AQUACULTURE ENGINEERING

SECOND EDITION

ODD-IVAR LEKANG

WILEY-BLACKWELL

Aquaculture Engineering

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Second Edition

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WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

This edition first published 2013 © 2013 by John Wiley & Sons, Ltd.
First edition published 2007 © 2007 by Odd-Ivar Lekang

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Registered Office
John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
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Library of Congress Cataloging-in-Publication Data

Lekang, Odd-Ivar, author.
Aquaculture engineering / Odd-Ivar Lekang, Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, Drobakveien, Norway. – Second Edition.
pages cm
Includes bibliographical references and index.
ISBN 978-0-470-67085-9 (hardback) – ISBN (invalid) 978-1-118-49607-7 (obook) – ISBN (invalid) 978-1-118-49861-3 (emobi)
1. Aquacultural engineering. I. Title.
SH137.L45 2013
639′.8–dc23

2012040911

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover images: *Main image*: Large land-based on-growing fish farm. *Smaller images (from left to right)*: Fish distribution in a tank with optimal flow conditions; UV light used for disinfection of inlet water to a fish farm (see figure 10.2 in chapter 10 for more details); Well boat collecting fish from sea cages for slaughtering.
Cover design by Meaden Creative

Set in 9.5/11.5pt Times Ten by SPi Publisher Services, Pondicherry, India

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Preface

The aquaculture industry, which has been growing at a very high rate for many years now, is projected to continue growing at a rate higher than most other industries for the foreseeable future. This growth has mainly been driven by static catches from most fisheries and a decline in stocks of many major commercially caught fish species, combined with the ever-increasing need for marine protein due to continuing population growth. An increased focus on the need for fish in the diet, due to mounting evidence of the health benefits of eating more fish, will also increase the demand.

There has been rapid development of technology in the aquaculture industry, particularly as used in intensive aquaculture where there is high production per cubic metre farming volume. It is predicted that the expansion of the aquaculture industry will lead to further technical developments with more, and cheaper, technology being available for use in the industry in future years.

The aim of this book is to give a general overview of the technology used in the aquaculture industry. Individual chapters focus on water transfer, water treatment, production units and additional equipment used on aquaculture plants. Chapters where equipment is set into systems, such as land-based fish farms and cage farms, are also included. The book ends with a chapter on systematic methodology for planning a full aquaculture facility.

The book is based on material successfully used on BSc and MSc courses in intensive aquaculture given at the Norwegian University of Life Sciences (UMB) and refined over many years, the university having included courses in aquaculture since 1973. In 1990 a special Master's course was developed in aquaculture engineering (given in Norwegian), and from 2000 the university has also offered an English language international Master's programme in aquaculture (see details at www.umb.no).

During the author's compilation of material for use in this book, and also for earlier books covering similar fields (in Norwegian), many people have given useful advice. I would like especially to thank Svein Olav Fjæra and Tore Ensby. Further thanks also go to my colleagues at UMB: B.F. Eriksen, P.H. Heyerdahl, T.K. Stevik and, from earlier, colleagues and students: V. Tapei. Mott, A. Skar, P.O. Skjervold, G. Skogesal and D. E. Thommassen.

New chapters have been included in this edition and I would like to thank my colleagues Bjørn Frode Eriksen, John Mosby and Asbjørn Bergheim (IRIS) for good discussions.

Tore Ensby has drawn the majority of the line illustrations contained in the book (in a couple of instances based on figures from accredited third party sources). All the photographs included in the book have been taken by the author.

O.I. Lekang

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

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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.

Depemding 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

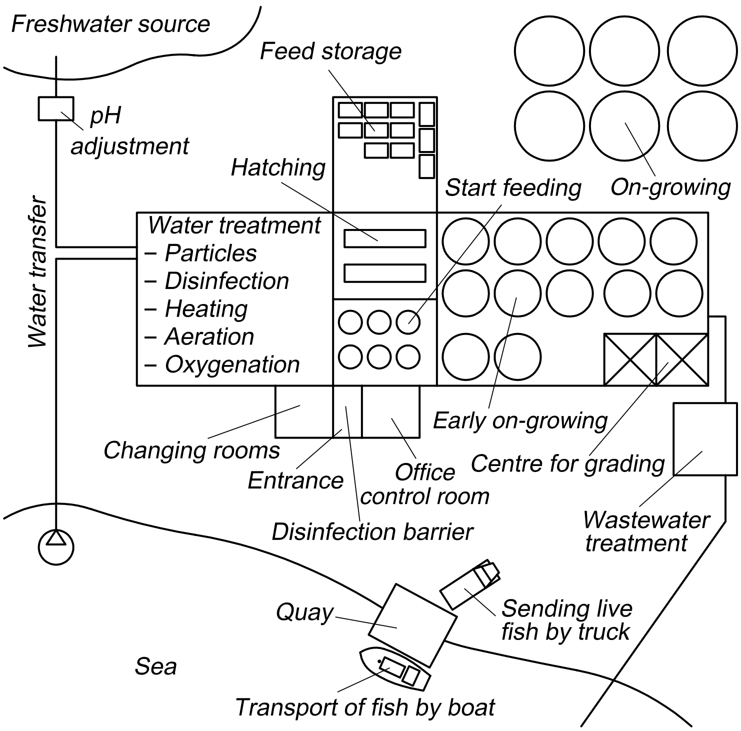

Figure 1.1 Example of major components in a land-based hatchery and juvenile production plant.

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 limited 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.

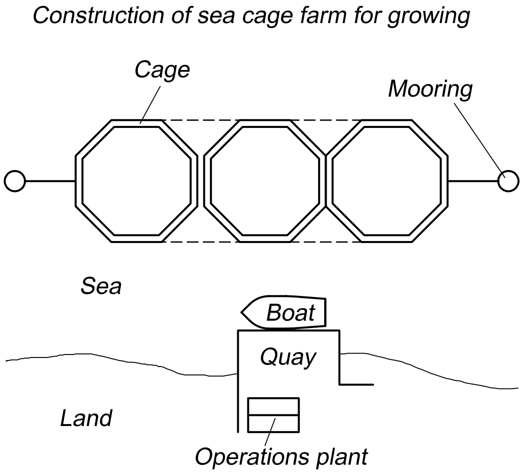

Figure 1.2 Example of major components in an on-growing sea cage farm.

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.

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2
Water Transport

2.1 Introduction

All aquaculture facilities require a supply of water. It is important to have a reliable, good-quality water source and equipment to transfer water to and within the facility. The volume of water needed depends on the size of the facility, the species and the production system, and in some cases can be very large, up to several hundred cubic metres per minute (Fig. 2.1). This is equivalent to the water supply to a fairly large village, considering that in Norway a normal value for the water supply per person is up to 180 litres per day.

If the water supply or distribution system fails, it may result in disaster for the aquaculture facility. This also emphasizes the importance of appropriate knowledge in this area. Correct design and construction of the water inlet system is an absolute requirement in order to avoid the problems that may become apparent, for example, when the inlet system is too small and the water flow rate to the facility is lower than expected.

The science of the movement of water is called hydrodynamics, and in this chapter the important factors of this field are described with emphasis on aquaculture. In addition, a description of the actual materials and parts for water transport are given: pipes, pipe parts (fittings) and pumps. Much more specific literature pertaining to all these fields is available (basic fluid mechanics,[1–3] pipes and pipe parts,[4–6] pumps[7–9]).

2.2 Pipe and pipe parts

2.2.1 Pipes

Pipe materials

In aquaculture the common way to transport water is through pipes. However, in some cases open channels are also used: for transport into the farm, for distribution inside the farm and for exit from the farm. They are normally built of concrete and are quite large, so the water is transported at low velocity. Channels may also be excavated in earth, for example to supply the water to earth ponds. The advantages of open channels are their simple construction and the ease with which water flow can be controlled visually; the disadvantages are the requirement for a constant slope over the total length and that there can be no pressure in an open channel. Other disadvantages include the greater exterior size compared with pipes, and the noise inside the building when water is flowing.

Plastics, mainly thermoplastics, are the most commonly used materials for pipes. Thermoplastic pipes are available in many different qualities with different characteristics and properties (Table 2.1). Thermoplastic is a type of plastic that becomes liquid when heated and hard when cooled.[10] Thermoplastic pipes can be divided into weldable (typically polyethylene, PE) and glueable (polyvinyl chloride, PVC) depending on the way the pipes are connected. The opposite of thermoplastic is hardened plastic,

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Figure 2.1 The supply of water to a fish farm can be up to several hundred cubic metres per minute, as here for a land-based fish farm for growing of marked size Atlantic salmon.

Table 2.1 Typical characteristics of actual pipe materials.

Material	Temperature range (°C)	Common pressure classes (bar)	Common size range (mm)
PE	−40 to +60	3.2, 4, 6, 10 and 25	20–1600
PP	0 to +100	10 and 16	16–400
PVDF	−40 to +140	16	16–225
PVC-U	0 to +60	4, 6, 10, 16 and 25	6–400
PVC-C	0 to +80	16	16–225
ABS	−40 to +60	16	16–225

such as fibreglass, which comprises a plastic matrix impregnated with glass fibres; after hardening it is impossible to change its shape, even by heating. Fibreglass can be used in critical pipes and pipe parts, but only in special cases (see later).

It is also important that materials used for pipes are non-toxic for fish.[11] Copper, much used in piping inside houses, is an example of a commonly used material that is not recommended for fish farming because of its toxicity. In the past, steel, concrete or iron pipes were commonly used, but today these materials are seldom chosen because of their price, duration and laying costs.

PE pipes are of low weight, simple to handle, and have high impact resistance and good abrasion resistance. Nevertheless, these pipes may be vulnerable to water hammer or vacuum effects (see section Pressure class). PE pipes are available in a wide variety of dimensions and pressure classes; they are normally black or grey but other colours are also used. Small diameter pipes may be delivered in coils, while larger sizes are straight, with lengths commonly between 3 and 6 m. PE may be used for both inlet and outlet pipes. PE piping must be fused together for connection; if flanges are fused to the pipe fittings, pipes may be screwed together.

PVC is used in pipes and pipe parts inside the fish farm and also in outlet systems. This material is of low density and easy to handle. Pipe and parts are simple to join together with a special solvent cementing glue. A cleaning liquid dissolves the surface and makes gluing possible. A large variety of pipe sizes and pipe parts is available. When using this kind of piping, attention must be given to the temperature: below 0°C this material becomes brittle and will break easily. PVC is also vulnerable to water hammer. There are questions concerning the use of PVC materials because poisonous gases are emitted during burning of leftover material. There is a trend against more use of PE.

Fibreglass may be used in special cases, for example in very large pipes (usually over 1 m in diameter). The material is built up in two or three layers: a layer of polyester that functions like a glue; a layer with a fibreglass mat that acts as reinforcement; and quartz or sand. The ratio between these components may vary with the pressure and stiffness needed for the pipe. A pipe is normally constructed with several layers of fibreglass and polyester. Fiberglass has the advantages that it tolerates low temperatures, is very durable and may be constructed so that it can tolerate water hammer and vacuum effects. The disadvantage is the low diversity of pipes and pipe parts available. For joining of parts, the only options are to construct sockets on site using layers of polyester and fibreglass, or to use pipes equipped with flanges by the manufacturer that can be screwed together with a gasket in between.

Materials such as polypropylene (PP), acrylonitrile–butadiene–styrene (ABS) and polyvinyl difluoride (PVDF) have also been introduced for use in the aquaculture industry, but to a minor degree and for special purposes only. They are also more expensive than PE and PVC.

Pressure class

Each pipe and pipe part must be thick enough to tolerate the pressure of water flowing through the system. To install the correct pipes it is therefore important to know the pressure of the water that will flow through them. The pressure (PN) class indicates the maximum pressure that the pipes and pipe parts can tolerate. The pressure class is given in bar, where 1 bar = 10 m water column (mH_2O) = 98 100 Pa; for instance, a PN4 pipe will tolerate 4 bar or a 40-m water column. This means that if the pressure inside the pipe exceeds 4 bar the pipe may split. In fish farming, pressure classes PN4, PN6 and PN10 are commonly used. Pipes of different PN classes vary in wall thickness: higher pressure requires thicker pipe walls. Pipes of higher PN class will of course cost more, because more material is required to make them.

A complete inlet pipe, from the source to the facility, may be constructed with pipes of different PN classes. If, for instance, the water source to a fish farm is a lake located 100 m above the farm, a PN4 pipe can be used for the first 40-m drop, a PN6 pipe for the following 20-m drop, and a PN10 pipe on the final 40-m drop.

Some problems related to pressure class are as follows:

- *Water hammer*: this can occur, for instance, when a valve in a long pipe filled with water is closed rapidly. This will generate high local pressure in the end of the pipe, close to the valve, because it takes some time to stop the moving mass of water inside the pipeline. The result is that the pipe can 'blow'. Rapid closing of valves must therefore be avoided. Water hammer may also occur with rapid starting and stopping of pumps. However, this can be difficult to inhibit and it may be necessary to use special equipment to damp the water hammer effect. A tank with low-pressure air may be added to the pipe system: if there is water hammer in the pipes, the air in this tank will be compressed and this reduces the total hammer effect in the system.
- *Vacuum*: this may be generated in a section of pipe, for example, when it is laid at different heights (over a crest) and which then functions as a siphon (Fig. 2.2). A vacuum may then occur on

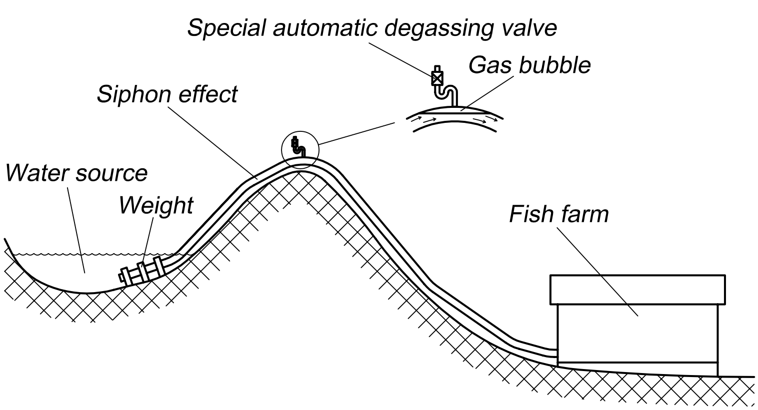

Figure 2.2 A vacuum may occur inside the pipe on the top crest causing deformation.

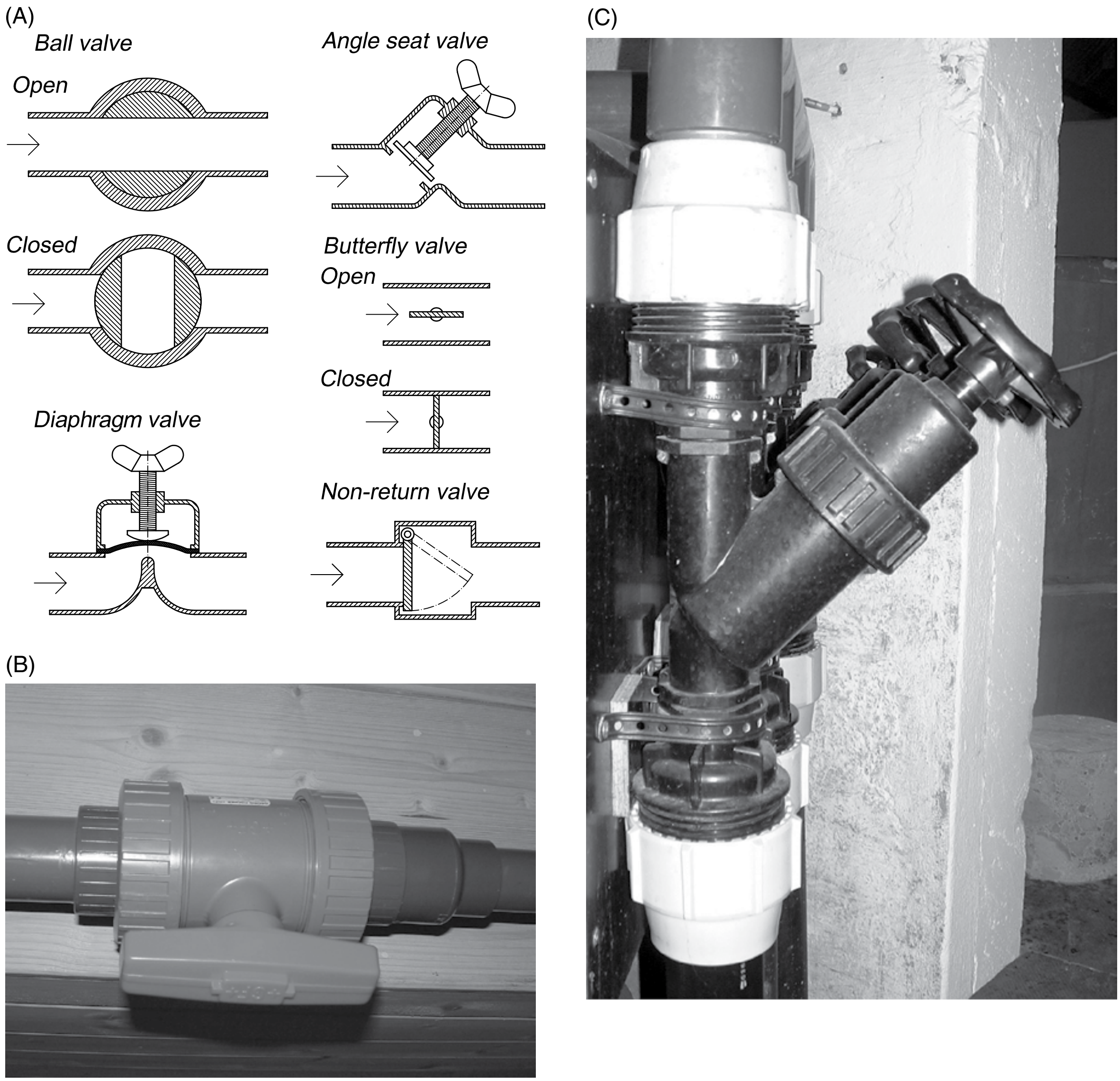

Figure 2.3 Valve types used on aquaculture facilities: (A) diagrams showing valve cross-sections; (B) ball valve; (C) angle seat valve; (D) diaphragm or membrane valve; (E) butterfly valve.

the highest crest. It is recommended that such conditions are avoided, because the pipeline may become deformed and collapse because of the vacuum. Pipes are normally not certified for vacuum effects; however, if vacuum effects are possible, it is recommended that a pipe of higher pressure class is used where the vacuum may occur. By using pipes with thicker walls, higher tolerance to vacuum effects is achieved; alternatively, a fibreglass pipe which tolerates a higher vacuum could be employed.

Classification of pipes

Pipe diameters are standardized. A number of sizes are available for various applications in different industries. In aquaculture, pipes with the following external diameters (mm) are generally used: 20, 25,

(D) (E)

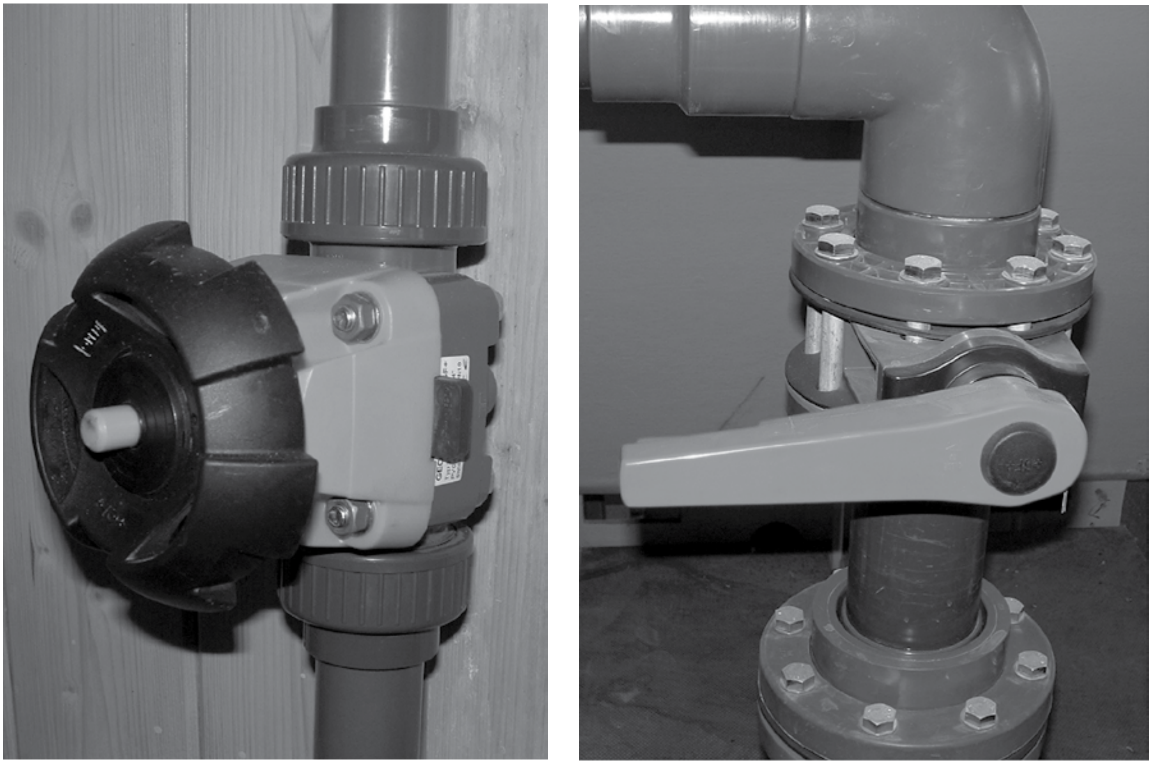

Figure 2.3 *Continued*.

32, 40, 50, 63, 75, 90, 110, 125, 160, 180, 200, 225, 250, 280, 315, 355, 400, 450, 500, 560 and 630. The internal diameter, used when calculating the water velocity in the pipeline, is found by subtracting twice the wall thickness. Higher pressure class pipes have thicker walls than lower pressure class pipes.

All pipes and pipe parts must be marked clearly by the producer. For pipes the marking print on the pipe is normally every metre, and for pipe parts there is a mark on every part. The following is included in the standardized marking: pipe material, pressure class, external diameter, wall thickness, producer and the date when the pipe was produced. It is important to use standardized pipe parts when planning fish farms.

2.2.2 Valves

Valves are used to regulate the water flow rate and the flow direction. Many types of valve are used in aquaculture (Fig. 2.3). Which type to use must be chosen on the basis of the flow in the system and the specific needs of the farm. Several materials are used in valves, such as PVC, ABS, PP and PVDF, and the material chosen depends on where the valves will be used. Large valves may also be fabricated in stainless or acid-proof steel.

Ball valves are low-cost solutions used in aquaculture. The disadvantage is that they are not very precise and are best used in an on–off manner or for approximate regulation of water flow. The design is simple and consists of a ball with an opening in the centre. When turning it will gradually open or close, but it is difficult to achieve exact regulation.

Valves containing a membrane pulled down by a piston are called diaphragm or membrane valves. These valves can regulate water flow very accurately. They cost considerably more than a ball valve, and the head loss through the valve is significantly higher. Angle seat valves have a piston standing in an angled ‘seat’. When the screw handle is turned the piston moves up or down, gradually reducing the opening. This type of valve is also capable of accurate flow regulation, but is quite expensive and also has a higher head loss than a ball valve. For accurate flow regulation, for instance on single tanks, diaphragm valves or angle seat valves are recommended. However, when selecting these types of valves it is important to be aware that the head loss can be over five times as high as with a ball valve.

Butterfly valves are usually located in large pipes (main pipeline or part pipelines) and regulate water flow by opening or closing a throttle. A slide valve or gate valve can be used in the same situation. This consists of a gate or slide that stands vertically in the water flow, which is regulated by lifting or lowering the plate by a spindle. This valve type is also used in large-diameter pipelines, but both butterfly valves and sluice valves are quite expensive, especially in large sizes. However, it is better to use too many valves than too few. It is always an advantage to have the facility to turn off the water flow at several places in the farm, for instance for maintenance. Conversely, these types of valves are not recommended for precise regulation of water flow.

The check or 'non-return' valve is used to avoid the backflow of water, so that water can only flow in one direction in the pipe system. In many cases it is used in a pump outlet to avoid backflow of water when the pump stops. Normally the valve comprises a plate or ball that closes when the water flow reverses. Triple-way valves may regulate the flow in two directions to create a bypass. Many other types of valves are available, for instance electrically or pneumatically operated valves that make it possible to regulate water flow automatically. In new and advanced fish farms such equipment is of increasing interest, especially when saving of water is necessary.

It is important to remember, however, that all valves create a head loss, the size of which depends on the type of valve being used; for example, diaphragm valves have a high head loss. This must be considered when planning the farm. When deciding which valve types to use, it is essential to have enough pressure to ensure that the correct flow rate is maintained through the valves; if the head loss is too high, water flow into or inside the farm will be decreased.

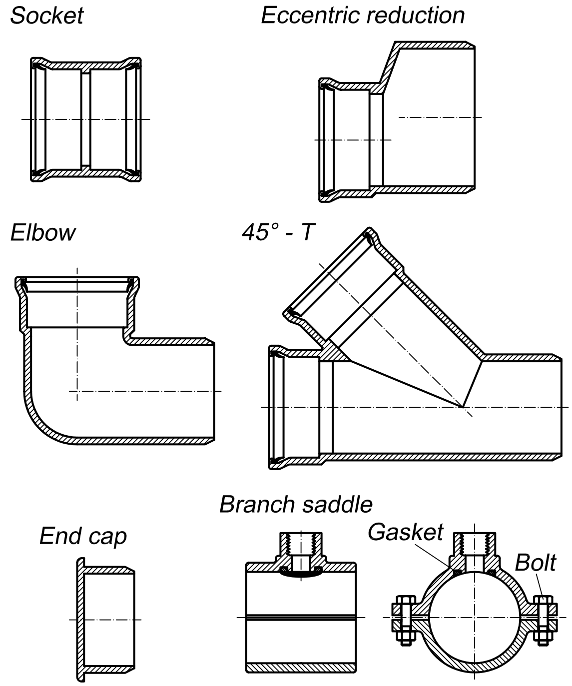

Figure 2.4 Cross-sections of fittings used in aquaculture.

2.2.3 Pipe parts: fittings

A large variety of pipe parts can be found, especially for PE and PVC pipes (Fig. 2.4). Various bends or elbows are normally used in aquaculture. T-pipes are also used to connect different pipes. Different conversion parts allow the connection of pipes or equipment with different diameters. Sockets, flanges or unions are used to connect pipes or pipe parts. Sometimes end-caps are used to close pipes that are out of use. A particularly useful part is the repair socket, which allows connection of an additional pipe (a T-pipe) to a pipeline where the water in the installation flows continuously, which means that connections can be made to pipelines that are in use.

2.2.4 Pipe connections: jointing

The connection or jointing of pipes and pipe parts may be executed in various ways depending on the material used to make the pipe and the pipe part (Fig. 2.5). For PE, fusing (heating) is the only possible jointing method. This process may be carried out by a blunt heating mirror or by electrofusion.