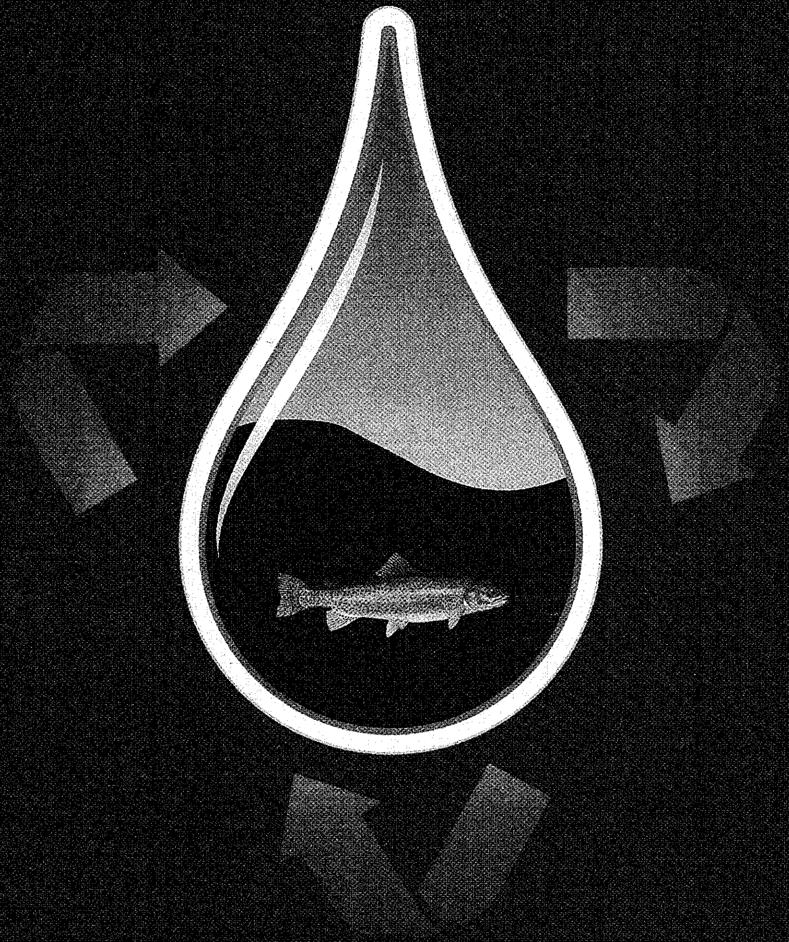
A Guide to
Recirculation Aquaculture

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

Author: Jacob Bregnballe



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Author: Jacob Bregnballe

Copenhagen, 2010

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
Fisheries Officer for Central and Eastern Europe
FAO

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. In 2006 global capture production peaked at around 90 million tonnes, while aquaculture production has maintained an annual growth rate of about six percent with a global production of nearly 52 million tonnes.

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. This book is a joint publication from EUROFISH, FAO SEUR and the AKVA group.

Aina Afanasjeva
Director
Eurofish

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 his own fish farm, Asnæs Fiskeopdræt A/S, in Denmark, 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 Sales 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 25 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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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 200 litres of new water per kilo of fish produced, whereas 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. A traditional flow-through system for trout will typically use around 30 m^3 per kilo of fish produced.

Figure 1.1 An indoor recirculation system.

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 the most environmentally friendly way of producing fish at a commercially viable level.

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

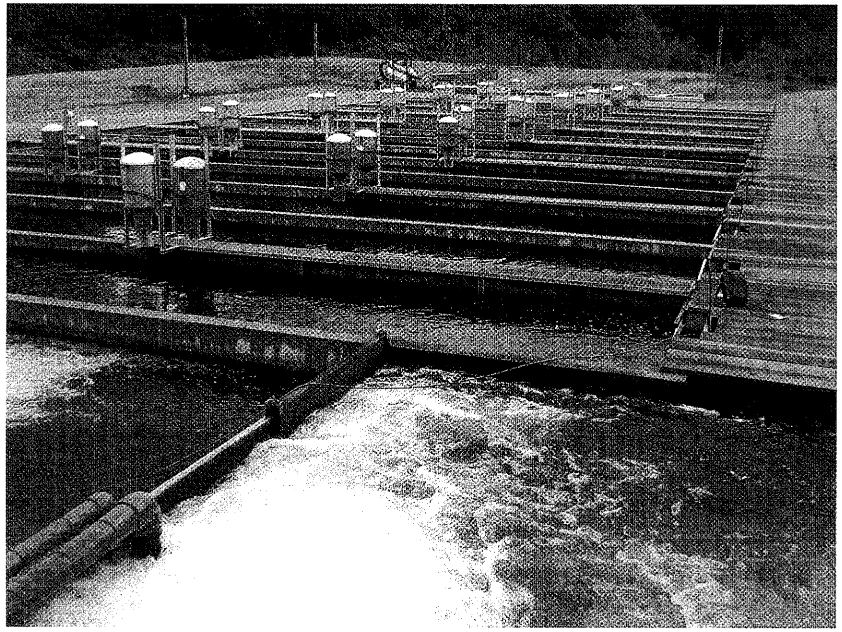


Figure 1.2 An outdoor recirculation farm.

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.

Controlling parameters such as water temperature, oxygen levels, or daylight for that matter, give 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.

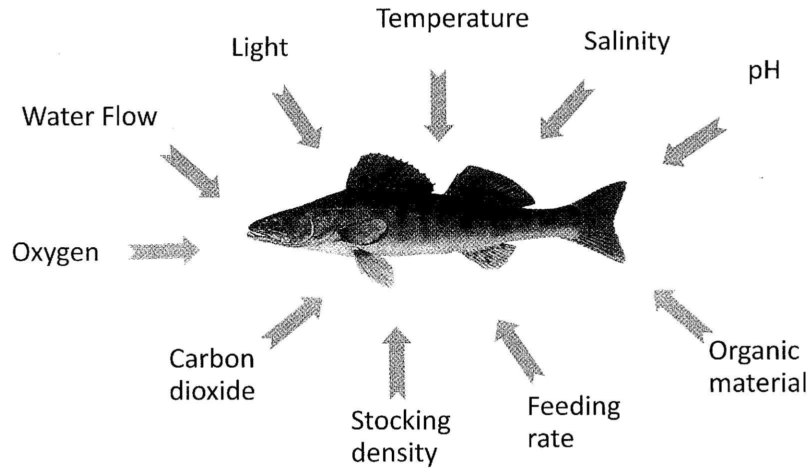


Figure 1.3 Some of the parameters affecting the growth and well-being of a fish.

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. Normally water from 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 surrounding environment.

Aquaculture is not for everyone; it 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.

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 system, etc. depending on the exact 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 solids (SS) and organic matter. Carbon dioxide and

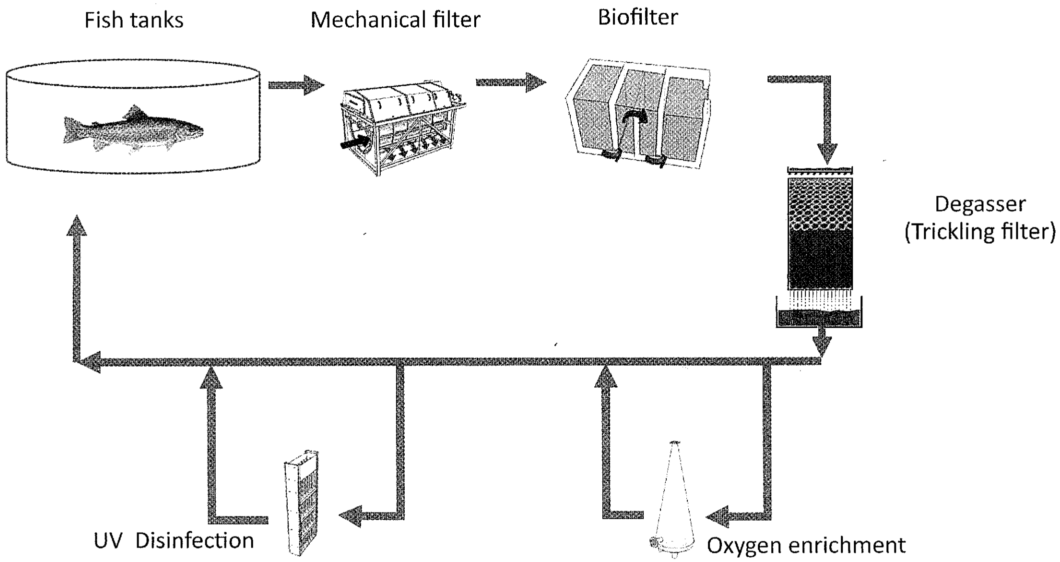


Figure 2.1 Principle drawing of a recirculation system. The basic water treatment system consists of mechanical filtration, biological treatment and aeration/stripping. Further installations, such as oxygen enrichment or UV disinfection, can be added depending on the requirements.

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.

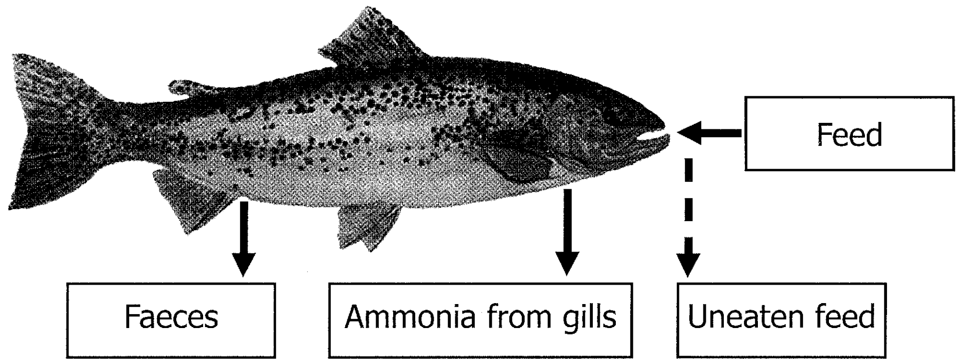


Figure 2.2 Eating feed and using oxygen results in fish growth and excretion of waste products.

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 constituted 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 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.

	Fish size, gram	Protein	Fat
3 mm	40 – 125	44 %	26 %
4.5 mm	100 – 500	43 %	27 %
6.5 mm	400 – 1200	42 %	28 %

Composition, %	3.0 mm	4.5 mm	6.5 mm
Fish meal	35	34	32
Fish oil	21	22	23
Blood meal	10	10	10
Peas	10	10	10
Soya	9	8	10
Wheat	14	15	14
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

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

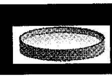
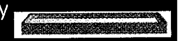
Tank properties	Circular tank 	D-ended raceway 	Raceway type 
Self-cleaning effect	5	4	3
Low residence time of particles	5	4	3
Oxygen control and regulation	5	5	4
Space utilization	2	4	5

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

performance of the species reared.

If the fish is bottom dwelling, the need for 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 organic particles have a relatively short residence time of a few minutes, depending on tank size, due to the hydraulic pattern and gravitational forces. The whole water column in the tank is moving around the centre. A vertical inlet with horizontal adjustment is an efficient way of controlling the current in such tanks.

In a raceway, no gravitational forces can be created to make a current, and 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 on the tank design. For all types of tanks, the inclination of the bottom has no importance with regards to the self-cleaning effect, but it will make complete draining easier when

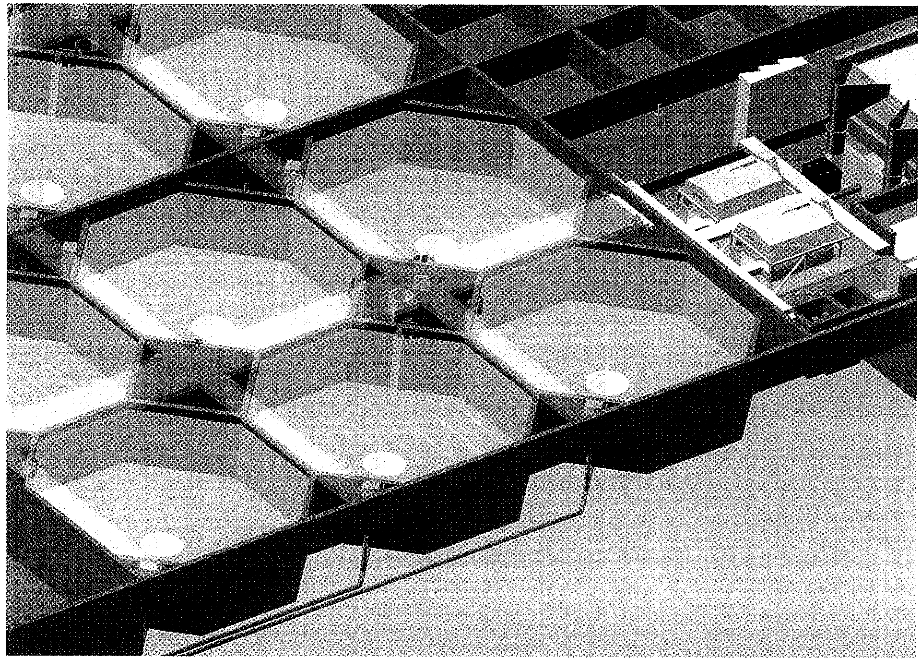


Figure 2.5 An example of octagonal tank design in a recirculation system saving space yet achieving the good hydraulic effects of the circular tank. Source: AKVA group.

the tank is emptied.

Circular tanks take up a lot of 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 that will give better space utilization than circular tanks, and at the same time the positive hydraulic effects of the circular tank are achieved. 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 erecting containments.

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.

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 adjust the oxygen level up or down depending on the situation as the effect of more oxygen added will be detected almost immediately by the oxygen probe in the tank. 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 in a raceway is near the outlet. This downstream oxygen gradient will

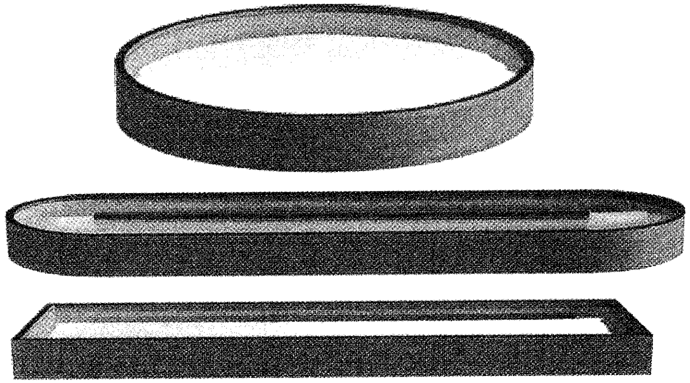


Figure 2.6 Circular tank, D-ended raceway and raceway type.

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.

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 can be fitted with water level alarms, oxygen probes for oxygen control and alarms, and emergency oxygen diffusers.

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).

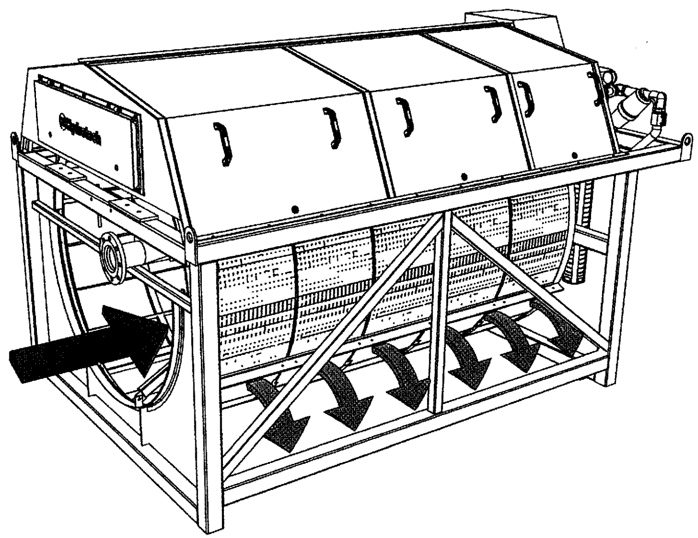


Figure 2.7 Drumfilter. Source: Hydrotech.

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 the 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:

Result of nitrification:

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

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

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

- The acid produced from the nitrification process.

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.

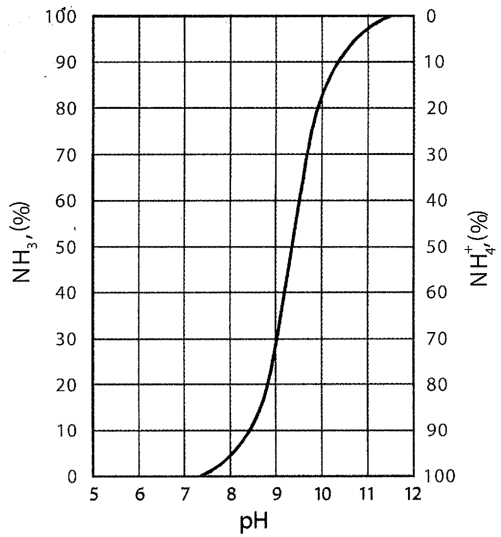


Fig 2.8 The equilibrium between ammonia (NH_3) and ammonium (NH_4^+) at 20 °C. The toxic ammonia is absent at pH below 7, but rises fast as pH is increased.

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

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 if a level below 0.02 mg/L of ammonia is to be ensured. Although lower pH levels minimises the risk of exceeding this toxic ammonia limit of 0.02 mg/L, the fish farmer is recommended to reach a level of minimum pH 7 in order to reach a higher biofilter efficiency. As illustrated, the total concentration

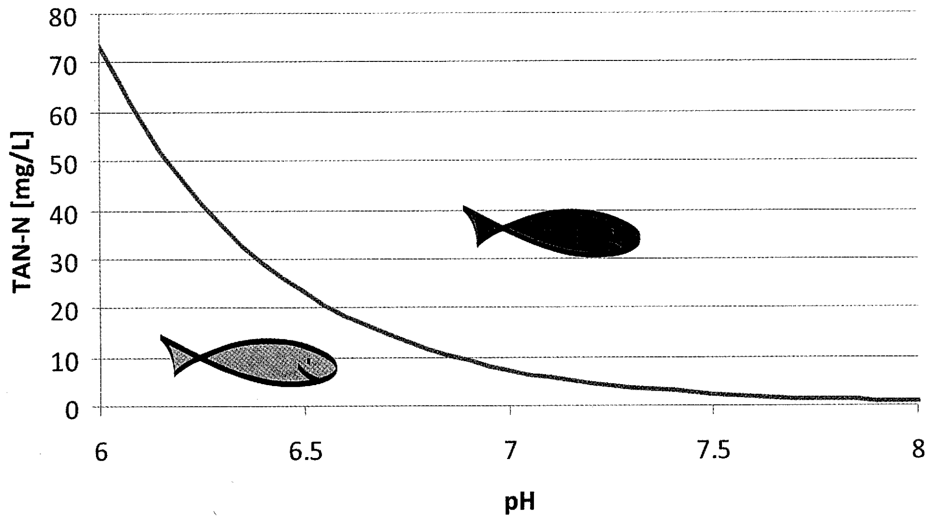


Figure 2.9 The relation between measured pH and the amount of TAN available for breakdown in the biofilter, based upon a toxic ammonia concentration of 0.02mg/L.

of TAN to be allowed is thereby significantly reduced.

Nitrite (NO_2^-) is formed at the intermediate step in the nitrification process, and is toxic to fish at levels above 2 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 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 at a minimum, 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.

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

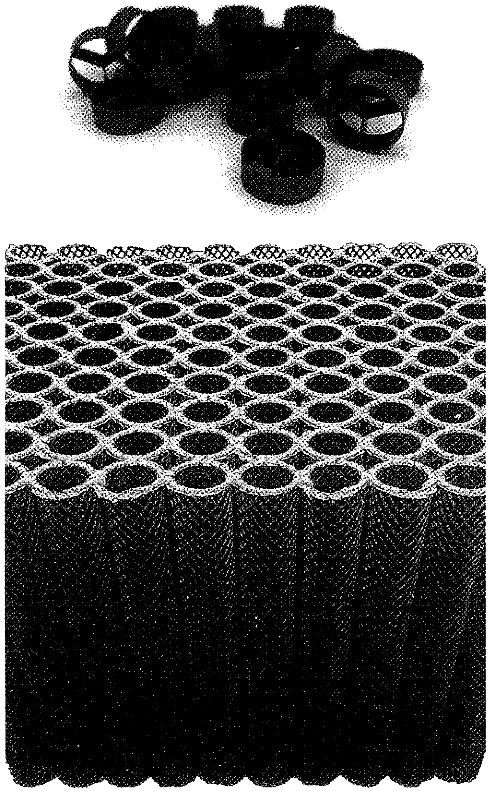
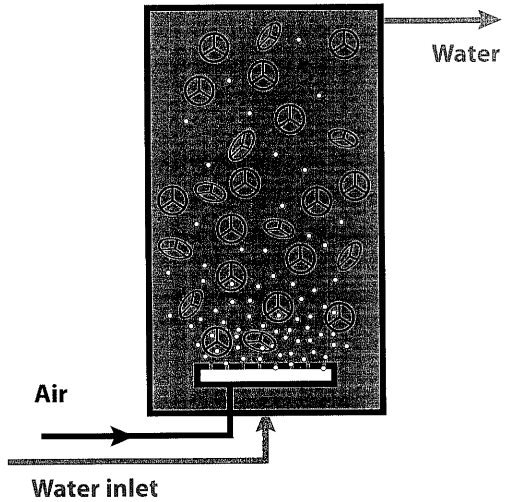


Figure 2.10 Moving bed media on top and fixed bed media on bottom.

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 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.

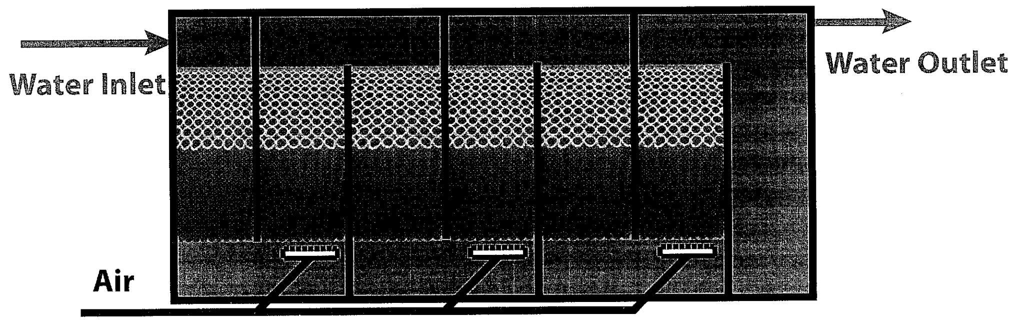


Figure 2.11 Moving bed (top) and fixed bed biofilters (bottom).

Degassing, aeration and stripping

Before the water runs back to the fish tanks the accumulated gases 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 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 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.

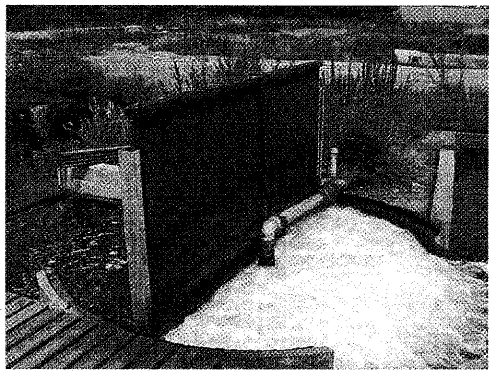


Figure 2.12 Aeration well system.

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

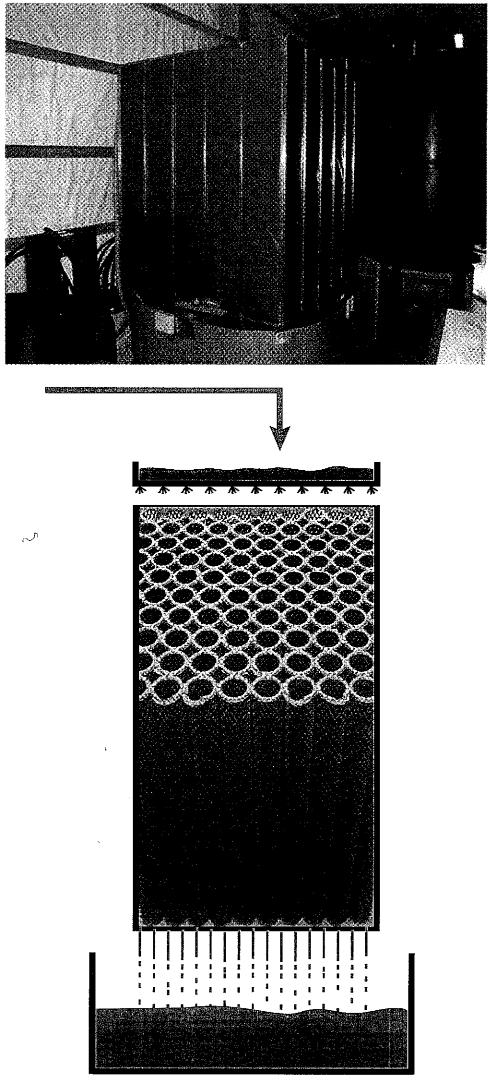


Figure 2.13 Photo and drawing of trickling filter wrapped in a blue plastic liner to eliminate splashing on the floor (Billund Akvakulturservice, Denmark). The aeration/stripping process is also called CO_2-stripping. The media in the trickling filter typically consists of the same type of media as used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

The aeration well system is however not as efficient for removing gases as the trickling filter system. 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. The trickling filter is often referred to as a CO_2 –stripper.

Oxygenation

The aeration process of the water 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 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 saturation higher than 100% in the inlet water is however often preferred in order to have sufficient oxygen available for a high and stable fish growth. Higher saturation levels call for an oxygenation 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 oxygen cones or deep shafts 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 pressure of typically around 1.4 bar in the cone. Pumping water under pressure into

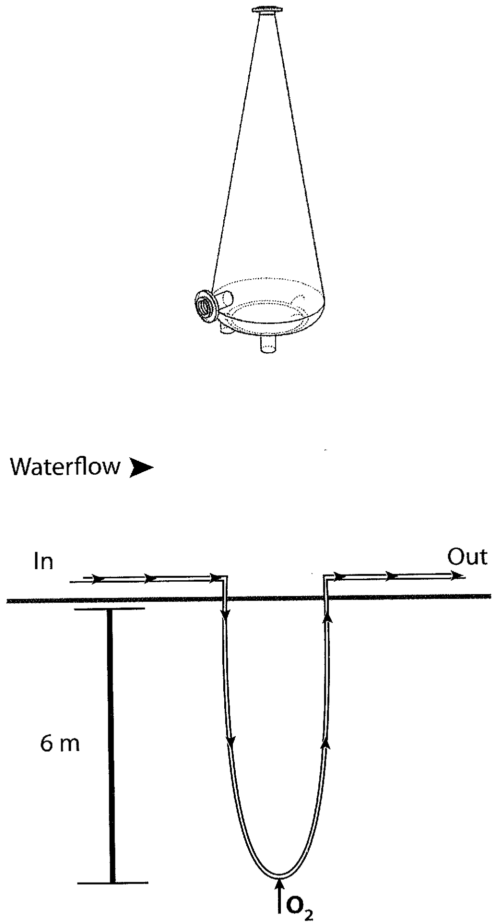


Figure 2.14 Oxygen cone and deep shaft.

the oxygen cone consumes a lot of electricity. In the deep shaft the pressure is reached by digging a pipe loop down to for example 6 metres depth, and injecting the oxygen at the bottom of the loop. The pressure from the water column above, in this case 0.6 bar, will force the oxygen into the water. The advantage of the deep shaft is that pumping costs are low, but the installation is troublesome and more expensive.

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 out of 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 cm2 (μWs/cm^2). The efficiency depends on the size and species of the target organisms and the turbidity of the water. In order 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

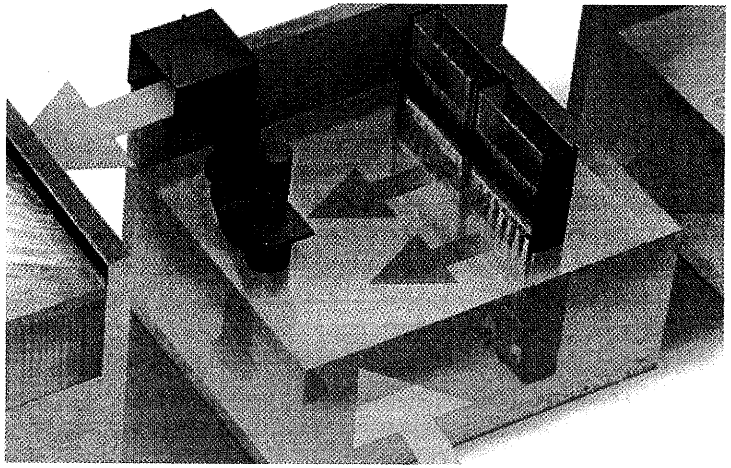


Figure 2.15 UV treatment system. Source: AKVA group.

work under water to give maximum efficiency, lamps fitted outside the water will have little or no effect because of water surface reflection.

Ozone

Today, ozone (O_3) is seldom used in fish production itself as the effect of over-dosing can cause severe injury to the fish. In fish farms placed inside buildings ozone can also be harmful to the people working in the area as they may inhale too much ozone. However ozone treatment is an efficient way of destroying unwanted organisms by the heavy oxidation of organic matter and biological organisms. Ozone treatment can be preferred when the intake water to a recirculation system needs to be disinfected. In many cases, however, UV treatment is a good and safe alternative.

pH regulation

The nitrifying process in the biofilter produces acid and the pH level will fall. 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 making the system easier to maintain. Anyone handling acids or bases must be careful as it can severely burn eyes and skin.

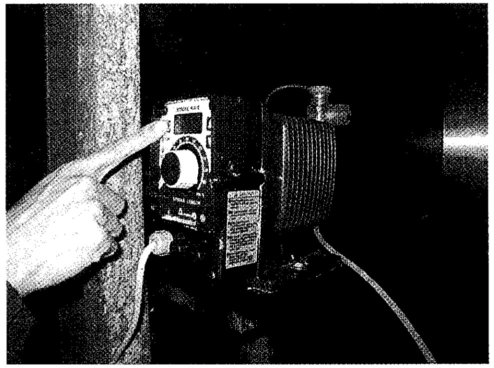


Figure 2.16 Dosage pump for pH regulation by preset dosing of NaOH. The pump can be connected to a pH sensor for fully automatic regulation of pH level.

Safety precautions must be taken, and glasses and gloves must be worn while handling the chemicals.

Heat exchange

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 a closed recirculation system inside an insulated building 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.

In the wintertime in cold climates simple heating using an oil boiler connected to a heat exchanger to heat up the recirculated water is most often sufficient. The use of energy for this kind of heating depends mostly on the amount of cool intake water used and its temperature, although some heat also escapes from the building. In some cases, a heat recovery system, consisting of a titanium plate exchanger, can also be installed. The process water in the recirculation system is used to heat up (or cool down) the intake water by passing the water through the plate exchanger. The system is regulated by the use of a water temperature sensor connected to a temperature control unit that regulates the function of the titanium plate exchanger.

Pumps

Different types of pumps are used for circulating the process water in the system. Pumping requires 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 for every recirculation cycle, 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.

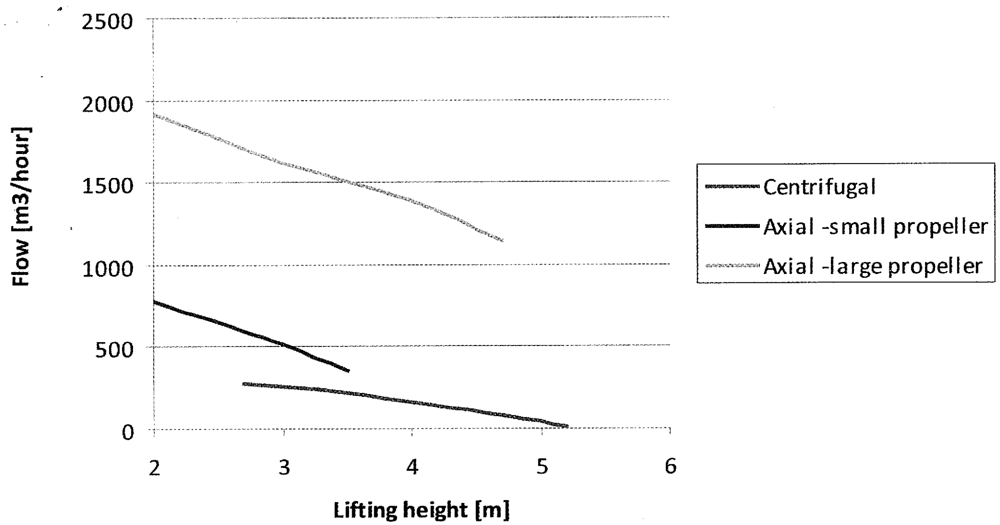


Figure 2.17 Example describing the use of different types of pumps. High pressure pumps (centrifugal pumps) are used to pump smaller water volumes at high lifting height, and low pressure pumps (propeller pumps) are used to pump larger volumes at lower lifting heights.

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.

The total lifting height in most systems today is less than 2 metres, which makes the use of low pressure pumps most efficient. 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, the water is driven 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 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

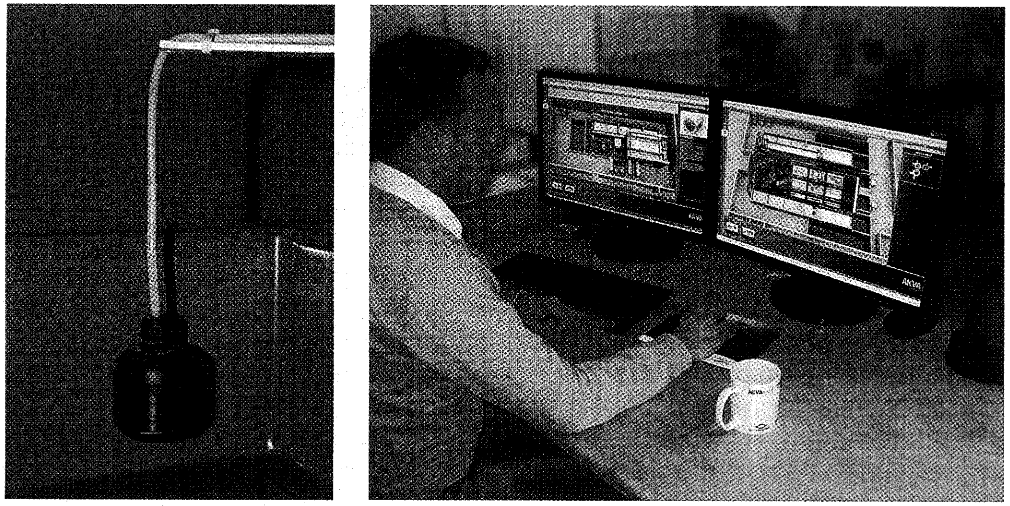


Figure 2.18 An oxygen probe (Oxyguard) is calibrated in the air before being lowered into the water for on-line measurement of the oxygen content of the water. Surveillance can be computerized with a large number of measuring points and alarm control.

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 fish alive.

To back up the electrical supply, a generator is necessary. In many cases the toxic ammonia will build up in the system when the water is not circulating. This problem will be the next to overcome after the oxygen availability has been solved by the oxygen back-up system. It is therefore important to get the water flow up and running within an hour or so.

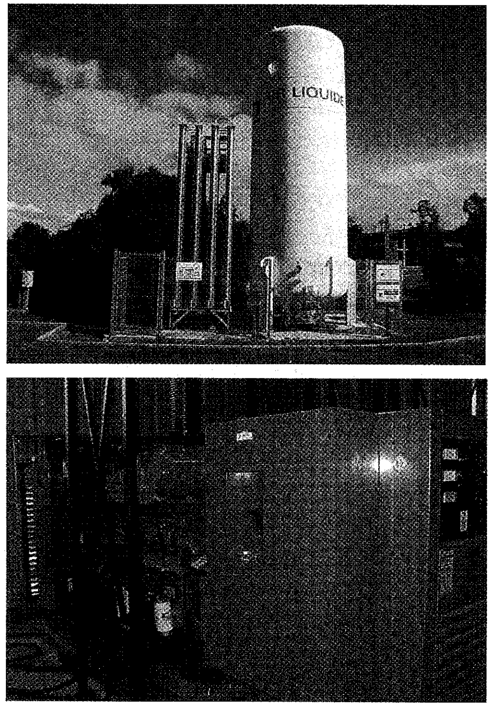


Figure 2.19 Oxygen tank and emergency generator.

Intake water

Water used for recirculation should

preferably be from a disease-free source or 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 sandfilter for microfiltration and a UV or ozone system for disinfection.

3. Fish species in recirculation

A recirculation system is a costly affair to build and to operate, 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 of the production is to sell the fish at a high price and at the same time to 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. The water temperature is therefore of major importance when it comes to fish farming. 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.

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

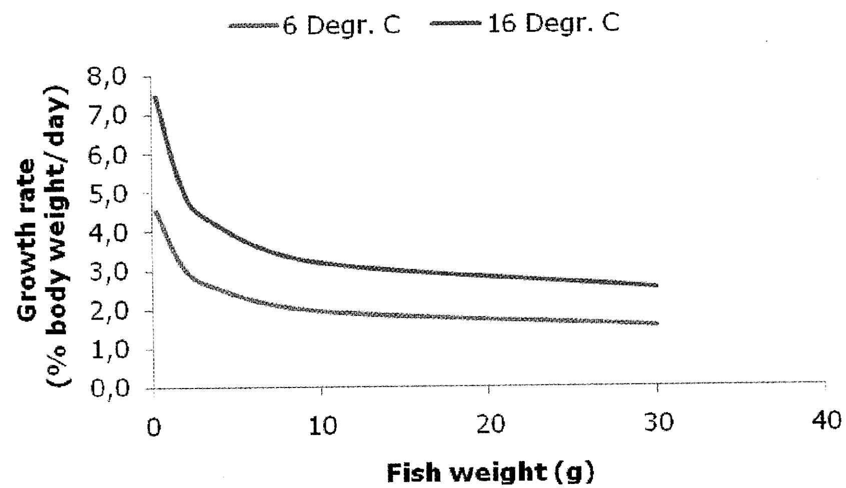


Figure 3.1 Growth rate of rainbow trout at 6 degrees and at 16 degrees C as function of fish size.

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.

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

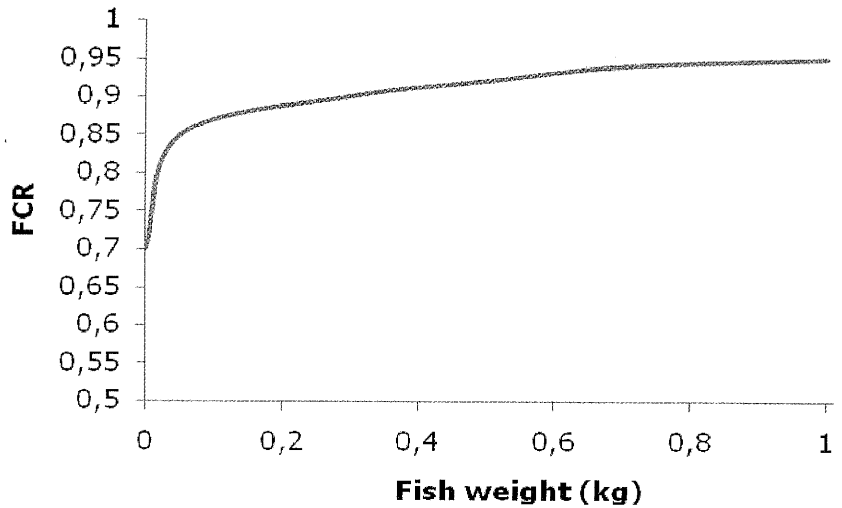


Figure 3.2 Feed conversion rate (FCR) of rainbow trout in a recirculation system, related to fish weight at 15-18 degrees C.

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 the figure it can be seen that carp, of which we are only talking of some 5 different species, is by far the most dominant species. 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 is limited, the

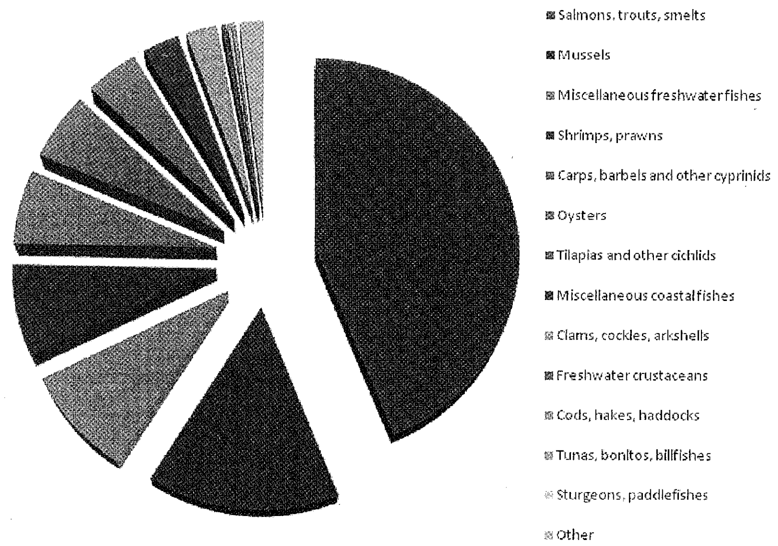


Figure 3.3 Global farmed fish production. Source: FAO.

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.

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 is 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 model 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 future, perhaps 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 a specific fish species in recirculation depends on many different factors, such as the profitability, environmental concerns, biological suitability etc., see Figure 3.4.

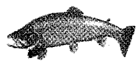
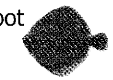
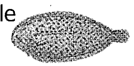
Species	Current status	Market
Atlantic salmon 	Easy to culture. Smolt grown in recirculation is successful. Growing large salmon in recirculation might be a future success.	Global market dominated by Norwegian producers.
Rainbow trout 	Easy to culture. Recirculation widely used from fry rearing up to portion size fish.	Tough competition often based on local market conditions.
Pike perch 	Difficult to culture. Larval stage troublesome. Grow-out relatively straight forward.	Fair prices. Demand expected to grow as wild stocks fall.
Sturgeon 	Easy to culture. Requires skill in larval rearing and in harvest of caviar.	Good market conditions for meat and caviar.
Eel 	Successful species in recirculation. Reproduction is not possible. Wild catch of fry (elvers) is necessary.	Limited market with varying price levels.
Barramundi 	Requires knowledge in larval rearing. Relatively straight forward in grow-out.	Sold primarily in local markets at a fair price.
Grouper 	Requires knowledge in larval rearing. Relatively straight forward in grow-out.	Sold primarily in local markets at good prices.
Seabass/ seabream 	Larval phases require skill. Grows well in recirculation.	Tough market conditions.
Turbot 	Skill required for larval rearing. Grows very well in recirculation	Fair market prices depending on local market conditions.
Sole 	Not yet fully developed new species in aquaculture. Different obstacles.	High prices
Cod 	Fry rearing successful in recirculation. Grow-out of larger cod needs further development.	Prices fluctuating still depending on wild stock catch.

Figure 3.4 Different species reared in recirculation with a few comments on the current status.

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.

Four major issues should be addressed before launching a project:

- Price and market for the fish in question
- Site selection and production technology
- Work force including a committed manager
- Financing the project all the way to a running business

As discussed earlier, the very first thing to identify is whether the fish in question can be sold at acceptable prices and in sufficient volumes. It is therefore important to carry out a proper market survey before any further steps are taken.

It is also important to identify what kind of production system will be needed to make the product in question, and also find out where to build it. A pre-project design will most often be helpful, so that the relevant authorities can be approached for permits for construction, water usage, discharge etc.

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 manager, who is fully committed to the job, wanting to succeed as much as the shareholders do.

The requirement for financing is far too often underestimated. The capital costs are very high when starting up a new plant from scratch, and investors seem to forget that producing fish is a long-term affair. The time from starting the construction and getting the first pay-back from fish sold takes typically from one to two years. Careful preparation of budgets is therefore of vital importance.

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, in the following, a draft

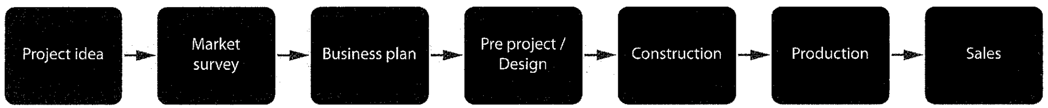


Figure 4.1 Flow from project idea to end product.

for a 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.).

A good introduction for starting up a business can be seen at:

www.businesslink.gov.uk/bdotg/action

and samples of business plans are available at:

www.bplans.co.uk/sample_business_plans.cfm (Palo Alto Software Ltd).

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

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 - 1500	4,5	0,35	0,55	0,65	0,75	0,85	0,85	0,75	0,60	0,40
1500 - 3000	6,5	0,20	0,35	0,45	0,55	0,65	0,65	0,55	0,45	0,30
3000 - 5000	9,0	0,15	0,25	0,34	0,39	0,44	0,49	0,44	0,34	0,20
5000 - 10000	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 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, 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, and "K_n" is the fish weight at the "n"th day. 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.

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

- Investment budget (total capital costs)
- Operational expenses budget (starting up the business)
- Cash budget (business up and running)

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. For new EU countries there are support programmes that in some case can support up to 70% of the needed investment.

Investment budget (capital costs)	**100%**
Building	36%
Equipment	26%
Concrete for water treatment	12%
Fish tanks	12%
Piping	3%
Installation	2%
Transport	2%
Heating and chilling	2%
Feed and light systems	2%
Electrical work	1%
Grading equipment	1%
Walkways	1%

Figure 4.4 Example of investment budget for a fully recirculation in-house system with estimated figures in percent.

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. Purchase of land is not included.

Construction costs depend not only on local building costs, but also on fish species and farm size. Generally grand total investment cost all included will reach up to 10 EUR per kg produced for systems of 100 tons per year with all facilities from broodstock over weaning and fry rearing to final grow-out. The less expensive end systems will cost as little as 2.5 EUR per kg produced for systems of 1,000 tons designed only for grow-out and without roofing. Examples from western European countries of the establishment costs are in the area of 3 million EUR for a complete 1,000 tonnes recirculation outdoor trout farming system (in 2009). The overall costs are highly dependent on whether the system is supposed to take care of 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 and biological stages among other things. There is a clear tendency that the higher the rate of recirculation, the higher the probability of choosing a facility installed inside a building.

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 m2 per 100 tonnes fish (pelagic). The larger the total production the smaller the area needed per 100 tonnes produced.

From Figure 4.5 it is interesting to

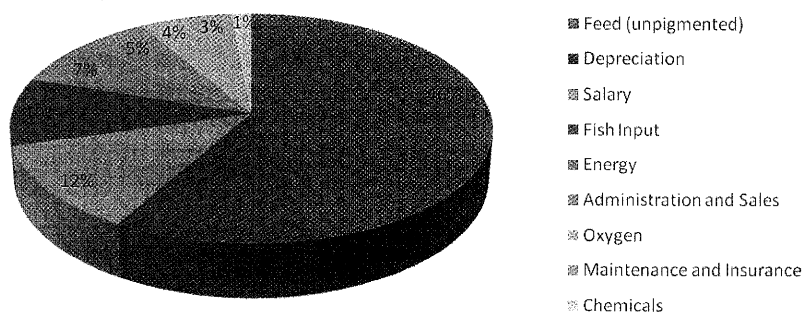


Figure 4.5 Example of cost distribution of a large farm for portion sized trout (2000 tons/year) taking in fingerlings and growing them to 300-500 grams. Total production cost per kilo live fish produced is less than 2 EUR per kg. The total investment cost for such a fully recirculation in-house system is around 4 EUR per kg production (total 8 mio. EUR).

note that the consumption of energy is only 7% of the costs. Focusing on the usage of electricity 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 direct costs. Stepping up the way from a few hundred tonnes per year towards a thousand does though give significant reductions in costs. The benefit of going up in farm size depends greatly on which species is reared, and the way of extending the production must be carefully considered. Wise planning may save a lot work and money.

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.

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, and 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 a good day's job on the fish farm and then going home has changed into tuning a machine that runs constantly 24 hours a day. Surveillance of the whole system ensures that the farmer has access to information concerning the state of the system at all times, and an automatic alarm system will call him if there is an emergency.

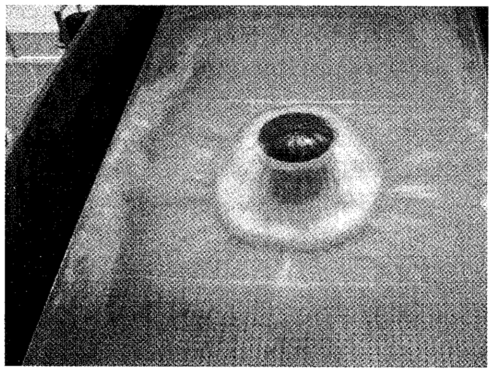


Figure 5.1 Water quality and flow in filters and fish tanks should be examined visually and frequently. Top plate of traditional trickling filter before water is trickling down through the filter media.

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 off 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
- Switch on the alarm system 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 filter elements and bearings on mechanical filters
- Search for "dead water" in system and take precautions
- Check filter sumps - no sludge must be observed

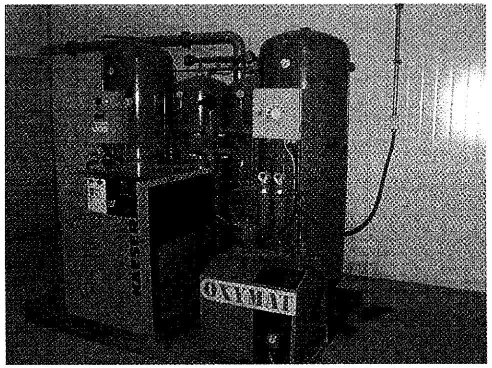


Figure 5.2 Oxygen generator. Control and service of special installations must be taken care of.

6-12 months:

- Clean UV sterilizer (see manual), change lamps yearly
- Change oil and oil-filters and air-filter on compressor.
- Check if clean inside (sump) the cooling towers
- Clean biofilter thoroughly if necessary
- Renew electrolyte, zinc, and membrane in oxygen probes
- Rinse nozzles on drum filters

Managing the recirculation system requires continued 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 will be shut down and started up again for new batches of fish. These changes affect the system

as a whole, but especially the biofilter is sensitive to 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 unfavorable or even toxic to fish. However, it is impossible to give exact data on these levels as the toxicity depends on many things, such as fish species, temperature and pH. Adaptation of fish to the environmetal conditions in the system will also influence the toxicity.

The toxicity of the nitrite peak can be eliminated by adding salt to the system (see also Chapter 2). An indication of preferable levels for different physical and chemical water quality parameters in a recirculation system is shown in Figure 5.4 on the next page.

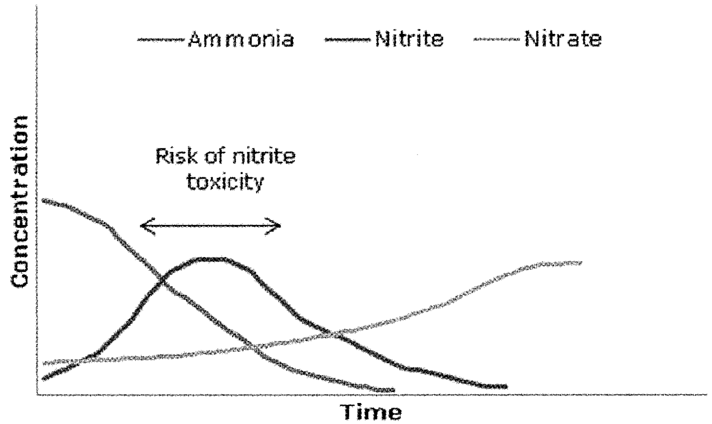


Figure 5.3 Fluctuations in the concentration of different nitrogen compounds from start-up of a biofilter.

Parameter	Formula	Unit	Normal	Unfavourable Level
Temperature		^oC	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 Indication of preferable levels for different physical and chemical water quality parameters in a recirculation system.

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. The biological processes in the system will to a certain extent 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 farm will still have to be dealt with.

Waste 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 discharge volume from the recirculation cycle.

Treating the waste leaving the recirculation system can be accomplished in different ways. Quite often a secondary mechanical water treatment is installed in order to concentrate the sludge in the waste water. The sludge fraction will go on to a sludge accumulation facility for sedimentation or further mechanical dewatering, before it is spread on land, typically as fertiliser on agricultural farms. Mechanical dewatering also makes the sludge easier to handle, and minimises the volume whereby disposal or possible fees becomes cheaper. On the downside, mechanical dewatering is associated with higher investment and running costs.

The cleaned waste water from the secondary treatment will usually have a high concentration of nitrogen and phosphorous. This so-called overflow or reject-water, can be discharged to the surroundings, river, etc., or it can be returned into the recirculation system. The content of nutrients in this overflow water can be removed by directing it to a plant lagoon, a root zone or seepage system, where phosphorous and nitrogenous compounds are absorbed. The content of nitrogen in the overflow 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. The reason for using denitrification inside the recirculation system is to reduce the amount of nitrate in the process water in order to minimize the need for new water in the system. The reason for using denitrification outside the recirculation system is to reduce the discharge of nitrogen into the environment. As an alternative to the use of methanol, sludge from, for example, mechanical filters can be used as the carbon source. Using sludge requires tight management of the denitrification chamber, and back-washing and cleaning the chamber becomes more difficult. In any case, an efficient denitrification chamber can reduce the nitrogen content in the effluent water to a minimum.

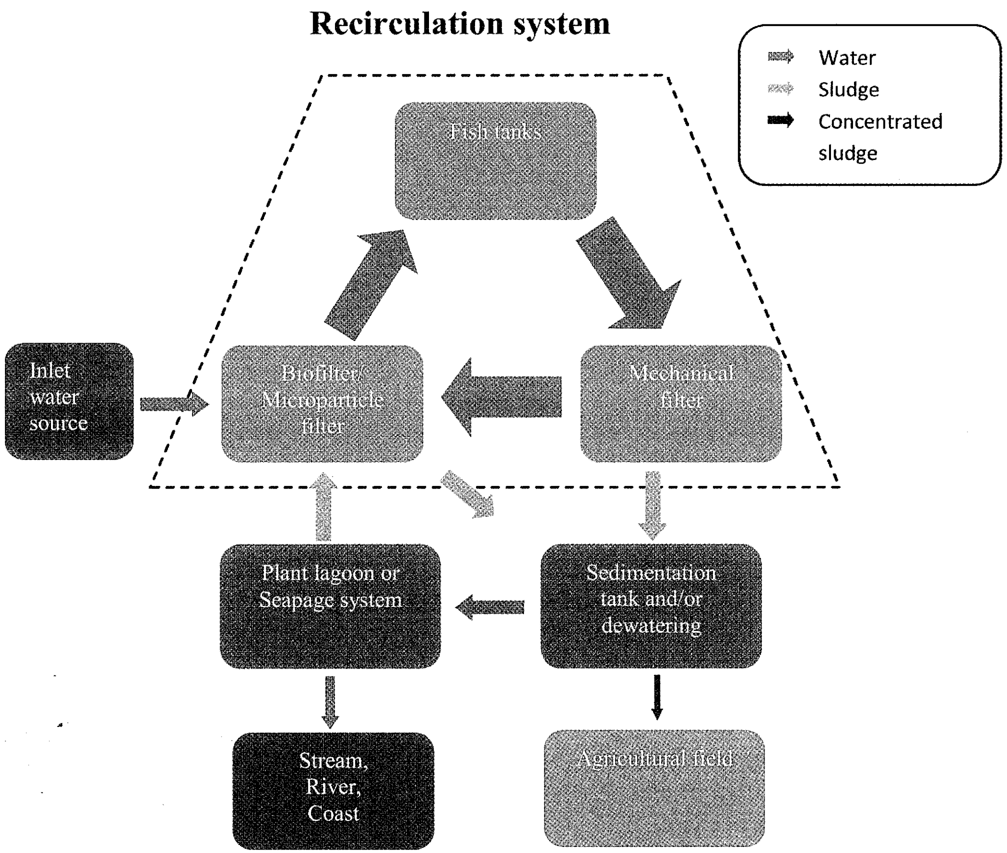


Figure 6.1 The pathways of sludge and water inside and outside a recirculation system. The higher the rate of recirculation, the lower the amount of water let out from the system (dotted line), and the lower the amount of waste water to be treated.

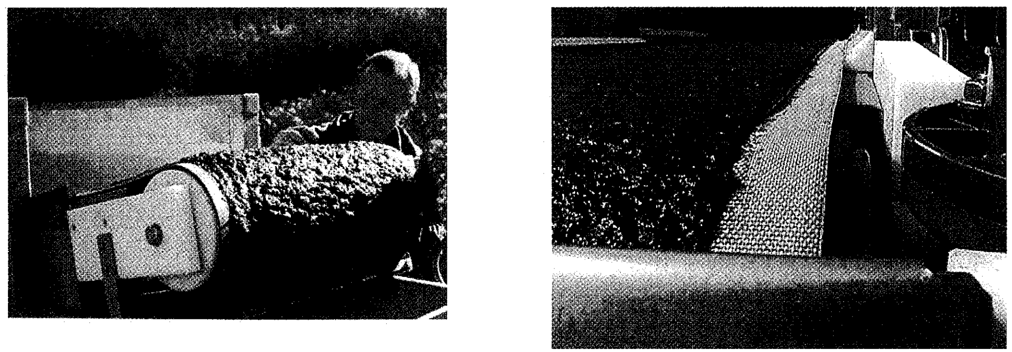


Figure 6.2 Hydrotech belt filter used for dewatering the sludge. Source: Hydrotech.

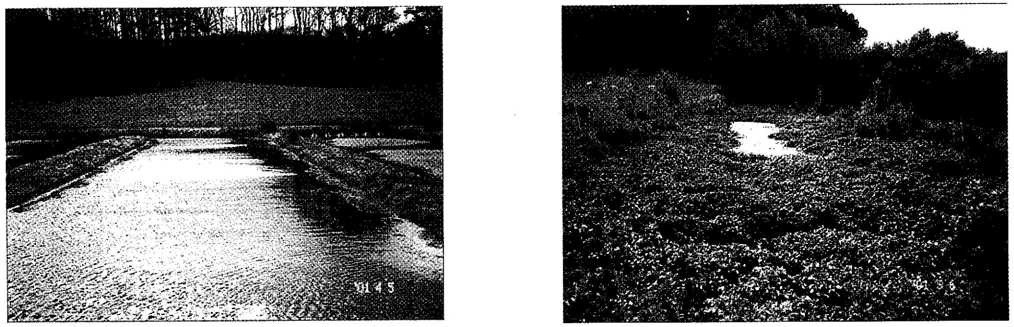


Figure 6.3 A plant lagoon placed after a recirculation trout farm in Denmark – before and after overgrowing. Source: Per Bovbjerg, DTU Aqua.

It is important to notice that fish excrete waste in a different way than other animals such as pigs or cows. Nitrogen is mainly excreted as urine

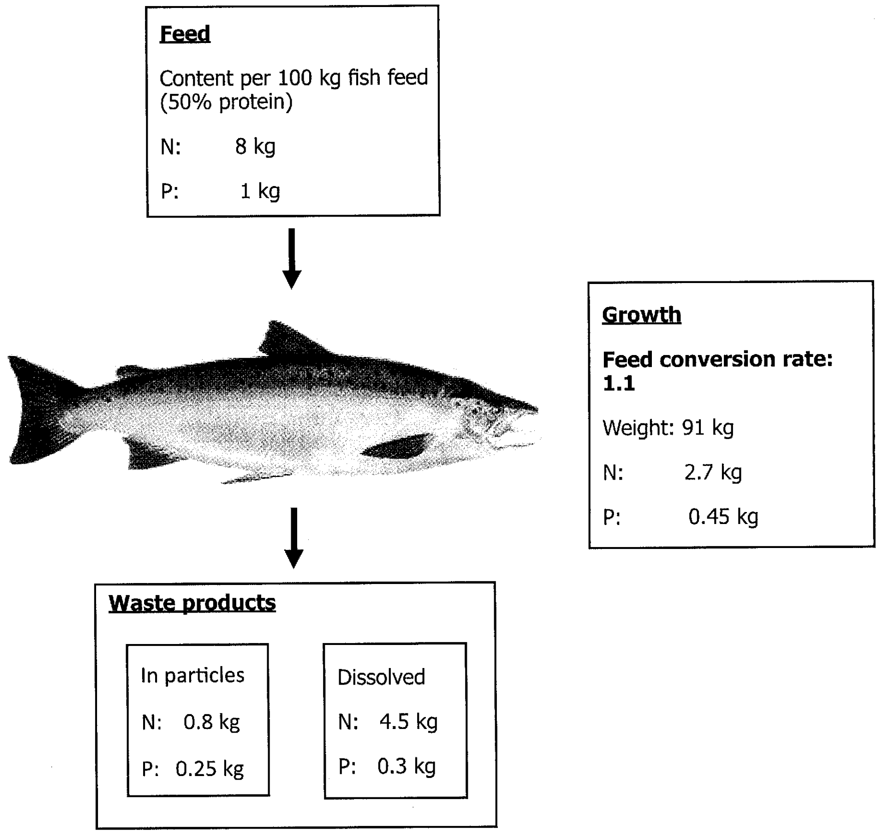


Figure 6.4 Excretion of Nitrogen (N) and Phosphorus (P) from farmed fish. Note the amount of N excreted as dissolved matter. Source: Environmental Protection Agency, Denmark.

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.

It is important that faeces from the fish tanks are carried 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 6.5 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 a growing number of cases, no water at all will return to the surrounding environment such as a nearby river. After a first step waste water treatment, the small amount of water remaining can simply be allowed to seep into the ground in a nearby area. In any case, the total volume discharge water will be significantly lower than that from a traditional fish farming system – see Figure 6.6.

Parameter	Race-way	Race-way	Race-way	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 6.5 Removal of Nitrogen (N), Phosphorous (P) and Suspended Solids (SS) from mechanical filter.
Source: Fisheries Research Station of Baden-Württemberg, Germany.

Recirculation is an efficient way of reducing the impact from fish farming on the surroundings, but the waste water treatment requires tight management on a daily basis to make the treatment system work efficiently. 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.

Discharge from different types of fish farms at 1,000 tonnes production per year	Nitrogen discharge kg/year	Water consumption m^3/day
Traditional flow-through	38,000	250,000
Semi-recirculation	2,000	10,000
Full recirculation	250	1,500

Figure 6.6 Example of discharge from traditional flow-through, semi-recirculation, and full recirculation model farming. Source: Danish Aquaculture.

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.

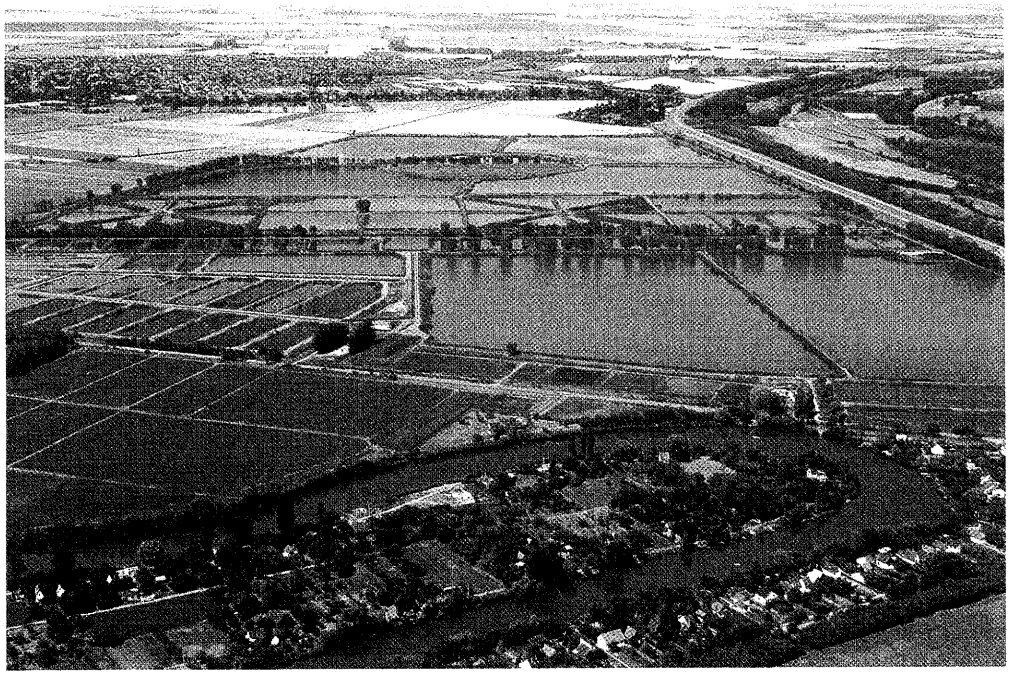


Figure 6.7 Combined intensive-extensive fish farming systems in Hungary. The number of opportunities seems unlimited. Source: Lazlo Varadi, Research Institute for Fisheries, Aquaculture and Irrigation (HAKI), Szarvas, Hungary.

7. Disease

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.

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

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

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 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

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 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.

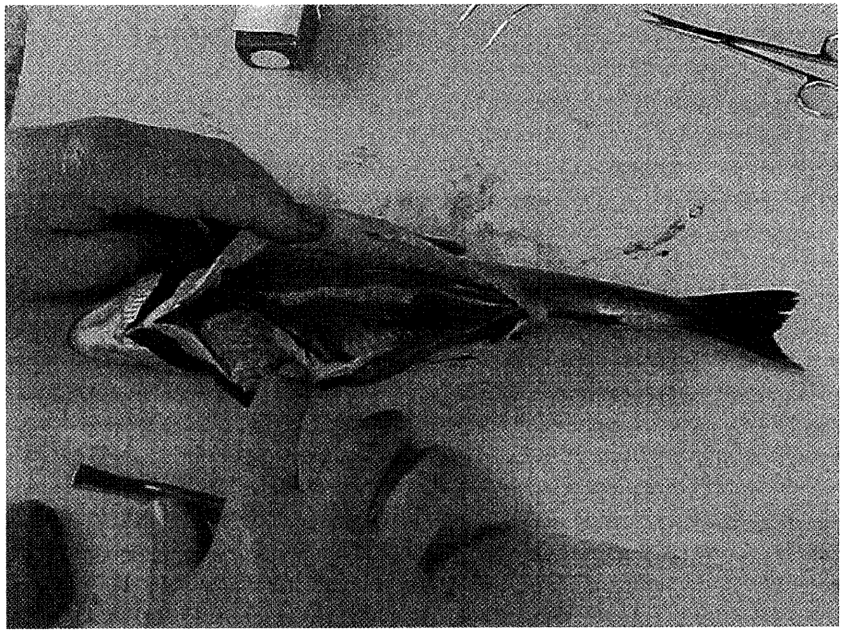


Figure 7.3 Dissection of rainbow trout suffering from inflated swim bladder. A symptom probably due to super saturation of gases in the water.

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 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 however a feasible way of treating millions of individuals in a short time, for example when disinfecting eggs in iodine. 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 o/oo and new results suggests killing of the bottom living stages at 15 o/oo. Fish contains around 8 o/oo 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 o/oo 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.

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.

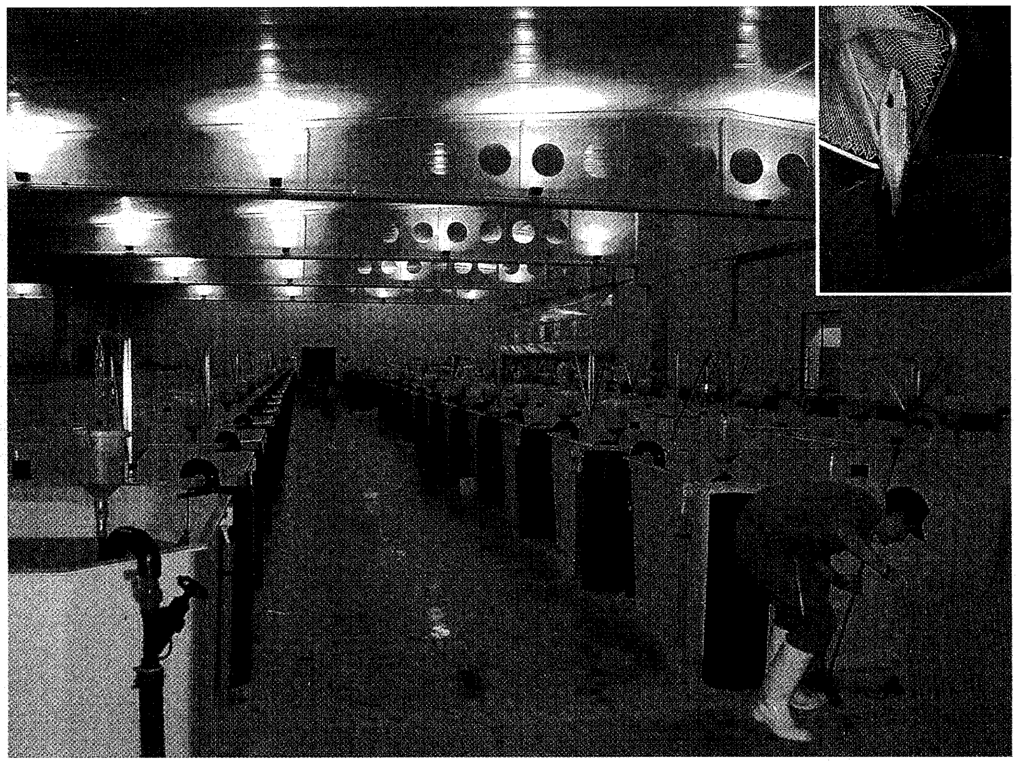


Figure 8.1 A recirculation smolt farm in Chile. Source: Bent Højgaard.

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.

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

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

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

and a more efficient production with reduced costs, investment costs included. The positive effect of the environmental impact can be seen in Chapter 6 Figure 6.6.

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 scientist 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.

Mega farms

The size of fish farms is constantly growing as world production in aquaculture rises. Today, an average sea cage farm in Norway is producing around 5,000 tonnes of salmon per year, just at one site. In freshwater aquaculture farms are growing in size too, and the fight for space and water is intensifying in a number of countries, especially in Asia.

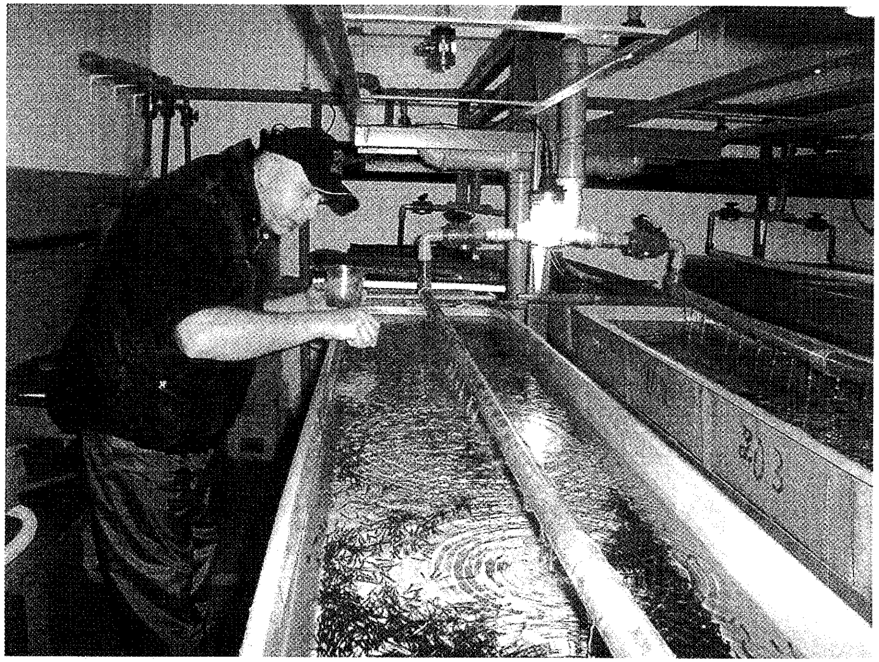


Figure 8.4 Photo from Bosanska Krupa in Bosnia-Herzegovina, where a re-stocking project similar to the one on Funen has been initiated with help from FAO. The species concerned are brown trout, grayling and Danube salmon. Source: Regional Office for Europe and Central Asia (REU), Food and Agriculture Organization of the UN (FAO).

Also, the environmental impact from aquaculture is a growing concern. Recirculation aquaculture offers several advantages that can be beneficial in mass fish production. In some areas sea farms are not popular, and land based farms in the form of recirculation plants are seen as a future way of producing farmed fish. The footprint is low and so is the water consumption. Food safety and control is high, and the output is constant and foreseeable.

In future, recirculation mega farms will most probably be constructed in order to minimize the environmental impact as well as bringing production costs to a minimum while producing a constant daily volume for the market. Such farms may be placed close to large cities or in areas with high population rates where fresh fish can be supplied readily to consumers.

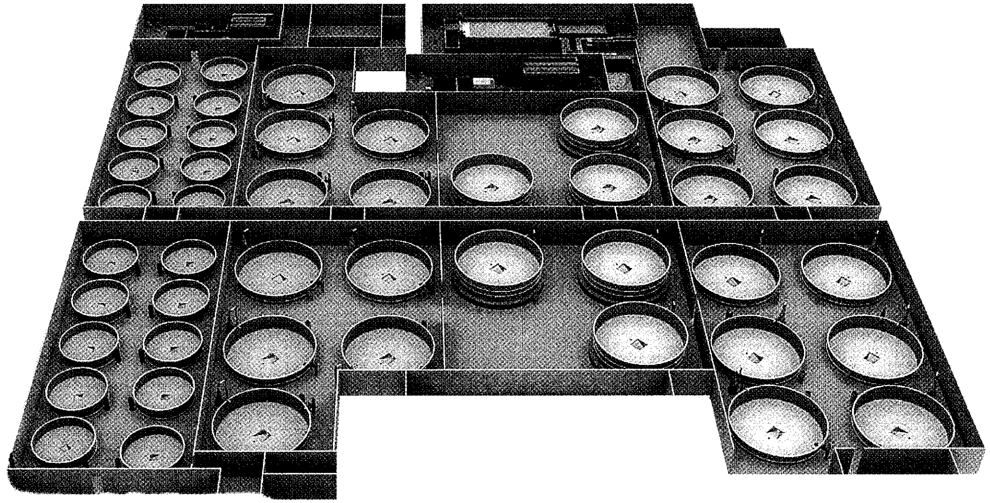


Figure 8.5 A 3D drawing of mega farm with 15 meter diameter tanks reaching tank volumes of more than 500 m^3 each. Source: AKVA group.

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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	Discharge permission 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	Saltwater or fresh water? Salt content of seawater	
2.02	Available water source Seawater, river, well, ground water, borehole	
2.03	How much water 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
- Description of water treatment and handling of waste water
- Case stories from different recirculation projects

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