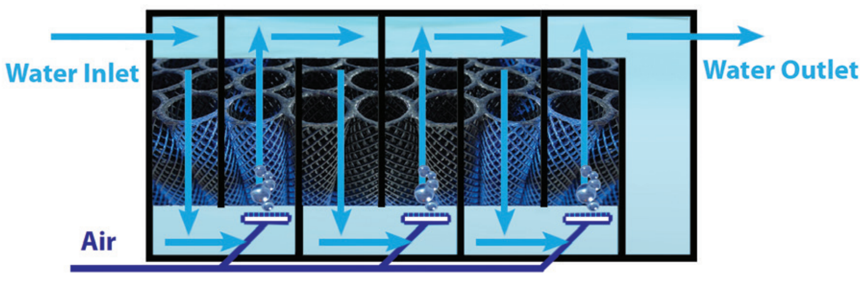


Figure 2.11 Moving bed (top) and fixed bed biofilters (bottom).

types of filter is more or less the same. In the fixed bed filter, however, fine organic particles are also removed as these substances adhere to the bacterial film. The fixed bed filter will therefore act also as a fine mechanical filtration unit removing microscopic organic material and leaving the water very clear. The moving bed filter will not have the same effect as the constant turbulence of water will make any adhesion impossible.

Both filter systems can be used in the same system, or they can be combined; using the moving bed to save space and the fixed bed to benefit from the adhering effect. There are several solutions for the final design of biofilter systems depending on farm size, species to be cultured, sizes of fish, etc.

Degassing, aeration, and stripping

Before the water runs back to the fish tanks accumulated gases, which are detrimental to the fish, must be removed. This degassing process is carried out by aeration of the water, and the method is often referred to as stripping. The water contains carbon dioxide (CO_2) from the fish respiration and from the bacteria in the biofilter in the highest concentrations, but free nitrogen (N_2) is also present. Accumulation of carbon dioxide and nitrogen gas levels will have detrimental effects on fish welfare and growth. Under anaerobic conditions hydrogen sulphide (H_2S) can be produced, especially in saltwater systems. This gas is extremely toxic to fish, even in low concentrations, and fish will be killed if the hydrogen sulphide is generated in the system.

Aeration can be accomplished by pumping air into the water whereby the

Figure 2.12 Aeration well system.

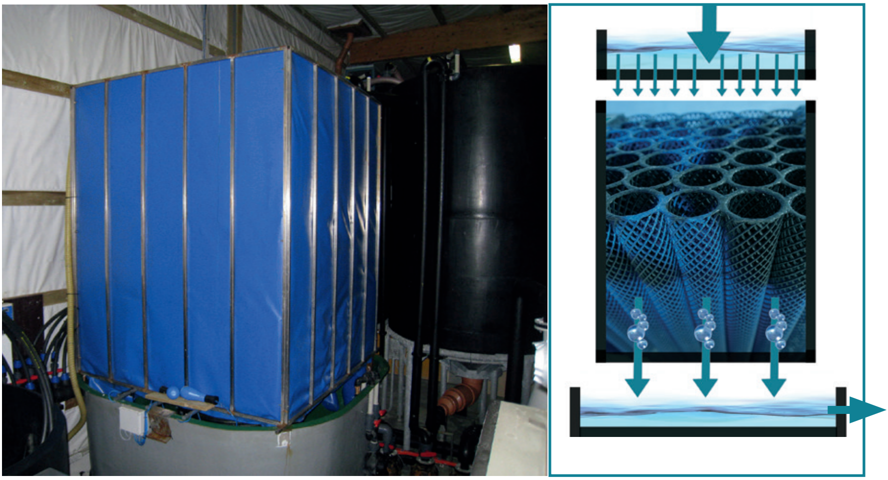


Figure 2.13 Photo and drawing of trickling filter wrapped in a blue plastic liner to eliminate splashing on the floor (Billund Akvakulturservice, Denmark). The aeration/stripping process is also called CO_2-stripping. The media in the trickling filter typically consists of the same type of media as used in fixed bed biofilters – see figure 2.10.

turbulent contact between the air bubbles and the water drives out the gases. This underwater aeration makes it possible to move the water at the same time, for example if an aeration well system is used (see figure 2.12).

The aeration well system is however not as efficient for removing gases as the trickling filter system, also called a degasser. In the trickling system, gases are stripped off by physical contact between the water and plastic media stacked in a column. Water is led to the top of the filter over a distribution plate with holes, and flushed down through the plastic media to maximise turbulence and contact, the so called stripping process.

Oxygenation

The aeration process of the water, which is the same physical process as degassing or stripping, will add some oxygen to the water through simple exchange between the gases in the water and the gases in the air depending on the saturation level of the oxygen in the water. The equilibrium of oxygen in water is 100% saturation. When the water has been through the fish tanks, the oxygen content has been lowered, typically down to 70%, and the content is reduced further in the biofilter. Aeration of this water will typically bring the saturation up to around 90%, in some systems 100% can be reached. Oxygen

Figure 2.14 Oxygen cone for dissolving pure oxygen at high pressure and a sensor (probe) for measuring the oxygen saturation of the water. Source: AKVA group/ Oxyguard International.

saturation higher than 100% in the inlet water to the fish tanks is however often preferred in order to have sufficient oxygen available for a high and stable fish growth. Saturation levels above 100% call for a system using pure oxygen.

Pure oxygen is often delivered in tanks in the form of liquid oxygen, but can also be produced on the farm in an oxygen generator. There are several ways of making super-saturated water with oxygen contents reaching 200-300 %. Typically high pressure oxygen cone systems or low head oxygen systems, such as oxygen platforms are used. The principle is the same. Water and pure oxygen are mixed under pressure whereby the oxygen is forced into the water. In the oxygen cone the pressure is accomplished with a pump creating a high pressure of typically around 1.4 bar in the cone. Pumping water under pressure into the oxygen cone consumes a lot of electricity. In the oxygen platform the pressure is much lower, typically down to about 0.1 bar, and water is simply pumped through the box mixing water and oxygen. The difference in the two kinds of systems is that the oxygen cone solution uses only a part of the circulating water for oxygen

Figure 2.15 Oxygen platform for dissolving pure oxygen at low pressure while pumping water around in the farm. The system typically increases the level dissolved oxygen to just above 100% when entering the fish tanks depending on flow rates and farm design. Source: FREA Aquaculture Solutions

enrichment, whereas the oxygen platform is used for the main recirculation flow often in combination with the overall pumping of water round in the system.

Whatever method is used, the process should be controlled with the help of oxygen measurement. The best way of doing so is to have the oxygen probe measuring after the oxygenation system at normal atmospheric pressure, for example in a measurement chamber delivered by the supplier. This makes the measurement easier than if it was made under pressure, since the probe will need to be wiped clean and calibrated, from time to time.

Ultraviolet light

UV disinfection works by applying light in wavelengths that destroy DNA in biological organisms. In aquaculture pathogenic bacteria and one-celled organisms are targeted. The treatment has been used for medical purposes for decades and does not impact the fish as UV treatment of the water is applied outside the fish production area. It is important to understand that bacteria grow so rapidly in organic matter that controlling bacterial numbers in traditional fish farms has limited effect. The best control is achieved when effective mechanical filtration is combined with a thorough biofiltration to effectively remove organic matter from the process water, thus making the UV radiation work efficiently.

The UV dose can be expressed in several different units. One of the most widely used is micro Watt-seconds per cm^2 (µWs/cm^2). The efficiency depends on the size and species of the target organisms and the turbidity of the water. In order

Figure 2.16 Closed and open UV treatment systems: For installation in a closed piping system and in an open channel system respectively. Source: ULTRAAQUA.

to control bacteria and viruses the water needs to be treated with roughly 2 000 to 10 000 µWs/cm^2 to kill 90% of the organisms, fungi will need 10 000 to 100 000 and small parasites 50 000 to 200 000 µWs/cm^2.

UV lighting used in aquaculture must work under water to give maximum efficiency, lamps fitted outside the water will have little or no effect because of water surface reflection.

Ozone

The use of ozone (O_3) in fish farming has been criticised because the effect of over-dosing can cause severe injury to the fish. In farms inside buildings, ozone can also be harmful to the people working in the area as they may inhale too much ozone. Thus correct dosing and monitoring of the loading together with proper ventilation is crucial to reach a positive and safe result.

Ozone treatment is an efficient way of destroying unwanted organisms by the heavy oxidation of organic matter and biological organisms. In ozone treatment technology micro particles are broken down into molecular structures that will bind together again and form larger particles. By this form of flocculation, microscopic suspended solids too small to be caught can now be removed from the system instead of passing through the different types of filters in the recirculation system. This technology is also referred to as water polishing as it makes the water clearer and free of any suspended solids and possible bacteria adhering to these. This is especially suitable in hatchery and fry systems growing small fish, which are sensitive to micro particles and bacteria in the water.

Ozone treatment can also be used when the intake water to a recirculation system needs to be disinfected.

It is worth mentioning that in many cases UV treatment is a good and safe alternative to ozone.

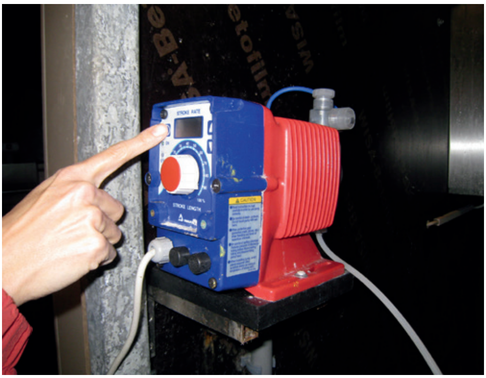


Figure 2.17 Dosage pump for pH regulation by preset dosing of NaOH. The pump can be connected to a pH sensor for fully automatic regulation of pH level.

pH regulation

The nitrifying process in the biofilter produces acid, thus the pH level will drop. In order to keep a stable pH a base must be added to the water. In some systems a lime mixing station is installed dripping limewater into the system and thereby stabilizing pH. An automatic dosage system regulated by a pH-meter with a feedback impulse to a dosage pump is another option. With this system it is preferable to use sodium hydroxide (NaOH) as it is easy to handle and making the system easier to maintain. Sodium hydroxide is a strong alkaline that can severely burn eyes and skin. Safety precautions must be taken, and glasses and gloves must be worn while handling this and other strong acids and bases.

Water temperature regulation

Maintaining an optimal water temperature in the culture system is most important as the growth rate of the fish is directly related to the water temperature. Using the intake water is a fairly simple way of regulating the temperature from day to day. In an indoor recirculation system the heat will slowly build up in the water, because energy in the form of heat is released from the fish metabolism and the bacterial activity in the biofilter. Heat from friction in the pumps and the use of other installations will also accumulate. High temperatures in the system are therefore often a problem in an intensive recirculation system. By adjusting the amount of cool fresh intake water into the system, the temperature can be regulated in a simple way.

If cooling by the use of intake water is limited a heat pump can be used. The heat pump will utilize the amount of energy normally lost in the discharge water or in the air leaving the farm. The energy is then used for cooling the circulating water inside the farm. A similar way of lowering heating/cooling cost can be achieved by recovering the energy by the use of a heat exchanger. Energy in the discharge water from the farm is transferred to the cold incoming intake water or vice versa. This is done by passing both streams into the heat exchanger where the warm outlet water will lose energy and heat up the cold intake water, without mixing the two streams. Also on the ventilation system a heat exchanger for air can be mounted utilizing energy from the out-going air and transferring it to the in-going air, thereby reducing the need for heating significantly.

In cold climates heating of the water can be necessary. The heat can come from any source like an oil or gas boiler and is, independent of energy source, connected to a heat exchanger to heat the recirculated water. Heat pumps are an environmental friendly heating solution, and can utilize energy for heating from the ocean, a river, a well or the air. It can even be used to transfer the energy from one recirculation system to another, and thereby heat one system and cool another. Usually it utilizes energy from e.g. the ocean using a titanium heat exchanger, moves the energy to the recirculation that is calling for heating and releases the heat through another heat exchanger.

Pumps

Different types of pumps are used for circulating the process water in the system. Pumping normally requires a substantial amount of electricity, and low lifting heights and efficient and correctly installed pumps are important to keep running costs at a minimum.

The lifting of water should preferably occur only once in the system, whereby the water runs by gravity all the way through the system back to the pump sump. Pumps are most often positioned in front of the biofilter system and the degasser as the water preparation process starts here. In any case, pumps should be placed after the mechanical filtration to avoid breaking the solids coming from the fish tanks.

Calculation of the total lifting height for pumping is the sum of the actual lifting height and the pressure losses in pipe runs, pipe bends and other fittings. This is also called the dynamic head. If water is pumped through a submerged biofilter before falling down through the degasser, a counter pressure from the biofilter will also have to be accounted for. Details on fluid mechanics and pumps are beyond the scope of this guide.

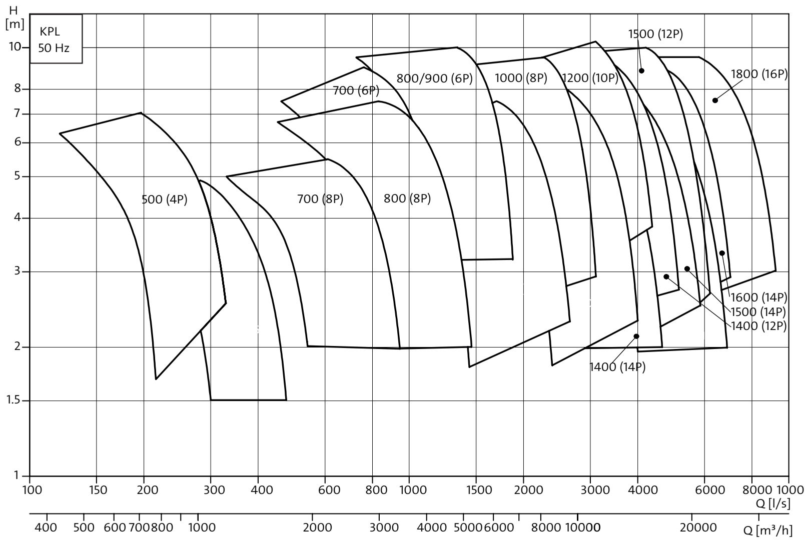


Figure 2.18 Lifting pumps type KPL for efficient lifting of large amounts of water. Lifting pumps are often used for pumping the main flow in the recirculation system. Correct selection of pump is important to keep the running costs down. Frequency control is an option to regulate the exact flow needed depending on the fish production. H is the lifting height and Q is the volume of water lifted. Source: Grundfos

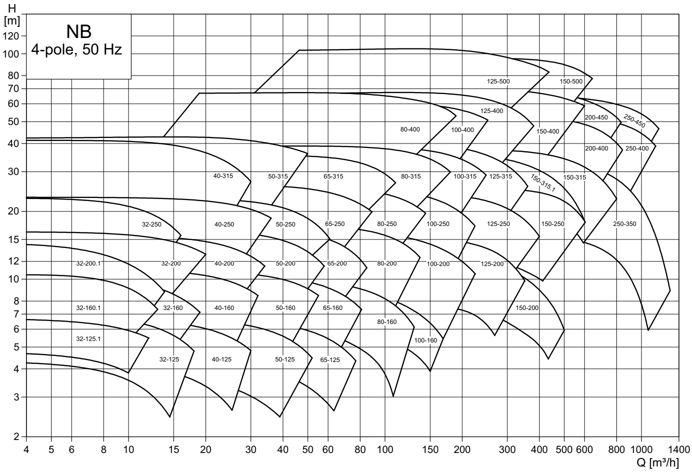


Figure 2.19 Centrifugal pumps type NB for pumping water when high pressure or high lifting heights are needed. The range of centrifugal pumps is wide, so these pumps are also efficiently used for pumping at lower lifting heights. Centrifugal pumps are often used in recirculation systems for pumping secondary flows as for example flows through UV systems or for reaching high pressure in oxygen cones. H is the lifting height and Q is the volume of water lifted. Source: Grundfos

The total lifting height in most intensive recirculation systems today is around 2-3 metres, which makes the use of low pressure pumps most efficient for pumping the main flow around. However, the process of dissolving pure oxygen into the process water requires centrifugal pumps as these pumps are able to create the required high pressure in the cone. In some systems, where the lifting height for the main flow is very low, the water is driven without the use of pumps by blowing air into aeration wells. In these systems the degassing and the movement of water are accomplished in one process, which makes low lifting heights possible. The efficiency of degassing and moving of water is however not necessarily better than that of pumping water up over the degasser, because the efficiency of aeration wells in terms of using energy and the degassing efficiency is lower than using lifting pumps and stripping or trickling the water.

Monitoring, control, and alarms

Intensive fish farming requires close monitoring and control of the production in order to maintain optimal conditions for the fish at all times. Technical failures can easily result in substantial losses, and alarms are vital installations for securing the operation.

In many modern farms, a central control system can monitor and control oxygen levels, temperature, pH, water levels and motor functions. If any of the parameters moves out of the preset hysteresis values, a start/stop process will try to solve the problem. If the problem is not solved automatically, an alarm will start. Automatic feeding can also be an integrated part of the central control system. This allows the timing of the feeding to be coordinated precisely with a higher dosage of oxygen as the oxygen consumption rises during feeding. In less sophisticated systems, the monitoring and control is not fully automatic, and personnel will have to make several manual adjustments.

Whatever the case, no system will work without the surveillance of the personnel working on the farm. The control system must therefore be fitted with an alarm

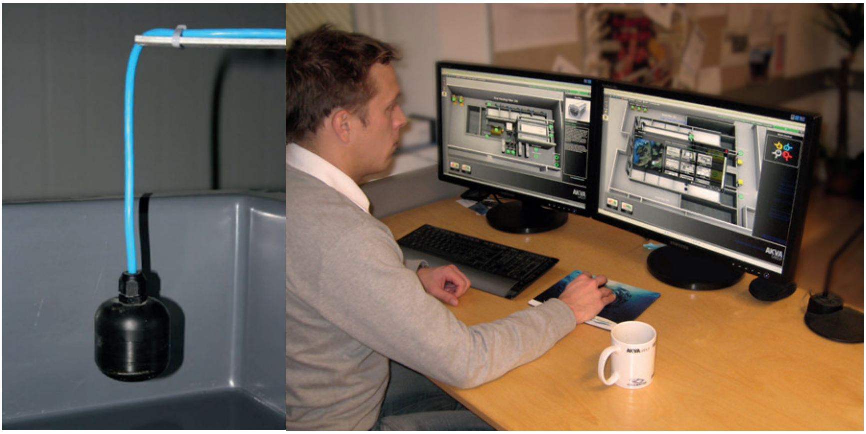


Figure 2.20 An oxygen probe (Oxyguard) is calibrated in the air before being lowered into the water for on-line measurement of the oxygen content of the water. Surveillance can be computerized with a large number of measuring points and alarm control.

system, which will call the personnel if any major failures are about to occur. A reaction time of less than 20 minutes is recommended, even in situations where automatic back-up systems are installed.

Emergency system

The use of pure oxygen as a back-up is the number one safety precaution. The installation is simple, and consists of a holding tank for pure oxygen and a distribution system with diffusers fitted in all tanks. If the electricity supply fails a magnetic valve pulls back and pressurized oxygen flows to each tank keeping the

Figure 2.21 Oxygen tank and emergency electrical generator.

fish alive. The flow sent to the diffusers should be adjusted beforehand, so that the oxygen in the storage tank in an emergency situation lasts long enough for the failure to be corrected in time.

To back up the electrical supply, a fuel driven electrical generator is necessary. It is very important to get the main pumps in operation as fast as possible, because ammonia excreted from the fish will build up to toxic levels when the water is not circulating over the biofilter. It is therefore important to get the water flow up and running within an hour or so.

Intake water

Water used for recirculation should preferably come from a disease-free source or be sterilised before going into the system. In most cases it is better to use water from a borehole, a well, or something similar than to use water coming directly from a river, lake or the sea. If a treatment system for intake water needs to be installed, it will typically consist of a sand filter for microfiltration and a UV or ozone system for disinfection.

Chapter 3: Fish species in recirculation

A recirculation system is a costly affair to build and to operate. There is competition on markets for fish and production must be efficient in order to make a profit. Selecting the right species to produce and constructing a well functioning system are therefore of high importance. Essentially, the aim is to sell the fish at a high price and at the same time keep the production cost at the lowest possible level.

Water temperature is one of the most important parameters when looking at the feasibility of fish farming, because fish are cold blooded animals. This means that fish have the same body temperature as the temperature of the surrounding water. Fish cannot regulate their body temperature like pigs, cows or other farmed animals. Fish simply do not grow well when the water is cold; the warmer the water, the better the growth. Different species have different growth rates depending on the water temperature, and fish also have upper and lower lethal temperature limits. The farmer must be sure to keep his stock within these limits or the fish will die.

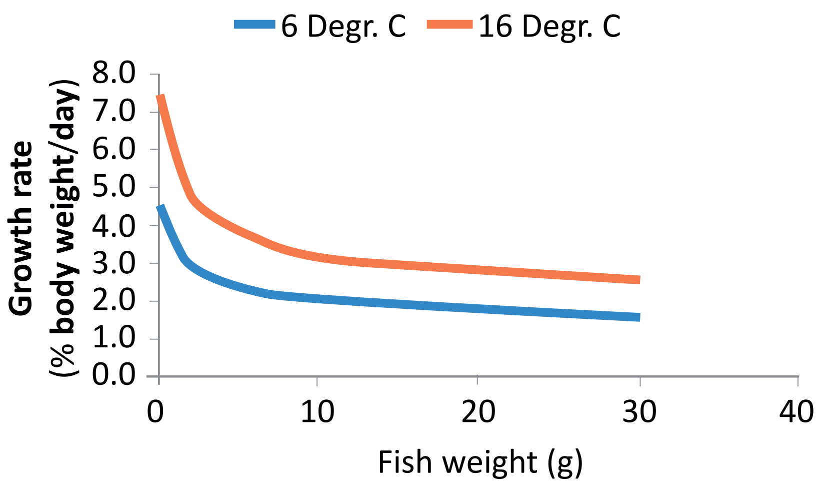


Figure 3.1 Growth rate of rainbow trout at 6 degrees and at 16 degrees Celsius as function of fish size.

Another issue affecting the feasibility of fish farming is the size of the fish grown in the farm. At any given temperature, small fish have a higher growth rate than large fish. This means that small fish are able to gain more weight over the same period of time than large fish – see figure 3.1.

Small fish also convert fish feed at a better rate than large fish - see figure 3.2. Growing faster and utilising feed more efficiently will of course have a positive influence on the production costs as these are lowered when calculated per kilo of fish produced. However, the production of small fish is just one step in the whole production process through to marketable fish. Naturally, not all fish produced in fish farming can be small fish, and the potential for growing small fish is therefore limited. Nevertheless, when discussing what kind of fish to produce in recirculation systems, the answer, first and foremost, will be small fish. It simply makes sense to invest money in fry production, because you get more out of your investment when farming small fish.

The cost of reaching and maintaining the optimal water temperature all year round in a recirculation facility is money well spent. Keeping fish at optimal rearing conditions will give a much higher growth rate in comparison to the often sub-optimal conditions in the wild. Also, it is important to note that all the advantages of clean water, sufficient oxygen levels, etc. in a recirculation system have a positive effect on survival rate, fish health, etc., which in the end gives a high quality product.

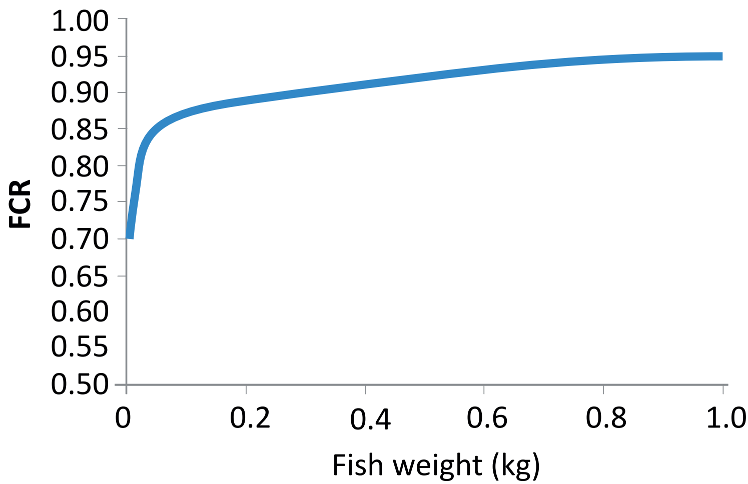


Figure 3.2 Feed conversion rate (FCR) of rainbow trout in a recirculation system, related to fish weight at 15-18 degrees Celsius.

Compared to other farmed animals there is a large variety of fish, and many different fish species are farmed. In comparison, the market for pigs, cattle or chicken is not diversified in the same way as fish. The consumer does not ask for different species of pigs, cattle or chicken, they just ask for different cuts or sizes of cuts. But when it comes to fish, the choice of species is wide, and the consumer is used to choosing from a range of different fish, a situation which makes many different fish species interesting in the eyes of any fish farmer. Over the past decade some hundred aquatic species have been introduced to aquaculture and the rate of domestication of aquatic species is around hundred times faster than that of the domestication of plants and animals on land.

Looking at the world production volume of farmed fish, the picture is not in favour of a multi species output. From figure 3.3 it can be seen that carp, of which we are only talking of some 5 different sub-species, is by far the most dominant. Salmon and trout are next in line, and this is only two species. The rest amounts to some ten species. One therefore has to realise that although there are plenty of species to be cultured, only a few of these go on to become real successes on a world-wide scale. However, this does not mean that all the new fish species introduced to aquaculture are failures. One just has to realise that the world production volume of new species is limited, and that the success and failures of growing these species depend very much on market conditions. Producing a small volume of a prestigious fish species may well be profitable as it fetches a high price. However, because the market for prestigious species

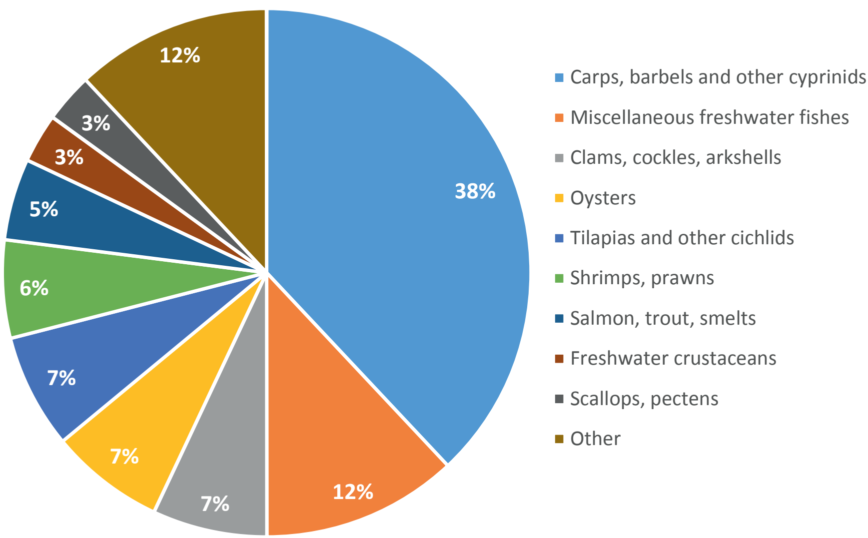


Figure 3.3 Distribution of global farmed seafood production in 2013. Source: FAO

is limited, the price may soon go down if production and thereby availability of the product rises. It can be very profitable to be the first and only one on the market with a new species in aquaculture. On the other hand, it is also a risky business with a high degree of uncertainty in both production and in market development.

When introducing new species in aquaculture it should also be remembered that it is wild species, which are being captured and tested in aquaculture. Domestication is most often a long and troublesome task. There are many impacts, which will influence growth performance, such as high genetic variation in growth rate, feed conversation rate, survival rate and problems with early maturation and disease susceptibility. Thus it is very likely that the performance of fish from the wild does not correspond to the expectations of the aquaculturist. Also, viruses in wild stocks can be brought in, of which some only appear after several years breeding, resulting in a demoralising experience.

To give general recommendations on which species to culture in recirculation systems is not an easy task. Many factors influence the success of a fish farming business. For example, local building costs, cost and stability of electricity supply, availability of skilled personnel, etc. Two important questions though should be asked before anything else is discussed: does the fish species being considered have the ability to perform well in a recirculation facility; and secondly is there a market for this species that will fetch a price high enough and at volumes large enough to make the project profitable.

The first question can be answered in a relatively simple manner: seen from a biological point of view, any type of fish reared successfully in traditional aquaculture can just as easily be reared in recirculation. As mentioned, the environment inside the recirculated fish farm can be adjusted to match the exact needs of the species reared. The recirculation technology in itself is not an obstacle to any new species introduced. The fish will grow just as well, and often even better, in a recirculation unit. Whether it will perform well from an economic point of view is more uncertain as this depends on the market conditions, the investment and the production costs and the ability of the species to grow rapidly. Rearing fish with generally low growth rates, such as extreme cold water species, makes it difficult to produce a yearly output that justifies the investment made in the facility.

Whether market conditions are favourable for a given species reared in a recirculation system depends highly on competition from other producers. And this is not restricted to local producers; fish trading is a global business and competition is global too. Trout farmed in Poland may well have to compete with catfish from Vietnam or salmon from farms in Norway as fish are easily distributed around the world at low cost.

It has always been recommended to use recirculation systems to produce expensive fish, because a high selling price leaves room for higher production costs. A good example is the eel farming business where a high selling price allows relatively high production costs. On the other hand, there is a strong tendency to use recirculation systems also for lower priced fish species such as trout or salmon.

The Danish recirculation trout farm concept is a good example of recirculation systems entering a relatively low price segment such as portion sized trout. However, it is necessary for such production systems to be huge, operating in volumes from 1 000 tonnes and upwards, in order to be competitive. In the future, perhaps in some areas growing large salmon will move from sea cage farming to land-based recirculation facilities for environmental reasons. Even an extremely low priced fish product such as tilapia will probably become profitable to grow in some kind of recirculation system as the fight for water and space intensifies.

The suitability of rearing specific fish species in recirculation depends on many different factors, such as the profitability, environmental concerns, biological suitability. In the tables below fish species have been grouped into different categories depending on the commercial feasibility of growing them in a recirculation system.

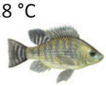
It should be mentioned that for small fish the use of recirculation is always recommended, because small fish grow faster and are therefore particularly suited to a controlled environment until they have reached the size for on-growing.

Good biological performance and acceptable market conditions make the following fish interesting for production to market size in recirculation aquaculture:

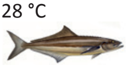
Species	Current status	Market
Arctic char *(Salvelinus alpinus)* 14 °C 	Arctic char or cross breeds with brook trout has a long track record of growing well in cold water aquaculture.	Sold in specific markets at fair to good prices.
Atlantic salmon, smolt *(Salmo salar)* 14 °C 	Small salmon are called smolt. They are grown in freshwater before transfer to saltwater for grow-out. Smolts are raised in recirculation systems with great success.	The market for salmon smolt is usually very good. Demand is constantly increasing.
Eel *(Anguilla anguilla)* 24 °C 	Proven successful species in recirculation. Cannot reproduce in captivity. Wild catch of fry (elvers) is necessary. Considered threatened species.	Limited market with varying price levels. Some buyers will refuse to buy because of threatened species status.
Grouper *(Epinephelus spp.)* 28 °C 	Saltwater fish grown primarily in Asia. Many different grouper species. Requires knowledge in spawning and larval rearing. Grow-out relatively straight forward.	Sold primarily in local markets at good prices in areas where production by many small producers is taking place.
Rainbow trout *(Oncorhynchus mykiss)* 16 °C 	Easy to culture. Recirculation in freshwater widely used from fry rearing up to portion size fish. Larger trout can also be grown in recirculation whether fresh or saltwater.	Relatively tough competition in most markets. Products need to be diversified.
Seabass/ Seabream *(Dicentrarchus labrax / Sparus aurata)* 24 °C 	Saltwater aquaculture fish in a highly developed cage farming industry. Larval phases require good skills. Proven to grow well in recirculation.	Generally tough market conditions, but can fetch good prices for fresh fish in some local areas.
Sturgeon *(Acipenser spp.)* 22 °C 	Group of freshwater fish of many species relatively easy to culture. Skills required in different biological stages. Farming in recirculation systems is increasing.	Fair market conditions for meat. The caviar business seems to expand in high-end markets.

Species	Current status	Market
Turbot *(Scophthalmus maximus)* 17 °C 	Good skills required in broodstock and hatchery management. Grows very well in recirculation.	Generally tough international market conditions. Local market prices can be higher.
Whiteleg shrimp *(Penaeus vannamei)* 30 °C 	Most common shrimp species in aquaculture. Grow-out in recirculation systems has been proven successful. The production method is developing.	Shrimp prices are generally good and high in comparison to fish prices.
Yellowtail amberjack *(Seriola lalandi)* 22 °C 	Yellowtail amberjack, or kingfish, is a saltwater species proven to perform well in cages and in land based systems.	Market prices good. Sold in specific markets.

Low market prices make the following fish challenging to produce with a profit in recirculation aquaculture, and good marketing and sales efforts are important:

Species	Current status	Market
African catfish *(Clarias gariepinus)* 28 °C 	Freshwater fish very easy to culture. A robust and fast growing fish that performs well in recirculation. Production must be very cost efficient.	Moderate to low prices. Most fish are sold live in local markets. Strong marketing effort required.
Barramundi *(Lates calcarifer)* 28 °C 	Also called Asian seabass. Lives in both fresh and saltwater. Requires knowledge in larval rearing. Relatively straight forward in grow-out.	Sold primarily in local markets at fair prices. International market expected to grow as global marketing increases.
Carps *(Cyprinus carpio)* 26 °C 	All carp species will grow very well in recirculation aquaculture systems. Keeping down production costs at a minimum is the main issue.	Carps are regarded as a low price species in most markets, but can fetch higher prices in some markets.
Pangasius *(Pangasius bocourti)* 28 °C 	This catfish is grown in big earth ponds primarily in Vietnam. Impressive ability to survive and grow at sub-optimal conditions.	Low end product in the global fish market leaves no room for production costs.
Perch *(Perca fluviatilis)* 17 °C 	Freshwater fish proven to grow well in recirculation although not widely used.	Limited market with fluctuating prices.
Tilapia *(Oreochromis niloticus)* 28 °C 	One of the most predominant aquaculture fish, which is robust and fast growing. Production cost must be kept to a minimum to be competitive.	Sold in the world market at low to moderate prices. Can fetch higher prices locally.
Whitefish *(Coregonus lavaretus)* 15 °C 	Coregonus is a group of freshwater fish that can be grown in aquaculture and in recirculation systems.	Prices relatively low as there is strong competition from wild caught species.

Very challenging to grow these fish at a commercial viable scale in recirculation aquaculture or in aquaculture in general, because it is either difficult to manage biologically or/and because of tough market conditions:

Species	Current status	Market
Atlantic cod *(Gadus morhua)* 12 °C 	Fry rearing proven to be successful in recirculation. Grow-out of larger cod needs further development and is as such not suited for recirculation.	Prices are fluctuating as market is heavily affected by wild stock catches.
Atlantic salmon, Large *(Salmo salar)* 14 °C 	Larger salmon are grown in sea cages to reach market size of 4-5 kilos. Grow-out in land based systems using recirculation is under development.	Global market dominated by Norwegian marketing. Trend towards certified products.
Bluefin tuna *(Thunnus thynnus)* 24 °C 	Fattening of wild caught fish is the only profitable farming technology. Controlling full cycle at a commercial level in aquaculture is still under development.	Can fetch very high prices in a turbulent worldwide market for tuna.
Cobia *(Rachycentron canadum)* 28 °C 	Fairly new saltwater aquaculture fish of good meat quality. Grow-out in cage culture. Output seems to be growing, although there are many obstacles in breeding.	Market is not well developed and the fish is unknown in most markets.
Lemon sole *(Microstomus kitt)* 17 °C 	Not yet fully developed new species in aquaculture due to different obstacles in biology, such as feeding, etc.	High-end product fetching stable and high prices.
Pike-perch *(Sander lucioperca)* 20 °C 	Freshwater fish difficult to farm. Larval stage troublesome, grow-out seems a little easier. Only a few successful recirculation systems for pike-perch.	Good and fair prices. Demand expected to grow as wild stocks fall and consumption increases.

Chapter 4: Project planning and implementation

The idea of building a recirculation fish farm is often based on very different views on what is important and what is interesting. People tend to focus on things they already know or things they find most exciting, and in the process forget about other aspects of the project.

Five major issues should be addressed before launching a project:

- Sales prices and market for the fish in question
- Site selection including licences from authorities
- System design and production technology
- Work force including a committed manager
- Financing the complete project all the way to a running business.

Sales prices and market

The very first thing is to find out if the fish can be sold at acceptable prices and in sufficient volumes. It is therefore important to carry out a proper market survey before further steps are taken. Fish prices in the shops are very different from the prices you will receive ex farm. Bringing fish from the farm to display at the supermarket is a long process involving procedures for killing, gutting, packing and transport. The costs involved can be significant, and the costs must be included in the overall calculations. The supermarket and so called middlemen will take their share of the profit, and the loss in weight from gutting the fish will of course make a significant difference in the final weight of the fish you are getting paid for.

Site selection and licensing

Selection of a good site is extremely important. Although recirculation technology claims to be water saving the need for water in fish farming is obvious. Ground water is by far the most preferred water source, because of its purity and relatively cold temperature. Water taken directly from rivers, lakes or the sea is not recommended. If seawater is used, it is advisable to construct sand drains or use borehole water. The site selection is also directly linked to the work load when seeking approval from local, regional, or national authorities to build a fish farm. Much too often it is underestimated how long and how difficult it is to get a permission for discharging water from a fish farm. Although the discharge water has been treated thoroughly and all particle removed the nutritious reject water is always of concern to the authorities. It is advisable to have a pre-project made, so that the relevant authorities can be approached in due time for obtaining permits for construction, water usage, discharge, etc.

System design and technology

Many fish farmers tend to design and build systems or solutions themselves, which at first glance is understandable as you want to keep costs down and to have your own ideas incorporated. The best solution is, however, to approach a professional system supplier and discuss the ideas for the technology in mind, and find out together the optimal solution for building the farm. The fish farmer should spend his time operating and optimizing the fish farm operation instead of getting involved in detailed technical solutions and design work. System suppliers most often work in a very systematic way bringing the project afloat from basic design to construction and final start-up of the farm. Some system suppliers even support day-to-day farm management and operational procedures to ensure a proper hand-over and long term success.

Work force

Finding skilled employees is vital, so that the management of the farm can be well taken care of. It is of utmost importance to find an overall operational farm manager, who is fully committed to the job, wanting to succeed as much as the shareholders do. Fish are living creatures and require tight management on a daily basis to grow in a healthy and sound environment. Mistakes or mismanagement will immediately have a huge impact on production and fish welfare. As the aquaculture industry grows and become more professionalised the need for well-educated employees becomes evident. Training and education is increasingly becoming an important part of modern aquaculture.

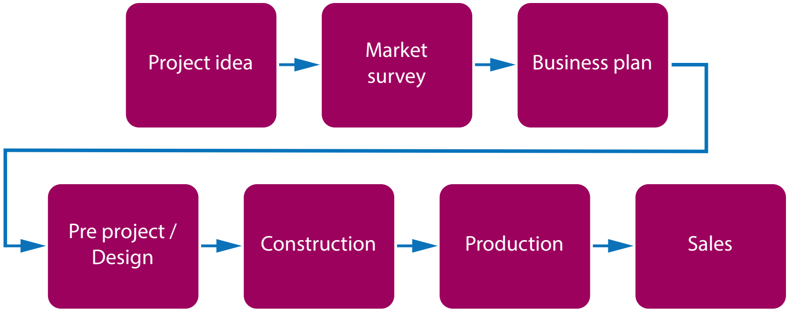


Figure 4.1 Flow from project idea to end product

Financing

The requirement for financing of the complete project is often seriously underestimated. The capital costs are very high when building and starting up a new fish farm, and investors seem to forget that growing fish to market size requires patience. The time from starting the construction and getting the first pay-back from fish sold takes typically from one to two years. Cash flow is thus slow in the beginning, and it is recommended to stock more fish into the system in the starting phase and to sell off this excess number of fish at a smaller size in the first year until the production logistics have reached the planned daily output of volumes and sizes. Another important issue is to have all costs included when estimating the total need for investment and working capital, and to have a contingency pool available for unexpected malfunctions or needs. In a recirculation system the technology and the biological functioning are inter-dependent. This means that if any of the technology solutions have not been installed or are under-dimensioned or do not work, the recirculation principle will suffer severely. In the end this will affect fish welfare and growth performance resulting in poor fish quality and lower output than planned.

In order to get a systematic overview of the whole project, a business plan should be elaborated. It is beyond the scope of this guide to go into details on how to write a business plan or how to conduct a market survey for that matter. Detailed information on such subjects must be sought elsewhere. However, a draft business plan and examples of budgets and financial calculations are given in order to guide the reader and make him aware of the challenges when setting up a fish farming project.

1. Executive Summary:

Objective, mission and keys to success

2. Company Summary:

Company ownership, partners

3. Products:

Analysis of produce

4. Market Analysis Summary:

How is the segmentation in the market?
What will be the target market?
What does the market need?
Competitors?

5. Strategy and Implementation Summary

Competitive edge
Sales strategy
Sales forecast

6. Management Summary

Personnel plan and company
Organisation

7. Financial Plan

Important assumptions
Break-even analysis
Projected profit and loss
Cash flow and balance sheet

Figure 4.2 Main items of a business plan (modified from Palo Alto Software Ltd.).

An introduction for starting up a business and samples of business plans are available at resources like:

www.bplans.com
www.bplans.co.uk

It is also important to plan in detail the production of the fish, and incorporate the plan carefully into the budgets. The production plan is the basic working document when it comes to the success or failure of the production output.

The production plan should be revised regularly as farmed fish most often perform better or worse in practice than planned in theory. Working out a production plan is basically a matter of calculating the growth of the fish stock, typically from one month to the next. Several software programs are available for calculating and planning the production. They are however all based on computation of interest using the growth rate in percent per day of the fish in question. The growth rate depends on the species of fish, the size of fish and the water temperature. Different species of fish have different optimal rearing temperatures depending on their natural habitat, and smaller fish have higher growth rates than larger fish.

The feed intake, and the feed conversion rate (FCR) of the feed, is of course an integrated part of these calculations. An easy way of approaching the production plan is to obtain a feeding table for the fish in question. Such tables are available at the feed manufacturers, and the tables take into consideration the fish species, the size of fish, and the water temperature (see figure 4.3).

Dividing the feeding rate by the FCR will give you the growth rate of the fish. The weight gain from one day to the other can hereafter be calculated using the computation of interest expressed by:

$$K_n = K_0(1+r)^n$$

where "n" is the number of days, "K_0" is the fish weight at day 0, "K_n" is the fish weight at the "n"th day, and "r" is the rate of growth. A fish of 100 grams growing at 1.2% per day will in 28 days weigh:

$$K_{28\ days} = K_{100\ gram}\ (1+0.012)^{28\ days}$$

$$= 100\ \ (1.012)^{28} = 139.7\ gram$$

Whatever the size or numbers of fish, this equation can be used for calculating the growth of the fish stock, making a precise production plan and incorporating when to grade and divide the fish into more tanks. Also, it should be remembered to subtract losses in the population when working out the production plan. It is advisable to calculate on a monthly basis, and to use a mortality factor of approximately 1% per month depending though on experience. A month should not be calculated as 30 full days as there will normally be days in a month where the fish are not fed due to managerial procedures, which is why 28 days is used in the example above.

Fish size (g)	Pellet size (mm)	13 °C	15 °C	17 °C	19 °C	21 °C	23 °C	25 °C	27 °C	29 °C
50-100	3.0	0.60	0.89	1.04	1.19	1.39	1.44	1.34	1.19	0.99
100-200	3.0	0.50	0.80	0.99	1.09	1.19	1.24	1.14	0.99	0.80
200-800	4.5	0.45	0.70	0.85	0.94	1.04	1.04	0.94	0.85	0.70
800-1 500	4.5	0.35	0.55	0.65	0.75	0.85	0.85	0.75	0.60	0.40
1 500-3 000	6.5	0.20	0.35	0.45	0.55	0.65	0.65	0.55	0.45	0.30
3 000-5 000	9.0	0.15	0.25	0.34	0.39	0.44	0.49	0.44	0.34	0.20
5 000-10 000	9.0	0.12	0.20	0.28	0.31	0.35	0.39	0.35	0.28	0.16

Figure 4.3 Example of recommended feeding rate for different sizes of sturgeon given in percentage of fish weight at different water temperatures. Feeding should be adapted to the production strategy and rearing conditions, likewise the choice of feed type. Feeding according to the recommended level will give the best FCR thus saving feed costs and lowering excretion. Pushing the feeding rate to a higher level will enhance growth at the expense of a higher FCR. Source: BioMar.

To sum up on the budgets required in the business plan, these include:

- Investment budget (CAPEX)
  (capital expenditure, total capital costs)
- Operational expenses budget (OPEX)
  (operational expenditure, running the business)
- Cash budget
  (liquidity, business up and running)

Investment budget	100% (capital costs)
Civil works: Land development, building, concrete and construction, piping, electrics, walkways	46%
Recirculation system: Design and equipment, freight and installation	35%
Fish tanks	12%
Feed and light systems	2%
Heating, chilling, ventilation	2%
Fish handling incl. pipes	2%
Operational equipment	1%

Figure 4.4 Example of investment budget for a fully recirculation in-house system with estimated figures in percent. The distribution cost will vary depending on type of system, fish species, and location.

It is always advised to consult a professional accountant to make thorough budgets in order to account for all expenses. A well documented budget is also necessary for convincing investors, getting a bank loan and for approaching funding institutions.

The investment budget depends strongly on the construction of the recirculation plant, which again depends on the country and local conditions in the construction area. An example of an investment budget with estimated figures in percent is shown in figure 4.4. Purchase of land is not included.

Construction costs depend not only on local building costs, but also on fish species and farm size. The costs are also highly dependent on whether the farming system shall breed all fish stages or just the grow-out phase, and if the system is to be installed inside a building or not. Such decisions depend on climate, fish species, aim of the production, etc. There is a clear tendency that the higher the rate of recirculation, the higher the need for installing the system inside a building.

Generally, total investment cost all included will reach up to 12-14 EUR per kg produced for in-house systems of 100 tons per year with all facilities such as hatchery, weaning, fry and grow-out. The larger the harvesting size of the fish

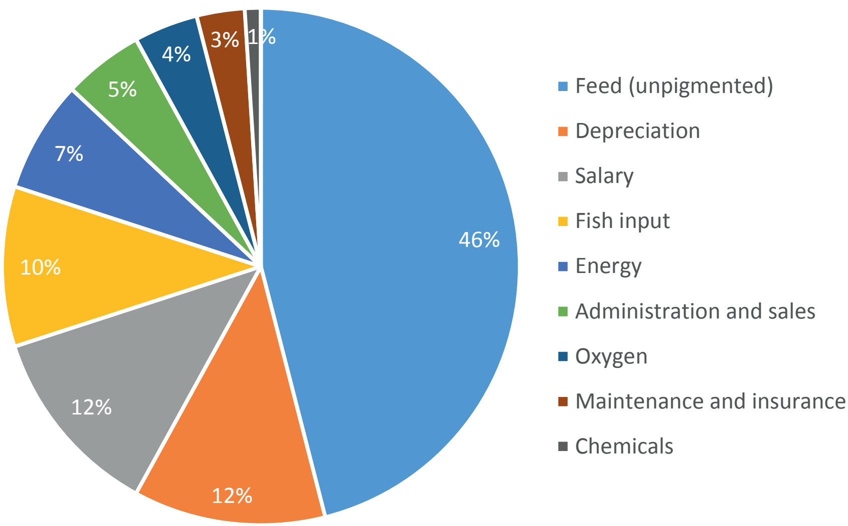


Figure 4.5 Example of cost distribution of a large farm for portion sized trout (2 000 tonnes/year) taking in fingerlings and growing them to 300-500 grams. Total production cost per kilo live fish produced is less than 2 EUR per kg. The total investment cost for such a fully recirculation in-house system is around 4 EUR per kg production (total 8 mio. EUR).

farmed the higher the investment cost, because growing larger fish requires more system and tank space to produce the same tonnage when compared to smaller fish. Thus systems for producing large fish, such as market size salmon of 4-5 kg will also reach 12-14 EUR per kg produced per year. In the other end of the scale, less advance outdoor recirculation systems used only for final grow-out of smaller sized fish, such as portion sized trout, will cost around 4-5 EUR per kg produced per year when designed for 1 000 tons or more.

Regarding purchase of land, the footprint of a recirculation plant also depends on fish species and the intensity of the production. In general, the footprint of a recirculation facility is roughly about 1 000 m^2 per 100 tonnes fish. The larger the total production the smaller the area needed per 100 tonnes produced, because the tanks are larger and can be built deeper. A large fish farm of 1 000 tonnes will thus require only 7 000 m^2. More land will often be needed for surrounding works such as water intake, water discharge treatment, fish loading, roads, etc.

From figure 4.5 it is interesting to note that the consumption of energy is only 7% of the costs. Focus on the electricity consumption is of course important, however, it is by no means the dominant cost. In fact this is equivalent to many traditional farms where the use of paddle wheels, return pumps, oxygen cones and other installations use quite a substantial amount of energy.

The cost of feed is by far the most dominant cost, which also means that good management is the most important factor. Improving the FCR will have a significant impact on the efficiency of the production.

As in other food producing sectors, the larger the production unit the lower the cost of production per unit produced. The same applies to fish farming. However, it seems that making production systems much larger than 2 000 tonnes per year does not give a significant reduction in investment costs. Stepping up the way from a few hundred tonnes per year towards a thousand does though give significant reductions in costs, both with regards to investment and running costs. The benefit of going up in farm size depends greatly on which species is reared, and the way of expanding production must be carefully considered.

The appendix has a checklist of biological and technical issues that can affect the implementation of a recirculation system. This check-list is most suitable for identifying details and possible obstacles when the project is about to be realised.

Chapter 5: Running a recirculation system

Moving from traditional fish farming to recirculation significantly changes the daily routines and skills necessary for managing the farm. The fish farmer has now become a manager of both fish and water. The task of managing the water and maintaining its quality has become just as important, if not more so, than the job of looking after the fish. The traditional pattern of doing the daily job on a traditional flow-through farm has changed into fine tuning a machine that runs constantly 24 hours a day. Automatic surveillance of the whole system ensures that the farmer has access to information on the farm at all times, and an alarm system will call if there is an emergency.

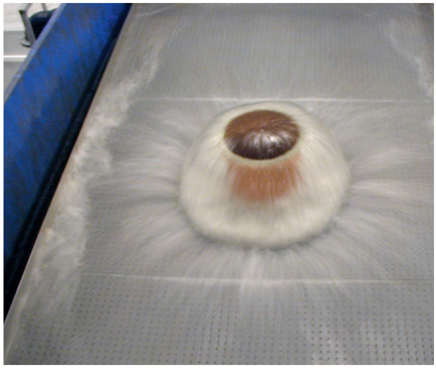


Figure 5.1 Water quality and flow in filters and fish tanks should be examined visually and frequently. Water is distributed over the top plate of a traditional trickling filter (degasser) and distributed evenly through the plate holes down through the filter media.

Routines and procedures

The most important routines and working procedures are listed below. Many more details will occur in practice, but the overall pattern should be clear. It is essential to make a list with all the routines to be checked each day, and also lists for checking at longer intervals.

Daily or weekly:

- Visually examine the behaviour of the fish
- Visually examine the water quality (transparency/turbidity)
- Check hydrodynamics (flow) in tanks
- Check distribution of feed from feeding machines
- Remove and register dead fish
- Flush outlet from tanks if fitted with stand-pipes
- Wipe off membrane of oxygen probes
- Registration of actual oxygen concentration in tanks

- Check water levels in pump sumps
- Check nozzles spraying on mechanical filters
- Registration of temperature
- Make tests of ammonia, nitrite, nitrate, pH
- Registration of volume of new water used
- Check pressure in oxygen cones
- Check NaOH or lime for pH regulation
- Control that UV-lights are working
- Register electricity (kWh) used
- Read information from colleagues on the message board
- Make sure the alarm system is switched on before leaving the farm.

Weekly or monthly:

- Clean the biofilters according to the manual
- Drain condense water from compressor
- Check water level in buffer tank
- Check amount of remaining O_2 in oxygen tank
- Calibration of pH-meter
- Calibration of feeders
- Calibrate O_2 probes in fish tanks and system
- Check alarms – make alarm tests
- Check that emergency oxygen works in all tanks
- Check all pumps and motors for failure or dissonance
- Check generators and make a test-start
- Check that ventilators for trickling filters are running
- Grease the bearings of mechanical filters
- Rinse spraybar nozzles on mechanical filters
- Search for "dead water" in system and take precautions
- Check filter sumps - no sludge must be observed.

Figure 5.2 Oxygen generator. Control and service of special installations must be taken care of.

6-12 months:

- Clean UV sterilizer, change lamps yearly
- Change oil and oil-filters and air-filter on compressor
- Check if the cooling towers are clean inside
- Check if degasser is dirty and clean if necessary
- Clean biofilter thoroughly if necessary
- Service the oxygen probes
- Change spraybar nozzles in mechanical filters
- Change filter plates in mechanical filters.

Water quality

Managing the recirculation system requires continuous registration and adjusting to reach a perfect environment for the fish cultured. For each parameter concerned there are certain margins for what is biologically acceptable. Throughout the production cycle each section of the farm should if possible be shut down and started up again for a new batch of fish. Changes in production affect the system as a whole, but especially the biofilter is sensitive to dry outs or other alterations. In figure 5.3 the effect on the concentration of nitrogen compounds leaving a newly started biofilter can be observed. Fluctuations will occur for many other parameters of which the most important can be seen in figure 5.4. In some situations parameters may raise to levels which are unfavourable or even toxic to fish. However, it is impossible to give exact data on these levels as the toxicity

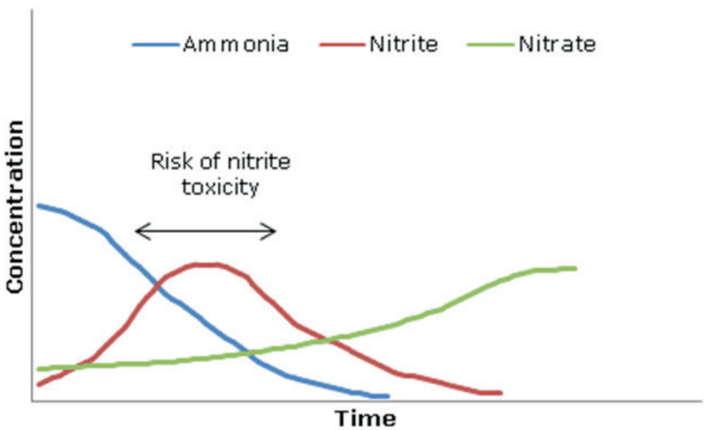


Figure 5.3 Fluctuations in the concentration of different nitrogen compounds from start-up of a biofilter.

depends on different things, such as fish species, temperature and pH. The fish will most often adapt to the environmental conditions of the system and thus tolerate higher levels of certain parameters, such as carbon dioxide, nitrate or nitrite. Most important is to avoid sudden changes in the physical and chemical parameters of the water.

The toxicity of the nitrite peak can be eliminated by adding salt to the system. A salt concentration in the water of just 0.3 o/oo (ppm) is sufficient to inhibit the the toxicity of nitrite. Suggested levels for different physical and chemical water quality parameters in a recirculation system are shown in figure 5.4.

Parameter	Formula	Unit	Normal	Unfavourable level
Temperature		^{o}C	Depending on species	
Oxygen	O_2	%	70-100	< 40 and > 250
Nitrogen	N_2	% saturation	80-100	> 101
Carbon dioxide	CO_2	mg/L	10-15	> 15
Ammonium	NH_4^+	mg/L	0-2.5 (pH influence)	> 2.5
Ammonia	NH_3	mg/L	< 0.01 (pH influence)	> 0.025
Nitrite	NO_2^-	mg/L	0-0.5	> 0.5
Nitrate	NO_3^-	mg/L	100-200	>300
pH			6.5-7.5	< 6.2 and > 8.0
Alkalinity		mmol/L	1-5	< 1
Phosphorus	PO_4^{3-}	mg/L	1-20	
Suspended solids	SS	mg/L	25	> 100
COD	COD	mg/L	25-100	
BOD	BOD	mg/L	5-20	> 20
Humus			98-100	
Calcium	Ca^{++}	mg/L	5-50	

Figure 5.4 Preferable levels for different physical and chemical water quality parameters in a recirculation system.

Biofilter maintenance

The biofilter must be working at optimal conditions all times in order to secure a high and stable water quality in the system. The following is an example of procedures for maintenance of the biofilter.

Figure 5.5 Principle drawing of biofilter made of polyethylene (PE) plastic. Normally PE biofilters are placed above ground level fitted with a sludge discharge valve for easy flushing and cleaning. The sludge water is lead to the waste water treatment system outside the aquaculture recirculation system. The picture on the right reveals the size of a large PE biofilter. Source: AKVA group.

Biofilter maintenance includes:

- Brush the top plate every second week to avoid bacteria and algae developing and eventually blocking the holes in the perforated top plate
- Brush and clean the microbubble diffusers in the process water pipe from last biofilter chamber to microparticle filter every second week
- Regular monitoring and cleaning schedule

Figure 5.6 The flow pattern in the shown multi chamber PE biofilter goes from left to right and upstream in each chamber. Most of the organic material is removed by heterotrophic bacteria in the first chamber. The consequent low organic load in the latter chambers secures a thin nitrifying biofilm for converting ammonia to nitrate. The last chamber is called a microparticle filter and is designed for removal of very fine particles that have not been removed by the mechanical filter. Source: AKVA group.

The following parameters should be checked regularly:

- Check the distribution of air bubbles across each of the biofilter chambers. Over time the biofilter will accumulate organic matter, which will impact the distribution of air bubbles and increase the size of the bubbles

- Check the height between the water surface level in the biofilter and the PE cylinder wall top edge to identify flow changes through the biofilter and microparticle filter

- Regularly measure the water quality parameters that have most relevance to the biofilter

- Closely monitor the remaining volume of base or acid used for dosing.

Cleaning and flushing for sludge removal in biofilter

A mix of inorganic material, dislodged biofilms and other organic matter that is difficult to break down by the microorganisms may accumulate below the biofilter. This should be removed by the sludge removal system placed in the chambers.

For sludge removal flush follow the protocol below:

- Bypass the PE biofilter that is to be cleaned
- Open outlet discharge valve for few seconds (approx. 10 sec.)
- If sludge pump is installed: Pump the sludge from PE biofilter and check for a brown coloration in the water
- Continue this procedure for all biofilters and microparticle filters (and turn off the sludge when finished). Ensure there is no siphoning from the biofilter chambers via the sludge pump. If there is a possibility of losing water this way, shut all the outlet discharge valves.

Simple cleaning of biofilter using air

Twice a week it is recommended to apply a simple cleaning protocol. In this procedure the PE biofilters are cleaned by air.

For simple biofilter clean follow the protocol below:

- Do not change the flow to the biofilter
- Open the air cleaning valves on the first PE biofilter
- Check with that the cleaning blower is ready for operation. Turn this blower on
- Direct all cleaning air to biofilter 1 for 10-15 minutes. The process water flow through the biofilter will transfer the loosened organic materials to the following chamber
- Direct all cleaning air to the next PE biofilter for 10-15 minutes. Continue the procedure through to the last biofilter. Exclude the microparticle filter
- All the loosened organic material finds its way to the microparticle filter.

Microparticle filter cleaning

The regularity of cleaning the microparticle filter depends on the loading on the system. As a guideline it is recommended to clean the microparticle filter every week.

For simple micro-particle filter cleaning follow the protocol below:

- Stop the flow through the PE biofilters
- Reduce the water level to 100 mm below the top plate of the microparticle filter using the sludge discharge valve (use the sludge pump if available)
- Shut the air cleaning valves on all PE biofilter chambers. Open the microparticle filter chamber air cleaning valve
- Check with the engineer that the cleaning blower is ready for operation. Turn this blower off
- Direct all cleaning air to the microparticle filter for 30 minutes. This volume of air raises the water level to near the outlet boxes. The foul water should not be allowed to exit the outlet box
- Following the cleaning discharge the entire microparticle filter volume using the protocol described for the sludge removal flush.

Deep cleaning of biofilter

If the head difference between biofilter and/or microparticle filter chambers is increasing and the normal head difference cannot be re-established by normal cleaning, then a biofilter deep clean procedure is required. Use regular measurements in each biofilter chamber, between the top of the water level and the PE cylinder top edge to identify flow problems through the biofilter and microparticle filter.

Before completing a deep rinse shut the aeration off in the given chamber for two hours before completing the clean. The given chamber will then act like a microparticle filter for this short period collecting extra waste which is to be discharged during the cleaning process. As a guideline it is recommended that all areas of the biofilters are deep cleaned every month.

For deep biofilter filter cleaning follow the protocol below:

- Stop the flow through the PE biofilters
- Use heavy aeration for 30 minutes in the filter(s) to be cleaned. Then completely empty the given filter(s) using the protocol described for the sludge removal flush.

Sodium hydroxide (NaOH) cleaning

If severe blocking in biofilter system is identified, complete a sodium hydroxide cleaning. Severe blocking may be identified by continuous problems with head difference between the chambers, signs of uneven aeration across the top of the chamber and/or reduced biofilter performance.

For a sodium hydroxide cleaning follow the protocol below:

- Empty the filter section
- Refill with freshwater and a sodium hydroxide solution (NaOH, adjusted to pH 12)
- Leave this to work for an hour with aeration and then empty the filter again using the protocol described for sludge removal flush.

This treatment should only be necessary if the biofilter has not received maintenance regularly. It will take several days (app. 10-15 days) until the sodium hydroxide cleaned chamber is back at full capacity.

Trouble shooting biofilter problems:

Problem	Reason	Solution
Increased turbidity	Too much aeration	Lower aeration
	Reduced flow rate to biofilter	Open valve between degasser and biofilter, increase flow
Increasing TAN level	Too much aeration, reduced nitrification performance due to damage to the biofilm	Lower aeration
Increasing nitrite & TAN levels	Too high organic loading	Make sure feeding does not exceed system specs. Check mechanical filter function.
Decreasing nitrate level	Anaerobic activity	Increase aeration, clean biofilter
Hydrogen sulphide (H_2S) production (smell rotten egg when cleaning)	Anaerobic activity	Increase aeration, clean biofilter
Increasing alkalinity	Anaerobic activity	Increase aeration, clean biofilter
Reduced flow to biofilter	Closed inlet valves partly	Open valve between degasser and biofilter, increase flow
	blocking of biofilter, insufficient cleaning of the biofilter	Clean biofilter according to schedule & production specific demands
Reduced or no aeration	Blower failure	Check blower, intake air filter, fuse and power

Figure 5.7 Table of problems with reasons and possible solutions.

Precautions

Water that is under aeration has a lower density than normal water making swimming impossible!

An operator should only walk on the biofilter top plates whilst wearing a safety harness! Correct footwear must be worn, and care must be taken on the extremely slippery surface!

Follow all instructions with regards to safety procedures for the use of tools, chemicals, machines or any other!

Oxygen control

Dissolved oxygen (DO) is one of the most important parameters in fish farming, and it is important to understand the relationship between % saturation and mg/l. When water is saturated with air it has a DO of 100% saturation. A correct monitoring of the oxygen levels on the farm is vital for the overall performance of the fish.

The oxygen content in milligram oxygen per litre of water depends on the temperature and barometric pressure. At a barometric pressure of 1 013 mbar 100% saturation equals 14.6 mg/l at 0°C, but only 6.4 mg/l at 40°C. This means that in cold water there is much more oxygen available for the fish to consume than in warm water. Thus farming fish in warm water requires even more intense oxygen monitoring and control than farming in cold water.

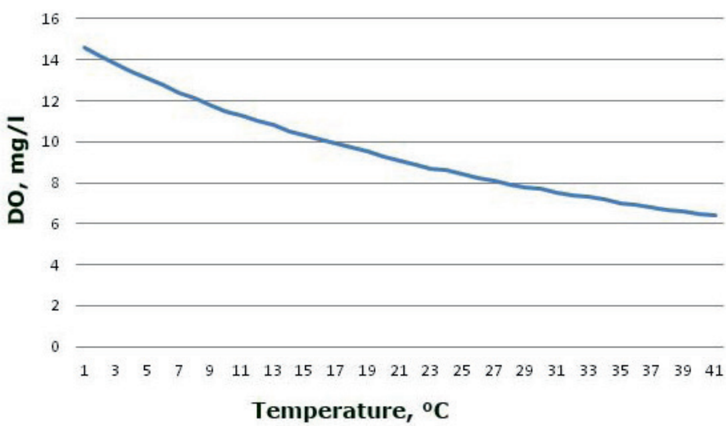


Figure 5.8: Concentration in mg/l at 100% saturation of dissolved oxygen (DO) in fresh water. The concentration is higher in cold water than in warm water.

Dissolved oxygen in fresh water												
mm Hg		700	710	720	730	740	750	**760**	770	780	790	800
mbar		933	946	960	973	986	1000	**1013**	1026	1040	1053	1066
Temperature												
°C	°F											
0	32	13.4	13.6	13.8	14.0	14.2	14.4	**14.6**	14.8	15.0	15.2	15.4
5	41	11.8	11.9	12.1	12.3	12.4	12.6	**12.8**	12.9	13.1	13.3	13.4
10	50	10.4	10.5	10.7	10.8	11.0	11.1	**11.3**	11.4	11.6	11.7	11.9
15	59	9.3	9.4	9.5	9.7	9.8	9.9	**10.1**	10.2	10.3	10.5	10.6
20	68	8.4	8.5	8.6	8.7	8.8	9.0	**9.1**	9.2	9.3	9.4	9.6
25	77	7.6	7.7	7.8	7.9	8.0	8.1	**8.2**	8.4	8.5	8.6	8.7
30	86	6.9	7.0	7.1	7.2	7.3	7.4	**7.5**	7.6	7.7	7.8	7.9
35	95	6.4	6.5	6.6	6.7	6.8	6.8	**6.9**	7.0	7.1	7.2	7.3
40	104	5.9	6.0	6.1	6.2	6.2	6.3	**6.4**	6.5	6.6	6.7	6.7

Figure 5.9 Dissolved oxygen in fresh water in mg/l at 100% oxygen saturation.

There is also a difference of the availability of dissolved oxygen in fresh water versus saltwater. In fresh water the availability of oxygen is higher than in saltwater (see figures 5.9 and 5.10).

Dissolved oxygen in saltwater						
Salinity parts per thousand		0	10	20	30	40
Temperature						
°C	°F					
0	32	14.6	13.6	12.7	11.9	11.1
5	41	12.8	11.9	11.2	10.5	9.8
10	50	11.3	10.6	9.9	9.3	8.7
15	59	10.1	9.5	8.9	8.4	7.9
20	68	9.1	8.6	8.1	7.6	7.2
25	77	8.2	7.8	7.4	7.0	6.6
30	86	7.5	7.1	6.8	6.4	6.1
35	95	6.9	6.6	6.2	5.9	5.6
40	104	6.4	6.1	5.8	5.5	5.2

Figure 5.10 Dissolved oxygen in saltwater in mg/l at 100% oxygen saturation.

Modern equipment has sensors for temperature and barometric pressure to give you correct values at all times. If you are measuring oxygen in saltwater, simply write in the level of salinity in the menu of the oxygen meter and the meter will automatically adjust accordingly.

This means that calibration of for example a hand held oxygen meter is quite simple.

Figure 5.11 Handy Polaris oxygen meter for measuring oxygen content of the water in mg/l and % saturation. Source: Oxyguard International.

Turn on the Polaris. It should show 100.5%. Small variations from this can be due to changes in humidity or in the actual oxygen concentration of the air. If calibration is needed and wiping the membrane does not help select “Calibrate” and press “OK” to start. Progress is shown on the display. When “Calibration done” is shown press “OK”. If calibration is blocked and an error message appears you can either choose “Field” calibration precision or force a calibration by holding “OK” depressed when “Calibrate – Please wait” is shown. The result will not necessarily be precise – “Calibrate” will blink in the display when making measurements. Re-calibrate under more stable conditions when possible.

Set the salinity by using the arrow buttons, “OK” and “Esc” to set the salinity to that of the water you measure in. Then both mg/l and % sat measurements are correct.

To measure, turn the Polaris on and immerse the probe in the water. In still water move the probe, 5-10 cm/sec is enough. After use rinse the probe in clean water and wipe the meter dry if it is wet. If an error occurs then “Error”, “Warning” or “Calibrate” will blink in the display. More information is shown in the status list – see “Status List”.

Polaris will block calibration if conditions are unsuitable – an error message will be displayed. Changing or low temperature can, for example, make it difficult to calibrate outdoors. The sensitivity of the automatic check can be changed – see “Calibration Precision”.

Accurate measurements need accurate calibration, which in turn needs stable conditions. Polaris checks and only permits calibration if conditions are stable.

The sensitivity of this check can be changed – see “Calibration Precision”.

When not in use store Polaris in its pouch in a place where the temperature is moderate and stable. It will then be easy to check calibration and, if needed, re-calibrate with the probe in the pouch in the same place before taking Polaris into use.

Note that if “Renovate Probe” flashes in the display the probe must be renovated.

Education and training

Management of the fish farm is just as important as having the right technology installed. Without properly educated and trained people the efficiency of the farm will never become satisfactory. Fish farming in general requires a wide range of competencies from broodstock and hatchery management, weaning and nursing of fish larvae, fry and fingerling production to grow-out of market size fish.

Training and education is available in many forms from practical hands-on courses to academic studies at universities. A combination of theory and practice is the best combination to gain an all-round understanding of how to run a recirculation aquaculture system.

The following is a listing of the areas that should be considered when building up an educational program.

Basic water chemistry

Understanding the basic chemical and physical water parameters important for the farm operation, such as ammonium, ammonia, nitrite, nitrate, pH, alkalinity, phosphorus, iron, oxygen, carbon dioxide and salinity.

System technology and management in general

Understanding different system designs, primary and secondary water flows. Production planning, feeding regimes, feed conversion rate, specific growth rate relations, registration and calculations of fish size, numbers and biomass. Knowledge of emergency installations and emergency procedures.

Consumables

Understanding fish feed compositions, feeding calculations and distribution, water consumption levels and sources, electricity and oxygen consumptions, pH adjustments by the use of sodium hydroxide and lime.

Parameter readings and calibration

Understanding readings from sensors of oxygen, carbon dioxide, pH, temperature, salinity, pressure, etc. Ability to test and calculate levels of ammonia, nitrite, nitrate, TAN and understanding the nitrogen cycle. Calibration of devices for measuring oxygen, pH, temperature, carbon dioxide, salinity, waterflow, etc. PLC and PC settings for alarms, emergency levels, etc.

Machinery and technical installations

Understanding the mechanics and maintenance required for the system, such as for the mechanical filter, the biofilter system including fixed bed and moving bed, degassers, trickling filters and denitrification filters. Operational knowledge of UV systems, pumps, compressors, temperature control, heating, cooling, ventilation, oxygen injection systems, emergency oxygen systems, oxygen generator and oxygen back-up systems, pH regulation systems, pump frequency converter systems, electrical generator systems, PLC and PC systems, automatic feeding systems.

Operational knowledge

Practical knowledge from working on a fish farm including handling of broodstock, eggs, fish larvae, fry and fingerling and grow-out of larger fish for market. Hands-on experience from fish handling, grading, vaccination, counting and weighing, mortality handling, production planning and other daily work at farm level. Understanding the importance of biosecurity precautions, hygiene, fish welfare, fish diseases and correct treatment.

Management support

When starting a recirculation system there are many things to attend to and it can be difficult to prioritize and focus on the right items. To have the system up and running at optimal level and at full production is most often extremely challenging.

Supervision or management support of the day-day production conducted by a professional end experienced fish farmer can be a way to overcome the starting phase and to avoid mismanagement. Also continuous education and training on site of the farm personnel can be a part of the support.

The fish farmer should build a team of skilled personnel to run the fish farm 24 hours a day 7 days a week. The team members will most often work in shifts to account for night watch and work on weekends and holidays.

Personnel in the team should consist of:

- One manager with overall responsibility for the day-to-day practical management on the fish farm
- Assistants referring to the manager with responsibility for practical work on the farm with special emphasis on the husbandry of the fish
- One or more technicians with responsibility for maintenance and repair of technical installations
- Other workers for miscellaneous work will most often have to be hired.

It is important to make sure that the team actually has the time available to undergo training on site in order to optimize their skills. Quite often training is neglected because the daily work has higher priority and there seems to be no time at all for learning. This is however not the right way to build a new business. Any chance of increasing knowledge and working in a more efficient and professional way should have the highest priority.

Service and repair

A service and maintenance program should be made for the recirculation system to ensure that all parts are working at all times. In the beginning of this chapter routines have been listed and care should be taken on how to solve any malfunctions. It is recommended to make service agreements with suppliers of different equipment to have professional service at hand and at regular intervals.

It is also important to secure efficient sparepart deliveries together with the service regimes. A complete sparepart package for the most important items together with redundancy machinery such as water pumps and blowers should be stored at the farm for immediate use.

Chapter 6: Waste water treatment

Farming fish in a recirculation system where the water is constantly reused does not make the waste from the fish production disappear. Dirt or excretions from the fish still have to end somewhere.

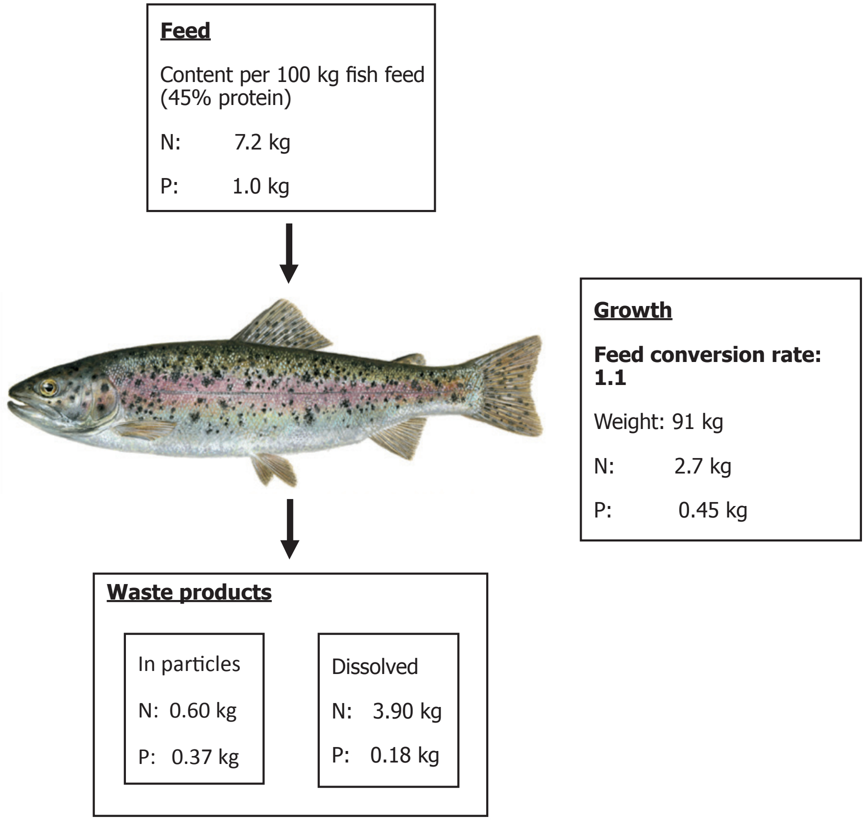


Figure 6.1 Excretion of nitrogen (N) and phosphorus (P) from farmed fish. Note the amount of N excreted as dissolved matter. Source: Biomar and the Environmental Protection Agency, Denmark.

The biological processes within the RAS will in a smaller scale reduce the amount of organic compounds, because of simple biological degradation or mineralisation within the system. However, a significant load of organic sludge from the RAS will still have to be dealt with.

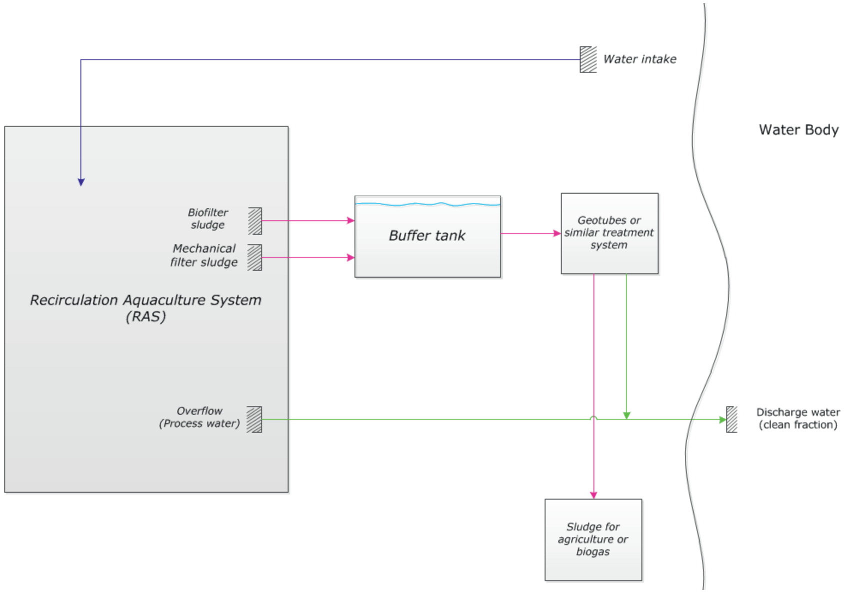


Figure 6.2 Sketch of flows to and from a recirculation aquaculture system.

Most RAS will have an overflow of process water for balancing the water going in and out of the system. This water is the same water as the fish are swimming in, and is as such not a pollutant unless the discharged amount of water from the overflow is excessive and the yearly discharge through this point escalates. The more intensive the rate of recirculation, the less water will be discharged through the overflow.

The waste water leaving the recirculation process typically comes from the mechanical filter, where faeces and other organic matters are separated into the sludge outlet of the filter. Cleaning and flushing biofilters also adds to the total waste water volume from the recirculation cycle.

Treating the waste water leaving the RAS can be accomplished in different ways. Quite often a buffer tank is installed prior to the sludge treatment system where sludge is separated from the discharge water. Sludge will go to an accumulation facility for sedimentation or further mechanical dewatering, before it is spread on land, typically as fertilizer and soil improvement on agricultural farms, or it can be used in biogas production for generating heat or electricity. Mechanical dewatering also makes the sludge easier to handle and minimises the volume whereby disposal or possible fees becomes cheaper.

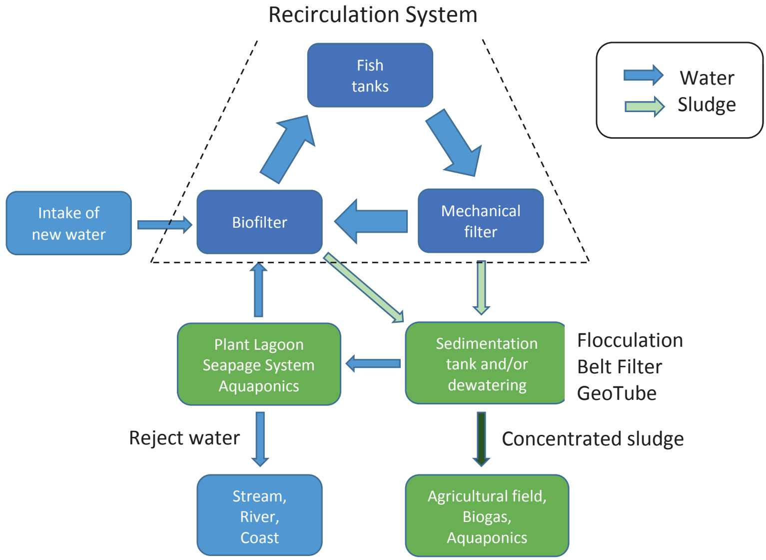


Figure 6.3 The pathways of sludge and water inside and outside a recirculation system. The higher the rate of recirculation, the lower the amount of water let out from the system (dotted line), and the lower the amount of waste water to be treated. Source: Hydrotech.

Figure 6.4 Hydrotech belt filter used as secondary water treatment for dewatering the sludge.

Figure 6.5 A plant lagoon placed after a recirculation trout farm in Denmark - before and after overgrowing. Source: Per Bovbjerg, DTU Aqua.

The cleaned waste water from the sludge treatment will usually have a high concentration of nitrogen, whereas the phosphorus can be almost removed completely in the sludge treatment process. This discharge water is called reject water, and is most often discharged to the surroundings, river, sea, etc. together with the overflow water from the RAS. The content of nutrients in the reject water and in the overflow water can be removed by directing it to a plant lagoon, root zone or seepage system, where remaining phosphorous and nitrogenous compounds can be further reduced.

As an alternative, the reject water can be used as fertilizer in aquaponics systems. Aquaponics are systems where the waste from the fish is used for

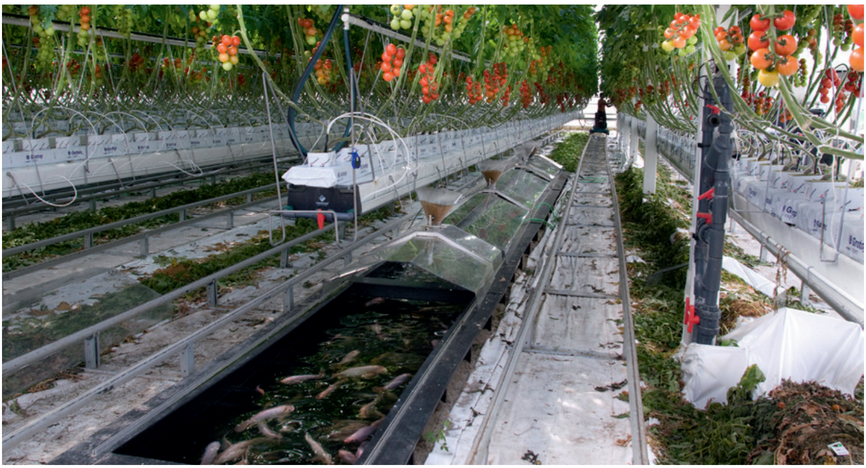


Figure 6.6 The EcoFutura project explored the possibility of cultivating tomatoes with the growing of Nile tilapia (Oreochromis niloticus). Source: Priva (Netherlands)

growing vegetables, plants or herbs, typically inside greenhouses. For larger fish farming systems it is recommended that the sludge is used for agricultural land and biogas, whereas the reject water is used for the aquaponics as this is simpler to handle and adjust with regards to cultures in greenhouses.

The content of nitrogen in the discharge water can also be removed by denitrification. As described in chapter 2, methanol is most commonly used as the carbon source for this anaerobic process, which transforms nitrate to free nitrogen to the atmosphere thus removing the nitrate from the reject water. Denitrification can also be used inside the recirculation system to reduce the amount of nitrate in the RAS process water in order to reduce the nitrate concentration, thus minimizing the need for new water in the system. The use of denitrification outside the recirculation system is carried out in order to reduce the discharge of nitrogen into the environment. As an alternative to the use of methanol, the reject water coming from the sludge treatment system can be used as the carbon source. Using reject water as carbon source requires tight management of the denitrification chamber, and back-washing and cleaning the chamber can become more difficult. In any case, an efficient denitrification system can reduce the nitrogen content in the effluent water significantly.

It should be noted that fish excrete waste in a different way than other animals such as pigs or cows. Nitrogen is mainly excreted as urine via the gills, while a smaller part is excreted with faeces from the anus. Phosphorous is excreted with the faeces only. The main fraction of the nitrogen is therefore dissolved completely in the water and cannot be removed in the mechanical filter. The removal of faeces in the mechanical filter will catch a smaller part of the nitrogen fixed in the faeces, and to a larger extent the amount of phosphorous. The remaining dissolved nitrogen in the water will be converted in the biofilter mainly to nitrate. In this form nitrogen is readily taken up by plants and can be used as fertilizer in agriculture or simply be removed in plant lagoons or root zone systems.

Parameter	Raceway	Raceway	Raceway	Self cleaning tank	Self cleaning tank	Self cleaning tank
	40 µ	60 µ	90 µ	40 µ	60 µ	90 µ
	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %	Efficiency, %
Tot-P	50-75	40-70	35-65	65-84	50-80	45-75
Tot-N	20-25	15-25	10-20	25-32	20-27	15-22
TSS	50-80	45-75	35-70	60-91	55-85	50-80

Figure 6.7 Removal of nitrogen (N), phosphorus (P) and suspended solids (SS) from mechanical filter. Source: Fisheries Research Station of Baden-Württemberg, Germany.

Faeces from the fish tanks should flow immediately to the mechanical filter without being crushed on the way. The more intact and solid the faeces are, the higher the level of removed solids and other compounds. Figure 6.7 shows the estimated removal of nitrogen, phosphorous and suspended solids (organic matter) in a mechanical filter of 50 micron.

The higher the rate of recirculation the less new water will be used, and the less discharge water will need to be treated. In some cases, no water at all will return to the surrounding environment. However, this kind of "zero discharge" fish farming is costly to build and the running costs for the waste treatment are significant. Also, daily operation of the waste treatment will require significant attention to make it work efficiently. For zero-discharge fish farming one should also be aware that a certain amount of water exchange is always needed to prevent the accumulation of metals and phosphorous compounds in the system. The bottom line is that authorities and the fish farmer must agree on a discharge permission that allows protecting the environment whilst having an economical viable fish farming business.

500 tonnes trout production				
Type of farm and type of treatment	Consumption of new water per kg fish produced per year	Consumption of new water per cubic meter per hour	Consumption of new water per day of total system water volume	Nitrogen discharge, kg per year
Flow-through with settlement pond	30 m^3	1 700 m^3/h	1 000 %	20 tonnes N
RAS with sludge treatment and plant lagoon	3 m^3	170 m^3/h	100 %	10 tonnes N
RAS super intensive with sludge treatment and denitrification	0.3 m^3	17 m^3/h	10 %	5 tonnes N

Figure 6.8 Comparison of discharge of nitrogen at different recirculation intensities. The calculations are based on a theoretical example of a 500 tonnes/year system with a total water volume of 4 000 m^3, where 3 000 m^3 is fish tank volume. It is not the degree of recirculation in itself that reduces the discharge of nitrogen, but the application of waste water treatment technology. However, a more intensive rate of recirculation makes it increasingly easier to treat the waste water as this is reduced in volume.

Combining intensive fish farming, whether recirculation or traditional, with extensive aquaculture systems, such as for example traditional carp culture, can be an easy way to handle biological waste. The nutrients from the intensive system are used as fertilizer in the extensive ponds when the excess water from the intensive farm flows to the carp pond area. Water from the extensive pond area can be reused as process water in the intensive farm. Growth of algae and water plants in the extensive ponds will be eaten by the herbivorous carp, which in the end are harvested and used for consumption. Efficient rearing conditions are obtained in the intensive system and the environmental impact has been accounted for in combination with the extensive pond area.

Figure 6.9 Combined intensive-extensive fish farming systems in Hungary. The number of opportunities seems unlimited. Source: Laszlo Varadi, Research Institute for Fisheries, Aquaculture and Irrigation (HAKI), Szarvas, Hungary.

Chapter 7: Disease

For the innovative entrepreneur there are several opportunities in this kind of recycled aquaculture. The example of combining different farming systems can be developed further into recreational businesses, where sport fishing for carp or put & take fishing for trout can be part of a larger tourist attraction including hotels, fish restaurants and other facilities.

There are many examples of recirculation systems operating without any disease problems at all. In fact, it is possible to isolate a recirculation fish farm completely from unwanted fish pathogens. Most important is to make sure that eggs or fish stocked in the facility are absolutely disease free and preferably from a certified disease free strain. Make sure that the water used is disease free or sterilised before going into the system; it is far better to use water from a borehole, a well, or a similar source than to use water coming directly from the sea, river or lake. Also, make sure that no one entering the farm is bringing in any diseases, whether they are visitors or staff.

Whenever possible, a thorough disinfection of the system should be carried out. This includes any new facility ready for the very first start-up as well as for any existing system that has been emptied of fish and is ready for a new production cycle. It should be remembered, that a disease in one tank of a recirculation system will most certainly spread to all the other tanks in the system, which is why preventive measures are so important.

Figure 7.1 Foot bath with 2 % iodine solution for preventing the spread of disease.

In recirculation systems using eggs from wild fish, for example for the purpose of re-stocking, getting eggs from certified disease free strains is not possible. In such cases, there will always be a risk of introducing diseases living inside the egg, such as IPN (Infectious Pancreas Necrosis), BKD (Bacterial Kidney Disease) and possibly herpes virus, which cannot be eliminated by disinfecting the eggs. An example of a prevention scheme is shown in figure 7.2.

A good way to prevent contamination with pathogens within the system is to physically separate the different stages in the production. The hatchery should therefore work as an isolated closed system, as should the fry unit and the grow-out unit. If any brood stock is kept, this should also be isolated in a unit of its own. This way, stamping out a disease becomes easier to carry out in practice.

Some farms have been constructed after the "all in all out" principle, meaning that each unit is emptied completely and disinfected before new eggs or fish are stocked. For eggs and smaller fish, which are grown over a shorter period of time before they are moved on, this is certainly good management, and should always be carried out in practice. For larger fish this is also good practice, however this

What to remember	How is it done?
Clean source of new water	Preferably use ground water. Disinfect using UV. In some cases use sand filter and ozone.
Disinfection of system	Fill system with water and bring pH up to 11-12 by the use of sodium hydroxide NaOH. Approximately 1 kg per m^3 water volume depending on buffer capacity.
Disinfection of equipment and surfaces	Dip or spray with an iodine solution of 1.5% or according to instructions. Leave for 20 minutes before wash off in clean water.
Disinfection of eggs	Leave egg batch (eyed rainbow trout eggs) in solution of 3 dl of iodine per 50 litres of water for 10 minutes. Change solution for every 50 kg eggs disinfected.
Staff	Change clothing and foot wear when entering facility. Wash or disinfect hands.
Visitors	Change of foot wear or use footbath for dipping shoes (2 % iodine solution). Wash or disinfect hands. "Do not touch" policy for visitors inside the facility.

Figure 7.2 An example of a prevention scheme.

Figure 7.3 Dissection of rainbow trout suffering from inflated swim bladder. A symptom probably due to super saturation of gases in the water.

kind of management easily becomes inefficient. Taking all the fish out of a grow-unit before stocking a new batch, is logistically difficult when dealing with large volumes of fish. It easily becomes uneconomical, because of inefficient utilization of the capacity of the system.

Treating fish diseases in a recirculation system is different from treating them on a traditional fish farm. On a traditional fish farm, the water is used only once before leaving the farm. In a recirculation system, the use of biofilters and the constant recycling of water calls for a different approach. Pouring in medication will affect the whole system including fish and biofilters, and great care must be taken when treatment is carried out. It is very difficult to give exact prescriptions on the dose needed to cure a disease in a recirculation system, because the effect of the medication depends on many different parameters such as hardness of water, content of organic matter, water temperature and flow rates. A great deal of practical experience is therefore the only way forward. Concentrations must be increased carefully from each treatment to the next to avoid killing the fish or the biofilter. Always remember the term "better safe than sorry". In any case of a disease outbreak, a local veterinarian or fish pathologist must prescribe the medication and explain how to use it. Also, the safety instructions should be read carefully as some drugs may cause severe injuries to people if used improperly.

Treatment against ecto-parasites, which are parasites sitting on the outside of the fish on the skin and in the gills, can be carried out by adding chemicals to the water. Any fungal infections will have to be treated in the same way as infestations with ecto-parasites. In freshwater systems the use of ordinary salt (NaCl) is an efficient way of killing most parasites including bacterial gill disease. If a cure with salt does not work, the use of formalin (HCHO) or hydrogen peroxide (H_2O_2) will usually be sufficient to cure any remaining parasitic infections. Bathing fish in a solution of praziquantel and flubendazol have also proven to be very efficient against ecto-parasites.

Mechanical filtration has also proven to be quite efficient against the spreading of ecto-parasites. Using a filter cloth of 70 micron will remove certain stages of Gyrodactylus, and a 40 micron cloth can remove different kinds of parasite eggs.

The safest way of carrying out a treatment is to dip the fish in a bath with a solution of the chemical. However, in practice this is not a feasible method as the volume of fish that needs to be handled is often too large. Instead fish are kept in the tank as the inlet water is switched off, and oxygenation or aeration of the tank is carried out by the use of diffusers. A solution of the chemical is added to the tank and the fish are allowed to swim in the mixture for a period of time. Later, the inlet water is opened, and the mixture slowly diluted as the water in the tank is exchanged. The water running out from the tank will be diluted by the rest of the recirculation system so that the concentration in the biofilter will be significantly lower than in the tank treated. This way a relatively high concentration of the chemical can be obtained in an individual tank with the purpose of killing the parasite, yet lowering the effect of the chemical on the biofilter system. Both fish and biofilters can adapt to treatment with salt, formalin and hydrogen peroxide by slowly increasing the concentrations from one treatment to the next. When

Figure 7.4 Eggs from rainbow trout. It is advisable to disinfect fish eggs before bringing them into the recirculation system to prevent disease. Source: Torben Nielsen, AquaSearch Ova.

a tank full of fish has been treated, this water can also be pumped out of the system to a separate compartment for degradation instead of being recirculated in the system.

Using the dipping technique for eggs is an easy way of treating millions of individuals in a short time, for example when disinfecting trout eggs in iodine (figure 7.2). This method can also be used for treating eggs that have been infected with fungus (*Saprolegnia*) simply by dipping the eggs into a solution of salt (7 ‰) for 20 minutes.

In hatcheries, where fish are removed as soon as they are ready to feed, the efficiency of the biofilter is less important as the level of ammonia excreted from eggs and fry is very little. Treatment is therefore easier to carry out, because one only has to focus on the survival of eggs and fish. Also, it is worth noting that the total volume of water in a hatchery is small, and a complete water exchange with new water can be carried out rapidly. Therefore, a successful treatment in a hatchery by treating the whole system in one go, can be done safely.

Treatment of a complete system in larger recirculation facilities is a more sensitive operation. The basic rule is to keep concentrations low, and to carry out the treatment over a longer period of time. This requires care and experience. The concentration should be slowly increased from each treatment to the next, leaving several days in between without treatment in order to carefully monitor the effects on fish mortality, behaviour and water quality. Typically, an adaptation will take place for both fish and biofilter, so the concentration can be increased with no adverse effects and the probability of killing the parasite is enhanced. Salt is excellent for longer treatment periods, but formalin too has been successfully used for intervals of 4-6 hours. The biofilter simply adapts to the formalin and digests the substance like any other carbon coming from the organic compounds in the system.

As pointed out previously, it is not possible to give exact concentrations and recommendations on the use of chemicals in a recirculation system. Fish species, size of fish, water temperature, hardness of water, the amount of organic substances, exchange rate of water, adaptation, etc. must all be taken into consideration. The guidelines below are therefore very approximate.

Salt (NaCl): Salt is relatively safe to use, and can be used in fresh water for treating Ich (*Ichthyophthirius multifilis* or white spot disease) and the common fungus saprolegnia. Ich in the pelagic phase can be killed at 10 ‰ and new results suggests killing of the bottom living stages at 15 ‰. Fish contains around 8 ‰ salt in their body fluids, and most freshwater fish will tolerate salinities in the water around this level for several weeks. In hatcheries a concentration of 3-5 ‰ will prevent infections with fungus.

Formalin (HCHO): Low concentrations of formalin (15 mg/L) for long periods of time (4-6 hours) have shown good results in the treatment of *Ichthyobodo necator* (Costia), *Trichodina sp.*, *Gyrodactylus sp.*, sessile ciliates, and Ich. Formalin is degraded relatively fast in the biofilter at about 8 mg/h/m2 biofilter area at 15°C. Formalin can however reduce the bacterial nitrogen conversion rates in the biofilter.

Hydrogen peroxide (H_2O_2): Not widely used, but experiments have shown promising results as a substitute for formalin at concentrations between 8-15 mg/L for 4-6 hours. The biofilter performance can be inhibited for at least 24 hours after treatment, but the efficiency will return to normal within a few days.

Use of other chemicals such as copper sulphate or chloramin-t is not recommended. These are very effective for the treatment of for example bacterial gill disease, however the biofilter will most probably suffer severely and the whole recirculation process and the production may be seriously damaged.

For treatment against bacterial infections, such as furunculosis, vibriosis or BKD, the use of antibiotics is the only way to cure the fish. In some cases fish can become infected with parasites living inside the fish, and the way to remove these is also with antibiotics.

Antibiotics are mixed into the fish feed and fed to the fish several times every day over, for example, 7 or 10 days. The concentration of antibiotics must be sufficient to kill the bacteria, and the prescribed concentration of medication and the length of the treatment must be carefully followed, even if the fish stop dying during the treatment. If treatment is stopped before the prescribed treatment period, there is a high risk that the infection will start all over again.

Treatment with antibiotics in a recirculation system will have a small effect on the bacteria in the biofilter. However, the concentration of antibiotics in the water, compared to that inside the fish being treated with medicated feed, is relatively low, and the effect on bacteria in the biofilter will be much lower. In any case, one should carefully monitor the water quality parameters for any changes because they may indicate an effect on the biofilter. Adjustment of the feeding rate, use of more new water or changing the flow of water in the system may be necessary.

Several antibiotics can be used, such as sulfadiazine, trimethoprim or oxolinic acid according to the prescription by the local veterinarian.

Treatment against IPN, VHS (Viral Hemorrhagic Septicemia) or any other virus is not possible. The only way to get rid of viruses is to empty the whole fish farm, disinfect the system and start all over again.

Chapter 8: Case story examples

Salmon smolt production in Chile

Growth in the Chilean salmon production during the 90s required an increasing supply of smolts from freshwater to be stocked in cages for grow-out at sea. Smolts were produced in river water or in lakes, where the water was too cold and the environment was suffering. Introducing recirculation helped smolt farmers to produce vast amounts at a significantly lower cost in an environmentally friendly manner. Also, the optimal rearing conditions resulted in faster growth, which made it possible to produce four smolt batches per year instead the previous one batch a year technology. This shift made the whole chain of production much smoother with a constant flow of smolt being stocked into the cages from where large salmon would be harvested at a constant rate at the right size ready for the market.

Figure 8.1 A recirculation smolt farm in Chile. Source: Bent Højgaard.

Turbot farming in China

Saltwater recirculation is a growing business producing many species such as grouper, barramundi, kingfish, halibut, flounder, etc. Turbot is a well suited species for recirculation technology which has been adopted also by Chinese producers. Production results from such installations have shown that turbot perform very well in a completely controlled environment. The optimal temperature for rearing turbot differs with size, and turbot are generally sensitive to changes in living conditions. The elimination of such changes apparently pays back in turbot farming as turbot of 2 kilos can be produced in two years compared to 4 years under normal rearing conditions.

Figure 8.2 A turbot farm in China. Source: AKVA group.

Model trout farms in Denmark

Denmark is without doubt the forerunner in environmentally safe trout farming. Strict environmental regulations have forced the trout farmers to introduce new technology in order to minimize the discharge from their farms. Recirculation was introduced by developing so-called model fish farms to increase production while at the same time lowering the environmental impact. Instead of using huge amount of water from the river, a limited amount of ground water from the upper layers is pumped into the farm and recirculated. The effect is significant, a more constant water temperature all year round together with a modern facility results in higher growth rates and a more efficient production with reduced

Figure 8.3 A Danish model farm. Source: Kaare Michelsen, Danish Aquaculture.

costs, investment costs included. The positive effect of the environmental impact can be seen in Chapter 6.

Recirculation and re-stocking

Clean rivers and lakes and natural wild stocks have become an important environmental goal in many countries. Conserving nature by restoring natural habitats and re-stocking of endangered fish species or strains is one among many initiatives.

Sea trout is a popular sport fish that occupies many rivers in Denmark, where almost every river has its own strain. Genetic mapping carried out by scientists has made it possible to distinguish between different strains. When the sea trout becomes mature, it migrates back from the sea to its home river to spawn. In the part of Denmark called Funen, rivers have been restored and the remaining wild strains have been saved by a re-stocking programme involving recirculation aquaculture. Mature fish are caught by electrical fishing and eggs are stripped and reared in a recirculation facility. Approximately one year later, the offspring are re-stocked into the same river from where their parents were caught.

Different strains have been saved and in due time the sea trout will hopefully be able to survive by itself in this habitat.

Most importantly, this programme has also resulted in a significant better chance of catching sea trout when sport fishermen are fishing from the shores of Denmark. Fishing tourism has therefore become a good earning for local businesses such as hotels, camping sites, restaurants, etc. All in all, a win-win situation for both nature and local commercial interests.

Aquaponics

Growing plants and fish together has been accomplished already thousand years ago in ancient China. The plants grow by using the nutrients excreted from the fish, and both fish and plants can be harvested for consumption. In modern aquaculture the combination of growing fish in a recirculation system and growing greenhouse plants in hydroponics using nutrient water without soil is named "aquaponics". The technology has yet to become industrialized, but is widely used in small scale around the globe.

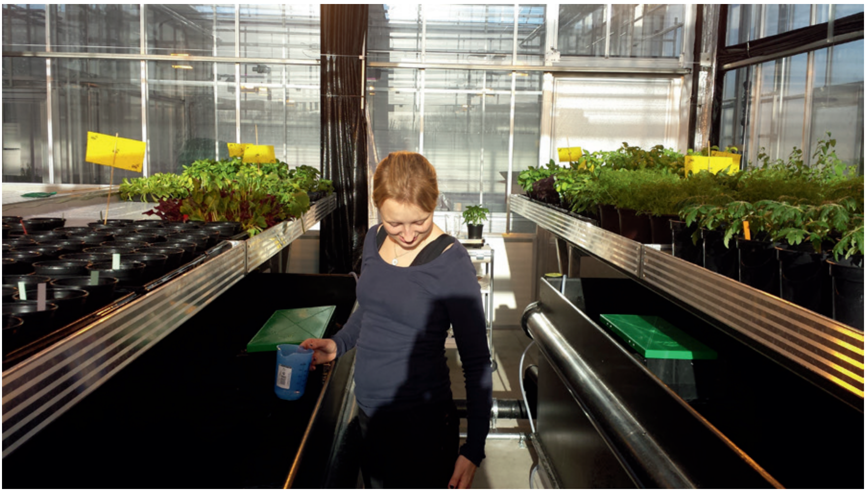


Figure 8.4 Photo of aquaponics research at Institute of Global Food & Farming near Copenhagen, Denmark. The system is built in an existing greenhouse facility, and includes fish rearing tanks and salad tables together with a recirculating water system with two independent water loops. One of the loops run through a water filtering system and can be routed to plant tables or back to fish tanks. The other loop supplies water directly to plant tables for growing lettuce or herbs such as sage, basil and thyme. Source: Paul Rye Kledal, Institute for Global Food & Farming.

Mega farms

The size of fish farms is constantly growing as world production in aquaculture rises. Today, an average sea cage farm in the sea of Norway is producing around 5 000 tonnes of salmon per year, just at one site. Land based systems of this size have yet to be seen, but new recirculation projects for salmon and trout of these volumes are emerging.

Combining land based farms with cage farming is a very efficient way of production and probably the most competitive set-up. Small fish are produced on land in efficient and controlled systems before they are released into large sea cages for grow-out. In some areas cage farming is not popular, and land based farms in the form of recirculation plants are seen upon as a future way of producing farmed fish. The footprint is low and so is the water consumption. Although production costs are still higher than in cages, the systems have high food safety and complete control, and the output is constant and foreseeable.

Figure 8.5 A 2 000 tonnes salmon farm in Hirtshals, Denmark under the construction phase in 2013. The system is based on recirculation technology and is covered by a building for completion to control temperature and have high biosecurity. Salmon are grown from eggs to 4 kg size in 2 years in large tanks reaching almost 1 000 m^3 each. The white bigbags in the foreground are packed with biomedia ready for installation in the biofilter chambers. Source: Axel Søgaard/AKVA group.

Future of recirculation

Pre-ongrowing of fish in recirculation systems to reach larger sizes before releasing them into the sea cages is a way of increasing profitability. The Norwegian salmon farming industry is investing in large recirculation facilities with the aim of producing smolt to larger sizes. Smolts are typically 100 gram today when released in cages. An increase to 300 gram before stocking will improve health and growth rates significantly in the farming period until harvest at market size of typically 4-5 kg.

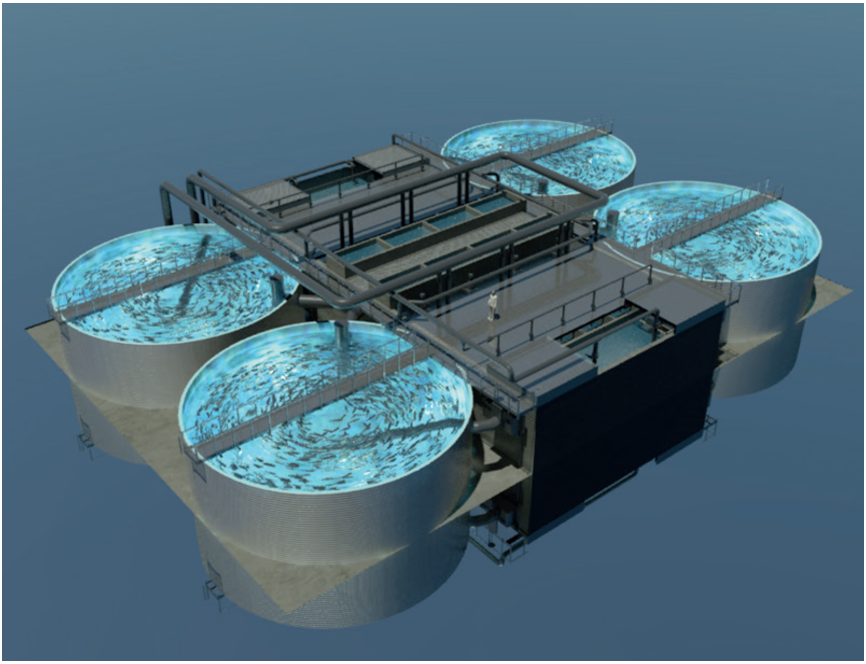


Figure 8.6 Recirculation systems become increasingly larger with bigger tanks to accommodate for increasing production volumes. Shifting smolt sizes in Norway from 100 gram to 300 gram will triple the land based production, thus current Norwegian smolt production on land of around 35 000 tonnes per year will increase to around 100 000 tonnes.

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Appendix

Checklist to be used when implementing a recirculation system		
1.0	Project information	
1.01	Describe aim, purpose, goal of project	
1.02	Species to be farmed	
1.03	Production per year, in tonnes, in numbers	
1.04	Size of fish in / out - production plan	
1.05	Number of batches per year	
1.06	Estimate of Feed Conversion Rate (FCR)	
1.07	Existing drawings or other information available	
1.08	Has discharge permission been granted? Restrictions, consent levels, etc.	
1.09	Available farm manager or fish specialist	
1.10	Other vital information, special problems, etc.	
2.0	Site information	
2.01	Is it saltwater or freshwater? Salt content of seawater	
2.02	Available water source. Seawater, river, well, ground water, borehole	
2.03	How much water is available? Liters / second	
2.04	Water temperature. Summer / winter Day / night fluctuations	

2.05	Water analysis. Results pH	
2.06	Weather conditions, max / min air temperature Hard winters, extreme summer heat, etc.	
2.07	Building ground conditions	
2.08	Ground temperature, max / min	
2.09	Ground area available Shape of building area	
2.10	Available space for waste water treatment Settlement ponds, seepage area, etc.	
2.11	Ground level zero reference	
2.12	Local power supply, specify	
3.0	Content of facility	
3.01	Hatchery	
3.02	Nursery / First feed	
3.03	Pre Grow-out / Fry	
3.04	Grow-out	
3.05	Broodstock	
3.06	Live feed production	
3.07	Purge Unit	
3.08	Quarantine unit – in Acclimatization unit – out	
3.09	Water intake treatment	
3.10	Waste water treatment	
3.11	Grading / Harvesting / Live Delivery	

3.12	Processing / Packing Cold store / Ice machine	
3.13	Laboratory / Workshop Office / Canteen	
3.14	Emergency generator	
3.15	Oxygen generator / Emergency oxygen tank	
3.16	Water heating / Chilling system	
3.17	Building requirements, Insulation	
3.18	Architecture, Surroundings	

Key Features

- Assists farmers to convert to recirculation aquaculture
- Introduction to the technology and the methods of management
- Advise on good practise shifting to recirculation aquaculture
- Running a recirculation system, including education and training
- Case stories from different recirculation projects

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