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# A CLOSED SEA WATER FLOW-THROUGH-SIPHON SYSTEM FOR THE CULTIVATION AND REARING OF MARINE ANIMALS

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## ABSTRACT

A closed sea water-flow-through siphon system has been developed and described. Studies were made on the effect of activation of biological filter bed through "seeding", turnover rate, water quality management, carrying capacity and overall control of the system.

## INTRODUCTION

Various types of aquaculture methods employing open, semiopen and closed sea water system are used in the field of mariculture for the successful cultivation, maintenance and management of marine animals. Though considerable achievement has been made from time to time in this field, no method as yet is entirely satisfactory. Hence, attempts are being made to develop and refine the existing techniques and design new models to meet local needs. Kinne (1976) has discussed the various developments in the cultivation of marine organisms, water quality management and technology.

To create marine conditions in the laboratory is, of course, impossible, but a system should maintain the quality of the media as near to the *in situ* conditions as possible. In the present paper a closed-sea-water-circulating system which is simple, efficient and can be conveniently used anywhere is described. Special references are also made to its efficiency in nitrification and in particular to its special advantages. Some of the principles used in designing this system come from the design of Nair, Gopalakrishnan, George Peter and Rao (1978), but, many modifications have been made to improve working efficiency and the practical use of the system.

## MATERIALS AND METHODS

An automatic flow-through-siphon system is used to maintain the circulation of the water from the head tank (a1) to the rearing tanks (e1-e5) and from there to the receiving tank (a2) for filtration (Fig. 1). The head tank, the rearing tank, the physico-chemical filters (c1 and c2) and the receiving tank are kept at different heights (Fig. 1). This difference in heights is made to maintain a steady and constant automatic-feed back-system from the head tank and also for avoiding overflow from the rearing tanks in case of pump or electric failure. Depending on the local conditions and need any corresponding increase or decrease in the size of the system, or in the various heights in the setting up can be made.

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Salinity was measured with an araometer (Seewasser Araometer, Richter and Wiese, Berlin-SW-61) which was calibrated against a salinity autoanalyser (Autosol· Model 8400, Guildline Instruments Ltd., Canada); pH, by using a pH meter type 29 (Knick, Elektronische Messgerate, Berlin-37, BRD); oxygen, by using an oxygen meter (Model D-812, OX 156, Wiss. Techen. Werkstatten, Weilheim, BRD); ammonium by colorimetric method (Benesch and Mangelsdorf, 1972); phosphate, by using an autoanalyser (Mangelsdorf, 1972); nitrate and nitrite, by the methods of Grasshoff (1976).

*Description and assembly of the system :*

A general flow diagram of the system is given in Fig. 1. The system essentially consists of two larger tanks (a1 and a2) made out of polyester reinforced with fibreglass (430 l: 93 x 68 x 75 cm). The head tank (a1), which is kept at a height of 60 cm from the floor level, functions as the supply tank where filtered and renewed seawater is stored and supplied. The filtered water, before being supplied to the rearing tanks, is well aerated with a specially designed aerating system (m3). Pressurized air is forced through an "L" shaped polyvinylchloride (PVC) tube (diam. 1·5 cm) which opens into aerator stones fitted as illustrated in Fig. 1. The aerator stones are downwardly directed to facilitate uniform bubbling through all the stones. The whole aerating system is kept at an angle of 45° from one of the corners. This allows aggregation of foam at two opposite corners of the tank. From there the foam can easily be removed. On one side of the tank an automatic salinity control mechanism (u1) is provided having a PVC cylindrical reservoir (10·1). The reservoir is provided with two outlets (u5 and u4) which are regulated by a sliding piston made of solid PVC. The piston is connected to a plastic ball (the float, u2) with a PVC rod and is ensheathed in a PVC tube (u3) for its free movement with the float as the water level changes. Before the system is operated, the level of the tank (u1) is adjusted to level 'b2' to keep the float over the surface of the water. The tank (u1) when filled with fresh water functions as an automatic salinity control. Due to evaporation, water is lost from the reservoir moving the float and, thus, the piston away from the outlets (u5 and u4). This allows movement of water from the reservoir (u1) into the head tank (a1) replacing water lost due to evaporation. From the head tank, water is led through a silicon tube (diam. 12 mm, h1), to the main distribution tube (d1, polyethelene; length, 1·5 m, diam. 3·6 cm). The silicon tube is provided with a valve (v1) to regulate flow. The proximal end of the tube which is inside the head tank is fitted with a filter (i1), nylon gauze 200μ) to prevent large particles from entering the distribution system. At the distal end of the distribution tube (d1) there are two outlet valves (v2 and v11). Between the two valves there is a bulbous section which is made of glass or transparent polyvinyl material. The distal end of the tube is tightly closed with a screwable cap which allows cleaning of the tube when required. From the main distribution tube there are five equidistant and downwardly directed outlets fitted with glass control valves (va-ve). The glass valves are connected with a length of silicon inlet tubing (f1 to f5; diam. 4 mm) which directs the water into the rearing tanks. The rearing tanks (e1-e5, 30 x 22 x 24 cm) are kept on an elevated platform, 75 cm above the floor level (Fig. 1). A set of filters is attached to the inside walls of each rearing tank into which open the inlet (va-ve) and outlet (f6-f10) tubes respectively. These filters are made of polyvinyl, cut and fitted with nylon gauze as illustrated in Fig. 2-c. Water from the rearing tank is led through outlet tubes (f6-f10) into the common collecting tube (d2). From there to the receiving tank (a2) the water

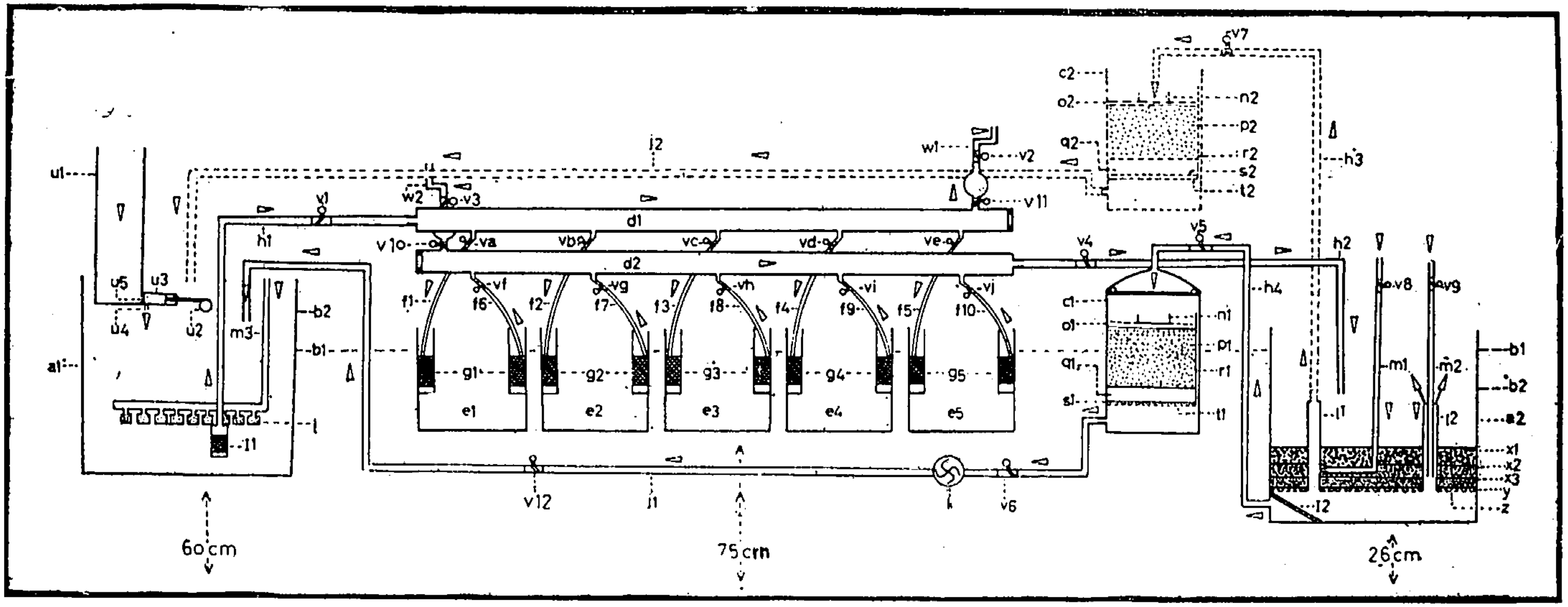

*Fig.* 1. Schematic flow – diagram for automatic flow – through – siphon system :

a1–Head tank;
a2–Receiving tank;
b1–Water level prior to operation;
b2–Water level at operation;
c1 & c2–Physico-chemical filters;
d1 & d2–Main supply and receiving tubes;
e1 to e2–Rearing tanks;
f1 to f2–Inlet tubing;
g1 to g5 & i1 to i2–Nylon gauze filters;
j1 & j2–Supply tubes;
k–Electric pump;
1–Aerator stones;
m1, m2 & m3–Air inlets;
n1 & n2–Glass bowls;
o1 & o2–Glass wool;
p1 & p2–Activated carbon;
q1 & q2–Perlon;
r1 & r2–Polyvinyl tube;
s1, s2 & y–Nylon gauze;
t1, t2 & z–Porous PVC sheets;
u1–Fresh water reservoir;
u2–Float;
u3–Piston;
u4 & u5–Outlets;
v1 to v12 & va to vj–Glass control valves;
w1 & w2–Outlet valves;
x1–Gravel;
x2– Coarse sand;
x3–Crystal sand;
l1 and l2–Polyvinyl tubes.

moves through a length of silicon tube (h2)· The main collecting tube is similar to the main distribution tube in design and construction· The main distribution and receiving tubes are kept at different heights and the distal end of the tubes are kept slightly elevated, as illustrated in Fig· 1· The tubes are supported by two wooden stands on either side (Fig· 2 a and b) of the same platform on which the rearing tanks are kept· The receiving tank (a2), which is exactly of the same size as the head tank, is provided with a biological filter· The filter is set up on a perforated PVC sheet (2 mm pore size, thickness 15 mm) which is fixed at a height of 12 cm from the bottom of the tank· The PVC sheet is given adequate support from the bottom of the tank to take the heavy load of the filter bed· Two polyvinyl tubes of 10 and 15 mm (l1 and l2) are fixed on the PVC sheet (Fig· 1)· A fine nylon gauze is spread over the porous PVC sheet· The edges of the nylon gauze and the edges of the PVC sheet are glued with silicon gel to the walls of the tank, to prevent the flow of water through the edges of the filter bed· Over the nylon gauze, a layer of crystal sand (1–2 mm grain size, height, 60 mm); a layer of coarse sand (2–5 mm grain size, height 80 mm); and a layer of gravel (5–15 mm grain size, height 100mm) are uniformly spread· The receiving tank is kept at a height of 26 cm above the floor level· It is provided with an outlet situated at a height of 50 mm above the bottom of the tank and is below the level of the filter bed· The outlet is fitted with a length of silicon tube (h4; diam· 12 mm) which is in turn connected to the inlet of a physico-chemical filter (c1) where the tube is provided with a 3-way valve (v5)·

The cylindrical physico-chemical filter (c1) is made of PVC (height 50 cm; width 25 cm) with a removable air-tight lid (rubber gasket) which must be sealed while in operation· The physico-chemical filter is equipped with a porous (2 mm pore size) PVC sheet (t1) of 25 cm diameter fixed at a height of 8 cm above the bottom of the container· Towards one edge of the PVC sheet is fixed a thin polyvinly tube (r1) which allows the escape of any trapped air from the collecting chamber· On the PVC sheet is spread a nylon gauze (200μ) and both are glued to the surrounding wall of the filter·

Further support for the PVC sheet is provided from the bottom of the container· Over the nylon gauze are the tightly packed layers of perlon (q1; height 10 cm), granulated activated carbon (p1; height 22 cm) and glass wool (o1, height 5 cm)· On top of the glass wool is placed a fairly thick perforated glass disc (diam· 24 cm) which helps to keep the various layers as packed as possible· A small glass bowl (n1) is glued at the centre of the glass disc, to provide uniform distribution of incoming water· After filtration, the water is pumped (electric pump–Eheim–type 381, k) from the collecting chamber through a hole (diam· 12 mm) and into the head tank via a length of silicon tubing (j1; diam· 12 mm)· Two glass valves (v6 and v12) help to regulate the pumping rate· Just above the physico-chemical filter, which is connected with the pump, is one more filter of the said type (c2)· However, this filter should not be air tight, because it is connected with an air lift mechanism (Fig· 1)· Pressurized air is introduced to the system via silicon tubing (ml, diam· 6 mm) and then into a vertical polyvinyl tube (l1 diam· 15 mm), the top of which is connected with another silicon tube (h3; diam· 10 mm)· Water is thus drawn up from the collecting chamber of the biological filter through this tube to the physico-chemical filter (c2)· After passing through the physico-chemical filter the water accumulating in the collecting chamber of the physico-chemical filter is fed by gravity to the head tank through a delivery tube (j2; diam· 12 mm)·

## *Operation of the System:*

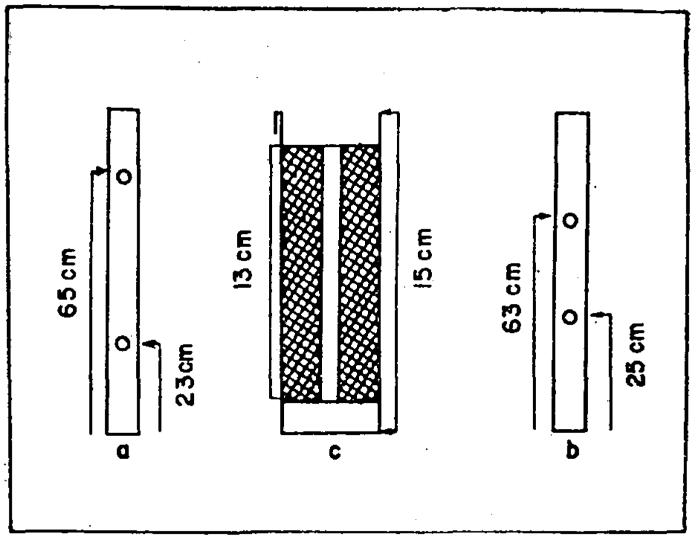

*Fig. 2.* a- & b- Wooden stands; c - Nylon gauze filter. (Provided inside the rearing tank)

Before the system is put to operation, the biological filter has to be activated by seeding with nitrifying bacteria to optimize the efficiency of the filter. This was achieved here by allowing running sea water to pass through the filter bed for a period of 10 days. Once the filter bed is conditioned, sea water or brackish water of desired quality has to be added to all tanks-head tank, rearing tanks, and the collecting tank-to the level indicated (b1). The physico-chemical filter (c1) should then be totally filled with water. After filling, the lid should be replaced and tightly screwed to prevent any air leakage. Before starting the electric pump all valves provided (v5, v6 and v12) should be opened. Once in operation, the pump will draw water from the collection chamber of the physico-chemical filter which in turn will draw water from the bottom of the biological filter bed. Before water is allowed to pass through the physico-chemical filter, it is routed through a nylon gauge (i2) to avoid the entry of large-sized particles into the filter.

As water is pumped through the system, the water level in the filter tank (a2) will fall to b2 resulting in a corresponding rise (to b2) in the head tank. At this stage, air trapped inside the main distribution and collecting tubes (d1 and d2) and associated tubes should be removed through the outlet valves (w1 and w2) with the aid of a vacuum pump. All control valves provided in connection with the supply and collecting systems should be kept open. When the vacuum pump (connected to outlet w1) is started, the air in all the tubes is replaced by water. Once the bulbous portion of the 'outlet system' is found filled with water, valve (v2) should be immediately closed, and the vacuum pump turned off. This results in an automatic flow of water into the rearing tanks. The same procedure is adopted to remove air from the main collecting tube (d2). Water will then flow back to the biological filter bed through the silicon tube(h2). As long as the water level in the head tank is kept higher (either by pumping or by air lift) than the levels in the rearing and the receiving tanks, water will automatically circulate through the system. The arrows (Fig. 1) indicate the direction and course of water flow.

Water brought in by the delivery tube from the rearing tank is filtered through the filter bed. Filtering action of the bed is aided by suction due to the constant removal of water from below the filter bed. Water thus filtered is recirculated through the filter bed several times. This is achieved through the introduction of compressed air through a silicon tube (m2) and then into a polyvinyl tube (l2) as illustrated in Fig. 1. This recycling process allows not only efficient oxygenation in the filter bed, but also gives ample time for the nitrifying bacteria to act on the toxic metabolic byproducts and to convert them to relatively non-toxic substances. The free ends of all tubes associated with the circulation of water should be kept submerged. This allows completely closed operation of the system. The electric pump and the air lift should be used alternately to obtain maximum efficiency of the physico-chemical filters. The rate of water flow through the air lift pump can be controlled by adjusting valves (v8 and v7).

*Maintenance :*

The overall efficiency of the biological and physico-chemical filters depends upon the capacity of these filters to denitrify and otherwise renew the recirculating water over a long period of time. Excessive sedimentation, which is likely to exceed microbial degradation of metabolic waste products in the biological filter, may be avoided by the following methods. Suitable filters (g1-g5) should be provided in the rearing tanks. These filters prevent easy passage of any particulate matter or excess food from the rearing tanks into the biological filter. Any excess food found remaining in the rearing tanks should be removed immediately to avoid decomposition. When fine nylon gauze filters are used they should be cleaned periodically. During the removal and reinstallation of the filters for cleaning, care should be taken to see that the free ends of all tubes are always submerged. These filters should be kept above the bottom of the rearing tanks (Fig. 1) to avoid excess clogging by the accumulation of excreta or deposition of suspended matter. In the case of extreme sedimentation, periodic stirring of the upper part of the filter bed and removal of the sediment, or rerouting of the water through a settling tank is recommended.

The glass wool (o1 and o2) in the upper most part of the physico-chemical filters may also become periodically clogged with suspended material. The wool should, in this case, be replaced. To maintain the maximum absorption efficiency of the activated charcoal, it should be removed, cleaned with fresh water and dried before replacing. If new charcoal is used, this should also be washed before being used.

After prolonged use, air bubbles may develop in or enter the system. These bubbles will be collected in the bulbous portion of the outlet valves (w1 and w2). When a large amount of air is noticed in the bulb, the lower valves (v10 and v11) should be closed. The upper valves (v2 and v3) which normally have to remain closed, should then be opened. The bulb should then be filled from above. When filled, the upper valves should be closed, and the lower valves again opened. The reservoir of the automatic salinity system should be kept filled with fresh water.

## RESULTS AND DISCUSSION

The efficiency of closed-water system depends upon : 1. the size and shape of the culture enclosures; 2. the culture water quality; 3. water treatment efficiency; 4. animal load; 5. rate of water replacement or recirculation; and 6. oxygen and carbon dioxide concentration as well as other parameters (Kinne, 1976).

The shape of the culture enclosures should depend on local needs and conditions. However, such enclosures which may leech toxic substances should be avoided. Plastic tubing which was used in the model system was found to produce a slimy substance after about 20 days. Small cultured invertebrates entangled in the slime were often found dead. After cleaning, the slime did not reform in the tubing.

Based on these observations, it is advisable to leave the plastic tubing in sea water for a period of about a month and then to clean it before use· Heat-resistant silicon tubing (used in this system) is highly recommended·

Special care should be taken while setting up the biological and physico-chemical filters, where most of the water renewal takes place· The conventional type of biological filter has a top layer of crystal sand, a second layer of coarse sand and a bottom layer of gravel (Hirayama, 1966 a and b)· With such a filter, the filtering efficiency depends on the tight packing of the various layers, because the fine filtration is effected in the top most layer· After a period of time clogging and the formation of small crevices through the crystal sand is quite likely· This may be aided by suction produced below due to the removal of water by the electric pump· The suction may also cause movement of the crystal sand into the coarse sand or coarse sand into the gravel· The crevices thus formed drastically lower the efficiency of the filter· The only advantage in such a filter is that, in the case of heavy sedimentation, removal from the top layer is easy· The system described here is equipped with a filter bed set up in the reverse order (Fig· 1), where the fine filtration is effected by the bottom most layer· Although the filtration efficiency is very high in such a system, the major disadvantage is that the top layers (gravel and coarse sand) allow the entry of particulate matter deep into the filter bed· This problem can, however, be avoided by providing suitable filters in the rearing tanks or by introducing a settling tank between the rearing tanks and the filter· The settling tank, when used, must be kept at the same level as the collecting tank· The advantage of such a filter bed is that the gravel, coarse sand and the crystal sand provide a much larger surface area for the colonization of oxidizing bacteria· This colonization is also aided by the recirculation of well oxygenated water through the filter· Under normal circumstances, crevice formation is not possible· Biological filters of more or less the same design have been used by Nair, Gopalakrishnan, George Peter and Rao (1978) in connection with closed sea water systems· These systems are being used to cultivate marine and estuarine invertebrates in tropical areas and have been found to work very efficiently for periods in excess of 3 years· The total surface area of the biological filter is very important in a closed system· As a general rule, the area of the filter bed should be equal to or exceed the area of the culture container (Kinne, 1976)· This rule is followed in the present design·

Biological filters used in large aquaria have been found to take about 60 days for effective nitrification (Saeki, 1963)· Preliminary observations made with a model system (capacity 110 l; 98 ml animal load composed of amphipods, isopods, and polychaetes) also support Saeki's findings (see Table I)· The length of time required for this activation process has been the subject of much study· It is known that the two types of nitrifying bacteria, *Nitrosomonas* and *Nitrobacter,* effect the nitrifying process in biological filters· Barrit (1933) and Chase (1948) suggested garden soil as a rich source of these nitrifying bacteria· Carmignani and Bennet (1977) suggested the use of gravel from existing biological filters as a possible trigger· In the present study running sea water, used as a 'seeding' source was allowed to pass through the filter bed for a period of 10 days before it was used· This resulted in an effective nitrification from the beginning (Table II)·

The efficiency of a closed-sea water culture system depends on 1· production rate of metabolic waste products like ammonia, urea, uric acid, protein and amino acids; 2· the conversion rate of these molecules to nitrite, nitrate and organic compounds, and 3· consumption of these molecules by introduced micro-organisms, algae and phytoplankton·

Ammonia in a closed system is mainly produced by metabolic byproducts and decaying organic matter· In the open ocean the ammonia concentration can vary from 0·1 to 10 µg-at/l (Kinne, 1976)· With the help of seeded filters Carmignani (1977) reported that a concentration of 143 µg-at/l of ammonia was reduced to negligible levels within 9 days· An ammonia concentration of 7·5 µg-at/l was found to decrease within 4 months to 2·1 µg-at/l (Nair, Gopalakrishnan, George Peter and Rao, 1978)· In the present system, which had an initial concentration of 3·42 µg-at/l ammonia was found to increase to a level of 15·9 µg-at/l after about 27 days (Table II)· The ammonia was oxidized and brought very near to the original level during the next 15 days· The oxidizing efficiency of biological filters increase with a decrease in temperature from 25 to 5°C (Haug and McCarty, 1972)· This may well account for the rapid ammonia oxidation rates noted in the present study, while the entire system was operated at 12°C constantly·

pH measurements can act as an indicator of ammonia concentration in sea water· The pH of normal sea water is between 7·8 and 8·2, and an increase in pH from 7·5 to 8·5 represents a 10 fold increase in concentration of ammonia (Kinne, 1976)·The work of Downing and Merkens (1955) indicates that *Salmo gairdnerii* (rainbow trout) can withstand a 10 fold higher concentration of ammonia at pH 7 than at pH 8· In the present system, the pH values fluctuated between 7·7 and 7·9 over a period of 3 months (Table II)· In a closed-sea water system pH values below 7·6 and above 8·2 are not desirable (Kinne, 1976)· In the case of low pH values, addition of calcium or magnesium oxides is recommended·

The survival period of an animal, even if it is at ammonia toxification levels, can be prolonged under high dissolved oxygen concentrations (Downing and Merkens, 1955)· With an ammonia concentration of 7·5 µg-at/l and 93% oxygen saturation, small invertebrates cultivated over a period of 2 years showed no noticeable change of any kind but not as efficient as before, again causing a reduction in nitrate levels (Table II)· A corresponding increase in ammonia was found with the increases in nitrate· This has been due to the decomposition of the algae in the absence of light· It is interesting to note that at high values of nitrate, ammonia and phosphate, the pH of the sea

*Table I*· Water quality at various time intervals (Data from the model system)

| No. of days | Salinity (°/oo) | pH | Nitrite (µg-at/l) | Nitrate (µg-at/l) | Ammonium (µg-at/l) | Phosphate (µg-at/l |
|---|---|---|---|---|---|---|
| 1 | 33·60 | 7·90 | 0·90 | 13·60 | 4·30 | 0·89 |
| 7 | 33·90 | 7·98 | 0·88 | 13·40 | 4·60 | 2·84 |
| 14 | 33·60 | 8·00 | 0·15 | 74·70 | 1·60 | 8·10 |
| 18 | 34·00 | 7·80 | 0·10 | 49·30 | 1·20 | 6·33 |
| 28 | 33·40 | 7·60 | 0·18 | 60·70 | 0·90 | 5·23 |
| 37 | 33·60 | 7·80 | 0·18 | 70·30 | 1·20 | 4·34 |
| 44 | 33·50 | 7·95 | 0·12 | 27·90 | 2·70 | 3·09 |
| 61 | 33·60 | 7·85 | 0·15 | 8·40 | 3·30 | 2·00 |
| 96 | 33·80 | 8·00 | 0·06 | 6·20 | 4.30 | 1·29 |

(Nair, Gopalakrishnan, George Peter and Rao, 1978)· Oxygenation in the present study is carried out at two stages, one in the biological filter bed, and the other in the head tank, where the oxygen level is close to saturation (Table II)· This allows well aerated water to flow through the rearing tanks without aeration in the tanks themselves· The specially designed aeration system (Fig·1) enables uniform bubbling of air in the head tank which allows foaming of the sea water· Metabolic byproducts and organic solids can accumulate in the foam produced (Short and Olson, 1970), which can be periodically removed· Various oxygenation methods and their efficiencies were studied and compared by Scott (1972)·

Nitrate and nitrite accumulation in a closed system are less dangerous than ammonia accumulation (Kelley, 1965)· However, very high nitrate levels may interfere with the respiratory process in invertebrates (Kinne, 1976)· In the open ocean, the nitrite levels vary between 0·01 and 4·0 µg-at/l and nitrate levels vary between 0·01 and 40 µg-at/l (Kinne, 1976)· In closed systems nitrite and nitrate levels should not exceed 2·1 and 322 µg-at/l respectively (King and Spotte, 1974)· An increase in nitrate can cause a decrease in the pH (Honing, 1934)· The oxidation of ammonia to nitrite and then to nitrate in a biological filter will take 28 to 60 days at temperatures varying between 21 and 26°C (Kawi, Yoshida and Kimata 1964; Spotte, 1970; Foster, 1974 and Hirayama, 1974)· Nitrite in the present study increased from 0·06 µg-at/l to 58·12 µg-at/l in 25 days· The values then decreased to 0·2 µg-at/l after another 40 days· This could be due to an increased turnover rate of the water through the filter bed· The concentrations of nitrate increased considerably (13·60–222·1 µg-at/l) over a period of 30 days· A corresponding increase in phosphate was also noticed (0·80–5·41 µg-at/l)· The green algae, *Chaetomorpha tortuosa, Ulva lactuca* and *Enteromorpha* and the phytoplankter *Dunaliella tertiolecta* were put in the filtering tank (a2) to bring down the nitrate and phosphate levels· The introduction of the algae with illumination from an underwater lamp caused a decrease in the nitrate concentration to 10·5 µg-at/l after 15 days (Table II)· The phosphate levels also dropped to a minimum of 0·4 µg-at/l, but only after 35 days· Without illumination over the next 25 days, the nitrate levels again climbed to 246 µg-at/l· With only week illumination the plants were effective,

*Table II.* Water quality at various time intervals ( data from the system )

| No. of days | Salinity (‰) | pH | Nitrite (µg-at/l) | Nitrate (µg-at/l) | Ammonium (µg-at/l) | Phosphate (µg-at/l) | Oxygen (mg/l) |
|---|---|---|---|---|---|---|---|
| 1 | 32·10 | 7·76 | 0·06 | 13·68 | 3·42 | 0·80 | 8·50 |
| 4 | 32·00 | 7·75 | 0·08 | 14·32 | 3·66 | 0·84 | 8·90 |
| 11 | 31·93 | 7·90 | 0·09 | 17·32 | 3·39 | 0·62 | 9·00 |
| 18 | 32·00 | 7·75 | 6·58 | 26·00 | 2·37 | 1·38 | 8·60 |
| 25 | 32·10 | 7·70 | 58·12 | 160·00 | 15·90 | 0·45 | 8·80 |
| 32 | 32·05 | 7·60 | 4·39 | 222·10 | 13·50 | 5·41 | 9·00 |
| 39 | 32·20 | 7·70 | 0·71 | 111·00 | 3·88 | 3·18 | 9·20 |
| 46 | 32·10 | 7·79 | 0·30 | 10·50 | 7·90 | 3·20 | 8·70 |
| 54 | 32·20 | 7·88 | 0·35 | 12·20 | 5·10 | 2·60 | 8·90 |
| 60 | 32·00 | 7·70 | 0·40 | 130·10 | 3·40 | 2·00 | 9·00 |
| 67 | 32·00 | 7·78 | 0·20 | 131·30 | 9·90 | 0·40 | 9·20 |
| 72 | 32·10 | 7·70 | 0·50 | 246·00 | 5·20 | 2·70 | 8·70 |
| 87 | 32·15 | 7·85 | 0·50 | 89·70 | 4·70 | 1·60 | 8·90 |
| 98 | 32·15 | 7·86 | 0·09 | 32·70 | 3·60 | 1·10 | 8·70 |

water decreased. If the water in the receiving tank is too turbid, algae may be cultivated in separate tanks and connected with the system.

The effect of algal water treatment has been demonstrated by various workers. Kinne (1976), employed *Enteromorpha, Ulva lactuca* and the phytoplankter *Dunaliella tertiolecta* for water quality management and Sorokin (1971) used *Enteromorpha* and *Chlorella* for controlling pH, to enrich the water with dissolved oxygen and for the removal of carbon dioxide. Siddall (1972) used *Oscillatoria* and *Chlorococcum* to reduce ammonia levels. Low levels of ammonia have been noted by Nair, Gopalakrishnan, George Peter and Rao (1978) as a result of rich diatom (*Navicula* sp.) growth in the rearing tanks.

The quality of the culture water depends to a large extent on the carrying capacity of the system. The carrying capacity is the optimum load of animals or plants which a system can support. To assess the carrying capacity, Saeki (1958) used ammonia as an index, and according to him, carrying capacity of a system can be increased by maximizing the turnover rate of the water through the filter bed. Hirayama (1965, b; 1966 a) used oxygen as an index. In the present system, the general water quality has been used to assess the carrying capacity. It was found that the system can support 1·648 kg of animal load and 0·75 kg of plant load under optimum conditions. A variety of animals have been used in the culture-system to assess the water quality under different conditions. According to Kelley (1963), a proportion of water to animal tissue of about 380 l to 0·45 kg is desirable. However, in the present system, the carrying capacity was found to be much higher. The total pumping rate of the filtered water to the head tank was restricted to 80 l/hr. This reduced rate was found sufficient, because of the efficient water quality management. This efficient water quality is partially a result of physico-chemical treatment of water, where most of the dissolved organic substances, inorganic nitrogen and phosphorus are removed. For closed-sea-water systems which exceed a capacity of 500 l, Spotte (1970) recommends the use of such physico-chemical filters or carbon contactors.

*Special advantages of the System :*

1. The simple, efficient siphon flow through system minimizes the use of complicated machinery.
2. The three stage level adjustment of the head tank, rearing tank, and the filter tank totally eliminates the possibility of an overflow in the case of electric or pump failure. At the same time, the siphon system maintains water flow uninterrupted over a longer period depending upon the storage capacity of the head tank.
3. Alternate use of the air lift and pump will extend the life of the activated charcoal used in the physico-chemical filters.
4. Effective turnover rate of well-oxygenated water through the biological filter will provide maximum time for the oxidizing bacteria to act on the various metabolic byproducts in the culture water.
5. The total flow rate, pumping rate or turnover rate of water can be altered as desired by adjusting the various valves provided.
6. Easily removable filters provided in the rearing tanks facilitates cleaning and reinstallation as and when required. These filters prevent the entry of large organisms or particulate matter into other parts of the system.

7. The inclined position of the main distribution and collecting tubes (d1 and d2) allows concentration of entrapped air bubbles inside the bulbous section of the outlet valves, from where they can be easily removed.
8. The stress on the animals reared, due to the widely practiced direct aeration process in the rearing tank is totally avoided.

*Precautions* :

1. Materials which are likely to leech out toxic substances when used with sea water should not be used as culture enclosures.
2. When PVC tubing is used for running water in a closed system it should be kept submerged in sea water for a minimum period of 30 days to allow leeching out of any toxic substances.
3. Air should not be allowed in the system.
4. Sufficient illumination should be given for algae being cultivated over the filter bed.
5. Smoke should not be allowed in closed culture rooms.
6. Preservatives or any sort of life endangering substances should be kept away from the vicinity of the system.
7. Materials used in handling the animals or plants cultivated must be totally clean and nontoxic.
8. Filtered air must be used for aeration to prevent petroleum products from the compressor coming in contact with the culture water. This can be achieved by providing glasswool filters.
9. Activated charcoal used in the physico-chemical filters should be periodically cleaned. Cleaning may be followed by application of heat or steam pressure which will regenerate the absorption power of the activated charcoal.
10. The top layer, glasswool, used in the physico-chemical filter should be changed from time to time.
11. Tubing, which has been clogged after prolonged use, should be cleaned, but any type of detergents should be totally avoided.

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