

# **A modified closed flow through siphon system for the cultivation of marine or estuarine organisms under simulated conditions**

**K. K. C. Nair, T. C. Gopalakrishnan,  
V. N. Sankaranarayanan, B.N. Desai**

*National Institute of Oceanography  
Regional Centre, Post Box 1913, Cochin - 682 018, India*

## **Abstract**

*Devices and technologies associated with closed sea water/brackish water recycling systems for the cultivation, maintenance and management of marine/brackish water organisms under controlled conditions without any water exchange are described. Hitherto known-designs and processes of closed water aquaculture systems mostly involve complicate machinery, low denitrification rates and consequent low carrying capacity. Overflow of culture water in case of electric or pump failure necessitating partial or full replacement of the culture media from time to time was also a common handicap. The existing designs have been refined and improved by additions and alterations at various stages for maximizing the efficiency and carrying capacity of the system, which registered a three fold increase (3.426 kg 1000 l<sup>-1</sup>) compared to conventional designs (1.18 kg 1000 l<sup>-1</sup>). The design can be scaled up or scaled down depending upon the needs.*

**Keywords:** *Closed flow, Siphon system, Marine, Estuarine*

## **1. Introduction**

Cultivation of marine organisms in recycling systems confers upon the investigator, independence from variations in salinity, temperature, turbidity, plankton blooms and increasing levels of pollutants, commonly occurring in the near shore environment. Chemical changes can be detected in the captive sea water within minutes after its removal from the sea. Major changes in the closed or semi-open sea water culture systems are decrease in pH and oxygen content concurrently with increase in the concentration of inorganic nitrogen compounds, carbon dioxide, phosphates, dissolved organic compounds and bacteria. Of these, loss of alkaline reserve, increase in ammonia concentration and decrease in oxygen content are the factors which first become critical.

The efficiency of sea water/brackish water closed culture systems depends upon the carrying capacity of the system, production rate of metabolic wastes like ammonia, urea, uric acid, protein and amino acids, the conversion rate of these molecules to nitrite and other

organic compounds and consumption of these molecules by the introduced microorganisms, algae and phytoplankton.

To create marine condition in the laboratory is of course impossible, but a system should be able to maintain the quality of the medium as close to the natural conditions as possible. With this in view, the present system is developed and is found to be most efficient and viable in artificial sea farming compared to the existing designs. Some of the principles used in the present modified design have come from the design of Nair *et al.*, (1978) and Nair and Anger (1980) with lot of innovations to improve the working efficiency. The systems designed is protected under Government of India's Patent Act (Patent No. 186483 dated 12.04.2002).

## 2. Material and methods

A scaled schematic flow diagram of the system is given in Fig. 1. The system mainly consists of four larger tanks of similar size (Fig. 1 A, E, F & G) made of reinforced fibre glass. The head tank (Fig. 1 A) which is kept at a height of 80 cms from the floor level functions as the supply tank where filtered and renewed sea water is stored. The water before being supplied to the rearing tanks is supersaturated with oxygen with a specially designed aerating system (Fig. 1 - A2 & A4). Pressurised air is forced through an 'L' shaped PVC tube (A4) which opens into a row of aquaria air stores (A2) fitted as illustrated. On the side of the head tank an automatic salinity control mechanism (Fig. 1-A1) is provided to compensate water loss due to evaporation and consequent salinity increase. This has mainly a cylindrical fresh water reservoir which is provided with an outlet which is regulated by float valve (Fig. 1-A3). Before the system is put to operation, the water level in the head tank (A) is adjusted to Q1-level to keep the float over the surface of water.

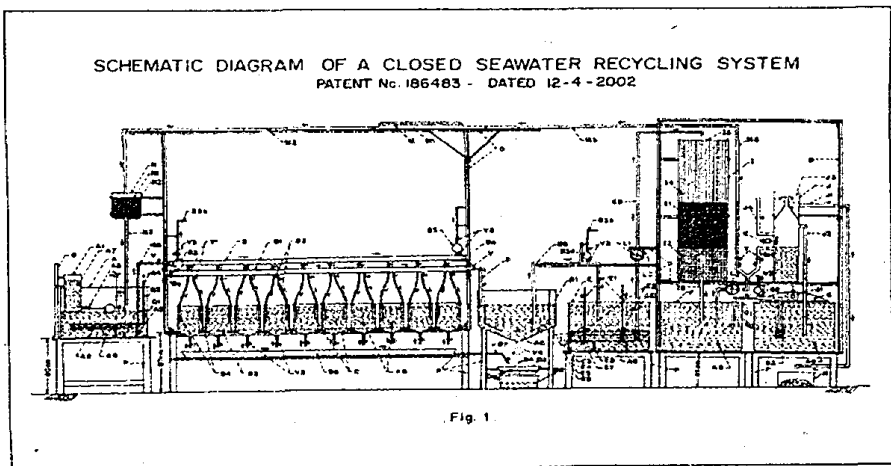


Fig. 1 Flow diagram of closed seawater recycling system

From the head tank water is led through a PVC tube (Fig. 1-A6) to the main distribution tube (Fig. 1-B). The lead tube (A6) is provided with a full way PVC valve (Fig. 1-V) to regulate the flow. The proximal end of this tube which is inside the head tank is fitted with a 300 m nylon gauze filter (Fig. 1-A5) to prevent large particles from entering the system. At the distal end of the main distribution tube (Fig. 1-B) and the main receiving tube (Fig. 1-B1) two specially designed separating funnels (Fig. 1-B3) with regulating valves (Fig. 1-V3) on either side of the bulb are fitted. Both ends of the distribution and receiving tubes are tightly closed with screwable caps which allow cleaning of the tube when required. To the main distribution tube (B) ten equidistant downwardly directed, outlets and to the main receiving tube (B1) ten similar inlets, with glass control valves (Fig. 1-V1) are connected. The glass control valves are connected with silicon tubing (Fig. 1-B2) which supply and drain out the water to and from the rearing tanks (Fig. 1-C) which are kept on an elevated wooden platform, 85 cm, above the floor level (Fig. 1).

The bottoms of the rearing tanks have a lower tapering cone separated from the upper cylindrical portion by nylon gauze of desired mesh size (Fig. 1-B5) to prevent entry of cultured animals to the bottom of the tank. The tapering cone ends up in a flush out PVC valve (Fig. 1-V2). These valves allow waste removal and cleaning when required. The water thus flushed out gets collected in a common drain (Fig. 1-B6) and gets routed through a PVC tube (Fig. 1-B7) to a glass wool filter (Fig. 1-D3). Into the same filter waste from the settling tank (Fig. 1-D1) is also emptied. In the glass wool filter (Fig. 1-D4) the suspended organic waste is filtered and the clean water is collected in a PVC tray (Fig. 1-D2). The filtered water is put back to the system for re-circulation to minimize the waste. Two removable filters (Fig. 1-B4) are attached to the inner wall of each rearing tank into which open the inlet and outlet (B2) respectively. These filters are made of PVC tubes cut and fitted with nylon gauze of desired mesh size as illustrated (Fig. 2-B4). These filters prevent the entry of cultured organisms into the other vital components of the system and also help to maintain independent cultures. Water from the rearing tank is led through the outlet tube into the common collecting tube (B1). The distal end of the main distribution tube (B) and receiving tube (B1) (where the separating funnels are located) are kept slightly elevated for the effective functioning of the separating funnels as air trap. From the main receiving tube (B1) water is led to the double walled settling tank (Fig. 1-D1) (which is kept at the same height as the rearing tanks) through PVC tube (Fig. 1-D) for removal of suspended waste, which is provided with a PVC valve (Fig. 1-V) to regulate the outflow in case of need. The inner wall of the double walled settling tank runs half way to the tapering cone. The double

walled construction of the settling tank allows effective settlement of the suspended load to the tail end of the tank. To the tail end is fitted a PVC flush out valve (Fig. 1-V4) which allows waste removal.

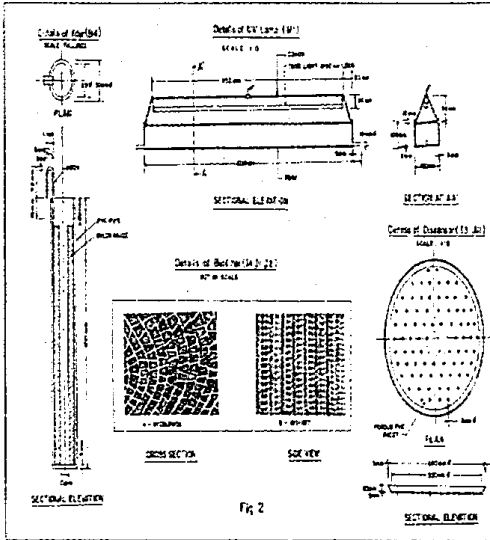


Fig. 2 Details of filters and positioning of UV lamp;

Fig. 3 The mangrove plants grown in fibre glass trays

From the settling tank water is led to the filter bed tank (Fig. 1-E) through a PVC tube (Fig. 1-D5). A glass separating funnel (Fig. 1-B3a) as described earlier is attached to the lead tube (D5). The altered conventional biological filter is set up on a perforated PVC sheet (Fig. 1-E7) which is fixed at a height of 15 cm from the bottom of the tank. The PVC sheet is supported by two solid blocks of PVC (Fig. 1-E8). Two PVC tubes of same size (Fig. 1-E2) and a third one larger in size (Fig. 1-E10) are fixed on the porous PVC sheet. The inner ends of all the three tubes reach below the PVC sheet and the smaller tubes end with a flaring collar. The flaring collars are provided to avoid entry of compressed air, led through silicon tube (E1), below the filter bed. A fine nylon gauze (120m) is spread (Fig. 1-E3) over the porous PVC sheet (E7). The edges of the PVC sheet and the edges of the nylon gauze are glued with silicon gel to the walls of the tank, to prevent the free flow of water through the edges of the filter bed. Over the nylon gauze, a layer of crystal sand, a layer of coarse sand and a layer of gravel (Fig. 1-E4 to E6) are evenly spread. The filter bed tank, the main receiving tank and the algal culture tank (Fig. 1-E, F & G) are kept at the same level (49 cm from floor level). Water is pumped from the bottom of the filter bed with a magnetic coupled fractional electric pump (Fig. 1-L1) through a PVC tube (Fig. 1-E9) which is inserted through the rigid PVC tube (E10) fixed on the filter bed hold.

Water pumped over the cylindrical trickling filter (Fig. 1-I) is uniformly spread over the filter through a circular porous fibres glass trough (Fig. 1-I3 & Fig. 2-I3) – the dispenser. The trickling biofilter which is made of reinforced fibre glass hold is filled with vertically and transversely packed hydropack (Fig. 1-I4 & I2 & Fig. 2-I4 & I2) and horizontally packed bionet (Fig. 1-I1 & Fig. 2-I1). The hydropack and bionet are light UV stabilized polyethylene material which has a lot of void space when packed and these will allow easy trickling of well aerated water from top to bottom. The water from the trickling filter is collected in the main receiving tank (Fig. 1-F) through a length of PVC tube (I5). The treated water is pumped by a magnetic pump (L2) through a length of PVC tube (Fig. 1-M3) to the UV sterilisation unit (Fig. 1-M & Fig. 2-M). Part of the water pumped is diverted to the foam tower (Fig. 1-J) and this diversion is brought by adjusting the PVC valves (Fig. 1-V) provided on lead tubes M3 & M4.

The foam tower and the ozonation unit is a bottle shaped unit having a collar around the narrow outlet on the top. The water brought in by the delivery tube (M4) is charged with ozone brought in by the lead tube (J4) from an ozonator. The water is agitated with an agitator, made of polypropylene blades, coupled with a fractional electric motor (Fig. 1-K). Owing to constant agitation ozone gets dissolved in water and it accelerates the remaining nitrification. The role of ozone in the reduction of yellow substances that get accumulated in recycling fish culture systems was demonstrated by Otte *et al.*, 1977. In the process the foam generated containing suspended organic waste flows out through the conical outlet on top of the foam tower into the form separator (Fig. 1-J3). The waste thus generated is led through a lead tube (Fig. 1-J1) and it is collected in a fibre glass container (Fig. 1-H) and discarded. The ozonated water flows out through the outlet (Fig. 1-J2) and gets collected in the algae/diatom/plant culture tank (Fig. 1-G). Algal culture tank is well illuminated from top (Fig. 1-G1) or submersible lamp can also be provided in case of intensive cultivation. For algal water treatment, species of *Enteromorpha*, *Ulva* and phytoplankton *Dunaliella* and *Chlorella* are commonly used. The algal water treatment was found effective in controlling pH, removal of carbondioxide, nitrate and phosphate which get accumulated as end products and at the same time enriching the culture water with oxygen. Cultivation of diatom *Navicula Sp.* was found to effect removal of ammonia and silicate.

Periodic harvesting of algae/diatom is recommended for avoiding over crowding which may lead to putrefication. The water after algal treatment is led back to the main receiving tank (Fig. 1-F) through a lead tube (Fig. 1-G2) which is also fitted with an air trap as in the case

of lead tube (Fig. 1-D5). The lead tube (G2) is fitted with a nylon gauze filter (Fig. 1-G3) of desired mesh size to avoid contamination of the remaining part of the system. The ozonated water routed through the algal culture tank and back to the main receiving tank gets mixed up with the remaining water brought in by the trickling filter. This partial ozonation is to avoid excess ozonation which may be harmful in high doses.

In large scale culture, employing the same principles, in place of diatom/algal culture for water treatment, mangrove plants such as *Rhizophora apiculata* and *Kandelia kandal* were found very effective for removal of dissolved nutrients and other end products in the culture media. The mangrove plants were grown in fibre glass trays as shown in Fig. 3 and introduced in tank G (Fig. 1) under proper illumination. Mangrove plants thus cultivated for water treatment can be replaced with fresh ones over a period of time when they attain relatively large size.

The water pumped back to the head tank is routed through UV sterilization unit (Fig. 1-M & Fig. 2-M-1) for partial removal of excess bacterial load if any. A four feet UV tube is mounted inside a conical fibre glass shade and the shade is kept seated over a specially designed Perspex tray (Fig. 1-M1 & Fig. 2-M1). The tray has an inlet and an outlet which is connected with the lead tubes (M3 & M2) respectively. Water entering through the inlet gets spread over the tray and runs out through an outlet. In water, UV penetrates only a maximum of 2 cm depth and hence partial sterilization. The UV treated water is led through the lead tube (Fig. 1-M2) to the activated charcoal filter (Fig. 1-N) which is kept over the head tank (A). The filter has a fibre glass hold fitted with activated carbon granules (Fig. 1-N2). The water entering the carbon filter is uniformly spread over the filter through a circular porous fibre glass trough - the dispenser (Fig. 1-N1 & Fig. 2-N1), as in the case of trickling filter. The activated carbon filter removes dissolved gases if any and the purified water is led to the head tank (A) through the lead tube (Fig. 1-N3). In the head tank (A), the water once again gets supersaturated with oxygen and the cycle is repeated.

### **3. Operation of the system**

The system after the installation has to be thoroughly washed with clean fresh water and the water should be allowed to remain within the various units of the system at least for ten days so as to allow any sort of leaching of toxic substances if any. Thereafter the water should be drained out and the system has to be rinsed once again with fresh water and the water drained off. Once the system is cleaned, the head tank, the culture tanks, the settling tank, the biological filter tank, the

main receiving tank and the algal culture tank will have to be filled with clean unpolluted filtered sea water/backwash water (Fig. A-8) up to the level indicated (Q1). The foam tower also will have to be filled up to the level marked inside. At this stage the salinity control mechanism will have to be fixed as shown in the figure (Fig. 1) and it should be filled with pure fresh water (Fig.A-7). Once the major tanks are filled with salt water, the air trapped in the main distribution system (B) should be removed through the outlet system (Fig. 1-B3) which is connected to a lead tube (Fig. 1-B3 b) from the vacuum pump. All control valves connected with the distribution and supply should be kept open while vacuum pump is put on. Once the pump is in operation, all the air in the distribution system will be replaced by water. Once the bulbous portion (B3) of the outlet system is filled with water, the valves (V3) should be immediately closed, and the vacuum pump turned off. This results in an automatic flow of water into the rearing tanks. Same procedure may be adopted in removing air from the main collecting system (B1), the lead tube (D5) from settling tank to the biological filter and the lead tube (G2) from algal culture tank to the main receiving tank. Once the trapped air is removed, the system is ready to establish its closed recycling.

The system before put to use will have to be activated. This is being done by inoculating the nitrifying bacteria belonging to *Nitrosomonas sp.* and *Nitrobacter sp.* extracted from sewage effluents/garden soil into the biological filter bed and the trickling biofilter. Use of gravel from existing biological filters was suggested by Carmigaina and Bennett, 1977 as a trigger. The effectiveness of commercial additives and seed media for accelerated nitrification is explained by Bower and Turner, 1981. After inoculation the water should be allowed to recycle by putting on the electric pumps (Fig. 1-L1 & L2) closing the valve (V) on the lead tube (M4) to foam tower. At this stage compressed and filtered air may be introduced to the aerating system (A4) in the head tank (A) and lead tube (E1) in the biological filter bed tank (E). This will bring about active growth of nitrifying bacteria in the biological filter bed and trickling biofilter within a period of 25-30 days.

Once the system is conditioned, animals to be cultivated are introduced into the culture tanks (C) and plants into the algal culture tank (G). At the initial stages, care may be taken to avoid excessive loading of the biomass. The valve (V) on lead tube M4 may be opened, the agitator (K), the illumination system (G1), the ozone source (J4) from the generator and the UV system will have to be put on. Now the system is ready for continuous operation. The life of the system depends on careful handling and optimum water quality management. As the water is pumped from the main receiving tank (F) water level in

the tank will fall down to Q2 level from Q1 and simultaneously in the head tank A, the water level will rise to Q2 level, thereby bringing about an automatic flow back to the main receiving tank through the various stages provided. The flow path of water, air and ozone are indicated by arrows. Once the flow starts, the automatic water level control which is linked with the electric motor (L2) will regulate the pumping intervals.

Water brought in from the culture tanks (Fig. 1-C) by the delivery tube (D) to the settling tank (D1) is desiltered in the settling tank. This water is fed to the biological filter tank (Fig. 1-E) where the initial filtration and processing is done by the filter. Filtering action of the bed is aided by the suction owing to the constant removal of water from below the bed by the pump (L1). Water filtered is recirculated through the filter bed several times. This is achieved through the introduction of compressed air through the silicon tube (E1) and then into the PVC tube (E2) 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 by-products. The second stage of nitrification is brought about in the trickling biofilter. The well aerated water, while trickling through the void spaces of the substrate (the hydropack and the bionet), gives ample time for the nitrifying bacteria to act on the remaining nitrogenous waste and convert them to relatively non-toxic substances. After all these processes, if nitrite ( $\text{NO}_2$ ) remains to be oxidized to nitrate ( $\text{NO}_3$ ), this is accomplished inside the foam tower with the aid of ozone as described earlier. Once the system is put to operation the free ends of all the tubes associated with the circulation of water should be kept submerged, except the lead tubes to the trickling filter and carbon filter.

#### **4. Maintenance**

The overall efficiency of the biological filter, trickling filter and carbon filter depend upon the capacity of these filters to nitrify and renew the culture water over a long period of time. Excessive sedimentation, which is likely to exceed microbial degradation of metabolic waste products in biological filters may be avoided by the following methods.

Suitable filters must be provided both at the inlet and outlet points in the rearing tanks. These filters prevent easy passage of any particulate matter or excess food from rearing tanks into the biological filter. Any excess food found remaining inside the rearing tanks should be cleaned periodically. When nylon gauze filters are used, they should be cleaned from time to time. The cleaning of the filters should be done only after closing the inlet and outlet valves provided in each tank or care should be taken to see that free ends of the tubes remain



submerged in water while removal. Periodic removal of sediments collected at the tapering cone of rearing tanks and settling tank will minimize clogging of biological filters. The glass wool provided inside the filter tray (D4) may be replaced from time to time. To maintain the absorption efficiency of the activated charcoal used in the charcoal filter, it may be replaced or rejuvenated by steaming followed by sun drying. When new charcoal is used it may be thoroughly washed and dried before use.

After prolonged use, air bubbles may develop in or enter the supply and delivery tubes of the system. These bubbles will automatically get collected inside the bulbous portions of the outlet system provided for removal of air. Care may be taken to see that the lower valve below the bulbous portion may be left open when the system is in operation. When large amount of air is noticed inside the bulb, the lower valve should be closed. The upper valve which normally have to remain closed should then be opened. The bulb should then be filled from above, when filled, the upper valve should be closed, and the lower valve again opened. The reservoir of the automatic salinity control should be kept filled with fresh water from time to time.

## **5. Results and discussions**

Major improvements brought about in this system from the existing conventional systems are independent conical flush out systems in the rearing tanks separated by nylon gauze sieves for efficient waste removal and cleaning of the water. Double walled conical settling tank between rearing tanks and biological filter for the removal of suspended sediments and physicochemical filter replaced by activated carbon filter and its shifting from the suction side to the delivery point, for effective rejuvenation. Altered conventional biological filter coupled with trickling filter for optimum denitrification. Ozonation and agitation for faster degradation of organic waste. Foam separation for removal of suspended solids. Partial UV sterilization for controlling excess bacterial load. Bypass algal/diatom culture/mangrove plants for the removal of excess nutrient accumulation.

The simple auto siphon system in the main flow path derived by the three stage level adjustment of the different tanks eliminates the possibility of an overflow due to electric or pump failure.

Altered biological filter (from top to bottom – gravel, coarse sand and crystal sand) instead of the conventional type (reverse of the above order) enhanced the growth of the nitrifying bacteria over a larger area in the filter bed in the presence of oxygen enriched water. Whereas in the conventional filters (Hirayama, 1965 a&b & 1966) the growth of bacteria was found confined to the upper 2 cm, below which the entry of oxygen enriched water was difficult because of the tight packing of the crystal sand on top. Here it was also noticed that fine filtration was

only at the topmost layer. After a period of time, clogging and formation of small crevices through the crystal sand was often noticed as a result of the suction below the filter bed by the electric pump. This suction might have caused the movement of crystal sand into the coarse sand and coarse sand into the gravel below. These crevices drastically lowered the efficiency of the filter bed. But in the altered filter bed the filtration efficiency was very high and was effected mainly at the bottom layer of crystal sand and the loosely packed middle and top layers allowed effective growth of the nitrifying bacteria. The filter bed in general should have an area which exceed the area of the culture containers (Kinne, 1976b). In biological filters it was found to take about 60 days for effective nitrification (Saeki, 1963). It is understood that two types of nitrifying bacteria (*Nitrosomonas* and *Nitrobactor*) bring forth effective nitrifying process in biological filters. The interactive process of the nitrifying bacteria in biological filters is reported by Gee *et al.*, 1990. The process of nitrification as a bacterial source is explained by Wood, 1986. The widely practiced direct aeration method in the culture tanks is avoided here which brought down the physiological stress on the cultured animals. Monoculture was possible with the help of independent filters in rearing tanks. Coupled use of biological filter with trickling filter and animal culture with algal/plant culture enhanced the efficiency of water treatment, carrying capacity, biorecycling, healthy nurturing and upkeep of the media. Once the system is found stabilized, it was put to operations and water quality was monitored for a period of 50 days (Tables 1 & 2). The essential pathways of nitrification in the system is as shown in Fig. 4.

Table 1. Water quality before nitrification (Trickling biofilter - Inlet)

Temp. (°C)	Salinity (psu)	pH	NH <sub>4</sub> (mg at l <sup>-1</sup> )	NO <sub>2</sub> (mg at l <sup>-1</sup> )	NO <sub>3</sub> (mg at l <sup>-1</sup> )
22.5		7.84	0.156	0.239	244.62
22.5		7.90	0.230	0.368	224.34
22.5		7.91	0.200	0.398	
22.5		7.96	0.142	0.202	227.08
22.5		8.03	0.114	0.126	
22.5		7.99	0.230	0.233	320.20
22.5	21.3	8.04	0.192	0.303	271.40
22.5		7.98	0.226	0.448	207.13
22.2		7.98	0.658	0.545	190.84
22.2		8.00	0.192	0.400	210.86
22.3		8.07	0.144	0.183	202.98
22.3		8.07	0.116	0.118	195.42
22.2		8.02	0.340	0.309	170.84
21.5	21.9	7.99	0.344	0.398	185.92
21.4		7.97	0.366	0.525	164.60

21.5		8.00	0.400	0.465	159.68
21.5		7.97	0.256	0.391	159.34
21.4		8.10	0.222	0.282	178.72
21.4		8.11	0.192	0.253	173.80
21.2		8.02	0.276	0.434	171.40
21.0	22.6	7.99	0.216	0.872	198.40
21.4		7.99	0.282	0.477	148.22
22.1		8.04	0.136	0.253	147.90
22.0		8.01	0.166	0.240	152.50
21.9		8.07	0.208	0.232	147.56
21.9		8.07	0.200	0.231	142.72
21.8		8.05	0.334	0.284	122.62
21.6	22.8	8.05	0.150	0.230	107.80
21.5		8.02	0.236	0.367	134.18
21.9		8.02	0.196	0.344	140.12
22.1		8.01	0.174	0.346	200.73
22.2		8.01	0.162	0.349	146.82
22.3		8.04	0.116	0.134	97.02
22.5		7.93	0.150	0.386	148.70
22.5	21.3	7.95	0.344	0.345	145.00
22.5		8.01	0.102	0.293	154.34
22.3		8.05	0.116	0.189	168.65
22.5		7.98	0.186	0.358	122.24
22.6		7.98	0.150	0.315	92.20
22.8		7.94	0.254	0.387	102.58
23.0		7.90	0.142	0.411	128.22
22.9	21.7	7.92	0.146	0.563	108.86
22.6		7.93	0.280	0.847	95.54
22.6		7.97	0.228	0.535	122.24
22.4		8.02	0.176	0.375	107.42
22.3		8.09	0.386	0.848	109.98
22.3		8.11	0.132	0.450	99.09
22.5	22.4	8.01	0.266	0.691	110.55
22.5	8.07	0.238	0.644		

Table 2. Water quality after nitrification (trickling biofilter - outlet)

Temp. (°C)	Salinity (psu)	pH	NH <sub>4</sub> (mg at l <sup>-1</sup> )	NO <sub>2</sub> (mg at l <sup>-1</sup> )	NO <sub>3</sub> (mg at l <sup>-1</sup> )
22.5		7.90	0.082	0.121	247.94
22.5		7.96	0.084	0.217	230.88
22.5		7.98	0.076	0.220	
22.5		8.02	0.056	0.111	220.53
22.5		8.08	0.028	0.073	
22.5		8.10	0.080	0.089	240.98

22.5	21.3	8.12	0.032	0.125	255.90
22.5		8.08	0.080	0.199	212.07
22.2		8.08	0.166	0.225	187.92
22.2		8.05	0.076	0.221	223.00
22.3		8.12	0.056	0.098	202.34
22.3		8.10	0.028	0.069	148.90
22.2		8.10	0.082	0.137	220.06
21.5	21.9	8.10	0.108	0.156	179.72
21.4		8.08	0.120	0.218	171.16
21.5		8.11	0.154	0.184	156.74
21.5		8.08	0.178	0.170	157.72
21.4		8.17	0.042	0.096	188.58
21.4		8.16	0.155	0.103	169.54
21.2		8.10	0.026	0.196	
21.0	22.6	8.07	0.044	0.341	162.64
21.4		8.07	0.116	0.228	160.00
22.1		8.07	0.062	0.138	149.86
22.0		8.06	0.058	0.129	147.92
21.9		8.11	0.144	0.110	174.70
21.9		8.12	0.142	0.108	147.75
21.8		8.07	0.172	0.102	126.40
21.6	22.8	8.09	0.142	0.183	105.54
21.5		8.05	0.132	0.210	135.70
21.9		8.04	0.112	0.168	143.10
22.1		8.03	0.056	0.161	164.00
22.2		8.05	0.142	0.258	155.38
22.3		8.06	0.038	0.113	147.20
22.5		7.95	0.108	0.239	141.20
22.5	21.3	7.97	0.196	0.276	145.00
22.5		8.04	0.036	0.177	130.40
22.3		8.08	0.078	0.112	132.32
22.5		8.01	0.136	0.261	123.74
22.6		7.99	0.102	0.219	98.84
22.8		7.96	0.088	0.175	107.04
23.0		7.93	0.078	0.196	95.53
22.9	21.7	8.03	0.054	0.138	101.80
22.6		8.04	0.068	0.270	100.30
22.6		8.10	0.080	0.149	122.60
22.4		8.11	0.054	0.110	110.74
22.3		8.15	0.078	0.289	105.18
22.3		8.20	0.078	0.244	92.58
22.5	22.4	8.10	0.052	0.204	111.84
22.5		8.13	0.024	0.186	

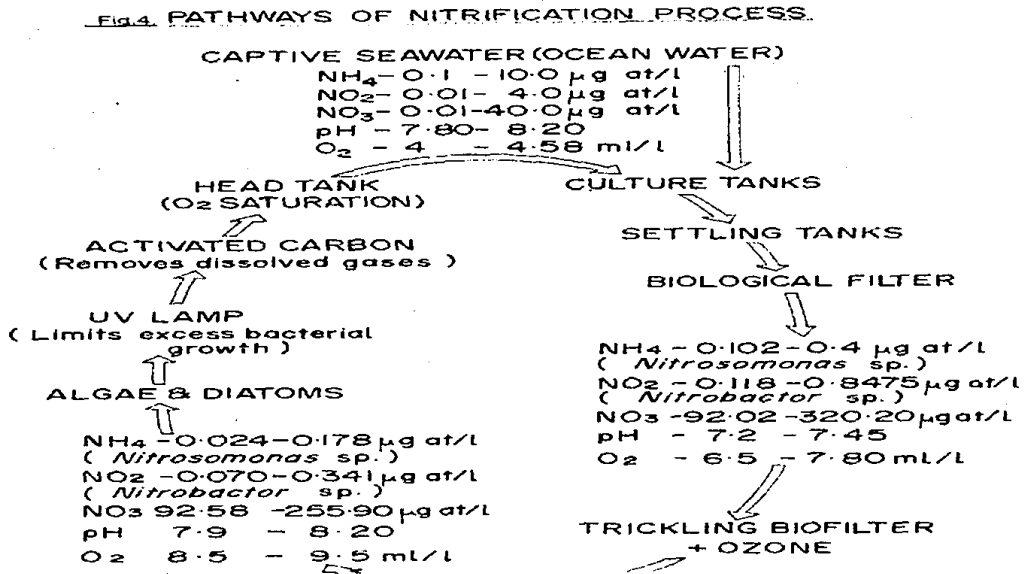


Fig. 4 Pathways of nitrification process

The success of the closed sea water/brackish water recycling systems depends upon the conversion rate of the metabolic wastes like ammonia, urea, uric acid, amino acids and protein into nitrite, nitrate and organic compounds. Other than size and shape of the culture enclosures, culture water quality, treatment efficiency, animal load, rate of water replacement or recirculation, oxygen and carbondioxide concentration.

The variation in ammonia concentration in the open ocean is from 0.1-10 mg-at l<sup>-1</sup> (Kinne, 1976 a, b). A reduction of ammonia concentration from 143 mg-at l<sup>-1</sup> to negligible levels within 9 days, with the help of seeded filters was reported by Carmigaina and Bennett (1977), 7.5 to 2.1 mg-at l<sup>-1</sup> within 4 months (Nair et al., 1978) and 15.9 to 3.42 mg-at l<sup>-1</sup> within 15 days (Nair and Anger, 1980). In the present system, the ammonia values ranged between 0.224 to 0.196 mg-at l<sup>-1</sup> (Table 2). In general, oxidizing efficiency of biological filters increase with decrease in temperature (Haug and Mc. Carty, 1972).

The pH, an indicator of ammonia concentration, ranged between 7.9 and 8.2 in the present system which is well within the pH range of 7.8 to 8.2 of normal sea water. An increase in pH by one unit represents a ten fold increase in the concentration of ammonia as reported by Kinne (1976 a, b). In a closed sea water recycling system, pH above 8.2 and below 7.6 are not congenial. pH can be altered by addition of calcium or magnesium oxides.

With the help of the specially designed aerating system (Fig. 1) in the head tank and in the biological filter bed the oxygen level in the culture medium was near saturation. Downing and Merkens (1955) have shown that survival period of animals can be prolonged under high oxygen concentration even at ammonia toxification levels.

Nitrite and nitrate levels in the open ocean are 0.01 – 4.0 mg-at l<sup>-1</sup> and 0.01 – 40 mg-at l<sup>-1</sup> respectively (Kinne, 1976 a, b). An increase in nitrate can cause a decrease in pH (Horing, 1934). At temperature varying between 21-26 °C, it is reported that the oxidation of ammonia to nitrite and then to nitrate in a biological filter will take 28 to 60 days (Kawi *et al.*, 1964; Spotte, 1970; Foster, 1974 and Hirayama, 1974). Permissible levels of nitrite and nitrate in closed systems are 2.1 and 322 mg-at l<sup>-1</sup> respectively (King and Spotte, 1974). In the present system, they were in the order of 0.29 and 255.90 mg-at l<sup>-1</sup>. The routing of the water through the coupled algal culture/plant system caused a considerable decrease in the nitrate concentration. The effect of algal water treatment has been demonstrated earlier by Kinne (1976), Sorokin (1971), Siddal (1972), Nair *et al.* (1978) and Nair and Anger (1980).

The present system is unique in its design and can support ~3.5 kg. Biomass1000 l<sup>-1</sup> of sea water which is three times compared to the conventional designs. It can be scaled up or scaled down according to requirements. The carrying capacity of the system can be further enhanced by increasing the turnover rate of well oxygenated water through the filter bed.

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