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# Culture systems categorized: The fundamentals

Aquaculture Department, Southeast Asian Fisheries Development Center

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# The **C** f u n d a m e n t a l s Culture systems categorized

**T**here are three basic categories of culture systems: open, semiclosed and closed systems. *Open system* culture generally refers to fish farming in natural bodies of water such as oceans, bays, estuaries, coastal lagoons, lakes or rivers. *Semiclosed* systems are those in which the culture water makes one pass through the system and is discharged. These are referred to as *flow-through* or *once-through* systems. The raceway falls into this category. *Closed* systems are those where the water is reconditioned and recirculated to culture units. These are also called the closed *recirculating* systems.

The open system is most often used for commercial and recreational fisheries. It is low-cost and requires limited management. A step beyond the open system is the *modified open system*. This involves the confinement of fish in enclosures, floating cages, net pens, baskets, trays, etc.

## CAGE CULTURE

The terms *enclosure*, *pen* and *cage* are sometimes used interchangeably. Enclosure as used in this text refers to a natural or semi-sheltered bay where the shoreline forms all but one side of the enclosure. In most cases, enclosures are separated from open water by a solid barrier or by a net or plastic mesh. The mesh size is typically small enough to retain the cultured fish but large enough to allow entry and exit of small fish and food organisms. Enclosures commonly range in size from about 0.1 ha to over 1,000 ha in surface area.

*Pens* are man-made, constructed from bamboo, wooden poles or stakes driven into the substrate. Pens range in size from about 1 m<sup>2</sup> to several hectares in surface area.

*Cages* are man-made and float off the bottom. They are much smaller than either enclosures or pens, ranging from about 1 m<sup>2</sup> to over 1,000 m<sup>2</sup> in surface area.

Cage culture makes use of existing water

bodies which can give nonland-owning sectors of the community access to fish farming. Lease agreements from local governing authorities eliminate the need to invest large amounts of capital in land. Cage farm management is less complex than land-based systems. Cage farms can be expanded by simply adding cages as experience grows. Cages are "mobile"; they can be moved to other sites to take advantage of better-quality water and more abundant food organisms, and to "escape" storms.

A negative side to cage culture is that farmers have no control over water quality conditions, and pollution is often responsible for serious damage. Also, cage installations are at the mercy of the weather and may suffer damage from high winds, tides and waves if they cannot be moved when storms approach.

Cages can have negative impacts on the aquatic environment. Large quantities of uneaten feed and feces are released which may adversely affect water quality. Cages take up space in public waters, which can make navigation hazardous or may deny access to certain areas by commercial and sportfishermen.

## Cage types

Four basic cage types are: fixed, floating, submersible and submerged. Cages are fabricated from wood with small openings on the sides and bottom or constructed with nets framed by wood or metal tubing (Fig. 1). The latter is lighter and has more open area at the sides to enhance water exchange. Both are covered to prevent escape of stock and predation. Hinged lids provide access for feeding and harvest, while locks discourage poaching. Floats allow the cages to rise and fall with fluctuating water levels. Larger cages and net pens have catwalks and working platforms to facilitate feeding, harvest and routine activities. Cages can also be fixed by anchors.

Both fixed and floating cages can be rigid or flexible. Rigid cages use a nonflexible framework as well as a stiff mesh material at the sides

Fig. 1. Common small aquaculture cages: a wooden cage with mesh sides and bottom (left) and a net cage framed in wood or metal (right).

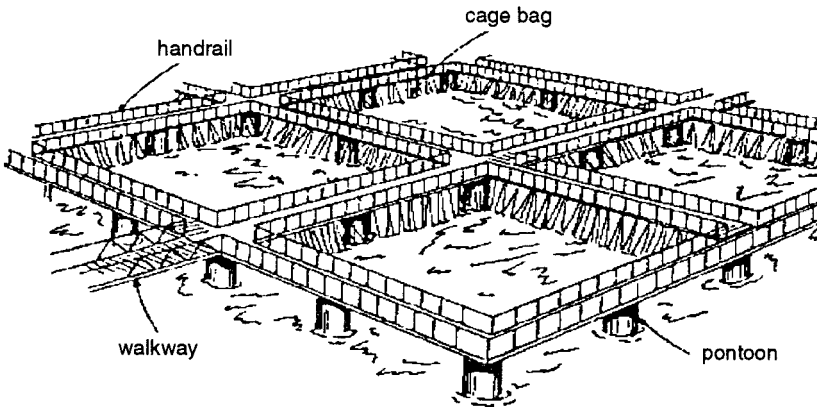
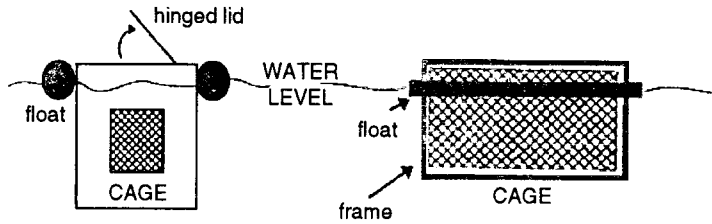


Fig. 2. Floating net pens can be grouped together.

and bottom. Rigid cages are used most often in swiftly flowing rivers and streams. Flexible cages are usually floating, with collars that support catwalks and working platforms. The collar assembly also supports the cage bag that contains the fish. Large net pens are up to 15 m<sup>2</sup>, and are often grouped so that walkways serve more than one pen (Fig. 2). Handrails may be built into walkways. Flotation devices include large vertical spars or pontoons.

Some cages can be rotated to control biofouling. They are usually cylindrical and are floated with the cylindrical axis lying horizontal and the cage rotated about the axis. Daily rotation allows all sections of the cage to be exposed to the sun, drying and killing the fouling organisms.

Submersible cages are used primarily in places prone to storms. The cages can be fixed and floating. A simple, submersible fixed cage is used for tilapia culture in the Philippines. The cages are fitted with net tops, and when a storm threatens, the rigging is untied, and the cages are lowered 1 m or so beneath the surface.

Cage design depends upon a number of

factors -- fish cultured, environmental conditions in the farm, type of culture whether extensive or intensive, and cost and availability of materials.

### Cage bag

The cage bag holds the fish. It can be round, square, rectangular, 6-sided or 8-sided. Round cage bags are stronger and make the most efficient use of materials at the least cost per unit volume. Also, schooling species like salmon and milkfish appear to be less stressed when cultured in round bags since they tend to swim in circles when enclosed. A disadvantage to round cages is that the surface area to volume ratio (SA:V) is small compared to other shapes, resulting in poor water exchange.

The ideal bag material should be strong and light. It should also be rot-, corrosion-, weather- and fouling-resistant, easily repaired, drag force-resistant, nonabrasive, and economical. Materials used to construct cage bags range from cotton and synthetic fibers to semirigid materials such as plastic and metal. Flexible cages are fabricated from fibers, either natural or synthetic.

Natural fibers are used very infrequently because they rot easily.

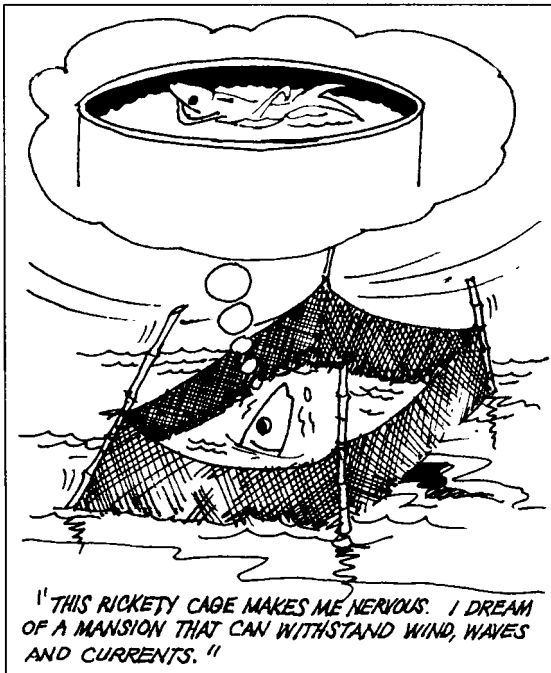
## Frames

The basic frame that supports the cage bag generally follows the shape of the bag. It can be made of bamboo, wood, metal or synthetic substances. Small, cottage-industry-type cage frames are normally fabricated from wood or plastic; larger cages are fabricated from galvanized steel or 90:10 copper-nickel alloy. Plastic or nylon fasteners are used to attach bags to the framework since metal fasteners tend to create galvanic cells and to corrode rapidly.

Bags and frames are designed with a freeboard extending above the water surface to prevent fish from jumping out. The height of freeboard is dependent on fish cultured as some are better leapers than others.

## Collars and supports

Fixed cages typically do not have collars. They are supported by bamboo poles, wooden posts or columns that are driven into the substrate. The support structure must be able to withstand the static vertical forces imposed on them by the weight of the cage, working staff, equipment, etc. while at the same time resisting dynamic forces exerted by wind, waves and currents.



A collar is normally used to support and buoy the cage bag and to help retain its shape, or used to support catwalks, which serve as work platforms. In many cage designs the flotation material is an integral part of the collar. Flotation can be provided by bamboo poles, hard or soft woods, foam-filled drums or tubing, or air-filled drums, tubing or pontoons.

## Linkages and groupings

Most small cages are moored individually, however, it is common practice in large cage farms to group several cages together.

Cage grouping depends upon (1) size of the farm, (2) site conditions, (3) cage design, (4) mooring design, and (5) environmental considerations. Cages in large farms are often grouped to house fish in various life stages or grouped according to species, if more than one species is being cultured at the same time.

## Mooring systems

Mooring systems consist primarily of lines and anchors, but some may also have floats.

Horizontal and vertical forces acting on cages and supporting structures should be considered in designing mooring systems. Mooring lines should not break easily. Lines are constructed from braided galvanized steel strands, open-link steel chain or braided natural or synthetic fibers.

The simplest and cheapest anchors are deadweight or block anchors consisting of bags of sand or stones, concrete blocks or large pieces of scrap metal. Deadweight anchors are typically inefficient, however, since they move across the substrate whenever the horizontal force (like current) exceeds the frictional force between the anchor and the substrate.

The embedding-type anchor is constructed to grip the substrate, e.g., a small boat anchor. However, embedding anchors are more expensive than deadweight anchors and must be dragged a certain distance over the substrate before they take hold.

An alternative mooring technique in lieu of using chains and anchors is to drive long poles into the substrate and attach the cages directly to them. If cages are located near the shore, land anchors can be used. Wooden stakes are driven into the ground, and the cages are tied to them with ropes or cables.

## POND CULTURE

Commercial fishpond production is profitable only when a combination of resources is available at a reasonable cost:

- (1) Large tracts of land with the proper soil, slope and topography
- (2) Large volume of good-quality water
- (3) A growing season where temperature does not fluctuate widely
- (4) Ready market for the product

Fishponds provide a static or dynamic environment. In static ponds (rain-fed ponds for instance), water does not flow although the ponds may be supplemented with pumped water. In dynamic ponds, water continuously flows or a certain percentage is exchanged daily.

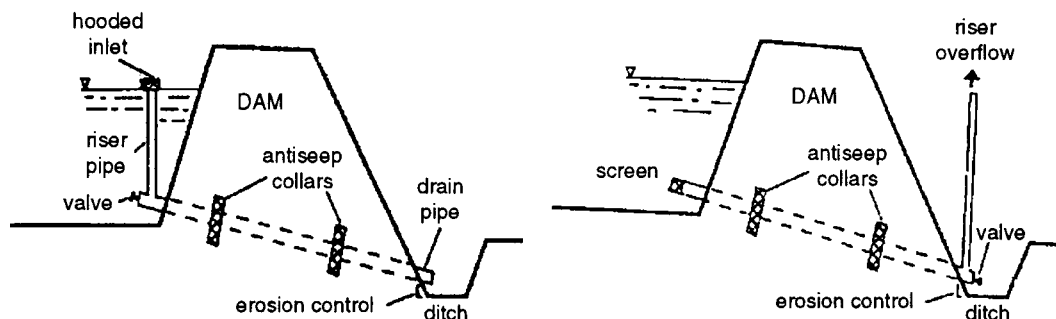


Fig. 3. Cross section of dam showing two types of drain commonly used: hooded inlet pipe (left) and outside drain valve (right). Also note use of antiseep collars.

There are two basic types of ponds: *watershed* and *levee*. The choice depends on topography, land slope, capital investment and level of production.

### *Watershed ponds*

*Watershed ponds* are created by constructing a dam or dike across a small stream. These are also called hill or embankment ponds, and are filled entirely by precipitation and runoff from the surrounding watershed. Watershed ponds are preferably constructed in gently sloping, shallow valleys rather than in deep valleys with steep slopes. Ponds built in shallow valleys can be cut and filled so that the finished basin has a uniform and shallow depth to facilitate harvest without draining. Additional soil is hauled from

other sites to build the dam.

Ponds must be located in areas where there are no runoffs from feedlots, orchards, root crops, or other sites where pesticides or manure are applied. The watershed should have sufficient grass cover to prevent erosion of soil into the pond. The site should be fenced to prevent livestock from trampling and damaging the pond slopes and the dam. A well is desirable even in areas of high rainfall. Well water can also be used to supplement runoff or refilling ponds drained for harvest.

Soils containing at least 20% clay by volume are suitable for fish ponds. Clays and silty clays are best. For dams, foundation soil must be able to support dam weight. Swampy, muddy or plastic soils should be removed and the dam constructed on the underlying consolidated soil material. Highly organic soils should not be used as foundation material since they decompose

and cause the dam to settle and eventually leak (and possibly fail altogether). Foundation material should have low permeability to prevent excessive seepage.

Detailed dam design is best left to a professional engineer, especially in the event that human life or valuable property may be lost due to dam failure.

Ponds should be constructed with two outlets: a mechanical and an emergency spillway. A mechanical spillway carries the normal water flow and can be designed to partially or completely drain the pond to facilitate harvest. There are two types (Fig. 3). The first, called a drop-inlet trickle tube, consists of a common interior riser pipe with a drainpipe. The crest of the riser maintains the desired water depth in the pond. A hood is

sometimes used to cover the riser inlet to prevent trash from entering.

The emergency spillway takes care of storm flows that exceed the capacity of the mechanical spillway. It is usually constructed at either end of the dam. Soil borings should be taken to locate an adequate site for an emergency spillway. Loose, sandy soils and other highly erodible soils should be avoided. Small farm ponds may not have an emergency spillway.

**Levee ponds**

Levee ponds are principally used for commercial fish, shrimp and crawfish production. They are constructed by digging holes in the ground and building levees around them (also called *excavated ponds*) or by impounding water above natural dikes or levees.

Levee ponds cannot be filled by surface runoff. Water must be pumped from a well or a surface source. A well is usually drilled after ponds are constructed so that it can be strategically located to make water delivery easy.

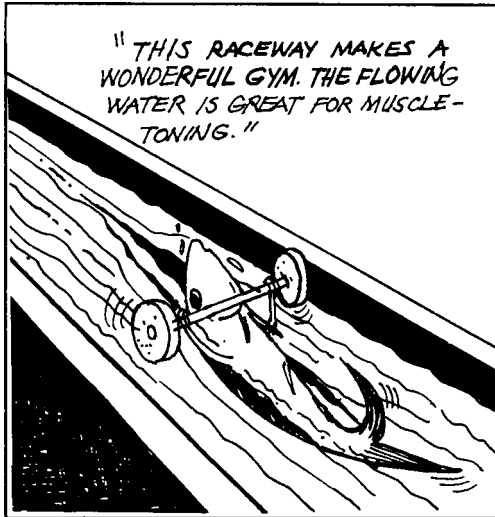
Ponds vary in sizes: 0.05-2.0 ha for nursery ponds, 0.25-10 ha for broodstock or grow-out ponds, 1-5 ha for intensive culture, and 0.01-0.05 ha for spawning ponds.

Rectangular ponds can be constructed adjacent to one another, making water supply and management practices easier. Square ponds are more economical to construct than rectangular ponds, but on steep slopes, rectangular ponds are easier to drain. Regardless of the shape, ponds should be no more than 213 m (700 ft) wide to make harvest by seining easy.

Soil that is removed when excavating ponds is usually used to construct the levees. These should be built to last and must be large and compact enough to support large trucks or heavy equipment. Wider levees are more convenient and more resistant to wave damage but are more expensive to build. Good pond management dictates that motorized vehicles should have access to ponds on at least two sides.

**RACEWAY CULTURE**

Raceways, also called flow-through systems, are culture units in which water flows continuously, making a single pass through the unit before being discharged. They are designed for highly intensive culture. Good water velocity is essential to the health of the culture stock and to flush wastes from the system. Water quality is maintained by manipulating water flow rate and by putting in place water treatment processes. Water quality and quantity are easier to manage in raceways than in ponds.



The number of fish that a flow-through system can support is dependent on water quality, management skills, local conditions and species biology, including the ability to tolerate crowding.

Flowing water forces the fish to "exercise." Studies have shown that exercised fish have better survival rates when stocked into the wild. The shallow water in raceways allows visual observation of the fish so that diet and

disease problems can be promptly corrected. Feeding and disease treatment are more easily managed in raceways than in ponds. On the negative side, raceways have higher risk of diseases due to stress caused by confinement and crowding.

Raceways can be designed simply (Fig. 4). Incoming water usually requires pretreatment -- aeration, heating or cooling, degassing or filtration -- before it can be used. Depending on the effluent water quality, discharged water may also require post-treatment before it can be released into the environment. Although earthen raceways are sometimes used, majority are constructed from concrete or cement blocks. Earthen raceways are sometimes lined with waterproof materials to reduce water leakage. Many small, experimental raceways are fabricated from wood, metal, fiberglass, plastic and other materials.

Multiple raceways are arranged in parallel or

in series (Fig. 5). Series raceways can be used in regions where there is sufficient land slope -- about 1-2% -- so that the outlet for one raceway serves as the inlet for the next in the series (Fig. 6). However, waste buildup can be a serious problem since the wastes from the upstream unit enter the next unit downstream. Wastes tend to increase as the water traverses through the system. The waste problem is somewhat alleviated if downstream culture units do not receive wastes from upstream units.

One major advantage of raceways is ease of harvest. Harvest is usually accomplished by pulling a seine from one end of the raceway to the other, crowding the fish into a small area where they can be netted. Some facilities have automated harvest screens or grader bars which allow smaller fish to escape from the crowding area to grow larger in the raceway.

## TANK CULTURE

Tanks are used for fry production or as temporary holding facilities for fingerlings or broodstock. Tanks may also hold aquarium fish for culture or for public display. Except for small operations, tanks are not normally used to produce food fish.

Tanks must be durable, portable, easy to clean and sterilize, non-corrosive and affordable. Its interior should be smooth and non-toxic. Non-toxic seals such as epoxy, fiberglass resin paint or waterproof liners can be used.

### Fabrication

Tanks are constructed from wood, concrete, plastic, fiberglass, metal and glass.

Inexpensive tanks can be easily fabricated from marine plywood. Plywood that are 19 mm thick (or thicker) are used so that tanks won't flex excessively when filled.

Concrete is practical for large tanks or pools. Properly reinforced with steel bars, concrete will last indefinitely. Concrete is best used to construct permanent facilities because of its weight and expense.

Plastic tanks are made of polymers including polypropylene, polyethylene, polybutylene, polyvinyl chloride (PVC), acrylics and vinyl. Each has its own set of good and bad features. A major

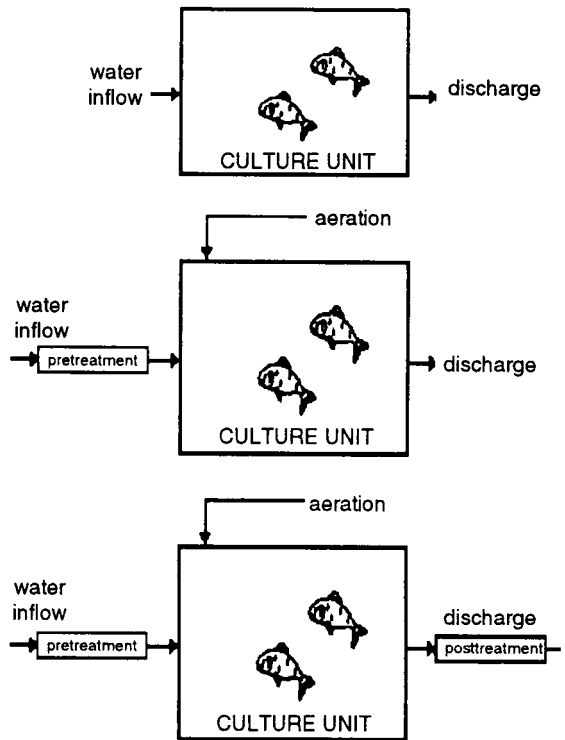


Fig. 4. Single-pass raceway systems (top to bottom): no treatment, with treatment and aeration, and with pre- and posttreatment.

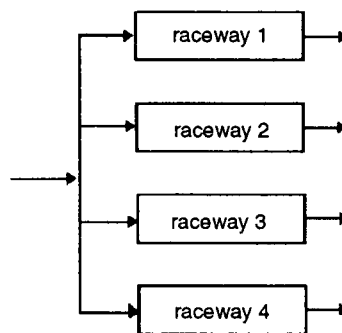


Fig. 5. Parallel raceway units.

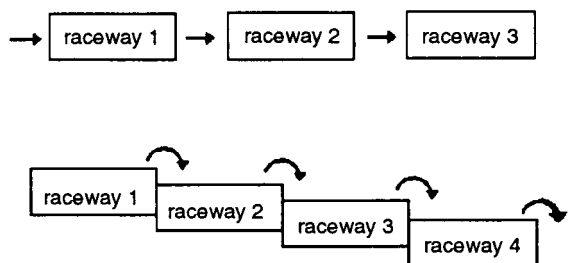


Fig. 6. Raceway units in series: on flat ground (top) and on sloping ground (bottom).

advantage of plastic tanks is that they are light-weight and portable. Repairs are also easier.

Fiberglass is preferred for tank culture since it is lightweight, strong, durable, modestly priced, inert in both fresh- and saltwater, and can withstand the effects of UV rays if used outdoors. Fiberglass tanks are normally gel-coated to smoothen the inner surface so that it can be easily cleaned and disinfected. The tanks can be easily drilled to install drains and fixtures.

Aluminum and steel are two metals commonly used to fabricate small tanks (several hundred liters and smaller) popular in hatcheries for rearing fry and fingerling. If used with caution, some aluminum alloys can be used for brackish- or saltwater culture. Some are rubber-coated but most are lined. Without coating or lining, zinc can leach from galvanized coating and cause heavy metal poisoning.

Glass culture units are found almost exclusively in the aquarium trade or for public display aquaria.

Waterproof liners can be used with tanks fabricated from virtually any material. These can substitute expensive coatings or sealers, eliminating toxicity by heavy metals, paints, treated wood or other substances. Liners can be custom-made to fit any tank size or shape. If carefully handled, these can last for 5-10 years.

### Shapes and sizes

Round tanks are commonly used for nursery or grow-out. Square and rectangular tanks make better use of available floor space since they can be placed side by side, but round tanks typically have better hydraulic characteristics.

Round tanks have either a flat or a sloping (conical) bottom. Although sloping round tanks are more expensive, they are more efficient at removing wastes. Flat-bottomed tanks will self-clean if there is adequate water velocity. Water circulation in round tanks does not allow dead areas where water hardly moves; wastes are also efficiently removed (Fig. 7). Round tanks have central standpipes that are fitted with outer pipes or sleeves. Openings near the tank bottom facilitate waste removal. Screens or grader bars that can be rotated around the central standpipe facilitate the removal of fish by crowding them into a small area where they are netted. Selective harvest is possible by using big nets to catch bigger-sized fish.

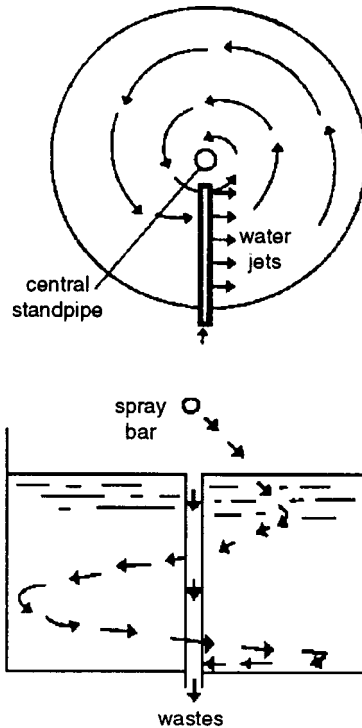


Fig. 7. Round tank: water circulation patterns (arrows, top) and water direction during draining (bottom).

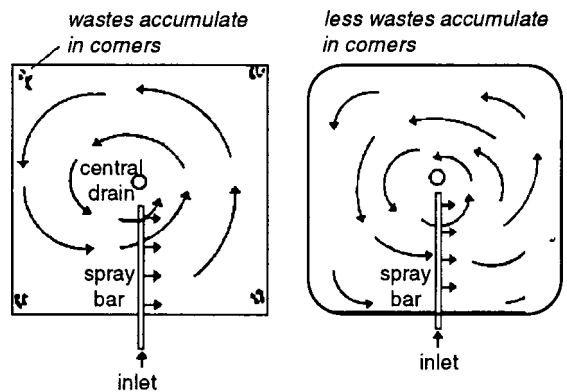


Fig. 8. Rectangular tanks: flow patterns (left); if modified -- with more rounded corners -- less wastes accumulate in corners (right).

Rectangular tanks and troughs are most often used for rearing fry and fingerlings in hatcheries. The bottom can slope towards one end or towards the center. In tanks that drain at one end, the water enters from a different end, much like a raceway. Flow patterns often form dead areas like tank corners. Fish may become



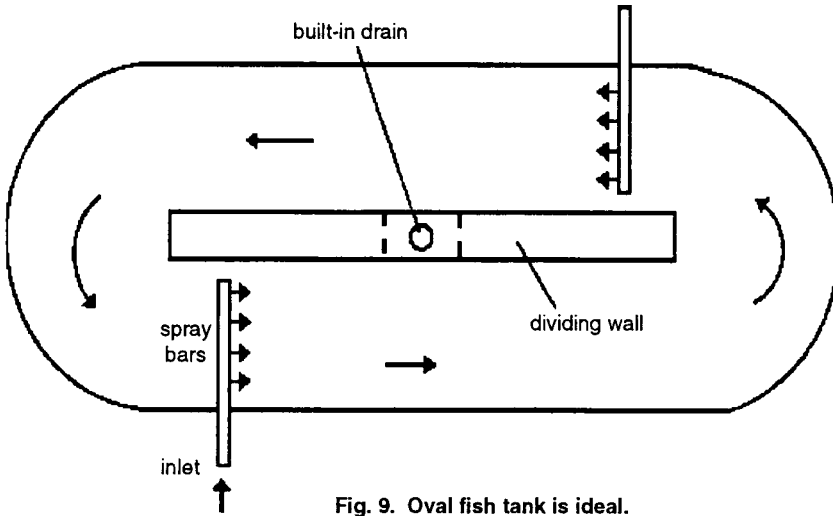


Fig. 9. Oval fish tank is ideal.

stressed, if not die, if metabolic wastes accumulate to dangerous levels. Fish collected from the wild and then placed into rectangular or square tanks tend to crowd into a corner where they may locally deplete the oxygen, or they may bash into the sides of the tank, causing serious injury.

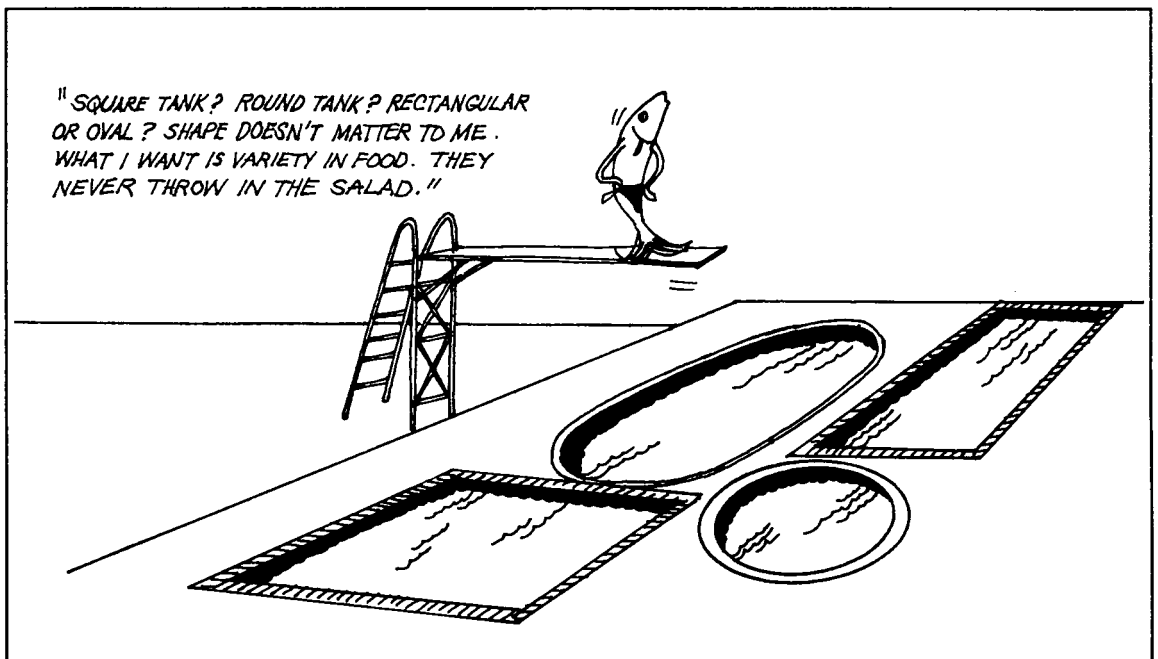
Square culture units have disadvantages similar to rectangular tanks in that wastes tend to accumulate in the corners (Fig. 8). The hydraulic characteristics of square tanks can approximate circular tanks by constructing them with rounded corners (Fig. 8). And like round tanks, a central or external stand pipe with screen may be used as drainage.

A compromise between the round and rectangular tank is the oval tank constructed with a partition that divides the tank (Fig. 9). Water flow is generated by spraying the inlet water through a nozzle or series of water

jets in the direction of circulation. In lieu of water jets or nozzles, a small paddle wheel can be installed. The outlet standpipe is normally placed at the center of the partition.

If floor space is limited, square or rectangular tanks can be stacked. The number of tanks in the stack depends on tank depth and ceiling heights. Bracing support must be strong enough to hold the tanks if filled to capacity. Space should be adequate for stocking, feeding, harvest and other activities. Elevated tanks can be drained completely by removing the central standpipe, but those on the ground must be pumped.

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## RECIRCULATING SYSTEMS

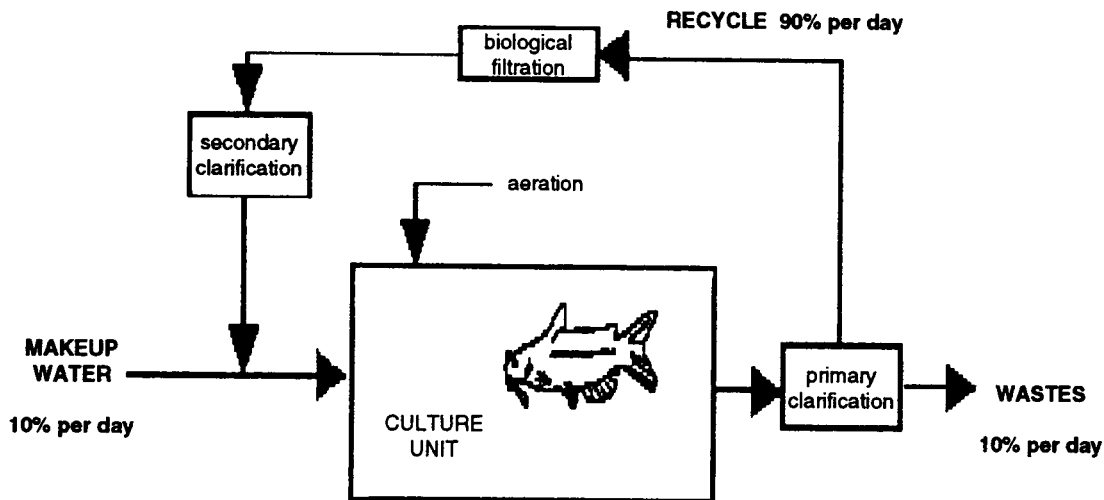


Fig. 10. A recirculating culture system utilizing 90% recycled water per day.

In recirculating systems, fish are confined at high densities. Normal culture density is 61-122 kg/m<sup>3</sup>, but densities in small-scale experimental systems have exceeded 545 kg/m<sup>3</sup>.

Economic analyses of recirculating systems indicate two key operating parameters:

- (1) system operation with minimal energy input
- (2) proper water purification

Aquaculture engineers are challenged to develop designs that optimize these criteria.

Contaminants that have negative effects on water quality are ammonia, urea, CO<sub>2</sub>, feces and other metabolic wastes. Organic wastes are further degraded to produce additional ammonia, nitrite and nitrate. In the close confines of recirculating systems, the effects of these substances are acidic water, depleted dissolved oxygen and increased turbidity, making water more inhospitable to the fish. In addition, many minerals and essential trace elements are lost.

The amount of wastes produced depends on the fish species cultured and life stage, system biomass, and the type and amount of feed given to the fish. The rate and degree of water quality degradation can be managed with proper water treatment. The principal treatment processes include screening, settling (sedimentation), granular media filtration, biological filtration, aeration and disinfection.

A generic recirculating system is illustrated in Fig. 10. *Primary clarification* includes screening, sedimentation, granular media filtration or a combination of any of the three. It is important to remove solids prior to biological filtration. Biofiltration lowers ammonia and nitrite levels. It is the heart of any recirculating system.

*Secondary clarification* usually follows biological filtration to remove the biological floc that frequently sloughs from the filter media. It is important that this material not be allowed to remain suspended. Secondary clarification includes sedimentation but may also include screening. Finally, aeration is added for basic life support system. The system is driven by a water pump (not shown in Fig. 10).

Water in recirculating systems completes the entire circuit many times daily. Depending on culture intensity, filtration may be required from two to four times per hour. At a minimum, the water should receive complete treatment one to two times per hour. A daily partial water exchange is necessary to control nitrate, remove pollutants and replenish minerals and trace elements. As much as 90% of the water can be recycled daily. The other 10% is "new" water. In effect, the total volume is replaced once every 10 days. Lightly loaded systems may fair well with a 3-5% daily water exchange. Systems employing 100% recycle are rare.

## Physical, chemical and biological processes used to recondition water for recycling

PHYSICAL	CHEMICAL	BIOLOGICAL
Screening	Aeration	Nitrification
Settling	Pure oxygen injection	Denitrification
Sand filtration	Alkalinity and hardness control	
Diatomaceous earth filtration	Carbon adsorption	
Centrifuging	pH control	
Temperature control	Reverse osmosis	
UV sterilization	Degassing	
Cartridge filtration	Foam fractionation	
Bag filtration	Ion exchange	
	Ozonation	

The bubbles create a foam at the top of the liquid column, and are discarded.

### *Biofiltration*

This technique utilizes living organisms to remove a substance from a liquid solution. Algae or higher green plants are used. *Biofilters* can remove ammonia and nitrite. It is generally accepted that, after oxygen, ammonia often becomes the limiting factor in recirculating systems.

Types of biofilters include

submerged, trickling, rotating disks or drums, fluidized beds and low-density media filters.

Submerged filters consist of a vessel filled with a media upon which nitrifying bacteria grow. Culture water is passed through the filter by a spray bar, and gravity pushes water downward through the unit. Completely submerged at all times, the media is supported by a perforated bottom through which the treated water drains and flows out of the unit. Rock is the most common type of media used in submerged filters. Limestone rock is popular since it provides buffering against rapid pH changes.

Trickling filters basically function the same as submerged filters except that the media is not submerged. Culture water trickles downward through the media and keeps the bacteria moist but not completely submerged.

Rotating media filters incorporate aspects of both fixed and suspended media operation. Fixed media are rotated in vessels through which the culture water (suspended media) flows.

In fluidized bed reactors, the media is contained in a vertical vessel with a cylindrical or square cross section. The media is kept in suspension or fluidized by the upward flow of water. The degree of fluidization depends on the upward flux of water through the vessel. Coarse sand is the most common media used.

Source: Lawson, Thomas B. 1995. **Fundamentals of Aquaculture Engineering**, Chapman & Hall, New York, NY 10119.

### *Screening*

The simplest and the oldest wastewater treatment process, screening is often used as pretreatment prior to the primary treatment. Screens placed across the waste stream can trap solids. Coarse ones are used to treat the raw effluent from the culture unit. It can also trap the biofloc that sloughs from biofilters.

### *Activated carbon*

Activated carbon is made by charring coal, pecan, coconut or walnut shells, wood or animal bones. These materials are heated to about 900°C in the absence of air. The charred material is then activated by exposing it to an oxidizing gas at high temperature. The gas creates a highly porous structure in the char and a large internal area. Activated carbon can remove volatile organics, color, odor and suspended solids.

### *Ion exchange*

Certain ions are displaced from an insoluble exchange material (resin) by ions of a different chemical dissolved in the wastewater. Ion exchange resins are manufactured in the form of tiny porous beads about 1 mm in diameter.

### *Foam fractionation*

This process removes dissolved organic carbon (DOC) and particulate organic carbon (POC) by adsorbing them onto the surfaces of air bubbles rising in a closed contact column.