

1 Introduction

1.1 Aquaculture engineering

During the past few years there has been considerable growth in the global aquaculture industry. Many factors have made this growth possible. One is developments within the field of aquaculture engineering, for example improvements in technology that allow reduced consumption of fresh water and development of re-use systems. Another is the development of offshore cages: sites that until a few years ago not were viable for aquaculture purposes can be used today with good results. The focus on economic efficiency and the fact that salaries are increasing have also resulted in the increased use of technology to reduce staff numbers.

The development of new aquaculture species would not have been possible without the contribution of the fisheries technologist. Even if some techniques can be transferred for the farming of new species, there will always be a need for technology to be developed and optimized for each species. An example of this is the development of production tanks for flatfish with a larger bottom surface area than those used for pelagic fish.

Aquaculture engineering covers a very large area of knowledge and involves many general engineering specialisms, such as mechanical engineering, environmental engineering, materials technology, instrumentation and monitoring, and building design and construction. The primary aim of aquaculture engineering is to utilize technical engineering knowledge and principles in aquaculture and

biological production systems. The production of fish has little in common with the production of nails, but the same technology can be used in both production systems. It is therefore a challenge to bring together both technological and biological knowledge within the aquaculture field.

1.2 Classification of aquaculture

There are a number of ways to classify aquaculture facilities and production systems, based on the technology or the production system used.

'Extensive', 'intensive' and 'semi-intensive' are common ways to classify aquaculture based on production per unit volume (m^3) or unit area (m^2) farmed. Extensive aquaculture involves production systems with low production per unit volume. The species being farmed are kept at a low density and there is minimal input of artificial substances and human intervention. A low level of technology and very low investment per unit volume farmed characterize this method. Pond farming without additional feeding, like some carp farming, is a typical example. Sea ranching and restocking of natural lakes may also be included in this type of farming.

In intensive farming, production per unit volume is much higher and more technology and artificial inputs must be used to achieve this. The investment costs per unit volume farmed will of course also be much higher. The maintenance of optimal growth conditions is necessary to achieve the growth

potential of the species being farmed. Additional feeding, disease control methods and effective breeding systems also characterize this type of farming. The risk of disease outbreaks is higher than in extensive farming because the organism is continuously stressed for maximal performance. Salmon farming is a typical example of intensive aquaculture.

It is also possible to combine the above production systems and this is called semi-intensive aquaculture. An example is intensive fry production combined with extensive on-growing. Aquacultural systems can also be classified according to the life stage of the species produced on the farm, for instance eggs, fry, juvenile or on-growing. Farms may also cover the complete production process, and this is called full production.

Depending on the type of farming technology used, there are also a number of classifications based on the design and function of the production unit. This will of course be species and life-stage dependent. For fish the following classifications may be used: (1) closed production units, where the fish are kept in an enclosed production unit separated from the outside environment; (2) open production units, where the unit has permeable walls (e.g. nets) and so the fish are partly affected by the surrounding environment. It is also possible to classify the farm based on where it is located: within the sea, in a tidal zone or on land.

Land-based farms may be classified by the type of water supply for the farm: water may be gravity-fed or pumped. In gravity-fed systems the water source is at a higher altitude than the farm and the water flows by gravity from the source to the farm. In pumped systems, the source can be at an equal or lower altitude compared with the farm. For tidal through-flow farms, water supply and exchange are achieved using the tide.

Farms can also be classified by how the water supplied to a farm is used. If the water is used once, flowing directly through, it is named a flow-through system. If the water is used several times, with the outlet water being recycled, it is a water re-use or recirculating aquaculture system (RAS). It is also possible to separate production systems as monoculture or polyculture: monoculture involves the production of only one species (e.g. fish), whereas polyculture involves the production of two or more (e.g. fish and rice). This is also named ‘integrated aquaculture’.

1.3 The farm: technical components in a system

In a farm the various technical components included in a system can be roughly separated as follows:

- Production units
- Water transfer and treatment
- Additional equipment (feeding, handling and monitoring equipment).

To illustrate this, two examples are given: a land-based hatchery and juvenile farm, and an on-growing sea cage farm.

1.3.1 Land-based hatchery and juvenile production farm

Land-based farms normally utilize much more technical equipment than sea cage farms, especially intensive production farms with a number of tanks. The major components are as follows (Fig. 1.1):

- Water inlet and transfer
- Water treatment facilities
- Production units
- Feeding equipment
- Equipment for internal fish transport and size grading
- Equipment for transport of fish from the farm
- Equipment for waste and wastewater treatment
- Instrumentation and monitoring systems.

Water inlet and transfer

The design of the inlet depends on the water source: sea water or fresh water (lakes, rivers), or surface water or groundwater. It is also quite common to have several water sources in use on the same farm. Further, it depends whether the water is fed by gravity or whether it has to be pumped, in which case a pumping station is required. Water is normally transferred in pipes, but open channels may also be used.

Water treatment facilities

Water is usually treated before it is delivered to the fish. Equipment for removal of particles prevents excessively high concentrations reaching the fish; additionally, large microorganisms may be removed by the filter. Water may also be disinfected to reduce

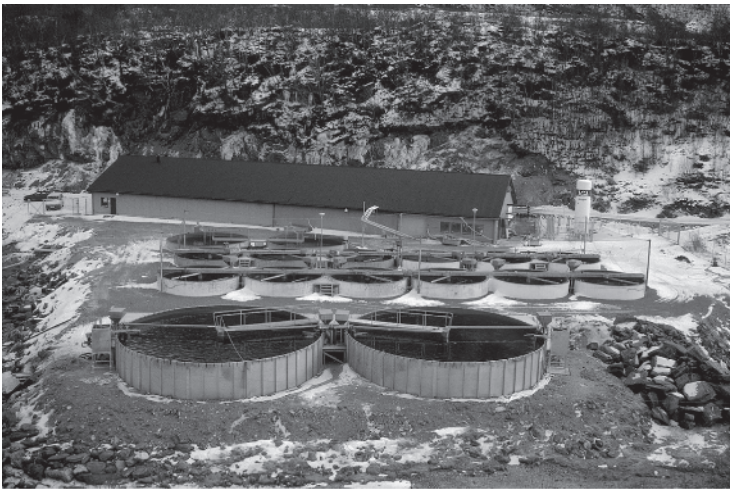
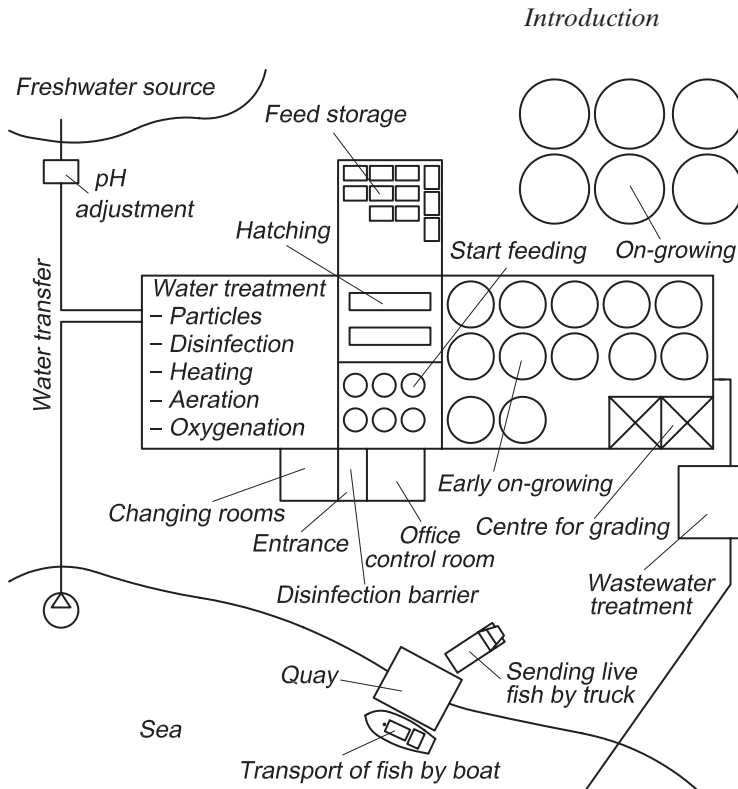


Figure 1.1 Example of major components in a land-based hatchery and juvenile production plant.

the burden of microorganisms, especially that used on eggs and small fry. Aeration may be necessary to increase the concentration of oxygen and to remove possible supersaturation of nitrogen and carbon dioxide. If there is lack of water or the pumping height is large, pure oxygen gas may be added to the water. Another possibility if the water supply is lim-

ited is to re-use the water, although this will involve considerable water treatment. For optimal development and growth of the fish, heating or cooling of the water may be necessary; in most cases this will involve a heat pump or a cold-storage plant. If the pH in a freshwater source is too low, pH adjustment may be part of the water treatment.

Production units

The production units necessary and their size and design will depend on the species being grown. In the hatchery there will either be tanks with upwelling water (fluidized eggs) or units where the eggs lie on the bottom or on a substrate. After hatching the fish are moved to some type of production tank. Usually there are smaller tanks for weaning and larger tanks for further on-growing until sale. Start-feeding tanks for weaning are normally under a roof, while on-growing tanks can also be outside.

Feeding equipment

Some type of feeding equipment is commonly used, especially for dry feed. Use of automatic feeders will reduce manual work on the farm. Feeding at intervals throughout the day and night may also be possible; the fish will then always have access to food, which is important at the fry and juvenile stages.

Internal transport and size grading

Because of fish growth it is necessary to divide the group to avoid fish densities becoming too high. It is also common to size grade to avoid large size variations in one production unit; for some species this will also reduce the possibilities for cannibalism.

Transport of fish

When juvenile fish are to be transferred to an on-growing farm, there is a need for transport. Either a truck with water tanks or a boat with a well is normally used. The systems for loading may be an integral part of the farm construction.

Equipment for waste handling and wastewater treatment

Precautions must be taken to avoid pollution from fish farms, including compulsory treatment of general waste. Dead fish must be treated and stored satisfactorily, for example put in acid or frozen for later use. Dead fish containing traces of antibiotics or other medicines must be destroyed by legal means. Whether wastewater treatment is necessary will depend on the conditions where the effluent

water is discharged. Normally there will at least be a requirement to remove larger suspended particles.

Instrumentation and monitoring

In land-based fish farms, especially those dependent on pumps, a monitoring system is essential because of the economic consequences if pumping stops and the water supply to the farm is interrupted: the oxygen concentration in the water will fall and may result in total fish mortality. Instruments are being increasingly used to control water quality, for instance to ensure optimal production.

1.3.2 On-growing sea cage farm

Normally a sea cage farm can be run with rather less equipment than land-based farms, the major reason being that water transfer and water treatment (which is not actually possible) are not necessary because the water current ensures water supply and exchange. The components necessary are as follows (Fig. 1.2):

- Production units
- Feeding equipment
- Working boat
- Equipment for size grading
- Base station.

Production units

Sea cages vary greatly in construction and size; the major difference is the ability to withstand waves, and special cages for offshore farming have been developed. It is also possible to have system cages comprising several cages, or individual cages. The cages may also be fitted with a gangway to the land. Sea cages also include a mooring system. To improve fish growth, a subsurface lighting system may be used.

Feeding equipment

It is common to install some type of feeding system in the cages because of the large amounts of feed that are typically involved. Manual feeding may also be used, but this involves hard physical labour for the operators.

Construction of sea cage farm for growing

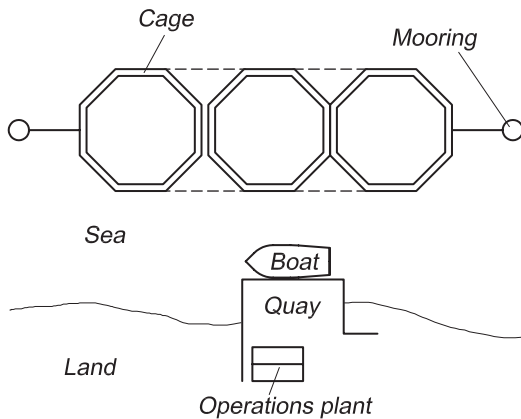


Figure 1.2 Example of major components in an on-growing sea cage farm.

Working boat

All sea cage farms need a boat, and a large variety of boats are used. Major factors for selection are size of the farm, whether it is equipped with a gangway, and the distance from the land base to the cages. Faster and larger boats are normally required if the cages are far from land or in weather-exposed water.

Size grading

Equipment for size grading can be necessary if this is included in the production plan. It may, however, be possible to rent this as a service from subcontractors.

Base station

All cage farms will include a base station; this may be based on land, floating on a barge, or both. The

base station can include storage rooms, mess rooms, changing rooms and toilet, and equipment for treatment of dead fish. The storage room includes rooms and/or space for storage of feed; it may also include rooms for storage of nets and possibly storage of equipment for washing, maintaining and impregnating them. However, this is also a service that is commonly rented from subcontractors.

1.4 Future trends: increased importance of aquaculture engineering

Growth in the global aquaculture industry will certainly continue, with several factors contributing to this. The world's population continues to grow as will the need for marine protein. Traditional fisheries have limited opportunities to increase their catches if sustainable fishing is to be achieved. Therefore, increases in production must

come from the aquaculture industry. In addition, the aquaculture industry can deliver aquatic products of good quality all year round, which represents a marketing advantage compared with traditional fishing. The increased focus on optimal human diets, including more fish than meat in the diet for large groups of the world's population, also requires more fish to be marketed.

This will present future challenges for aquaculture engineers. Most probably there will be an increased focus on intensive aquaculture with higher production per unit volume. Important challenges to this growth will be the availability of fresh water resources and good sites for cage farming. Because of the limited supplies of fresh water in the world, technology that can reduce water consumption per kilogram of fish produced will be important; this includes reliable and cost-effective re-use technology. By employing re-use technology it will also be possible to maintain a continuous supply of high-quality water independently of the quality of the incoming water. More accurate control over water quality will also be of major importance when establishing aquaculture with new species, especially during the fry production stage.

The trend to use more and more weather-exposed sites for cage farms will continue. Development of cages that can not only withstand adverse weather conditions but also be operated easily in bad weather, and where fish feeding and control can be performed, is important.

Rapid developments in electronics and monitoring will gradually become incorporated into the aquaculture industry. Intensive aquaculture will develop into a process industry where the control room will be the centre of operations and processes will be monitored by electronic instruments; robots will probably be used to replace some of today's manual functions. Nanotechnology will be exploited, by using more and smaller sensors for many purposes; an example would be to include sensors in mooring lines and net bags to monitor tension and eventual breakage. Individual tagging of fish will most probably also be a future possibility, which makes control of the welfare of the single individual possible, and could be important in the control of escaped fish.

The focus on the sustainability of aquaculture production is also increasing. This includes feed sources, escape of fish, use of water, and discharge from aquaculture. Zero discharge aquaculture will be a more important topic in the future.

1.5 This textbook

This book aims to provide a general basic review of the whole area of aquaculture engineering and is based on my two previously published books on aquaculture engineering written in Norwegian.^{1,2} Several of the illustrations in this book are based on illustrations in these previously published books. The textbook is primarily intended for the introductory course in aquaculture engineering for the Bachelor and Master degrees in aquaculture at the Norwegian University of Life Sciences (UMB). Several other textbooks dealing with parts of the syllabus are available and referred to in later chapters. The same is the case with lecture notes from more advanced courses in aquaculture engineering at UMB.

The focus of the book is on intensive fish farming, where technology is and will become increasingly important. Most of it concerns fish farming, but several of the subjects are general and will have much interest for molluscan and crustacean shellfish farmers.

Starting with water transport, the book continues with an overview chapter on water quality and the need for and use of different water treatment units, which are described in the following chapters. A chapter on production unit classification is followed by chapters on the different production units. Chapters devoted to additional equipment such as that for feed handling and fish handling, instrumentation, monitoring and buildings follow. Chapters on planning of aquaculture facilities and their design and construction conclude the book.

New in this edition are several chapters on water treatment and how fish metabolism affects water quality and on natural re-use systems for both nutrients and water, including polyculture, integrated aquaculture, aquaponics and biofloc systems. The increased focus on the interaction between the aquaculture industry and society is highlighted in these chapters.

References

1. Lekang, O.-I. & Fjæra, S.O. (1997) *Teknologi for Akvakultur*. Landbruksforlaget, Oslo [in Norwegian].
2. Lekang, O.-I. & Fjæra, S.O. (2002) *Teknisk Utstyr til Fiskeoppdrett*. Gan forlag, Oslo [in Norwegian].